Part 2 (primarily 2019 and on): Many references about buckling, wrinkling, crushing, crippling, crumpling, creasing, kinking, dimpling, folding, snapping, vibration, dynamic response and optimization of membranes, films, sheets, plates, panels, shells, tubes, nanotubes, pipes, thin-walled beam-columns, sandwich structures and soft structures.

Part 2 was introduced after Part 1 reached a length of almost 10000 pages. (NOTE: After a computer system update in June 2019 the length of Part 1 became about 8600 pages because more material now fits on a single page. Also, Part 2 became about 2200 pages, reduced from about 2600 pages for the same reason. At the end of 2020 Part 2 had about 7000 pages.) From now on Part 1 will remain essentially unchanged (except for the correction of errors, the inclusion of lists of references at the ends of a few articles for which these lists were previously unavailable, and the inclusion of previously unrecognized book titles in one of the Part 1 sections entitled “Book Cover Gallery”). All additional citations will be included in Part 2. This includes citations dated 2019 or after; citations of previously published papers not included in Part 1; citations of some earlier papers on fluid-structure interaction; citations of some earlier papers on chaos and nonlinear dynamic response; citations of papers (published from 2014 on) from the additional journals: Nonlinear Dynamics, Smart Materials & Structures, Soft Matter, Earthquake Engineering & Structural Dynamics, Shock and Vibration, Mathematical Problems in Engineering, Journal of the International Association for Shell and Spatial Structures, The Journal of the Acoustical Society of America, Structural and Multidisciplinary Optimization, Journal of Applied and Computational Mechanics and possibly from other journals not included in the list given at the beginning of Part 1. In March 2019 the citations of papers from 2014 - 2018 in International Journal of Structural Stability and Dynamics and the citations of papers from 2016 - 2018 in International Journal of Applied Mechanics were transferred from Part 1 to Part 2 in order to be able to include the list of references associated with each relevant citation without exceeding 10000 pages in Part 1.

With few exceptions, from now on all future effort on documenting the “shell buckling/vibration” field will generate additional entries only in Part 2 and in the image galleries of this website: “book cover gallery”, “shell buckling people” and “shell buckling images”

==== Some Pre-2019 Papers Not Included In Part 1 Found After Part 1 Maxpaged ==== 

Alexander K. Belyaev (1), Vladimir A. Polyanskiy (2), Nina A. Smirnova (2) and Aleksandr V. Fedotov (1)
(1) Institute for Problems of Mechanical Engineering RAS, 61 Bolshoi Ave. V.O., St. Petersburg 199178, Russian Federation
(2) Peter the Great St. Petersburg Polytechnic University, 29 Politekhnicheskaya St., St. Petersburg 195251, Russian Federation


ABSTRACT: It is necessary to provide the separation of the eigenmodes of elastic objects from the sensor signals and to make it possible to independently affect the modes with the use of actuators when realizing the
modal system of controlling an elastic object with distributed parameters. The present paper puts forward an identification procedure which allows separating the vibration modes of the object in measured and control signals in the absence of the object model simulation. The control operability of this procedure was verified by experiment through making a system of active suppression of forced bending vibrations of a metal beam. The experiment showed the high control efficiency of the realized modal system.

References listed at the end of the paper:


ABSTRACT: In the present paper, a review on piezoelectric sensing of mechanical deformations and vibrations of so-called smart or intelligent structures is given. After a short introduction into piezoelectric sensing and actuation of such controlled structures, we pay special emphasis on the description of some own work, which has been performed at the Institute of Technical Mechanics of the Johannes Kepler University of Linz (JKU) in the last years. Among other aspects, this work has been motivated by the fact that collocated control of smart structures requires a sensor output that is work-conjugated to the input by the actuator. This fact in turn brings into the play the more general question of how to measure mechanically meaningful structural quantities, such as displacements, slopes, or other quantities, which form the work-conjugated quantities of the actuation, by means piezoelectric sensors. At least in the range of small strains, there is confidence that distributed piezoelectric sensors or sensor patches in smart structures do measure weighted integrals over their domain. Therefore, there is a need of distributing or shaping the sensor activity in order to be able to re-interpret the sensor signals in the desired mechanical sense. We sketch a general strategy that is based on a special application of work principles, more generally on displacement virials. We also review our work in the past on bringing this concept to application in smart structures, such as beams, rods and plates.

References listed at the end of the paper:

Nowacki, J.P. Static and Dynamic Coupled Fields in Bodies with Piezoeffects or Polarization; Springer: Berlin, Germany, 2006.
Irschik, H.; Krommer, M.; Huber, H. Dynamic displacement tracking of a frame structure by piezoelectric patches: analytical solution
ABSTRACT: Thick-walled tubes made from isotropic and anisotropic materials are subjected to an internal pressure while the semi-analytical method is employed to investigate their elastic deformations. The contribution and novelty of this method is that it works universally for different loads, different boundary conditions, and different geometry of analyzed structures. Moreover, even when composite material is considered, the method requires no simplistic assumptions. The method uses a curvilinear tensor calculus and it works with the analytical expression of the total potential energy while the unknown displacement functions are approximated by using appropriate series expansion. Fourier and Taylor series expansion are involved into analysis in which they are tested and compared. The main potential of the proposed method is in analyses of wound composite structures when a simple description of the geometry is made in a curvilinear coordinate system while material properties are described in their inherent Cartesian coordinate system. Validations of the introduced semi-analytical method are performed by comparing results with those obtained from three-dimensional finite element analysis (FEA). Calculations with Fourier series expansion show noticeable disagreement with results from the finite element model because Fourier series expansion is not able to capture the course of radial deformation. Therefore, it can be used only for rough estimations of a shape after deformation. On the other hand, the semi-analytical method with Fourier Taylor series expansion works very efficiently.
well for both types of material. Its predictions of deformations are reliable and widely exploitable.

References listed at the end of the paper:


ABSTRACT: This paper deals with free flexural vibration modes and natural frequencies of a thin plate with general boundary conditions — a simply supported plate connected to its surroundings with torsional springs. Vibration modes were derived on the basis of the Rajalingham, Bhat and Xistiris approach. This approach was originally used for a clamped thin plate, so its adaptation was needed. The plate vibration function was usually expressed as a single partial differential equation. This partial differential equation was transformed into two ordinary differential equations that can be solved in the simpler way. Theoretical background of the computations is briefly described. Vibration modes of the supported plate with torsional springs are presented graphically and numerically for three different values of stiffness of torsional springs.

References listed at the end of the paper:

ABSTRACT: In this paper, single variable beam theories taking into account effect of transverse shear deformation are developed and applied for the bending, buckling and free vibration analysis of thick isotropic beams. The most important feature of the present beam theories is that unlike any other higher order theory, the proposed class of theories contains only one unknown variable and does not require shear correction factor. The displacement field of the present theories is built upon the classical beam theory. The theories account for parabolic distribution of transverse shear stress using constitutive relations, satisfying the traction free conditions at top and bottom surfaces of the beam. Governing differential equation and boundary conditions of these theories are obtained using the principle of virtual work. Results obtained for the displacements, stresses, fundamental frequencies and critical buckling loads of simply supported isotropic solid beams are compared with those obtained by other theories to validate the accuracy of the present theories.

References listed at the end of the paper:


ABSTRACT: A prior knowledge of group velocities of Lamb wave modes is a key for analysis of time signals in guided-wave based structural health monitoring. The identification of multiple wave modes may be complicated due to dependency of group velocity on frequency (dispersion). These dependencies for infinite plate of constant thickness can be calculated by a numerical solution of analytic equation. Two alternative approaches to determine group velocities of zero-order Lamb wave modes in aluminum plate were used in this work: Two-dimensional Fast Fourier Transform (2D-FFT) and methods of time-frequency processing. 2D-FFT requires a high number of time signals in equidistant points, therefore it was applied on data from finite element analysis of wave propagation in the plate. Group velocities for chosen frequencies were also determined using wavelet transform (WT) of signals as differences of times of arrival measured by a pair of piezoelectric transducers. The results from 2D-FFT and wavelet transform were compared to the analytic solution.

References listed at the end of the paper:

Eelco Jansen and Raimund Rolfes, “Modal interaction characteristics of an axially loaded composite cylindrical shell using Koiter’s imperfection sensitivity analysis”, 11th World Congress on Computational Mechanics (WCCM XI), 5th European Conference on Computational Mechanics (ECCM V) and 6th European Conference on Computational Fluid Dynamics (ECFD VI), Barcelona, Spain, July 20-25, 2014

ABSTRACT: Thin-walled cylindrical shells are used as main structural components in various branches of engineering. Buckling is the key design criterion for these thin-walled structures. Cylindrical shells typically exhibit unstable post-buckling behavior and their behavior is correspondingly very sensitive to small geometric or load imperfections. In this paper, an approach to assess the modal interaction characteristics of composite cylinders under axial loading and their effects on the load carrying capability is presented.

In recent years, extensive research, including the NASA Shell Buckling Knock-Down Factor (SBKDF) project, has been carried out in order to develop design approaches that lead to appropriate, not too conservative design loads [1-4]. Both deterministic and probabilistic approaches are under investigation within the EU FP7 project DESICOS. An important deterministic approach further pursued within DESICOS is the Single Perturbation Load Approach.

An alternative deterministic approach to define knock down factors is based on Koiter’s imperfection sensitivity theory. This theory has been applied to the buckling of composite shells both within a semi-analytical context [5] and within a Finite Element framework [6]. In [5], Koiter’s initial postbuckling theory was employed using a numerical solution of the governing Donnell-type differential equations, while in [6] a Finite Element based reduced order model with a small number of representative modes was used. In [6] it was shown that for a given imperfection pattern, for small imperfection amplitudes the limit-point buckling loads obtained with the reduced order model compare reasonably well with full model nonlinear analysis. The objective of the present work is to investigate the characteristics of specific relevant modal interactions and to determine how these interactions affect the decrease of the load carrying capability of composite shells.

In the present work, studies using both the semi-analytical and the Finite Element implementation of Koiter’s theory are carried out in order to identify relevant modal interactions for composite shells under axial loading. Using representative imperfection patterns, both modes affine to buckling modes and appropriate specific modes, for certain composite shells the reduction of the load carrying capacity is established.

References listed at the end of the paper:


ABSTRACT: A probability-based analysis method for predicting buckling loads of compression-loaded laminated-composite shells is presented, and its potential as a basis for a new shell-stability design criterion is demonstrated and discussed. In particular, a database containing information about specimen geometry, material properties, and measured initial geometric imperfections for a selected group of laminated-composite cylindrical shells is used to calculate new buckling-load knockdown factors. These knockdown factors are shown to be substantially improved, and hence much less conservative than the corresponding deterministic knockdown factors that are presently used by industry. The probability integral associated with the analysis is evaluated by using two methods; that is, by using the exact Monte Carlo method and by using an approximate
First-Order Second-Moment method. A comparison of the results from these two methods indicates that the First-Order Second-Moment method yields results that are conservative for the shells considered. Furthermore, the results show that the improved, reliability-based “knockdown” factor presented always yields a safe estimate of the buckling load for the shells examined.

References listed at the end of the paper:


ABSTRACT: The post-buckling behaviour of panels can be very sensitive to imperfections or variations in materials or geometry. This paper presents an efficient numerical model to calculate the effects of material stiffness variations on the non-linear response of a structure. This is done by first defining a geodesic mesh on which a unit variance random field is generated. This field uses the true geodesic distance on the structure to calculate how points in the field should be correlated. The fields generated are projected onto a 3D structural mesh which is used for assembly and post-processing of the structural model. The structural model, based on the Unified Formulation is capable of accurate non-linear calculations of both straight and curved elements. Baseline results generated using the implementation are compared to those in literature, and verified using Abaqus. Random material variations are then applied to the structure in a Monte Carlo analysis. The analyses show that the local variation of stiffness can have a variety of effects on the non-linear response of structures. Aside from the change of mean stiffness causing a change in bifurcation or limit point load, the different stiffness distributions can affect and trigger competing buckling modes and post-buckling modes and affect their corresponding post-buckling load-deflection paths.

References listed at the end of the paper:


ABSTRACT: In order to identify abilities and deficiencies of available analysis tools as well as to establish recommendations for buckling, post-buckling and collapse analysis of thin-walled aerospace structures the Group for Aeronautical Research and Technology in EURope (GARTEUR) launched a specific Action Group consisting of 10 partners from universities, research establishments and industry out of 7 European nations. These partners identified three different benchmarks with well-documented buckling tests. Then, finite elements tools to simulate the structural behaviour were methodically checked and selected, the benchmark computations were performed, evaluated and recommendations were derived. This paper reports on the results of Benchmark 3, an axially compressed CFRP panel that consists of a skin with nominally cylindrical shape, stiffened by stringers. The stringers were partially separated from the skin by impacting prior to the tests. Finally, the panel was axially compressed until collapse. DLR, the University of Karlsruhe, QinetiQ and Samtech applied different tools to simulate the behaviour of this panel during loading up to collapse. Linear and nonlinear analyses as well as buckling analyses were performed. Specific abilities and deficiencies of the tools considered were evaluated. Finally, based on the experience gained within the project, the partners derived recommendations with respect to the influence of parameters, the initial buckling load, the convergence behaviour, the simulation of load introduction and boundary conditions as well as the imperfection sensitivity.

References listed at the end of the paper:


ABSTRACT: This paper presents two new design tools for lightweight aerospace structures. The first tool is the Tailored Fibre Placement (TFP) design tool TACO. It is used to optimize the fibre orientations of structures made of Carbon Fibre Reinforcement Plastics (CFRP). The optimization concept is explained and results are given for a horizontal tail plane connection beam of an aircraft. The second tool, iBuck, is a fast, semi-analytical local buckling and post-buckling tool for stiffened panels that are loaded in-plane. The panels are assumed to be representative for an aircraft fuselage and are stiffened in axial and circumferential direction. Results are
presented for axially loaded panels and compared to FE-results.

References listed at the end of the paper:
[31] R. Degenhardt, H. Klein, A. Kling, H. Temmen, R. Zimmermann, „Buckling and Post-Buckling Analysis of Shells under Quasi-Static and Dynamic Loads“, DLR (German Aerospace Center), 2002

ABSTRACT: Cylindrical shells under axial compression are susceptible to buckling and hence require the development of enhanced underlying mathematical models in order to accurately predict the buckling load. Imperfections of the geometry of the cylinders may cause a drastic decrease of the buckling load and give rise to the need of advanced techniques in order to consider these imperfections in a buckling analysis. A deterministic buckling analysis is based on the use of so-called knock-down factors, which specifies the reduction of the buckling load of the perfect shell in order to account for the inherent uncertainties in the geometry. In this manuscript it will be shown that these knock-down factors are overly conservative and that the fields of probability and statistics provide a mathematical vehicle for realistically modelling the imperfections. Furthermore, the influence of different types of imperfection on the buckling load will be examined and validated with experimental results.

References listed at the end of the paper:


ABSTRACT: A methodology for analysing the degradation and collapse in postbuckling composite structures is proposed. One aspect of the methodology predicts the initiation of interlaminar damage using a strength criterion applied with a global-local analysis technique. A separate approach represents the growth of a pre-existing interlaminar damage region with user-defined multi-point constraints that are controlled based on the Virtual Crack Closure Technique. Another aspect of the approach is a degradation model for in-plane ply damage mechanisms of fibre fracture, matrix cracking and fibre-matrix shear. The complete analysis methodology was compared to experimental results for two fuselage-representative composite panels tested to collapse. For both panels, the behaviour and structural collapse were accurately captured, and the analysis
methodology provided detailed information on the development and interaction of the various damage mechanisms.

References listed at the end of the paper:
29. www.gom.com

ABSTRACT: With the evolution of composite materials and moreover of the manufacturing process of large composite structures, a new window of possibilities is opened from the optimization point of view. Currently, one has great materials and reliable manufacturing processes than can be used for extremely optimized structures. The problem is that even nowadays, some calculation processes make use of design guidelines based on data from 50 years ago, which limits the optimization process due to outdated allowable tolerances, increasing the final cost of the structure and putting on the edge the reliability of the entire design process.

Currently, imperfection sensitive shell structures prone to buckling are designed according to the NASA SP-8007 guideline, dating from 1968, using its conservative lower bound curve. In this guideline the structural behaviour of composite materials is not appropriately considered, since the imperfection sensitivity and the buckling load of shells made of such materials depend among other things on the lay-up design as well. In this context, a numerical investigation about the different methodologies to characterize the behaviour of imperfection sensitive composite structures subjected to compressive loads up to buckling is presented. A benchmark test is developed using a 500 mm diameter unstiffened composite cylindrical shell. A series of non-linear analyses considering geometric and thickness imperfection, obtained from real measurements, are carried out to characterize the knock-down factor of the benchmark test. The effect of each type of imperfection on the knock-down factor is compared against the experimental results.

References listed at the end of the paper:


ABSTRACT: Large scatter characterizes the collapse load of thin-walled structures due to their imperfection sensitivity. Random fields can be used to include imperfections in a finite element model. Principal component analysis and analytical covariance functions are matched to available correlation information of geometrical imperfection measurements. The random fields are realized by Karhunen-Loève expansion combined with Monte Carlo methods. The results of the different covariance models are compared with the deterministic collapse loads of the measured imperfections in the FE-model. This approach isolates the effect of the different covariance models from other inaccuracies such as boundary conditions, loading imperfections, etc. The results show that random fields models can improve predictions and the understanding of the structural behavior of thin-walled structures, especially by using data based PCA. Caution is recommended with regard to analytical covariance functions since they may fail to capture the complete behavior of the structure.

References listed at the end of the paper:
[2] V. Papadopoulos, G. Stefanou, and M. Papadrakakis. Buckling analysis of imperfect shells with stochastic non-Gaussian material...
ABSTRACT: The novel methodology for imperfection sensitivity analysis, presented in Barbero et al.\(^1\) is here applied for the evaluation of limit load of composite cylindrical shells. Koiter’s perturbation method is used to calculate the imperfection paths emanating from mode interaction bifurcations and the Monte Carlo method is used to test a large number of modes and all possible interactions among them. The computational cost is low because of the efficiency of Koiter’s method. The demands of Koiter’s method for accurate evaluations of higher order derivatives of the potential energy are met by a mixed, corotational element.

References listed at the end of the paper:


ABSTRACT: This paper presents the numerical implementation and illustrates the application and potential of a nonlinear elastic generalised beam theory (GBT) beam finite formulation to analyze the postbuckling behavior of laminated CFRP composite thin-walled prismatic cylindrical panels. This formulation (i) is based on a novel GBT cross-section analysis approach, (ii) accounts for the presence of initial geometrical imperfections and (iii) adopts an incremental iterative solution procedure employing the Newton–Raphson method and an arclength control strategy. No stiffness degradation or ply failure is taken into consideration and the material is deemed linear elastic and orthotropic. Numerical results concerning the local buckling and postbuckling behavior of stiffened CFRP cylindrical panels are presented and discussed — one of these panels was experimentally tested and numerically investigated in the context of the COCOMAT project. Taking full advantage of the GBT unique modal features, one is able to (i) examine the nature of the panel structural response, which is expressed in terms of deformation mode participations, and (ii) perform analyses involving very few d.o.f. (by preselecting a small set of deformation modes). The panel buckling loads and deformed configurations obtained from the GBT analyses are validated through comparison with either experimental data or values yielded by shell finite element analyses carried out in the code ABAQUS. In order to assess how the curvature affects the panel buckling and initial postbuckling behavior, a stiffened plate having a width identical to the cylindrical panel is also analyzed and the results obtained are compared with those determined for the corresponding curved panels.

References listed at the end of the paper:
1 R. Schardt, Verallgemeinerte Technische Biegetheorie (VTB), Berlin (Springer-Verlag, 1989). (German)


ABSTRACT: Test results obtained on laminated stringer stiffened composite cylindrical panels subjected to static and cyclic axial compression are presented. Some of the tested panels were pre-damaged in the vicinity of the stringers. The experimental results show that the tested specimen are not sensitive to damage and can be repeatedly buckled in deep postbuckling region without any degradation.

References listed at the end of the paper:
References listed at the end of the paper:


Abstract: Unstiffened composite cylindrical shells show a large scatter in the load levels that the structure can withstand before buckling occurs. Such scatter is greatly influenced by the unavoidable imperfections of the structure, introduced during the fabrication phase. It is thus of key importance to be able to accurately model such imperfections in a numerical computation, in order to recreate and predict the scatter shown in experimental buckling tests. The imperfections can be analyzed by means of random fields, inferring their statistical properties from available measurements. In this manuscript, evolutionary spectra are used to derive random fields of surface and material imperfections of cylindrical shells. A procedure based on a moving window averaging technique is proposed in order to accurately capture the variation of material properties due to imperfect thickness and laminate manufacturing. Finally, Monte Carlo simulations of compression and torsional buckling of cylinders are carried out to show the combined effect of surface and thickness imperfections in the scatter of the buckling limit load.

References listed at the end of the paper:
Furthermore, a series of Finite Element Modeling (FEM) variation of the first natural frequency of vibration with the applied compressive load was measured up to the buckling load of the grid stiffened composite cylindrical shells loaded in compression. Three specimens were fabricated using a new silicone rubber mold, and special silicone rubber mold, and specially-designed filament winding setup. The modal behavior of the grid-stiffened composite cylindrical shells was investigated by exciting the structures using modal hammer method in different applied compression load. Then, the variation of the first natural frequency of vibration with the applied compressive load was measured up to buckling during testing. Furthermore, a series of Finite Element Models (FEMs), including nonlinear effects.
such as geometric and thickness imperfection, are carried out in order to characterize the variation of the natural frequencies of vibration with the applied load and also compare it with the experimental results. Finally, the buckling test was performed to validate the experimental and numerical results of VCT approach. The results showed that the difference between the predicted buckling load using the VCT approach on the experimental results and numerical results with an experimental buckling load is 3.1% and 5.0%, respectively. Also, the current VCT approach has a very good correlation for grid-stiffened composite cylindrical shells when the maximum applied load is higher than 68% of the experimental buckling load.

References listed at the end of the paper:


ABSTRACT: Cylindrical shells enabling most advanced specific stiffness/strength designs for structural components in aerospace applications. Currently, imperfection sensitive shell structures prone to buckling are designed according to the NASA SP-8007 guideline [1], from 1968, using its conservative lower bound curve. In this guideline the structural behaviour of composite materials is not appropriately considered, since the imperfection sensitivity and the buckling load of shells made of advanced composites materials depend on the lay-up design. The most critical aspect for numerical -:: 3 570/ · .9 43 8 9 0 8 9 7:9 70 8 8038 9 ; 9 94 geometric and loading imperfections. A European project DESICOS [2] (New Robust DESign Guideline for Imperfection Sensitive COmposite Launcher Structures) is working on new methodologies to estimate the ultimate load of such structures. In this context an experimental buckling characterisation of a composite cylinder with three eccentric supports will be outlined. The study involves assessment of strain distribution correlating with various load introduction cases.

References listed at the end of the paper:
3 Hilburger, M.W., Developing the next generation shell buckling design factors and technologies, AIAA Proceedings, 2012.

ABSTRACT: The paper present a discussion related to the use of the “Single perturbation Load Approach” (SPLA) as a methodology to represent geometric imperfection of imperfection sensitive shell structures prone to buckling. In this context, the paper compares the effect of the SPLA on the buckling load of composite cylindrical shells against an alternative methodology, which combines several perturbation loads in different positions, called “Multiple Perturbation Load Approach”. The aim of this paper is to investigate if the SPLA is the worst geometrical imperfection case scenario to be used for finite element simulation. Since the paper is based on experimental results, a benchmark case is developed using a composite cylindrical shell with a radius over thickness ratio of 400. The results of buckling load using one, two and three perturbation loads distributed along the surface of the cylinder shown that the less conservative knock-down factors are obtained by using SPLA.

References listed at the end of the paper:


ABSTRACT: Thin-walled cylindrical composite shell structures can be applied in space applications, looking for lighter and cheaper launcher transport system. These structures are prone to buckling under axial compression and may exhibit sensitivity to geometrical imperfections. Today the design of such structures is based on NASA guidelines from the 1960’s using a conservative lower bound curve generated from a database of experimental results. In this guideline the structural behavior of composite materials may not be appropriately considered since the imperfection sensitivity and the buckling load of shells made of such materials depend on the lay-up design. It is clear that with the evolution of the composite materials and fabrication processes this guideline must be updated and / or new design guidelines investigated. This need becomes even more relevant when cutouts are introduced to the structure, which are commonly necessary to account for access points and to provide clearance and attachment points for hydraulic and electric systems. Therefore, it is necessary to understand how a cutout with different dimensions affects the buckling load of a thin-walled cylindrical shell structure in combination with other initial geometric imperfections. In this context, this paper present some observations regarding the buckling load behavior vs. cutout size and radius over thickness ratio, of laminated composite curved panels and cylindrical shells, that could be applied in further recommendations, to allow identifying when the buckling of the structure is dominated by the presence of the cutout or by other initial imperfections.

References listed at the end of the paper:
ABSTRACT: The effect of unreinforced circular cutouts on the buckling of circular cylindrical shells under axial compression.


ABSTRACT: A multi-mode reduced order approach for post-buckling analysis of dynamically loaded structures is presented. The post-buckling behavior of typical composite panels under dynamic loading is studied. In particular, nonlinear modal interactions are illustrated and explained.

References listed at the end of the paper:


ABSTRACT: Structural stability is an important design consideration for launch-vehicle shell structures and it...
is well known that the buckling response of such shell structures can be very sensitive to small geometric imperfections. As part of an effort to develop new buckling design guidelines for sandwich composite cylindrical shells, an 8-ft-diameter honeycomb-core sandwich composite cylinder was tested under pure axial compression to failure. The results from this test are compared with finite-element-analysis predictions and overall agreement was very good. In particular, the predicted buckling load was within 1% of the test and the character of the response matched well. However, it was found that the agreement could be improved by including composite material nonlinearity in the analysis, and that the predicted buckling initiation site was sensitive to the addition of small bending loads to the primary axial load in analyses.

References listed at the end of the paper:


ABSTRACT: A multi-objective Optimality Criteria (OC) is used to obtain optimum design of metal cylindrical shells under combined external loading. The objectives are to maximize the axial and hoop stiffness and minimize the mass of stiffened cylinders subject to the constraints, including functions of weight and buckling load, in such a way that the stiffened shell has no increase in weight and no decrease in buckling load, with respect to the initial unstiffened shell. The optimization process contains six design variables, including shell thickness, number of circular ring stiffeners, number of longitudinal stringer stiffeners, height of ring stiffeners, width of ring stiffeners, and longitudinal stiffener eccentricity from the shell centerline. In the analytical
solution, the Rayleigh-Ritz energy procedure is applied and the ring stiffeners are treated as discrete elements. The shapes of the ring and stringer stiffeners are assumed rectangular and Z, respectively. The shell is subjected to uniform axial and non-constant external pressure, simultaneously. The longitudinal stringers are placed in equal spacing, whereas the rings can be placed in an unequal space, due to the non-constant of external pressure over the cylinder length. The results show that the iteration numbers depend on the ring stiffener space states.

Chiara Bisagni, Potito Cordisco, Haim Abramovich and Tanchum Weller, “Cyclic buckling tests of CFRP curved panels”, 25th International Congress of the Aeronautical Sciences (ICAS), 2006

ABSTRACT: Experimental results obtained on three carbon fibre composite stiffened curved panels subjected to static and cyclic compression and shear loadings are presented. The results obtained from static tests performed on two panels are described in terms of global axial load vs. shortening curve, torque vs. rotation curve, and strain measurements.

A third panel was subjected to a cyclic loading, at 2 Hz, from above zero till 1.6 times its static buckling load, allowing the investigation of the effect of cyclic buckling in terms of axial load vs. shortening behaviour and strain measurements.

The obtained results show that this kind of structures can well work in the post-buckling field even if during their operative life the buckling load is reached thousands of times.

Richard Degenhardt, Jan Tessmer and Alexander Kling, “Collapse behaviour of thin-walled CFRP structures due to material and geometric nonlinearities – Experiments and simulation”, 26th International Congress of the Aeronautical Sciences (ICAS), 2008

ABSTRACT: Aerospace industry strives for significantly reduced development and operating costs. Reduction of structural weight at safe design is one possibility to reach this objective. Another one is the use of reliable simulation methods in order to minimize expensive and time consuming experimental design studies. DLR has developed improved concepts and tools for fast and reliable simulation of the buckling and the postbuckling behaviour of thin-walled structures up to collapse, respectively, which allow the exploitation of considerable reserves in primary fibre composite structures in aerospace applications [1-4]. For the validation of these concepts and tools, a sound database of experiments is needed. Such has grown considerably through many recent projects (e.g. EU-“COCOMAT” [5,6], EU-“POSICOSS”, ESA-“Probabilistic Aspects of Buckling Knock Down Factors — Tests and Analysis”, etc.). The paper presents first the experimental activities at the buckling test facility of the DLR Institute of Composite Structures and Adaptive Systems with an overview about buckling, postbuckling and collapse tests in combination with advanced measurement systems. Secondly, suitable computational methods are presented.

References listed at the end of the paper:

ABSTRACT: Adopting composite aero structures at safe design to operate in the postbuckling state, between the design limit and ultimate loads and possibly even below the design limit load, can potentially lead to significantly lighter aero structures. For this reason the research field related with buckling and postbuckling design, analysis and tests has drawn great attention and obtained some research achievements in current years. However, it is still difficult to predict the buckling and postbuckling strength of these structures.

The first part of the research consists in the design, manufacturing, measuring and testing of single stringer composite specimens. The specimens are in carbon fibers reinforced plastics, and consist of a skin panel with one stiffener, where the L-shaped stiffener is co-cured with the skin. The design is performed with numerical analysis using the finite element code ABAQUS to investigate the buckling and post buckling field under static compression. The tests are then performed under axial compression, where the compression load leads the panels to buckle.

The second part of the research consists in the study of the damage, including the damage modes as well as the damage propagation. Indeed, the out-of-plane deformation due to buckling causes progressive damage propagation. The results of the numerical analysis are compared to the experimental ones in terms of load-shortening curves, post-buckling shapes and progressive damage propagation.

References listed at the end of the paper:
ABSTRACT: In this work, a recently proposed nonlocal theory of bending is used in the analysis of eigenfrequencies of single-walled carbon nanotubes (SWCNTs). The nanotube vibration is analyzed in the form of a homogenized continuum. Classical treatment where a nanotube is approximated by standard beam theory, is replaced by the more sophisticated nonlocal method of material interactions where a nonlocal parameter is used. The eigenfrequencies are computed by the combination of analytical as well as numerical methods for four different carbon nanotube (CNT) supports. Various types of supports are considered for the analysis: fixed–simply supported, fixed–free, simply–simply supported and fixed–fixed. Due to the huge amount of computed data, only outcomes of eigenfrequency computations for the nanobeams of armchair type with fixed and simply supported ends, and different nonlocal parameters are represented in the form of graphs at the end of the article. The study shows how the nanotube eigenfrequencies depend on nonlocal parameters as well as on the length and diameter of CNTs. The obtained results are in good agreement with the results published in papers which were gained by different procedures.

References listed at the end of the paper:


ABSTRACT: An Element Free Galerkin Method (EFGM) for the analysis of degenerated shell structures is presented. The method is based on the Moving Kriging (MK) Interpolation function. The properties of the interpolation function possess the Kronecker delta property. With the MK Interpolation function no additional treatment required at the boundary conditions compared with that of using Moving Least Square (MLS) approximation. This deficiency of MLS at boundary condition has been definitely eradicated. The membrane and shear locking in the numerical analysis for degenerated shell problems has been alleviated by using higher order and removed by using quartic order of polynomials. Numerical benchmark examples for shell structures are presented to validate the proposed approach.

References listed at the end of the paper:
Defects in composite materials are created during manufacture to a large extent. To avoid them as much as possible, it is important that process simulations model the onset and the development of these defects. It is then possible to determine the manufacturing conditions that lead to the absence or to the controlled presence of such defects. Three types of defects that may appear during textile composite reinforcement or prepreg forming are analysed and modelled in the present paper. Wrinkling is one of the most common flaws that occur during textile composite reinforcement forming processes. The influence of the different rigidities of the textile reinforcement is studied. The concept of ‘locking angle’ is questioned. A second type of unusual behavior of fibrous composite reinforcements that can be seen as a flaw during their forming process is the onset of peculiar "transition zones" that are directly related to the bending stiffness of the fibers. The ‘transition zones’ are due to bending stiffness of fibres. The standard continuum mechanics of Cauchy is not sufficient to model these defects. A second gradient approach is presented that allows to account for such unusual behaviors zones' are due to bending onsets and developments during forming processes. Finally the large slippages that may occur during a preform forming are discussed and simulated with meso F.E. models used for macroscopic forming processes. It may occur during a preform forming are discussed and simulated with meso F.E. models used for macroscopic forming processes. Finally the large slippages that may occur during a preform forming are discussed and simulated with meso F.E. models used for macroscopic forming processes. Finally the large slippages that may occur during a preform forming are discussed and simulated with meso F.E. models used for macroscopic forming processes. Finally the large slippages that may occur during a preform forming are discussed and simulated with meso F.E. models used for macroscopic forming processes.


33. Sharma SB, Sutcliffe MPF, Chang SH. Characterisation of material properties for draping of dry woven composite material. Compos Part A 2003;34:1167–75.


ABSTRACT: Experimental testing on dry woven fabrics exhibits a complex set of evidences that are difficult to be completely described using classical continuum models. The aim of this paper is to show how the introduction of energy terms related to the micro-deformation mechanisms of the fabric, in particular to the bending stiffness of the yarns, helps in the modeling of the mechanical behavior of this kind of materials. To
this aim, a second gradient, hyperelastic, initially orthotropic continuum theory is proposed to model fibrous composite interlocks at finite strains. In particular, the present work explores the relationship between the onset of wrinkling appearing during the simulation of the deep drawing of a woven fabric and the use of a second gradient model. It is shown that the introduction of second gradient terms accounting for the description of in-plane and out-of-plane bending rigidities, decreases the onset of wrinkles during the simulation of deep-drawing. In this work, a quadratic energy, roughly proportional to the square of the curvature of the fibers, is presented and implemented in the simulations. This simple constitutive assumption allows to clearly show the effects of the second gradient energy on both the wrinkling description and the numerical stability of the model. The results obtained in second gradient simulations are descriptive of the experimental evidence of deep drawing whose description is targeted in this work. The present paper provides additional evidence of the fact that first gradient continuum theories alone cannot be considered fully descriptive of the behavior of dry woven composite reinforcements. On the other hand, the proposed second gradient model for fibrous composite reinforcements opens the way both to the more accurate simulation of complex forming processes and to the possibility of controlling the onset of wrinkles.

References listed at the end of the paper:


Ciarletta P (1), Destrade M (2), Gower AL (3)

(1) Department of Mathematics, Politecnico di Milano, Italy
(2) National University of Ireland, Galway, Ireland
(3) The University of Sheffield, UK


ABSTRACT: We propose two toy-models to describe, predict, and interpret the wrinkles appearing on the surface of skin when it is sheared. With the first model, we account for the lines of greatest tension present in human skin by subjecting a layer of soft tissue to a pre-stretch, and for the epidermis by endowing one of the layer’s faces with a surface tension. For the second model, we consider an anisotropic model for the skin, to reflect the presence of stiff collagen fibres in a softer elastic matrix. In both cases, we find an explicit bifurcation criterion, linking geometrical and material parameters to a critical shear deformation accompanied by small static wrinkles, with decaying amplitudes normal to the free surface of skin.

References listed at the end of the paper:


ABSTRACT: Six laboratory scale, mild steel pipes with the outside diameter-to-wall-thickness ratio, D/t about
40, were dented to about 15–20% of outside diameter $D_o$, by a hemispherical indenter with its diameter to pipe’s outside diameter ratio, $2a/D_o$ about 0.41. Three pipes had surface gouges running axially in them, and the remaining three were gouge free. Five of them were then collapsed by a bending moment followed by pressure burst tests. Experimental test data has been used to benchmark the finite element results, details of which are given in this paper. Good agreement between experimental and numerical results was obtained in the modeling of denting, but not so well in the modeling of bending — indicating the need for further work in order to address the discrepancies. DOI: 10.1115/1.2891913

References listed at the end of the paper:


13. MSC/Patran, 2001, ra2, PDA Engineering Software Product Division, Santa Ana, CA.


these structural behaviours of beams and plates at both micro- and macro- scales using the variational principle. Numerical results are computed using MATLAB and verified with the published results to demonstrate the accuracy and efficiency of the developed theoretical formulation. The numerical applications include: 1. the free vibration and buckling behaviours of FG and FG sandwich macrobeams under arbitrary boundary conditions and mechanical/thermal loads, 2. the static, free vibration and buckling behaviours of simply supported FG microbeams, and the free vibration behaviour of bidirectional FG microbeams under arbitrary boundary conditions, 3. the static, free vibration and buckling behaviours of simply supported FG-sandwich microplates under mechanical/thermal loads, and 4. the static, free vibration and buckling behaviours of FG-sandwich microplates with two opposite simply supported edges and various boundary conditions for other edges. The outcomes from this thesis emphasize the need of including couple stress in analyzing the structural behaviours of FG beams and plates at microscales. Some of them are presented at the first time and can be used as the benchmark results for numerical methods. These analytical methods can also be combined with other strong form methods to analyse various types of complex structures.

References listed at the end of the dissertation:


[126] Simsek M, Reddy JN. Bi-directional functionally graded materials (BDFGMs) for free and forced vibration of Timoshenko beams with various boundary conditions. Composite Structures. 2015;133:968-78.

[191] Thai HT, Uy B. Levy solution for buckling analysis of functionally graded plates based on a refined plate theory. P I Mech Eng

ABSTRACT: With increasing size of wind turbines, new approaches to load control are required to reduce the stresses in blades. Experimental and numerical studies in the fields of helicopter and wind turbine blade research have shown the potential of shape morphing in reducing blade loads. However, because of the large size of modern wind turbine blades, more similarities can be found with wing morphing research than with helicopter blades. Morphing technologies are currently receiving significant interest from the wind turbine community because of their potential high aerodynamic efficiency, simple construction and low weight. However, for actuator forces to be kept low, a compliant structure is needed. This is in apparent contradiction to the requirement for the blade to be load carrying and stiff. This highlights the key challenge for morphing structures in replacing the stiff and strong design of current blades with more compliant structures. Although not comprehensive, this review gives a concise list of the most relevant concepts for morphing structures and materials that achieve compliant shape adaptation for wind turbine blades.

References listed at the end of the paper:
6 Andersen PB, Gaunaa M, Bak C, Buhl T. Load alleviation on wind turbine blades using variable airfoil geometry, European Wind Energy Conference & Exhibition (EWEC), 27 February - 2 March 2006.
32 Daynes S, Weaver PM. A shape adaptive airfoil for a wind turbine blade, SPIE Smart Structures/NDE, San Diego, California, USA, 6-10 March 2011.
34 Thill C, Etches JA, Bond IP, Potter KD, Weaver PM. Corrugated composite structures for aircraft morphing skin applications, 18th International Conference of Adaptive Structures and Technologies, Ottawa, Ontario, Canada, 3-5 October 2007.
54 Johnson SJ, vanDam CP, Berg DE. Active Load Control Techniques for Wind Turbines. Sandia National Laboratories:
ABSTRACT: The loads on wind turbine components are primarily from the blades. It is important to control these loads in order to avoid damaging the wind turbine. Rotor control technology is currently limited to controlling the rotor speed and the blade pitch. As blades increase in length, it becomes less desirable to pitch the entire blade as a single rigid body, but there is a requirement to control loads more precisely along the length of the blade. This can be achieved with aerodynamic control devices such as flaps. Morphing structures are good candidates for wind turbine flaps because they have the potential to create structures that have the conflicting abilities of being load carrying, lightweight and shape adaptive. A morphing flap design with an anisotropic cellular structure is presented, which is able to undergo large deflections and high strains. An aeroelastic analysis couples the work done by aerodynamic loads on the flap, the flap strain energy and the required actuation work to change shape. The morphing flap model is manufactured, and its stiffness is measured.

References listed at the end of the paper:
Giurgiuțiu V, Chaudhry Z and Rogers CA (1995) Engineering feasibility of induced strain actuators for rotor blade active vibration...


ABSTRACT: This work presents the results of 21 shear tests on three types of honeycomb cores: the HRH-78-3/16-3.0, HRH-10-3/16-6.0 and an aluminium honeycomb core made of 5052 alloy with 3/8” cells. First, a benchmark of the different designs for shear testing of the honeycomb cores is made. Then, several double lap specimens were fabricated and tested while a 3D image correlation system was used to record the tests. An experimental analysis of the post-buckling phenomena of the HRH-78 W is presented. An artificial neural network is developed and used to visually identify the buckles of the test specimens. Finally, a detailed description of the behaviour of the structure including the postbuckling scenario is presented.

References listed at the end of the paper:


Danilo Karlicic (1), Dragan Jovanovic (2), Predrag Kozic (2) and Milan Cajić (1)
(1) Mathematical Institute of the SASA, Serbian Academy of Science and Arts, Serbia
(2) Faculty of Mechanical Engineering, University of Niš, Serbia

ABSTRACT: In this study, we develop a model to describe the free vibration behavior of a cracked nanobeam embedded in an elastic medium by considering the effects of longitudinal magnetic field and temperature change. In order to take into account the small-scale and thermal effects, the Euler-Bernoulli beam theory based on the nonlocal elasticity constitutive relation is reformulated for one-dimensional nanoscale systems. In addition, the effect of a longitudinal magnetic field is introduced by considering the Lorenz magnetic force obtained from the classical Maxwell equation. To develop a model of a cracked nanobeam, we suppose that a nanobeam consists of two segments connected by a rotational spring that is located in the position of the cracked section. The surrounding elastic medium is represented by the Winkler-type elastic foundation. Influences of the nonlocal parameter, stiffness of rotational spring, temperature change and magnetic field on the system frequencies are investigated for two types of boundary conditions. Also, the first four mode shape functions for the considered boundary conditions are shown for various values of the crack position.

References listed at the end of the paper:
Julijana Simonovic (1), Danilo Karlicic (2) and Milan Cajic (2)

(1) Faculty of Mechanical Engineering, University of Niš, Serbia
(2) Mathematical Institute of the SASA, Serbian Academy of Science and Arts, Serbia


ABSTRACT: The presented paper deals with the analysis of energy transfer in the visco-elliastically connected circular double-membrane system for free transverse vibration of the membranes. The system motion is described by a set of two coupled non-homogenous partial differential equations. The solutions are obtained by using the method of separation of variables. Once the problem is solved, natural frequencies and mode shape functions are found, and then the form of solution for small transverse deflections of membranes is derived.

Using the obtained solutions, forms of reduced kinetic, potential and total energies, as functions of dissipation of the whole system and subsystems, are determined. The numerical examples are given as an illustration of the presented theoretical analysis as well as the possibilities to investigate the influence of different parameters and different initial conditions on the energies transfer in the system.

References listed at the end of the paper:

Danilo Karlicic (1), Milan Cajic (1) and Sondipon Adhikari (2)
(1) Mathematical Institute of the Serbian Academy of Science and Art, Kneza Mihaila 36, Belgrade 11001, Serbia
(2) College of Engineering, Swansea University, Singleton Park, Swansea SA2 8PP, UK


ABSTRACT: We use the incremental harmonic balance (IHB) method to analyse the dynamic stability problem of a nonlinear multiple-nanobeam system (MNBS) within the framework of Eringen’s nonlocal elasticity theory. The nonlinear dynamic system under consideration includes MNBS embedded in a viscoelastic medium as clamped chain system, where every nanobeam in the system is subjected to time-dependent axial loads. By assuming the von Karman type of geometric nonlinearity, a system of m nonlinear partial differential equations of motion is derived based on the Euler–Bernoulli beam theory and D’Alembert’s principle. All nanobeams in MNBS are considered with simply supported boundary conditions. Semi-analytical solutions for time response functions of the nonlinear MNBS are obtained by using the single-mode Galerkin discretization and IHB method, which are then validated by using the numerical integration method. Moreover, Floquet theory is employed to determine the stability of obtained periodic solutions for different configurations of the nonlinear MNBS. Using the IHB method, we obtain an incremental relationship with the frequency and amplitude of time-varying axial load, which defines stability boundaries. Numerical examples show the effects of different physical and material parameters such as the nonlocal parameter, stiffness of viscoelastic medium and number of nanobeams on Floquet multipliers, instability regions and nonlinear amplitude–frequency response curves of MNBS. The presented results can be useful as a first step in the study and design of complex micro/nanoelectromechanical systems.

References listed at the end of the paper:
1. Pourkiaee, S.M., Khadem, S.E., Shahgholi, M., Bab, S.: Nonlinear modal interactions and bifurcations of a piezo-electric nanoresonator with three-to-one internal resonances incorporating surface effects and van der Waals dissipation forces. Nonlinear Dynam. 3(88), 1785–1816 (2017)
19. Ansari, R., Sahmani, S.: Small scale effect on vibrational response of single-walled carbon nanotubes with different boundary
ABSTRACT: In this investigation, a continuum mechanics based shear deformable shell element of the absolute nodal coordinate formulation (ANCF) is generalized to a laminated shell element for application to the modeling of fiber-reinforced rubber (FRR) structure of the physics-based ANCF tire model. The complex deformation coupling exhibited in fiber-reinforced composite materials can be automatically considered in the shear deformable laminated shell element using the continuum mechanics approach, and the element lockings are systematically eliminated by the assumed natural strain and enhanced strain approaches, thereby leading to a locking-free shear deformation ANCF laminated shell element. Furthermore, various nonlinear material models can be considered for each layer in a way same as solid elements. Using the ANCF laminated shell element developed, a physics-based ANCF tire model is developed by considering the detailed tire geometry and
material properties. The experimental validation of the tire model is conducted for the load-deflection curve to ensure that the fundamental structural tire properties can be correctly captured in the ANCF tire model. References listed at the end of the paper:


Hiroki Yamashita (1), Paramsothy Jayakumar (2), Mustafa Alsaleh (3), and Hiroyuki Sugiyama (1)
(1) Department of Mechanical and Industrial Engineering, University of Iowa, Iowa City, IA 52242, USA
(2) U.S. Army Tank Automotive Research Development and Engineering Center, Warren, MI 48397-5000, USA
(3) Caterpillar Inc., Product Development & Global Technology, Mossville, Illinois, USA


ABSTRACT: A high-fidelity physics-based deformable tire-soil interaction model that can be fully integrated into multibody dynamics computer algorithms is developed for use in off-road mobility simulation. To this end, the finite-element (FE) tire simulation capability based on the flexible multibody dynamics approach, which allows for modeling the coupling of the structural tire dynamics and transient tire friction under hard braking and concerning maneuvers, is further extended to off-road mobility simulations. A locking-free nine-node brick element is developed by introducing an additional center node to the standard 8-node brick element, which defines the second derivative of the global position vector at this node, to alleviate the element lockings without special techniques such as the enhanced assumed strain approach. This allows for a straightforward implementation of the multiplicative finite strain plasticity theory along with the capped Drucker-Prager failure criterion to model the large plastic soil deformation exhibited as sinkage on deformable terrains. The tire-soil interaction model is fully integrated into the monolithic multibody dynamics computer algorithm to ensure the accuracy and numerical stability under transient vehicle maneuvers. In order to identify soil parameters including cohesion and friction angle, the triaxial soil test is carried out, and the soil model developed is validated against the test data. Use of the high-fidelity physics-based tire-soil simulation model in off-road mobility simulations, however, leads to a very large computational model to consider a wide range of terrains. Thus, the computational cost dramatically increases as the size of the soil model increases. To address this issue, the moving soil patch technique is applied such that the soil behavior only in the vicinity of the rolling tire is solved to reduce the model dimensionality associated with the finite-element soil model. It is shown that use of
this approach leads to a significant reduction in computational time while ensuring the accuracy. Finally, the proposed off-road tire-soil simulation capability is validated against test data obtained from a soil bin mobility test facility, including the effect of wheel loads and tire inflation pressures on the longitudinal/cornering tire forces and the rolling resistance.

References listed at the end of the paper:


ABSTRACT: Assessing the mobility of off-road vehicles is a complex task that most often falls back on semi-empirical approaches to quantifying the vehicle–terrain interaction. Herein, we concentrate on physics-based methodologies for wheeled vehicle mobility that factor in both tire flexibility and terrain deformation within a fully three-dimensional multibody system approach. We represent the tire based on the absolute nodal coordinate formulation (ANCF), a nonlinear finite element approach that captures multi-layered, orthotropic shell elements constrained to the wheel rim. The soil is modeled as a collection of discrete elements that interact through contact, friction, and cohesive forces. The resulting vehicle/tire/terrain interaction problem has several millions of degrees of freedom and is solved in an explicit co-simulation framework, built upon and now available in the open-source multi-physics package Chrono. The co-simulation infrastructure is developed using a Message Passing Interface (MPI) layer for inter-system communication and synchronization, with additional parallelism leveraged through a shared-memory paradigm. The formulation and software framework presented in this investigation are proposed for the analysis of the dynamics of off-road wheeled vehicle mobility. Its application is demonstrated by numerical sensitivity studies on available drawbar pull, terrain resistance, and sinkage with respect to parameters such as tire inflation pressure and soil cohesion. The influence of a rigid tire assumption on mobility is also discussed.

References listed at the end of the paper:
Lorenzo Franzoni (1), Arthur Lebée (1), Florent Lyon (2) and Gilles Foret (1)
(1) Université Paris – Est, Laboratoire Navier (ENPC/ IFSTTAR/ CNRS). 6/8 Avenue B. Pascal 77455 Champs-sur-Marne, France
(2) Centre Scientifique et Technique du Bâtiment (CSTB). 84 Avenue J. Jaurès 77455 Champs-sur-Marne, France

“Bending behavior of regularly spaced CLT panels”, World Conference on Timber Engineering (WCTE 2016), Vienna, Austria, August 22-25, 2016

ABSTRACT: A regular alternation of lamellas and voids filled by insulating material within each layer of CLT [Cross Laminated Timber] can lead to cellular panels with improved acoustical, thermal and fire performance. In order to support the development of these innovative and lighter engineered wood products, their mechanical behavior is investigated in this paper by means of experiments and modeling. First, an experimental campaign
on spaced CLT panels and related results are presented. Then, both simplified and refined modelings are applied. The chosen accurate modeling is a periodic homogenization scheme handled by a plate theory [1] and based on unit-cell strain energy computation with FEM. It appears that the simplified approach can predict the bending stiffness (EI) of CLT panels with large voids but not their transverse shear stiffness (GA) which can be precisely predicted with the more refined modeling. Finally, the influence of several panel’s parameters on the mechanical response is pointed out as well.

References listed at the end of the paper:

[17] EN 16351 Timber Structures – Cross Laminated Timber – Requirements

A. Lebée [Université Paris-Est, Laboratoire Navier (ENPC, IFSTTAR, CNRS). École des Ponts ParisTech, 6 et 8 avenue Blaise Pascal. 77455 Marne-la-Vallée, France], “From Folds to Structures, a Review”. International Journal of Space Structures, 30(2):55–74, 2015. ABSTRACT: Starting from simple notions of paper folding, a review of current challenges regarding folds and structures is presented. A special focus is dedicated to folded tessellations which are raising interest from the scientific community. Finally, the different mechanical modeling of folded structures are investigated. This reveals efficient applications of folding concepts in the design of structures. References listed at the end of the paper:

ABSTRACT: "Image based simulation of large strain deformation of open celled foams", Materials Evaluation, January 2008

References listed at the end of the paper:

B. Notarberardino (1), P. Young (1), B. Walker (2), A. Abdul-Aziz (3) and G. Seidler (4)
(1) School of Engineering and Computer Science, University of Exeter, Harrison Building, North Park Rd., Exeter EX4 4QF, England
(2) Arup Campus, Blythe Valley Business Park, Solihull, West Midlands B90 8AE, England
(3) Cleveland State University, Department of Civil Engineering, NASA Glenn Research Center, Cleveland, Ohio
(4) Department of Physics, University of Washington, Seattle, Washington, USA

**ABSTRACT:** Finite element analysis is used to model the automatic cambering of the locust hind wing during promotion: the umbrella effect. It was found that the model required a high degree of sophistication before replicating the deformations found in vivo. The model has been validated using experimental data and the deformations recorded both in vivo and ex vivo. It predicts that even slight modifications to the geometrical description used can lead to significant changes in the deformations observed in the anal fan. The model agrees with experimental data and produces deformations very close to those seen in free-flying locusts. The validated model may be used to investigate the varying geometries found in orthopteran anal fans and the stresses found throughout the wing when loaded.

References listed at the end of the paper:


Jacek Chrósielewski (1), Jerzy Makowski (2) and Wojciech Pietraszkiewicz (3)

(1) Technical University of Gdańsk, Poland
(2) Ruhr University of Bochum, Germany
(3) Polish Academy of Sciences, Institute of Fluid-Flow Machinery, Gdańsk, Poland

“Large overall motion of flexible branched shell structures”, publisher and date not given in the pdf file. Most recent reference is dated 1999.

ABSTRACT: Within the six-field theory of branched shell structures, a time-stepping algorithm of the non-linear dynamic analysis in the manifold E³ ⊕ SO(3) is discussed. An indirect C⁰ interpolation procedure on SO(3) with a transport of approximation domain is developed. The results of some simulations of the 2D and 3D large motion of the flexible, elastic shell structures are presented.

References listed at the end of the paper:

ABSTRACT: Cold-formed built-up members are compression members that are common in multiple areas of steel construction, which include cold-formed steel joints and stud walls. These members are vulnerable to unique buckling behaviors; however, limited experimental research has been done in this area. Give this gap, experimental testing of 71 built-up members was conducted in this study. The variations of the test specimens include multiple lengths, intermediate welds, orientations, and thicknesses. The experimental testing was devised to observe the different buckling modes of the built-up C-channels and the effects of the geometrical properties; to check for applicability of multiple intermediate welding patterns; and to evaluate both the 2001 and 2007 editions of the American Iron and Steel Institute (AISI) Specification for built-up members in pure compression. The AISI-2001 and AISI-2007 were found to give inconsistent results that at times were un-conservative or overly conservative in terms of axial strength. It was also found that orientation of the member has an important impact on the maximum failure load on the member.

Jamshid Fazilati (1), Vahid Khalafi (1) and Hossein Shahverdi (2)
(1) Department of Aeronautical Science and Technology, Aerospace Research Institute, Tehran, Iran
(2) Department of Aerospace Engineering and Center of Excellence in Computational Aerospace Engineering, Amirkabir University of Technology, Tehran, Iran


ABSTRACT: In the present paper, the aero-thermo-elastic behavior of a finite (three-dimensional) cylindrical curved panel geometry made from functionally graded material under high supersonic airflow is investigated. A generalized differential quadrature formulation is adopted while a steady-state through-the-thickness thermal field is also assumed. The geometry curvature and structural nonlinearity effects are included based on von Karman–Donnell strain–displacement relations. The nonlinear piston theory of third order is utilized in order to predict the unsteady aerodynamics loads induced from surrounding supersonic air stream. The functionally graded material is considered with temperature-dependent properties distributed in the thickness according to a power law function. Derived from the equilibrium equations, the aero-thermo-elastic governing equations are reduced to number of ordinary differential equations through using of the generalized differential quadrature method where the structure response is derived using fourth-order Runge–Kutta technique. The contribution of some parameters including flow Mach number, flow dynamic pressure, thickness temperature gradient, and functionally graded material volume fraction index on the flutter response as well as route-to-chaos behavior are reviewed. The calculated results are compared with those available in the literature wherever available and the accuracy and quality of the adopted generalized differential quadrature formulation in analyzing the aero-thermo-elastic behavior of three-dimensional functionally graded curved panels is shown. It reveals that using a three-dimensional approach, if any of Mach number and panel’s upper surface temperature is increased, the route-to-chaos behavior is reached through quasi-periodic motions.

References listed at the end of the paper:
REFERENCES listed at the end of the paper:


ABSTRACT: A design procedure is presented to estimate the load carrying capacity of beam-column channel sections. A reduced cross-section is used to compensate for the reduction in the post-buckling stiffness. The non-linear stress distribution acting on the entire channel width is replaced by simplified linear distributions. Using this simplified concept, the maximum stress in the post-buckling state, is assumed to be carried entirely by both edges while the central region of the channel remains unstressed. Thus a fraction of the channel section is considered in resisting the applied loading. This approximation enables the structural engineer to deal with a simplified stress distribution to compute the ultimate strength instead of the non-linear one.

References listed at the end of the paper:


ABSTRACT: We investigate theoretically and experimentally the nonlinear responses of a clamped-clamped buckled beam to a variety of external harmonic excitations and internal resonances. We assume that the beam geometry is uniform and its material is homogeneous. We initially buckle the beam by an axial force beyond the critical load of the first buckling mode, and then we apply a transverse harmonic excitation that is uniform over its span. The beam is modeled according to the Euler-Bernoulli beam theory and small strains and moderate rotation approximations are assumed. We derive the equation of motion governing the nonlinear transverse planar vibrations and associated boundary conditions using the extended Hamilton’s principle. The governing equation is a nonlinear integral-partial-differential equation in space and time that possesses quadratic and cubic nonlinearities. A closed-form solution for such equations is not available and hence we seek approximate solutions.

We use perturbation methods to investigate the slow dynamics in the neighborhood of an equilibrium configuration. A Galerkin approximation is used to discretize the nonlinear partial-differential equation governing the beam’s response and obtain a set of nonlinearly coupled ordinary-differential equations governing the time evolution of the response. We based our theory on a multi-mode Galerkin discretization. To investigate the large-amplitude dynamics, we use a shooting method to numerically integrate the discretized equations and obtain periodic orbits. The stability and bifurcations of these periodic orbits are investigated using Floquet theory.

We solve the nonlinear buckling problem to determine the buckled configurations as a function of the applied axial load. We compare the static buckled configurations obtained from the discretized equations with the exact ones. We find out that the number of modes retained in the discretization has a significant effect on these static configurations. We consider three cases: primary resonance, subharmonic resonance of order one-half of the first vibration mode, and one-to-one internal resonance between the first and second modes. We obtain interesting dynamics, such as phase-locked and quasiperiodic motions, resulting from a Hopf bifurcation, snapthrough motions, and a sequence of period-doubling bifurcations leading to chaos.

To validate our theoretical results, we ran an experiment, which is a modified version of the experiment designed by Kreider and Nayfeh. We find that the obtained theoretical results are in good qualitative agreement with the experimental results. In the case of one-to-one internal resonance, we report, theoretically and experimentally, energy transfer between the first mode, which is externally excited, and the second mode.

References listed at the end of the thesis:

high node congruence is proposed. They correspond to particular geometrical constraints and that exhibit extensively, the question of the repetition of nodes in free-form structures has rarely been addressed yet. In this paper, a family of surfaces that can be optimized regarding typical geometrical constraints and that exhibit high node congruence is proposed. They correspond to particular meshes of moulding surfaces and are called...
isogonal moulding surfaces by the authors. The geometrical properties of these surfaces are discussed. In particular, it is shown how to derive Edge Offset Mesh from them. It is also demonstrated that they represent all the possible meshes parallel to surfaces of revolution. Finally, the reader is introduced to some computational strategies linked to isogonal moulding surfaces.

References listed at the end of the paper:


Springborn (2006) to generate minimal S-isothermic nets. The method takes as input a CMC (smooth or finely triangulated), remeshes its Gauss map with quadrangular faces, and rebuilds a CMC mesh via a parallel transformation. The resulting mesh is S-CMC, a geometric structure discovered by Hoffmann (2010). This type of mesh have planar quads and offset properties, which are of particular interest in the fabrication of gridshells. References listed at the end of the paper:


Romain Mesnil (1,2), Cyril Douthe (2), Olivier Baverel (2) and Bruno Leger (1)
(1) Bouygues Construction, France
(2) Laboratoire NAVIER, Ecole des Ponts, IFSTTAR, CNRS, (UMR 8205), Université Paris-Est (UPE), France


ABSTRACT: We introduce an intuitive method, called Marionette, for the modelling of free-form architecture with planar facets. The method takes inspiration from descriptive geometry and allows to design complex shapes with one projection and the control of elevation curves. The proposed framework achieves exact facet planarity in real time and considerably enriches previous geometrically constrained methods for free-form architecture. A discussion on the design of quadrilateral meshes with a fixed horizontal projection is first proposed, and the method is then extended to various projections and patterns. The method used is a discrete solution of a continuous problem. This relation between smooth and continuous problem is discussed and shows how to combine the marionette method with modelling tools for smooth surfaces, like non-uniform rational basis spline or T-splines. The result is a versatile tool for shape modelling, suited to engineering problems related to free-form architecture.

References listed at the end of the paper:

ThESHELL. Video of the Forum Solidays project. 2011. https://www.youtube.com/watch?v=jLq-

References listed at the end of the paper:


ABSTRACT: The Ephemerale Cathedral of Créteil at Paris, France, is a gridshell structure made of composite materials. Built in 2013, this 350 m² religious edifice is a temporary church meant to gather the parishioners during the two year renovation of their permanent cathedral. This large-scale prototype represents a first in the building industry which still shows excessive apprehension for the use of non-traditional materials such as composites, especially when it comes to structural applications.
References listed in the dissertation:


ABSTRACT: The last decades have seen the emergence of non-standard architectural shapes. Designers find themselves helpless with the geometrical complexity of these objects. Furthermore, the available tools dissociate shape and structural behaviour, which adds another complication. This dissertation takes the point of view based on invariance under geometrical transformations, and studies several strategies for fabrication-aware shape modelling. Three technological constraints have been identified and correspond to three independent contributions of this thesis.

The repetition of nodes is studied via transformations by parallelism. They are used to generalise surfaces of revolution. A special parametrisation of moulding surfaces is found with this method. The resulting structure has a high node congruence.

Cyclidic nets are then used to model shapes parametrised by their lines of curvature. This guarantees meshing by planar panels and torsion-free beam layout. The contribution of this dissertation is the implementation of several improvements, like doubly-curved creases, a hole-filling strategy that allows the extension of cyclidic nets to complex topologies, and the generation of a generalisation of canal surfaces from two rail curves and one profile curves.

Finally, an innovative method inspired by descriptive geometry is proposed to generate doubly-curved shapes covered with planar facets. The method, called marionette technique, reduces the problem to a linear problem, which can be solved in real-time. A comparative study shows that this technique can be used to parametrise shape optimisation of shell structures without loss of performance compared to usual modelling technique. The handling of fabrication constraints in shape optimisation opens new possibilities for its practical application, like gridshells or plated shell structures. The relevance of those solutions is demonstrated through multiple case-studies.


Surfaces. 38:67–93, 2008. 7.4.1
[226] H. Schober. Transparent shells - form topology structure. Ernst & Sohn, 2016. 1.1.3, 2.2.3, 2.2.4, 2.2.4, 3.1.1, 3.1.2, 3.3.3, 3.5.2, 7.3.6, 7.4.6
[262] W. Wang, J. Wallner, and Y. Liu. An angle criterion for conical mesh vertices. Geometry Pre-Print, 157:1–10, 2006. 2.3.4, 3.3.2, 3.5.2
[265] C. J. Williams. The definition of curved geometry for widespan structures. 2000. 2.4.1


INTRODUCTION: Les couvertures de bâtiment sont des structures spécifiques, leur chargement principal est en général leur propre poids. Chercher à concevoir ces structures les plus légères possible permet des avancées économiques, écologiques et esthétiques. Les méthodes constructives ont évoluées avec les époques et les matériaux disponibles, mais toujours autour de trois axes principaux : l’adaptation de la forme et du matériau, l’utilisation de la double courbure et la minimisation des efforts de flexion. C’est en cherchant à s’affranchir complètement des efforts de flexion sous poids propre que Frei Otto a développé les structures de gridshells. Ces coques discrètes à double courbure résultent de l’inversion d’un filet suspendu, elles sont donc les exacts funiculaires de leur propre poids. De plus, il met au point un procédé constructif original et très économique qui permet d’obtenir des surfaces gauches par déformation élastique et triangulation d’une grille plane sans rigidité en cisaillement et constituée d’éléments rectilignes standard. Après quelques réalisations mineures, le potentiel esthétique et mécanique de ces structures éclate avec la construction du gridshell de Mannheim en 1975. Pourtant le bâtiment ne fait pas école et reste pendant vingt-cinq ans le seul gridshell au monde, malgré des qualités remarquables sur le plan structurel. Deux raisons principales seront avancées pour expliquer cette situation : d’une part les méthodes de calcul de l’époque négligent la flexion dans les éléments et par conséquent ne permettent pas d’étudier précisément les contraintes dans la structure et d’autre part, les éléments
de la grille sont en bois lamellé-collé et leur état de flexion permanente pose des problèmes de fluage et de durabilité des assemblages. Dans le premier chapitre, après un historique des gridshells, on verra que les progrès de ces dernières années en matière de simulation numérique et les efforts de la filière bois pour rationaliser les profils ont permis un renouveau de ces structures en Angleterre avec les gridshells du musée de Downland et du Savill Building.

Il semble cependant possible d’aller plus loin dans cette rationalisation en proposant des solutions alternatives plus durables et plus performantes qui intègrent des nouveaux matériaux fibrés synthétiques en lieu et place de ce matériau composite anisotrope naturel qu’est le bois. Les polymères renforcés de fibres de verre ou de carbone sont relativement nouveaux dans le génie civil et la construction. Leurs applications actuelles copient les solutions techniques qui ont été optimisées pour l’acier (armature pour béton, renforcement par collage, poutrelle en I ou en H, etc.). Beaucoup plus souples que l’acier, les composites apparaissent rarement comme la solution la plus pertinente pour ces applications dans lesquelles les exigences de raideur conduisent à un surdimensionnement de la structure en terme de résistance. En revanche, les contraintes constructives des gridshells liées à leur processus de montage utilisent la déformabilité des éléments. Leur allongement élastique important et leur module d’Young élevé font donc des composites de bons candidats pour ce type de structure.

On remarque d’ailleurs que partout où une grande déformabilité et une grande raideur sont exigées en même temps, il s’imposent : ailes de planeur, arcs, skis, cannes à pêche, pare-chocs... Dans le deuxième chapitre, on démontrera donc que les composites verre/ré sine constituent véritablement une alternative intéressante au bois pour la construction des gridshells et on étudiera plus en détail le comportement mécanique de ces matériaux dans les conditions de flexion en grands déplacements qui sont celles des éléments d’un gridshell.

Effectivement, l’amplitude des déplacements qui interviennent durant le montage des gridshells est grande et leur calcul nécessite l’utilisation de méthodes numériques capables de prendre en compte des non-linéarités géométriques. Par le passé, trois méthodes ont été utilisées pour le calcul des gridshells : la méthode des densités de forces, la méthode de Newton-Raphson et la méthode de relaxation dynamique. C’est cette dernière qui a été choisie ici et qui sera exposée dans le troisième chapitre. Son principe consiste à remplacer la recherche de l’état d’équilibre statique par un calcul dynamique fictif qui, par amortissements successifs, va conduire à l’état d’équilibre statique. Les modèles utilisés pour le calcul dynamique et le calcul des efforts intérieurs sont exposés, ainsi qu’un modèle original pour la prise en compte des excentricités au niveau des liaisons. Viennent ensuite l’étude de la stabilité de l’algorithme et sa validation par de nombreuses comparaisons avec d’autres modèles analytiques et numériques, ce qui donnera l’occasion d’illustrer également la polyvalence de la méthode.

À la différence de la plupart des structures à double courbure existantes, la forme des gridshells ne peut pas être imposée : elle est l’unique forme d’équilibre qui satisfait un ensemble donné de contraintes géométriques et de conditions d’appui. La recherche de la forme est donc un enjeu en soi et elle fait l’objet du quatrième chapitre. Trois méthodes sont développées. La première a été systématisée par Frei Otto : elle repose sur l’étude de modèles réduits parfaitement tendus et conduit à des formes dont le contour ou les points d’appui sont imposés. La deuxième consiste l’un des objets de ce travail, elle est indissociable de l’utilisation de la méthode de relaxation dynamique et de la prise en compte de la raideur en flexion des éléments ; elle conduit à des formes dont les contours libres sont l’expression de la raideur naturelle de la matière. La troisième n’est qu’esquissée mais semble très prometteuse pour la conception de structures pour des enveloppes courbes, elle permet de fabriquer des grilles en équilibre sur des surfaces dont la forme est imposée.

Cependant la donnée de la forme ne suffit pas à définir une structure. Il faut bien entendu en étudier le comportement mécanique. Dans le cinquième chapitre, on aborde tout d’abord la question du règlement de construction de référence pour la définition des chargements et des critères de dimensionnement des éléments. Il semble aujourd’hui naturel que cette étude s’inscrive dans le cadre des Eurocodes. Il n’existe pas de tome spécifique dédié aux matériaux composites, mais des coefficients partiels de sécurité et des critères spécifiques ont déjà été proposés et seront examinés ici. À titre d’illustration, ils sont mis en œuvre dans l’étude d’un prototype de gridshell en composites construit à l’École Nationale des Ponts et Chaussées. Cette étude comprend la description des matériaux utilisés et l’identification de leurs propriétés mécaniques, la définition de la forme, l’étude de deux variantes de triangulation et celle du comportement sous chargement réglementaire. Chacune de ces étapes permet de mettre en lumière certains traits spécifiques du comportement des gridshells. Le sixième chapitre décrit la construction de ce prototype et le programme expérimental réalisé en collaboration avec l’École Nationale des Sciences Géographiques. Les différentes étapes du montage et les techniques utilisées sont tout d’abord expliquées, ainsi que les tests de chargement effectués sur la structure avant et après
triangulation. Les résultats de ces tests seront ensuite analysés afin notamment de quantifier l’effet de la triangulation. Ils seront également confrontés à un modèle numérique construit à partir du relevé des positions des appuis de la structure réelle. Cela permettra en outre de mieux comprendre le comportement d’ensemble de la structure et l’évolution des contraintes dans les éléments. Enfin, quelques éléments de bilan sur les coûts de ce prototype sont donnés afin de montrer sa compétitivité par rapport à des structures déjà exploitées industriellement dans la construction.

Le dernier chapitre rappellera les principaux résultats de ce travail et conclura sur l’efficacité des outils proposés pour l’analyse des structures élancées précontraintes en matériaux composites, la pertinence des structures de gridshells pour la réalisation de couvertures de moyenne ou de grande portée. Un dernier mot sera ajouté sur les perspectives de développement du programme et des méthodes, ainsi que sur les nouvelles applications envisageables.

References listed at the end of the dissertation:

R.A. Izadifard and M.R. Maheri (Department of Civil Engineering, Shiraz University, Iran), “Soil-structure interaction effects in buried cylindrical concrete structures”, Proceedings of the Tenth International Conference on Civil, Structural and Environmental Engineering Computing, B.H.V. Topping (Editor), Civil-Comp Press, Stirling, Scotland, Paper No. 271, January 2005
ABSTRACT: To design an underground structure against the earthquake or blast loading, the dynamic properties of such structures are often first established. In this paper, a finite element parametric dynamic analysis of the structure-soil system is carried out. The structures considered are cylindrical concrete structures and the main variable parameters include; the radius of the cylindrical structure (R), the ratio of the horizontal extent of the soil to the radius of the structure (L/R), the horizontal width of soil to the radius of the structure (H/R) and the ratio of depth of burial to the radius of the structure (D/R). It is shown that the conventional added-mass approach greatly overestimates the natural frequencies of the soil-structure system and the level of overestimation is more profound for the shallow-buried structures. For the deep-buried structures, the added-mass of soil dominates the response and the effect of the added-stiffness is reduced. Also it is found that the discrepancies in the results of the added-mass solution and the FE solution increase as the structure becomes more flexible.

References listed at the end of the paper:

ABSTRACT: Stiffened thin-walled steel cylinders have been used as compression elements in the field of offshore structures for many years. On-site durability of these structures may suffer from the harsh marine environment. Therefore, a structural health monitoring system that provides real-time structural feedback of the structure is mandatory to ensure the safe operations of an offshore structure. Hence, this study investigates the applicability of a new state-of-the-art methodology, called inverse finite element method (iFEM), for displacement and stress monitoring of offshore structures for the first time in the literature. Displacement and stress solutions obtained from iFEM analysis are compared to those of reference solutions.
References listed at the end of the paper:
(Cannot easily cut and paste them)

Shujuan Hou (1), Zhidan Zhang (1), Xujing Yang (1), Hanfeng Yin (1) and Qing Li (2)
(1) Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, China and College of Mechanical and Vehicle Engineering, Hunan University, Changsha, China
(2) School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Sydney,
ABSTRACT:

Purpose – The purpose of this paper is to optimize a new thin-walled cellular configuration with crashworthiness criteria, so as to improve the crashworthiness of components of a vehicle body.

Design/methodology/approach – ANSYS Parametric Design Language is used to create the parameterized models so that the design variables can be changed conveniently. Moreover, the surrogate technique, namely response surface method, is adopted for fitting objective and constraint functions. The factorial design and D-optimal criterion are employed to screen active parameters for constructing the response functions of the specific energy absorption and the peak crushing force. Finally, sequential quadratic programming-NLPQL is utilized to solve the design optimization problem of the new cellular configurations filled with multi-cell circular tubes under the axial crushing loading.

Findings – Two kinds of distribution modes of the cellular configurations are first investigated, which are in an orthogonal way and in a diamond fashion. After comparing the optimized configurations of the rectangular distribution with the annular distribution of the multi-cell fillers, it is found that the orthogonal way seems better in the aspects of crashworthiness than the diamond fashion.

Originality/value – The two new thin-walled cellular configuration are studied and optimized with the crashworthiness criteria. Study on the new cellular configurations is very valuable for improving the crashworthiness of components of a vehicle body. Meanwhile, the factorial design and the factor screening are adopted in the process of the crashworthiness optimization of the new thin-walled cellular configurations.

References listed at the end of the paper:


Hanfeng Yin, Jinle Dai, Guilin Wen, Wanyi Tian and Qiankun Wu (Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, Hunan, China), “Multi-objective optimization design of functionally graded foam-filled graded-thickness tube under lateral impact”, International Journal of Computational Methods, Vol. 5, No. 1, 1850088, 2018

ABSTRACT: Foam-filled thin-walled structure has been widely used in vehicle engineering due to its highly efficient energy absorption capacity and lightweight. Unlike the existing foam-filled thin-walled structures, a new foam-filled structure, i.e., functionally graded foam-filled graded-thickness tube (FGFGT), which had graded foam density along the transverse direction and graded wall thickness along the longitudinal direction, was first studied in this paper. Two FGFGTs with different gradient distributions subjected to lateral impact were investigated using nonlinear finite element code through LS-DYNA. According to the parametric sensitivity analysis, we found that the two design parameters n1 and n2, which controlled the gradient distributions of the foam density and the tube wall thickness, significantly affected the crashworthiness of the two FGFGTs. In order to seek for the optimal design parameters, two FGFGTs were both optimized using a meta-model-based multi-objective optimization method which employed the Kriging modeling technique as well as the nondominated sorting genetic algorithm II. In the optimization process, we aimed to improve the specific energy absorption and to reduce the peak crushing force simultaneously. The optimization results showed that the FGFGT had even better crashworthiness than the traditional uniform foam-filled tube with the same weight. Moreover, the graded wall thickness and graded foam density can make the design of the FGFGT flexible. Due to these advantages, the FGFGT was an excellent energy absorber and had potential use as the...
side impact absorber in vehicle body

References listed at the end of the paper:


Fang, J., Gao, Y., Sun, G., Qiu, N. and Li, Q. [2015b] “On design of multi-cell tubes under axial and oblique impact loads,” Thin-Walled Struct. 95, 115–126.


Hanfeng Yin (1), Youye Xiao (1), Guilin Wen (1) and Hongbing Fang (2)

(1) Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, Hunan, China

(2) Department of Mechanical Engineering and Engineering Science, The University of North Carolina at Charlotte, Charlotte, North Carolina, USA


ABSTRACT: As one of the most widely used safety devices on highways, W-beam guardrail plays an important role in protecting errant vehicles from entering dangerous zones or colliding with oncoming vehicles. As one of the most widely used safety devices on highways, W-beam guardrails play an important role in protecting errant vehicles from entering dangerous zones or colliding with oncoming vehicles. One common issue with the traditional W-beam guardrails (TWG) is tire snagging which often occurred when the wheel of a striking vehicle entangled with a guardrail post. Tire snagging reduces the redirection performance of the guardrail and can result in serious injuries to the occupants. In this study, a new W-beam guardrail, named as “η-shaped W-beam guardrail (η-WG)”, was developed using nonlinear finite element simulations combined with metamodeling-based design optimization methodology. The simulation results showed that tire snagging did not occur on the η-WG and the optimum design of the η-WG had an improved safety performance in vehicular crashes.

References listed at the end of the paper:


[21] Mak KK, Menges WC. Crash testing and evaluation of strong-post, W-beam guardrail system. Texas Transportation Institute, Texas A&M University, College Station; 1994.


References listed at the end of the paper:
Liu, Y.: Crashworthiness design of multi-corner thin-walled columns. Thin-Walled Struct. 46(12), 1329–1337 (2008a)
Liu, Y.: Optimum design of straight thin-walled box section beams for crashworthiness analysis. Finite Elem. Anal. Des. 44(3), 139–

Mrutyunjay Rout and Amit Karmakar (Department of Mechanical Engineering, Jadavpur University, Kolkata, India), “Free vibration of rotating twisted composite stiffened plate”, Proceedings of the First International Conference on Mechanical Engineering, Jadavpur University, Kolkata, India, January 4-6, 2018, Paper No. INCOM18-039, 2018
ABSTRACT: The paper presents a finite element model based on first-order shear deformation theory to investigate the free vibration response of the rotating twisted composite stiffened plate. An eight nodded isoparametric plate element having five degrees of freedom per node is combined with a three node disoparametric beam element of four degrees of freedom per node for modelling the plate and the stiffener element, respectively. The formulation adopted here employs constraint technique to calculate stiffness and mass matrices of the stiffener element placed inside the plate element, wherein the nodal degrees of freedom of the stiffener element are transferred to the plate element considering curvature and eccentricity to maintain the compatibility between plate and stiffener. The advantage of such method is that there is no further increase in the total number of degrees of freedom due to addition of the stiffener, thereby reducing the computational time.

ABSTRACT: Combined isogeometric analysis (IGA) and shape optimization, this paper provides a method that can accurately analyze Tailor Rolled Blanks (TRB) and optimize its thickness profile continuously. While existed traditional methods can hardly solve these problems. TRB has a continuous transition between the thick and thin and a better surface quality. We found in IGA, two-dimension NURBS could present TRB geometry model exactly, but Kirchhoff shell element whose control points are allocated different thicknesses could not simulate TRB effectively. So, this paper uses three-dimension NURBS element to exactly present and accurately analyze TRB. It could avoid error caused by inaccurate presentation of geometry model and decrease error caused by solution field (displacement) approximation in numerical computation. Meanwhile, the positions of control points are taken as design variables in process of optimizing thickness profile. It can avoid the appearance of “unrealistic” shape and save lots of time spent in traditional tediously mesh updating as well as having better accuracy. This method makes accurate analysis and continuous thickness optimization of TRB become possible. It pushes the development of TRB engineering and extends the applications of IGA optimization. Several examples including benchmarks and application used the proposed method verified its effectiveness, reliability and efficiency.

References listed at the end of the paper:
As physical entities, living cells possess structural and physical properties that enable them to withstand the physiological environment as well as mechanical stimuli occurring within and outside the body. Any deviation from these properties will not only undermine the physical integrity of the cells, but also their biological functions. As such, a quantitative study in single cell mechanics needs to be conducted. In this review, we will examine some mechanical models that have been developed to characterize mechanical responses of living cells when subjected to both transient and dynamic loads. The mechanical models include the cortical shell–liquid core (or liquid drop) models which are widely applied to suspended cells; the solid model which is generally used for adherent cells; the power-law structural damping model which is more suited for studying the dynamic behavior of adherent cells; and finally, the biphasic model which has been widely used to study musculoskeletal cell mechanics. Based upon these models, future attempts can be made to develop even more detailed and accurate mechanical models of living cells once these three factors are adequately addressed: structural heterogeneity, appropriate constitutive relations for each of the distinct subcellular regions and components, and active forces acting within the cell. More realistic mechanical models of living cells can...
References listed at the end of the paper:


Graphdiyne possesses not only high strength but also excellent ductility, making it possible to be used in future high-performance protective structures. In this paper, the mechanical properties of graphdiyne were firstly measured by AFM experiments, and the failure behavior during low velocity perforation was also investigated by molecular dynamics (MD) simulations. Firstly, the elastic modulus was measured to be about 218.5 GPa by AFM experiments, which is about half of its ideal value due to various defects and the layer
numbers of the synthesized graphdiyne film. Then, the nanoindentation processes of graphdiyne films were investigated by MD simulations, and the elastic modulus and strength were simulated to be about 489.04 GPa and 33.95 GPa, respectively. The failure behavior of the graphdiyne film was also studied in atomic level. Sequential broken of C=C, C≡C and CeC bonds and recombination of the broken bonds were observed to form a unique latchy crack. Furthermore, the effects of loading speed and indenter radius on the mechanical response of graphdiyne were investigated. A revised formula was developed for analyzing the mechanical properties of films in AFM experiments under various loading conditions.

References listed at the end of the paper:

[29] K.T. Wan, G. Shu, D.A. Dillard, A theoretical and numerical study of a thin clamped circular film under an external load in the
ABSTRACT: Nanoporous material functionalized liquid (NMFL) is now one of the candidates of advanced energy mitigation material, as supported by recent studies. In this study, quasi-static compression experiments and finite element (FE) simulations are conducted to investigate the energy absorption enhancement effect of NMFL as a filler in a thin-walled stainless steel tube. The influence of infiltration pressure (P_in), and the interaction effect between NMFL filler and tube wall are comprehensively explored. Results show that the filling with NMFL can enhance the energy absorption capacity of thin-walled tubes under axial compression by 25% at the present configuration, which comes from the nano-scale infiltration of NMFL by converting mechanical energy into excessive interfacial energy, and its interaction effect with thin-walled buckling. P_in has a significant impact on the energy absorption characteristics and buckling behavior.

References listed at the end of the paper:
References listed at the end of the paper:


Jun Xu (1), Yibing Li (2), Yong Xiang (3) and Xi Chen (1,4,5)
(1) Columbia Nanomechanics Research Center, Department of Earth and Environmental Engineering, Columbia University, New York, NY 10027, USA.
(2) State Key Laboratory of Automotive Safety and Energy, Department of Automotive Engineering, Tsinghua University, Beijing 100084, People’s Republic of China
(3) State Key Lab of Electronic Thin Films and Integrated Devices, School of Energy Science and Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan 611731, People’s Republic of China
(4) Department of Civil and Environmental Engineering, Hanyang University, Seoul 133-791, South Korea
(5) International Center for Applied Mechanics, SV Lab, Xi’an Jiaotong University, Xi’an 710049, People’s Republic of China


ABSTRACT: The dynamic impact response of giant buckyball C720 is investigated by using molecular dynamics simulations. The non-recoverable deformation of C720 makes it an ideal candidate for high-performance energy absorption. Firstly, mechanical behaviors under dynamic impact and low-speed crushing are simulated and modeled, which clarifies the buckling-related energy absorption mechanism. One-dimensional C720 arrays (both vertical and horizontal alignments) are studied at various impact speeds, which show that the energy absorption ability is dominated by the impact energy per buckyball and less sensitive to the number and arrangement direction of buckyballs. Three-dimensional stacking of buckyballs in simple cubic, body-centered cubic, hexagonal, and face-centered cubic forms are investigated. Stacking form with higher occupation density yields higher energy absorption. The present study may shed lights on employing C720 assembly as an advanced energy absorption system against low-speed impacts.

References listed at the end of the paper:
ABSTRACT: In this paper three dimensional free vibration and transient response of a cylindrical panel made of two directionally functionally graded materials (2D-FGMs) based on three dimensional equations of elasticity.
and subjected to internal impact loading is considered. Material properties vary through both radial and axial directions continuously. The 3D graded finite element method (GFEM) based on Rayleigh-Ritz energy formulation and Newmark direct integration method has been applied to solve the equations in space and time domains. The fundamental normalized natural frequency, time history of displacements and stresses in three directions and velocity of radial stress wave propagation for various values of span angle of cylindrical panel and different power law exponents have been investigated. The present results show that using 2D-FGMs leads to a more flexible design than conventional 1D-FGMs. The GFEM solution have been compared with the results of an FG thick hollow cylinder and an FG curved panel, where a good agreement between them is observed.

References listed at the end of the paper:


Atul Bhaskar (1), Enrique Cuan-Urquizo (1), Alessandra Bonfanti (1), Hayk Vasilyan (1), Tigran Saghatelyan(1), Loris Domenicale (1), S.J.A. Rizvi (2) and Naresh Bhatnagar (1)
(1) University of Southampton, UK
(2) Indian Institute of Technology, New Delhi, India


ABSTRACT: We consider a host of regular lattice architectures and present analytical and computational approaches to derive the structure-property relationship for such structured material by exploiting the translational periodicity of infinite lattices. Two specific geometries – the so-called hexagonal honeycomb and the woodpile lattice – are studied analytically and computationally. The elasto-plastic response in the case of the first, and the bending response of lattice beams for the second, is considered. These specific problems have been motivated by biostructures relevant to medical implants and scaffolds. We also present novel methods to additively manufacture such lattices. When possible, the response is obtained as an analytical function of the microstructural parameters described by the geometry of the repetitive elements of the lattice, such as characteristic diameter, length, or thickness. Alternative methods of manufacturing materials with random internal architectures are also presented. The relative strengths and weaknesses of the two classes of materials with respect to analysis and manufacture are discussed.

References listed at the end of the paper:
[9] Cuan-Urquizo, E., Bhaskar, A. Flexural elasticity of woodpile lattice beams, European Journal of Mechanics - A/Solids: under review. ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665 copyright © University POLITEHNICA Timisoara, Faculty of Engineering Hunedoara, 5, Revolutioni, 331128, Hunedoara, ROMANIA


ABSTRACT: On the basis of the Bloch’s theorem, the in-plane wave propagation in hexagonal and re-entrant lattice structures with cell walls of non-uniform thickness is investigated using the dynamic stiffness matrix in conjunction with the Wittrick–Williams algorithm. Special attention is devoted to the effects of the internal angle, the slenderness ratio and the material distribution on the directional and band gap behaviors. Results
show that the three considered parameters can significantly influence the band gap characteristics. For the wave propagation directionality, however, the internal angle is more prominent than the other two factors. The work expects to serve as a guide for the optimal design of directional mechanical filters.

References listed at the end of the paper:


ABSTRACT: Purpose – The purpose of this paper is to provide an efficient numerical solution for dynamic properties of sandwich tubes with honeycomb cores and investigate the effects of material distribution and relative density on the dynamic properties of the structure.

Design/methodology/approach – By introducing dual variables and applying the variational principle, the canonical equations of Hamiltonian system are constructed. The precise integration algorithm and extended Wittrick-Williams algorithm are adopted to solve the equations and obtain the dispersion relations of sandwich tubes. The effects of the material distribution and the relative density on the non-dimensional frequencies of the sandwich tubes are investigated. Findings – The validity of the procedure and programs is verified by comparing with other works. Dispersion relations of the typical sandwich tubes are obtained. Dramatic differences are observed as the material distribution and relative density of the sandwich structures vary. Originality/value – The work gains insight into the role of symplectic analysis in the structural dynamic properties and expects to provide new opportunities for the optimal design of sandwich tubes with honeycomb cores in engineering applications.

References listed at the end of the paper:
References listed at the end of the paper:

References


Wen Yang (1), Jian Xiong (1,2), Li-Jia Feng (1), Chong Pei (3) and Lin-Zhi Wu (1,4)
(1) Center for Composite Materials, Harbin Institute of Technology, Harbin, PR China
(2) State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi’an Jiaotong University, Xi’an, PR China
(3) Welding and Plastic Forming Division, Beijing Institute of Aeronautical Materials, Beijing, PR China
(4) Key Laboratory of Advanced Ship Materials and Mechanics, Harbin Engineering University, Harbin, PR China


ABSTRACT: Topological-reinforcement and material-strengthening were used and employed to improve the mechanical properties of lattice truss sandwich structures. This new type of three-dimensional aluminum alloy lattice truss (named enhanced lattice truss) sandwich structure, with a relative density ranging from 1.7% to 4.7%, was designed and fabricated by interlocking and vacuum-brazing method. The out-of-plane compression and shear properties of the enhanced lattice truss sandwich structures (both as-brazed and age-hardened cores) were experimentally and analytically investigated. Good correlations between analytical predictions and experiment results were achieved. Experimental results showed that the mechanical properties of the enhanced lattice truss cores were sensitive to the unit-cell size and parent-alloy properties (i.e. inelastic buckling and tangential modulus). The compressive and shear characteristics of enhanced lattice truss sandwich structures were discussed and found superior to competing lattice truss structures in low density area (0.046-0.124 g/cm³) of material property charts. The combination of topological-reinforcement and material-strengthening provided a way to achieve lightweight sandwich structures with high specific strengths and low densities.

References listed at the end of the paper:

References listed at the end of the paper:


Penglin Gao (1), Jose Sanchez-Dehesa (2) and Linzhi Wu (1)
(1) Center for Composite Materials and Structures, School of Astronautics, Harbin Institute of Technology, Harbin 150001, People’s Republic of China
(2) Wave Phenomena Group, Department of Electronic Engineering, Universitat Politècnica de València, Camino de vera s.n. (Building 7F), ES-46022 Valencia, Spain

“Poisson-like effect for flexural waves in periodically perforated thin plates”, Journal of the Acoustical Society of America, Vol. 144, No. 2, August 2018

ABSTRACT: The Poisson-like effect, describing the redirection of waves by 90 degrees, is shown to be feasible for flexural waves propagating in perforated thin plates. It is demonstrated that the lowest order symmetric leaky guided mode (S0 mode) is responsible for the splitting of wave motion in two orthogonal directions. The S0 mode shows a feature of stationary waves containing standing wave modes in one and two orthogonal directions for smaller and larger holes, respectively. The former case is well understood thanks to the phenomenon of Wood’s anomaly, which was first observed in optical gratings supposed to be transparent. On the contrary, the strong scattering caused by the larger holes leads to a mixed mode occurring when the incident wave is totally transmitted. The mixed mode easily couples with the incoming waves and, therefore, the Poisson-like effect activated under this mechanism is much stronger. Using the Poisson-like effect, a device is proposed in which about 82% of the incident mechanical energy is redirected to the perpendicular direction. Results obtained with arrays of free holes also apply to inclusions with parameters properly chosen. The findings may provide applications in beam splitting and waveguiding.

References listed at the end of the paper:


Matt P. Milner (1), Lihua Jin (2) and Shelby B. Hutchens (1)
(1) Department of Mechanical Science and Engineering, University of Illinois Urbana-Champaign, Urbana, IL, USA
(2) Department of Mechanical and Aerospace Engineering, University of California Los Angeles, Los Angeles, CA, USA


ABSTRACT: We report on crease morphology and evolution at the surface of contracting cavities embedded within elastomeric solids of varying composition (Sylgard 184: pre-polymer to crosslinker mixing ratios of 10 : 1, 12 : 1, 17.5 : 1, and 25 : 1). Cavity contraction is achieved through evaporation of an embedded 10 mL liquid droplet. In validation of recent theoretical predictions, strain-stiffening modeled via the Gent constitutive relation [Jin and Suo, JMPS, 2015, 74, 68–79] is found to govern both crease onset and crease density. Specifically, crease matches prediction using only experimentally-measured parameters. Neo-Hookean solids are found to prefer initiating creasing with many short creases that join to form a collapsed state with only a few creases, whereas creasing in Gent solids initiates with a few creases that propagate across the cavity surface. These experimental observations are explained by energy minimization using finite element simulation of a cylindrical crease geometry.

Lubing Wang (1,2), Sha Yin (1,2), Zhexun Yu (3), Yonggang Wang (4), T.X. Yu (5), Jing Zhao (6), Zhengchao Xie (6), Yangxing Li (3), Jun Xu (7,8)
(1) Department of Automotive Engineering, School of Transportation Science an Engineering, Beihang University, Beijing, 100191, China
(2) Advanced Vehicle Research Center (AVRC), Beihang University, Beijing, 100191, China
(3) Central Research Institute, Huawei Technologies Co., LTD, Longgang District, Shenzhen, 518129, China
(4) Mechanics and Materials Science Research Center, Ningbo University, Zhejiang 315211, China
(5) Department of Mechanical & Aerospace Engineering, The Hong Kong University of Science and
References listed at the end of the paper:

- Strankowski, M.; Korzeniewski, P.; Strankowska, J.; Anu, AS.; Thomas, S. Morphology, mechanical and thermal properties of thermoplastic polyurethane containing reduced graphene oxide and graphene nanoplatelets. Materials 2018, 11, 82.
ABSTRACT: In this paper, a new approach is proposed to identify sectional deformation modes of the doubly

Lei Zhang (1), Aimin Ji (1), Weidong Zhu (2), and Liping Peng (3)
(1) College of Mechanical and Electrical Engineering, Hohai University, Changzhou 213022, China
(2) Department of Mechanical Engineering, University of Maryland, Baltimore County, MD 21250, USA
(3) State Key Laboratory of Mineral Processing, Beijing General Research Institute of Mining and Metallurgy, Beijing 100260, China

“On the Identification of Sectional Deformation Modes of Thin-Walled Structures with Doubly Symmetric Cross-Sections Based on the Shell-Like Deformation”, Symmetry, Vol. 10, pp 759–, 2018
symmetric thin-walled cross-section, which are to be employed in formulating a one-dimensional model of thin-walled structures. The approach considers the three-dimensional displacement field of the structure as the linear superposition of a set of sectional deformation modes. To retrieve these modes, the modal analysis of a thin-walled structure is carried out based on shell/plate theory, with the shell-like deformation shapes extracted. The components of classical modes are removed from these shapes based on a novel criterion, with residual deformation shapes left. By introducing benchmark points, these shapes are further classified into several deformation patterns, and within each pattern, higher-order deformation modes are derived by removing the components of identified ones. Considering the doubly symmetric cross-section, these modes are approximated with shape functions applying the interpolation method. The identified modes are finally used to deduce the components of identified ones. Consecutive deformation patterns, and within each pattern, higher-order deformation shapes left. By introducing benchmark points, these shapes are further classified into several deformation patterns, and within each pattern, higher-order deformation modes are derived by removing the components of identified ones. Considering the doubly symmetric cross-section, these modes are approximated with shape functions applying the interpolation method. The identified modes are finally used to deduce the governing equations of the thin-walled structure, applying Hamilton’s principle. Numerical examples are also presented to validate the accuracy and efficiency of the new model in reproducing three-dimensional behaviors of thin-walled structures.

References listed at the end of the paper:


Praveen Nagarajan (Dept. of Civil Engineering, National Institute of Technology, Calicut, India), Possibly he downloaded the graduate course called, AE/Me/EMech 484 (See Sample_Introduction_AE-ME484.pdf);
Course Title: Applications, advantages and challenge of composites. Plan of the course AE/ME/EMech 484 (11 pages) “Chapter 7: Sandwich Structures” (Table of Contents):
Introduction to sandwich structures
Governing equations
Boundary conditions for a sandwich plate
Static analysis of sandwich plates of composite materials
Applicability of the first order shear deformation theory (FSDT)
Experiments on sandwich panels: verification of theoretical models
Buckling of sandwich plates
Sandwich or laminated plates subjected to dynamic loads
Free vibrations of sandwich plates
Response of a sandwich plate subjected to a dynamic lateral load
Local buckling of sandwich panels
Buckling of Honeycomb Core Sandwich Panels Subjected to In-Plane Compressive Loads – Design Formulae
Cylindrical Sandwich Shells Under Axially Symmetric Loads – Design Formulae
Joints in sandwich structures
Fatigue properties of sandwich core materials

References to the material in Chapter 7:

Abderrahmane Bentouhami and Boualem Keskes (Laboratoire de mécanique de précision appliquée, Institut d’Optique et Mécanique de Précision, Université Ferhat Abbas de Sétif, Algérie)
ABSTRACT: Sandwich panels have the best stiffness-to-lightness ratio, which is what makes them very useful in industrial applications. This paper is focused on a study of the buckling capacities of the core components under uniaxial compression. The critical buckling loads for various core densities and materials of honeycomb panels were experimentally and numerically investigated. The specimens under lateral loading showed three zones: zone 1 is the initial elastic state, followed by the plateau region in zone 2, while zone 3 shows a monotonically stiffening region, associated with the densification of the material. The effect of the core density and its materials on the behavior and the damage was highlighted. From the experiment it is clear that the buckling load of the specimens increases as the core density is increasing. In terms of stiffness and load at failure, the honeycomb sandwich panel had better mechanical characteristics than its components. The study also calculated the numerical buckling loads of the panels using the ABAQUS finite-element analysis program. The achieved experimental and numerical results were compared with each other. In conclusion, a good correlation between theory and experiment was found.
References (cannot cut and paste them easily)
M.A. Aiello and L. Costantino (Dept. of Engineering Innovation, University of Lecce, Italy), “Stability analysis of sandwich panels with core-skin delaminations”, Publisher and date not given in the pdf file; most recent reference is dated 2003

ABSTRACT/INTRODUCTION: Sandwich structures, made with two skins characterized from high mechanical performances and a core with lower mechanical properties, are widely used in different fields of engineering, mostly in aeronautic and aerospace industries. The success of sandwiches structures is mainly due to the possibility of optimising the structural response by an opportune choice of materials and geometry. In particular, the introduction of composite laminates, as skins materials, allows attaining an optimal solution in terms of mechanical response, weight and costs. More generally the tailor ability of the structures, on the basis of the specific application, makes such elements very attractive; in fact faces can be designed varying the geometry, the fibers orientation, the kind of materials by means the hybridisation technique. On the other hand the core materials can be varied in geometry and mechanical properties, from a more traditional rigid core material to a soft one.

The high performances of sandwich structures, in particular sandwich panels, allow a reduction of geometrical dimension, mostly as regard the thickness, obtaining very often a structure with high slenderness. For this reasons the predominant mechanisms of failure are those related to instability instead to the attainment of the ultimate strength. Different kinds of instability may take place, depending on sandwich panel properties, as global buckling, local buckling or even an interaction between local and global instability.

Several studies have been made on this topic and results are available in the literature [1], [2], [3], [4], [5], [6]. Stability problems become more critical in presence of imperfections, such delaminations. Delaminations can be caused both from mechanical or environmental conditions and can involve the laminas interface or the skin-core interface. The prediction of buckling load of delaminated plates and sandwiches have been studied from many researchers by utilizing both analytical and numerical approaches [7], [8], [9], [10], [11].

In the present paper a numerical, FEA, approach is presented to determine the initial buckling load of delaminated sandwich plates under compression, with the delamination zone interesting the skin-core interface. The utilized numerical model uses three dimensional brick elements for every constituent part taking into account the whole state of strain and stress; the analysed delamination zone is centred within the panel, rectangular in shape, and having dimensions D and H. Buckling loads and buckled panels configurations are evaluated varying the damage degree, that is the delaminated zone dimensions. Different kinds of skins and core are analysed and the buckling phenomenon, referring to initial buckling load and buckling configuration, is investigated varying some key parameters, as the panel aspect ratio, the mechanical properties of core and skins, the thickness of the skins and the core, the boundary conditions. A mesh sensitivity analysis has been also performed preventively.

References listed at the end of the paper:

ABSTRACT: Sandwich structures are efficient lightweight materials. Due to their design they exhibit very special failure modes such as global buckling, shear crimping, face-sheet wrinkling, face-sheet dimpling, and face/core yielding. The core of the sandwich is usually made of foams or cellular materials, e.g., honeycombs. Especially in the case of honeycomb cores the correlation between analytical buckling predictions and experiments might be poor (Ley, Lin, and Uy (1999)). The reason for this lies in the fact that analytical formulae typically assume a homogeneous core (continuous support of the facesheets). This work highlights problems of honeycomb core sandwiches in a parameter regime, where the transition between continuous and discrete support of the facesheets is studied. Periodic finite element unit cell models are utilized for this task, which offer the big advantage of a homogeneous load introduction to the structure. The finite element models are found to be well suited for all kinds of buckling predictions. Different uni- and bi-axial loadings are considered as well as influences of core height, core material, core geometry, and facesheet thickness are investigated. Finally, a new analytical approach is introduced for the unexpected core wall buckling under in-plane compression of the sandwich, which predicts the critical load very accurately.

References listed at the end of the paper:


ABSTRACT: A three-layer quasi 3D finite element model for buckling analysis of sandwich plates with laminated composite face-sheets is evaluated. In the model, the face-sheets are represented as Reissner-Mindlin plates and the core is modeled as a three-dimensional continuum. This representation allows accurate modeling for a wide range of core types. The three-dimensional problem is reduced to two dimensions by analytical through-thickness integration of the energy expressions for the evaluation of stiffness matrices. The stress stiffening effect is included in the quasi 3D model through the formulation of appropriate geometric stiffness matrices. Linearized buckling analyses of sandwich plates are performed. The purpose is to compute critical
loads and respective buckling modes from the solution of the eigenvalue problem by the subspace iteration method. A membrane state of stress can be easily established when applying the Reissner-Mindlin theory to the face-sheets. However, the quasi 3D formulation considers that the core behaves like a 3D structure connected to the face-sheets. This situation indicates the use of a general formulation that takes into account not only the membrane strains, but also all strain components to yield the geometric stiffness matrix.

Buckling problems are studied in order to validate the implemented code and demonstrate that linearized buckling loads of a sandwich plate may be strongly influenced by the variation of the core stiffness. The problem of buckling of sandwich plates with core discontinuity is also addressed.

References listed at the end of the paper:


ABSTRACT: The transverse compression and shear collapse mechanisms of a second order, hierarchical corrugated truss structure have been analyzed. The two competing collapse modes of a first order corrugated truss are elastic buckling or plastic yielding of the truss members. In second order trusses, elastic buckling and yielding of the larger and smaller struts, shear buckling of the larger struts, and wrinkling of the face sheets of the larger struts have been identified as the six competing modes of failure. Analytical expressions for the compressive and shear collapse strengths in each of these modes are derived and used to construct collapse mechanism maps for second order trusses. The maps are useful for selecting the geometries of second order trusses that maximize the collapse strength for a given mass. The optimization reveals that second order trusses made from structural alloys have significantly higher compressive and shear collapse strengths than their equivalent mass first order counterparts for relative densities less than about 5%. A simple sheet metal folding and dip brazing method of fabrication has been used to manufacture a prototype second order truss with a relative density of about 2%. The experimental investigation confirmed the analytical strength predictions of the
second order truss, and demonstrate that its strength is about ten times greater than that of a first order truss of the same relative density. DOI: 10.1115/1.2198243

References listed at the end of the paper:


ABSTRACT Fiber-reinforced plastic corrugated core sandwich panels were tested for buckling in uniaxial compression. Three types of corrugation i.e. sinusoidal, square and triangle of different thickness core of epoxy based were tested. The sandwich panels were fabricated using the hand layup method process. The two short edges of the sandwich panels were clamped, while the two long edges were simply supported for testing. A Bifurcation in the load versus engineering strain curve was noted in all cases. For all sandwich panels tested using corrugation core, the type of failure was easily identified as face sheet delamination followed by core shear failure. In the failed core panels there was little or no evidence of core remaining on the FRP face sheet, however, lower strain rate in the PVC foam core panels there were ample amounts of foam left on the FRP face sheet. It was concluded that although the buckling loads for the sinusoidal corrugated core panels showed very high buckling strength.

References listed at the end of the paper:
[10] Amir Shahdin, Laurent Mezeix, Christophe Bouvet, Joseph Morlier and Yves Gourinat, Fabrication and mechanical testing of

ABSTRACT: This paper deals with the buckling response and nonlinear behavior of sandwich panels with soft cores that have temperature-dependent mechanical properties and are subjected to thermally induced deformations and mechanical loads simultaneously. This study investigates the effects of the degradation of properties of the core as a result of rising temperature on the response of the sandwich panel. Analyses are carried out for cases of pure thermal loading, with either uniform or gradient temperature fields through the depth of the panel, as well as for thermal loading acting simultaneously with external mechanical loads. The formulation is based on variational principles along with the high-order sandwich panel approach. It takes into account the flexibility of the core in the vertical direction as well as the dependency of the mechanical core properties of the temperature distribution through the core depth. The stress and deformation fields of the core have been solved analytically, including the case where the temperature-dependent properties attain a complex pattern. The buckling equations are derived using the perturbation technique, yielding a set of nonlinear algebraic equations for the case of a simply-supported panel and a uniform temperature field. The critical temperatures and modes of wrinkling and global buckling are determined numerically for some foam types of core made by Rohacell and Divinycell. The nonlinear response caused by thermally induced deformations is presented for Divinycell foam core with different temperature distributions through the depth of the core. Finally, the nonlinear response caused by the simultaneous action of external mechanical loading and increased temperatures on the compressive or the tensile side of the panel, with a thermal gradient through the core depth, is presented. The interaction between elevated temperatures and mechanical loads changes the response from a linear into an unstable nonlinear one when the degradation of the mechanical properties due to temperature changes is considered and the panel is unrestrained. Moreover, the unstable nonlinear behavior becomes even more severe when the face, loaded in compression, is subjected to elevated temperatures. This study reveals that a reliable, realistic design of a sandwich panel that is subjected to elevated temperature (within working temperature range) and mechanical loads must take into account the degradation of the properties of the core as a result of the thermal field even at working temperature range, especially when cores made of foam are considered.

References listed at the end of the paper:

paths. Two main failure modes of collapse were recorded in the tests: core shear buckling and mixed circular interfacial debond. High sandwich columns with face/core debond. The edgewise compression tests were conducted on two type under axial compression”, MATEC Web of Conferences, Vol. 95, 07026, 2017 (ICMME 2016)

Chen Yue, Zhu Xi , Zhu Zi-xu and Li hua-dong (Dept. of Naval Architecture Engineering, Naval Univ. of Engineering, Wuhan, China), “Experimental studies of composite sandwich columns with face/core debond under axial compression”, MATEC Web of Conferences, Vol. 95, 07026, 2017 (ICMME 2016)

DOI: 10.1051/matecconf/20179507026

ABSTRACT: Experimental studies of buckling failure and debond propagation were carried out on composite sandwich columns with face/core debond. The edgewise compression tests were conducted on two type specimens. Namely, one containin throughthe-width rectangle face/core debond, and the other with embedded circular interfacial debond. High-speed photography technology has been used to record the debond propagating paths. Two main failure modes of collapse were recorded in the tests: core shear buckling and mixed buckling.
References listed at the end of the paper:


ABSTRACT: Past research into the local buckling behaviour of fully profiled sandwich panels has been based on polyurethane foams and thicker lower grade steels. The Australian sandwich panels use polystyrene foam and thinner and high strength steels, which are bonded together using separate adhesives. Therefore a research project on Australian sandwich panels was undertaken using experimental and finite element analyses. The experimental study on 50 foam-supported steel plate elements and associated finite element analyses produced a large database for sandwich panels subject to local buckling effects, but revealed the inadequacy of conventional effective width formulae for panels with slender plates. It confirmed that these design rules could not be extended to slender plates in their present form. In this research, experimental and numerical results were used to improve the design rules. This paper presents the details of experimental and finite element analyses, their results and the improved design rules.

References listed at the end of the paper:

18. Yang, D. and Hancock, G.J. (2002). Compression Test of Cold-Reduced High Strength Steel Stubs Columns. Research Report No

ABSTRACT: Despite of laminate or sandwich composite materials structure, mechanical behavior can estimate by methods or analytical relations like laminates classical theory according factors just like mechanical properties, fiber percentage, and product methods and etc. but generally these estimates are far from experimental results. This paper investigates about influence of product methods and different cores on buckling and post buckling behaviors of sandwich panels. Each panel was built by to quit different product method, hand layup or vacuum bag infusion procedure with different core. To build the panels an effort had made to choice materials which have usage in marine industry, special for high speed boats. Sandwich panels have 150x450 mm² dimensions and one simply support and one clamed support. After tests, numerical models results which drive from finite element software are compared with experimental data. The results represent that combined model is suitable for simulate buckling and post buckling behavior. After chosen the software model, different parameters were evaluated whom the link element has the most efficacy on numerical results.

References listed at the end of the paper:

Khaina Sad Saoud and Phillippe Le GrogneC (Mines Douai, Polymers and Composites Technology & Mechanical Engineering Department, Douai, France), “Buckling and post-buckling analysis of sandwich beam-columns”, 11th World Congress on Computational Mechanics (WCCM XI), 5th European Conference on
ABSTRACT/INTRODUCTION: Sandwich structures are increasingly used in many industrial applications, due to the attractive combination of a lightweight and strong mechanical properties. This compromise is realized thanks to the presence of different parts in the composite material, namely the skins and possibly core reinforcements or thin-walled core structure which are both thin/slender and stiff relative to the other parts, namely the homogeneous core material, if any. The buckling phenomenon thus becomes mainly responsible for the final collapse of such sandwiches. One usually distinguishes two types of geometric instabilities, namely the global buckling of the sandwich structure under overall compression and the so-called wrinkling (or local buckling) of the faces which may appear under various loadings. Global buckling can easily be viewed as the classical buckling of the equivalent homogenized structure and only involves the effective properties of the heterogeneous beam or plate in hand. Conversely, the wrinkling analysis requires the use of advanced models. This study first deals with the linearized buckling/wrinkling response of classical sandwich beam-columns (with homogeneous core materials). Based on a 3D elastic bifurcation analysis, closed-form analytical solutions of the critical loadings and the associated bifurcation modes are derived in a unified way for both mode types (global and local) and with various loading conditions [1]. The present analytical solutions are in much better agreement with reference numerical results, in comparison with previous analytical solutions from the literature, thanks to the particular choice of the kinematic hypotheses in the skins (modeled by Euler-Bernoulli beams) and the core layer (considered as a 2D continuous solid).

Then, the advanced post-buckling response of sandwich columns under axial compression is investigated. For this purpose, a specific home-made 2D finite element code is used. It includes (i) branch-switching procedures, that allow one to detect the true bifurcation points (without introducing any imperfection) and bifurcate onto a given branch, and (ii) arc-length methods, which enable one to deal with possible strong non-linearities (non-monotonous curves). The post-critical response of such structures is shown to be always stable after the primary (global or local) bifurcation mode. However, a secondary mode often occurs in practice and leads to an unstable post-buckling behavior, very sensitive to imperfections, as shown in Leotoing et al. [2]. The secondary bifurcation mode proves to be local when the primary mode is global and vice versa (see Figure 1 for an example of the successive deformed shapes during the post-buckling stage). Such a non-linear response is particularly observed when the first two (global and local) primary critical loads are close to each other, and it is referred to as the modal interaction phenomenon.

Finally, for efficiency purposes, an enriched beam finite element model is proposed, as an alternative to our robust but time-consuming 2D model. The main idea is to define the beam kinematics from the exact analytical mode shape of each layer, in order to capture local effects (such as the wrinkling of the faces) during the buckling and post-buckling analyses, following the example of Hu et al. [3].

References listed at the end of the paper:

Evan J. Pineda (1), David E. Myers (1), Daniel N. Kosareo (2) and Sotiris Kellas (3)
(1) NASA Glenn Research Center, Cleveland, Ohio
(2) Vantage Partners, LLC, Brook Park, Ohio
(3) NASA Langley Research Center, Hampton, Virginia
ABSTRACT: Four honeycomb sandwich panels, representing 1/16th arc segments of a 10 m diameter barrel section of the heavy lift launch vehicle, were manufactured under the NASA Composites for Exploration program and the NASA Constellation Ares V program. Two configurations were chosen for the panels: 6-ply facesheets with 1.125 in. honeycomb core and 8-ply facesheets with 1.000 in. honeycomb core. Additionally, two separate carbon fiber/epoxy material systems were chosen for the facesheets: in-autoclave IM7/977-3 and out-of-autoclave T40-800B/5320-1. Smaller 3- by 5-ft panels were cut from the 1/16th barrel sections. These
panels were tested under compressive loading at the NASA Langley Research Center. Furthermore, linear eigenvalue and geometrically nonlinear finite element analyses were performed to predict the compressive response of the 3- by 5-ft panels. This manuscript summarizes the experimental and analytical modeling efforts pertaining to the panel composed of 8-ply, T40-800B/5320-1 facesheets (referred to as Panel C). To improve the robustness of the geometrically nonlinear finite element model, measured surface imperfections were included in the geometry of the model. Both the linear and nonlinear, two-dimensional (2-D) and three-dimensional (3-D), models yield good qualitative and quantitative predictions. Additionally, it was predicted correctly that the panel would fail in buckling prior to failing in strength.

References listed at the end of the paper:

References listed at the end of the paper:


[25] ANSYS, General purpose finite element software, Version 13.0


ABSTRACT: Sandwich columns, comprising woven glass reinforced epoxy face sheets and PVC polymer foam core, have been tested under edgewise compressive loading. Failure is by Euler macrobuckling, shear macrobuckling or by face sheet microbuckling, depending upon the material combination and geometry of column. Simple analytical models are developed for the axial strength, and these are in good agreement with the experimental values for each failure mode. Collapse mechanism maps are constructed to illustrate the dependence of failure mode upon the geometry and relative density of the core; and minimum weight designs are determined as a function of the appropriate structural load index.

References listed at the end of the paper:


G. A. Kardomateas (1), G. J. Simitses (1,2), L. Shen (2) and R. Li (1)
(1) School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, USA
(2) University of Cincinnati, Cincinnati, OH, USA


ABSTRACT: The paper deals with the theoretical prediction of buckling loads for sandwich columns with metallic and laminated facings and foam or honeycomb core. The loading is a uniform axial compression, applied statically (very slowly) and suddenly with constant magnitude and infinite duration (step loading). The effect of length and boundary conditions is assessed and results are presented for the following cases: for a cantilever column, a simply supported column and a clamped column, for several lengths. Several fiber materials are used in the laminated facings. Two types of core were examined: alloy-foam or hexagonal glass-phenolic honeycomb. The facings are Boron-Epoxy, Graphite-Epoxy and Kevlar-Epoxy laminates with 0 degree orientation with respect to the column axis and a metallic one made out of aluminum. These various materials are employed to provide comparative data that can be used in design. Results, for the static case are generated by computer codes as well as by the use of closed form theoretical solutions. For the dynamic case, results are generated by the DYNA3D code.

References listed at the end of the paper

REFERENCES


K. Malekzadeh Fard (1) and H. Malek-Mohammadi (2)
(1) Department of Mechanical Engineering, Malek Ashtar University, Tehran, Iran
(2) Department of Mechanical Engineering Bu-Ali Sina University, Hamedan, Iran


ABSTRACT: In this paper, the behavior of free vibrations and buckling of the sandwich panel with a flexible core was investigated using a new improved high-order sandwich panel theory. In this theory, equations of motion were formulated based on shear stresses in the core. First-order shear deformation theory was applied for the procedures. In this theory, for the first time, incompatibility problem of velocity and acceleration field existing in Frostig’s first theory was solved using a simple analytical method. The main advantage of this theory is its simplicity and less number of equations than the second method of Frostig's high-order theory. To extract dynamic equations of the core, three-dimensional elasticity theory was utilized. Also, to extract the dynamic equations governing the whole system, Hamilton's principle was used. In the analysis of free vibrations, the panel underwent primary pressure plate forces. Results demonstrated that, as plate pre-loads got closer to the critical buckling loads, the natural frequency of the panel tended zero. The results obtained from the present theory were in good correspondence with the results of the most recent papers.

References listed at the end of the paper:
ABSTRACT: The low velocity impact response of a range of foam based sandwich structures has been investigated using an instrumented falling weight impact tower. Initially, the rate-sensitivity of the skin and core materials was investigated through a series of flexure and indentation tests. It was shown that the flexural modulus of the skins and all 11 foam materials did not exhibit any sensitivity to crosshead displacement rate over the conditions studied here. In addition, it was shown that the indentation response of the sandwich structures could be modelled using a simple indentation law, the parameters of which did not exhibit any sensitivity to loading rate. Low velocity impact tests on the sandwich structures resulted in a number of different failure modes. Shear fracture was found to occur in the PVC/PUR systems based on brittle core materials. In contrast, buckling failures in the uppermost composite skin were observed in the intermediate modulus systems, whereas initial damage in the higher modulus PVC/PUR systems took the form of delamination within the top surface skin. It has been shown that a simple energy balance model based on the dissipation of energy during the impact event can be used to successfully model the elastic response of foam based sandwich structures. The energy balance model is particularly useful since it can be used to establish the partition of energy during the impact process.

References listed at the end of the paper:


Hazizan Md. Akil (1) and W.J. Cantwell (2)
(1) School of Materials and Mineral Resource Engineering, University Sains Malaysia
(2) Department of Materials Science and Engineering, University of Liverpool


Stylianos Yiatros (1), M. Ahmer Wadee (2) and Christina Voellmecki (3)
(1) Dept. of Civil Engineering and Geomatics, Cyprus Univ. of Technology, Limassol, 3036, Cyprus
(2) Dept. of Civil and Environmental Engineering, Imperial College London
(3) Institut für Mechanik, Technische Univ. Berlin
ABSTRACT: An analytical pilot model for interactive buckling in sandwich struts with cores made from a functionally graded material based on total potential energy principles is presented. Using a Timoshenko beam approach, a system of nonlinear differential and integral equations is derived that predicts critical and secondary instabilities. These are validated against numerical simulations performed within the commercial finite-element package Abaqus. Good agreement is found, and this offers encouragement for more elaborate models to be devised that can account for face-core delamination—a feature where functionally graded materials are known to offer distinct advantages.

ABSTRACT: In present work, the critical buckling load of metallic foam composite sandwich panels is calculated by experimental, finite element methods (FEM) and theoretical analysis. The experimentally investigated is based on an edgewise compression test program to examine buckling failure and compressive properties. The metallic foam sandwich panels under edgewise compression tend to collapse in overall buckling mode. The most important factor that determines the overall buckling load of a sandwich panel under edgewise compression is the shear properties the metallic foam core. The sandwich beam theory and the FE model are developed for prediction of the buckling load of metallic foam sandwich structure. In despite of some differences existed among experimental data, FE and theoretical results, considering the existence of initial defects in sandwich structures which can’t be calculated in FE model and theory analysis, the differences are in the reasonable range. The FE program developed in this paper can effectively be used to simulation of edgewise compression response for metallic foam composite sandwich structures. Theoretical and FE model results are in agreement with experimental result.

Y.W. Kwon (1), M.C. Murphy (1) and V. Castelli (2)
(1) Mechanical Engineering Department, Naval Postgraduate School, Monterey, CA 93943
(2) Composite and Resins Branch, Naval Surface Warfare Center, Annapolis, MD 21402
ABSTRACT: An unbalanced and asymmetric sandwich composite structure consisting of Titanium 6-4 and glass-reinforced plastic (GRP) skins with a phenolic honeycomb core is being considered for construction of a surface ship mast which will enclose critical shipboard equipment. Stability of the structure is one of the major concerns in the design process. This research focuses on analytical and experimental studies of an unbalanced
composite sandwich beam subjected to a compressive axial load. The failure load (i.e., peak load) and failure mode of each skin material and the sandwich construction were measured at the laboratory. An analytical model was developed for predicting the failure load of the unbalanced and asymmetric sandwich composite configuration, including the transverse shear energy of the core material. The experimental data agreed very well with analytical prediction. Postbuckling failure, as well as residual strength after initial failure, were also studied.

References listed at the end of the paper:


ABSTRACT: A sandwich structure typically consists of two facesheets separated by lightweight core. Buckling is one of the critical failure modes for sandwich structure in particular for relatively large panels. A sandwich can be treated as a laminate where the core is just another ply with negligible stiffness and strength properties and thickness equal to the core thickness. Buckling is one of the critical failure modes for sandwich structure in particular for relatively large panels. The reason is that it is hard to design against all possible failure modes in the post-buckling regime and, as a result, buckling is usually considered to coincide with final failure. Wrinkling is a local buckling phenomenon where the facesheet of a sandwich buckles over a characteristic half-wavelength \( l \), which is unrelated to the overall length or width of the panel. This chapter also discusses sandwich intracellular buckling under compression and attaching sandwich structures.


ABSTRACT: A formula is derived for the buckling in compression of an orthotropic sandwich panel, with all edges simply-supported. Two special types of symmetrical sandwiches, that of a sandwich having zero core flexural stiffnesses and of a corrugated core sandwich, are considered, and curves giving the critical buckling end load per inch are presented. An approximate theory is also given for the bending of sandwich panels under the action of an axial compressive load and a uniform lateral pressure. Curves are presented giving the maximum bending moments in a corrugated core sandwich panel.

References listed at the end of the paper:


ABSTRACT: (Cannot cut and paste it.)


ABSTRACT: A sandwich structure is comprised of layered composite materials formed by bonding two or more thin facings or facesheets to a relatively thick core material. This article describes the sandwich panel failure modes. It tabulates the nomenclature and definitions for loads, geometry, and material properties. The article illustrates critical strength-check locations for a flat sandwich panel. It discusses the analysis methods formulated for flat rectangular honeycomb panels; curved sandwich panel; and for each of the various sandwich panel failure modes. The article concludes with a discussion on flat panel stability analysis methods.

ABSTRACT: A recent six degree-of-freedom interactive buckling analysis for sandwich struts is extended from isotropic to orthotropic core materials. The interaction, which involves an overall mode of buckling coupled with local wrinkling predominantly on one face, arises as a progressive destabilization from neutral bifurcation in the overall mode alone to a highly unstable secondary bifurcation in a combination of three independent buckling modes. The analytical model, which allows separately for bending and shear deformations in the core, is illustrated by application to a set of typical sandwich struts. An optimum core orthotropy that maximizes the interaction is found. In combination with the earlier optimum wavelength for local wrinkling, this suggests that secondary destabilization can occur almost immediately after the initial (triggering) bifurcation.

References listed at the end of the paper:


ABSTRACT: Compressed sandwich structures, comprising two stiff face plates separated by a softer core material, while designed principally as efficient integral structures, can lose this quality when faces buckle locally. Interaction between overall (Euler) buckling and local buckling of one face suggests that failure will localize into the centre. A variational formulation, leading to a pair of nonlinear differential equations subject to integral constraints, describes the post-buckling response. These are solved by a combination of numerical shooting and continuation techniques, such that the response far into the unstable post-buckling regime can be portrayed. Solutions with both linear and nonlinear constitutive core relations are compared with the results of an engineering (body-force) approach, and with those of earlier (periodic) Rayleigh–Ritz analyses. The latter demonstrate the extra destabilization that comes with localization.

References listed at the end of the paper:
Koiter, W. T. & Pignataro, M. 1976 A general theory for the interaction between local and overall buckling of stiffened panels.
WTHD 83. Delft: Delft University of Technology.

ABSTRACT: Recent work on the interactive buckling behaviour of compressed sandwich structures (Hunt & Wadee, 1997) is extended to orthotropic core materials. The variation of the material properties can tend to maximize the interactive effect such that overall and secondary localized modes are triggered almost simultaneously, giving rise to highly unstable post-buckling behaviour in systems of practical dimensions.

References listed at the end of the paper:

ABSTRACT: A progressive destabilization in compressed elastic structures of sandwich construction is identified, whereby a triggering bifurcation into an overall mode of buckling is rapidly followed by secondary bifurcation into an unstable combination of at least two local modes. A six degree-of-freedom analysis for a sandwich strut is provided, which tracks equilibrium paths for a perfect system, specifically pinpointing states of secondary bifurcation. The analytical model allows for the independent variation of bending and shear in the section, components that are found in significantly different combinations in the overall and local forms of buckling that make up the interaction. An optimum wavelength for local buckling is identified, which maximizes the interactive effect by bringing the primary and secondary bifurcations together. Examples of sandwich sections drawn from the literature are tested. Although the critical loads of two of the contributing modes are often considerably higher than the third (typically by multiples of two or more), the preference for the broken symmetry of the interactive form is such that secondary bifurcation into the combination of modes is always to be expected.

Alexander E. Lobkovsky, “Structure of crumpled thin elastic membranes”, PhD thesis, Department of Physics, University of Chicago, Department of Physics, Chicago, August 1996
ABSTRACT: In this thesis we explore forced crumpling of a thin elastic membrane. As in many problems that involve bending of elastic plates and shells, the limit of the vanishing membrane thickness leads to a boundary layer phenomenon. We argue that the structure of a crumpled sheet in that limit is simple. It consists of a collection of flat facets that are bounded by straight edges that in turn meet at sharp vertices. These edges become infinitely sharp in the small thickness limit. A boundary layer solution in the ridge region determines the details of how the singular limit of a sharp crease is approached. Most of the elastic energy is confined into
the ridges. A scaling law allows one to estimate the energy of a ridge given only its length and dihedral angle. Thus, if for a given compression factor, a crumpled sheet can be characterized in terms of the underlying ridge network, one can estimate its elastic energy and therefore its resistance to further compression.

References listed at the end of the dissertation:
(Cannot cut and paste them)

Kawai Kwok, “Mechanics of viscoelastic thin-walled structures”, PhD Dissertaint, California Institute of Technology, Pasadena, California, USA, 2013

ABSTRACT: Thin-walled structures made of polymers and reinforced polymer composites are prominent candidates for constructing large lightweight structures. A major challenge in designing polymer-based thin-walled structures is their time and temperature dependent behavior originating from material viscoelasticity and its interaction with the highly geometrically nonlinear response due to thinness of the walls. Although polymer viscoelasticity and geometric nonlinearity have been extensively studied, the mechanics of structures exhibiting both phenomena are not well understood.

This thesis presents a combination of experimental, numerical, and analytical investigations of the behavior of viscoelastic thin-walled structures. The first goal of this research is to establish general methods of analysis for two types of structural components, namely composite shells and polymer membranes, that will serve as the basis for full-scale structural analysis. The second goal is to demonstrate the capability of the developed methods by analyzing time and temperature dependent behavior of deployable structures and balloon structures. In the study of deployable structures, the deployment and shape recovery processes after stowage are investigated. Fundamental features of viscoelastic deployable structures are studied first with homogeneous polymer beams and shells. A simple closed-form solution describing the shape evolution of a beam after stowage is proposed. The effects of rate and temperature on the bending instability of shells are revealed.

Building on the understanding gained from the analysis of homogeneous structures, modeling techniques are developed for polymer composite structures. A micromechanical viscoelastic model for carbon fiber reinforced polymer thin shells is established through finite element homogenization and applied to evaluate the effects of long-term stowage in a representative composite deployable structure.

In the study of balloon structures, a membrane model is developed to study polymer balloon films with stress concentrations due to thickness variation. A nonlinear viscoelastic constitutive model is first formulated for the film material. The wrinkling instability behavior is incorporated into the model through correction of stress and strain states in the presence of wrinkling. Stress concentration factors in balloon films are predicted and measured with the membrane model and full-field displacement measurement techniques, respectively.

References listed at the end of the dissertation:
ABSTRACT:


ABSTRACT: As the engineering profession moves from prescriptive or “deemed-to-satisfy” approaches towards design methodologies based on quantification of performance, sophisticated modelling tools are increasingly needed, especially when complex combinations of demand and capacity are encountered. Recourse is invariably made to advanced computational tools to provide high fidelity solutions to large and complex problems, such as the response of structural systems or components to thermomechanical actions. Software packages based on the finite element method are most commonly used for such analyses. There are some essential prerequisites to effective use of advanced computational software for complex nonlinear problems, which are often ignored, particularly in professional practice. These include a thorough understanding of the underlying mechanics of the problem under consideration; a good appreciation of the approximation methods for modelling the problem properly (e.g. the choice between elements, continuum or structural, low or high order interpolation, degree of mesh refinement necessary and so on); and perhaps most importantly ensuring that the software is reliable and is able to reproduce established fundamental solutions to an acceptable degree of accuracy.

This thesis attempts to address most of these issues but focusses primarily on the last mentioned prerequisite and provides a range of novel and unprecedented fundamental solutions for beams, plates, and shallow shells subject to moderate or extreme thermomechanical loads such as those resulting from a fire. Geometric and material nonlinearities are included in the proposed formulations along with the most common idealised boundary conditions. Thermally induced deformations generate large displacements and require the solutions to account for geometric nonlinearity, while material nonlinearity arises from the degradation of the material at
elevated temperatures. In the context of structural performance under extreme thermal action (such as fire), a finite element procedure is employed to analytically characterise generic temperature distributions through the thickness of a structural component arising from different types of fire exposure conditions including: a “short hot” fire leading to a high compartment temperature over a relatively short duration; and a “long cool” fire with lower compartment temperatures, but over a longer duration.

Results have shown that despite the larger area under the long cool fire time-temperature curve, which traditionally represented the fire severity, the effect of the short hot fire on the nonlinear responses of beams, plates, and shallow shells is more pronounced. Also, the effect of temperature-dependent material properties is found to be more pronounced during the short hot fire rather than the long cool fire. Comparison studies have confirmed that while the current numerical and theoretical approaches for analysing of thin plates and shells are often computationally intensive, the proposed approach offers an adequate level of accuracy with a rapid convergence rate for such structures. The solutions developed can be used to: verify software used for modelling structural response to thermomechanical actions; help students and professionals appreciate the fundamental mechanics better; provide relatively quick solutions for component level analyses; and visualise internal load paths and stress trajectories in complex structural components such as composite shells that can help engineers develop deeper insights into the relevant mechanics. The formulations developed are versatile and can be used for other applications such as laminated composite or orthotropic shallow shells. A very significant by-product of developing such fundamental solutions is their potential use in the development of highly accurate hybrid elements for very efficient modelling of large problems. While this has not been fully developed and implemented in the current work, the requisite theoretical framework has been developed and reported in one of the appendices, which can be used to develop such elements and implement on an appropriate software platform.

References listed at the end of the dissertation:

Publications from the dissertation:
P. Khazaeinejad and A.S. Usmani, Temperature-dependent analysis of shallow shells and plates subjected to fire induced three-dimensional thermal gradients, in preparation to submit for review and publication.
P. Khazaeinejad and A.S. Usmani, Nonlinear analysis of heated beams: Modelling benchmarks, in preparation to submit for review and publication.

References listed at the end of the dissertation:


Theoretical development. Journal of Structural Engineering (see p. 98).


Z. Yao, K.J.R. Rasmussen (School of Civil Engineering, the University of Sydney, Sydney, NSW 2006, Australia), “Material and geometric nonlinear isoparametric spline finite strip analysis of perforated thin-walled steel structures - analytical developments”, Thin-Walled Struct., 49 (2011), pp. 1359–1373

ABSTRACT: This paper presents the analytical developments of the application of the Isoparametric Spline Finite Strip Method (ISFSM) to the material inelastic and geometric nonlinear analysis of perforated thin-walled steel structures. The general theory of the ISFSM is briefly introduced. The formulations of the kinematics, strain–displacement and constitutive assumptions are presented, and the tangential stiffness matrix is derived by applying the incremental equilibrium condition. The requirements for strip continuity and boundary conditions


are also discussed. In particular, the plasticity theory and the methods to integrate the ‘rate equations’ are
emphasized, and the related ‘backward Euler return method’ and use of a ‘consistent material modulus’ are
highlighted. The present isoparametric spline finite strip analysis is verified against a number of analyses of
perforated and non-perforated plates and plate assemblages, as described in the companion paper (Yao and
Rasmussen, submitted for publication) [1], demonstrating its accuracy and efficiency for the predictions of
the inelastic post-buckling behavior of perforated thin-walled steel structures.

References listed at the end of the paper:
[16] Abdel-Rahman NM. Cold-formed steel compression members with perforations, PhD dissertation. McMaster University, Canada; 1997.
[32] Eccher G, Rasmussen KJR, Zandonini R. Geometric nonlinear isoparametric spline finite strip analysis of perforated thin-walled...
[59] Ramberg J, Osgood WR. Description of stress strain curves by three parameters. NACA-TN 902, National Advisory Committee for Aeronautics (NACA); 1943.
[70] Ortiz M, Simo JC. An analysis of a new class of integration algorithms for elastoplastic constitutive relations. International

ABSTRACT: This thesis is devoted to the numerical solution of dynamic problems involving thin-walled structures. Special consideration is paid to the effects of contact-impacts. Thus, the main effort is concentrated on studies, development and computer program implementations of efficient algorithms for analysis of dynamically loaded shell structures, including contact-impacts and severe structural deformation.

Recent developments in the formulation of efficient finite elements for dynamically loaded shell structures are studied. A program implementation of a low-order four-node shell element with uniformly reduced integration is performed. The efficiency and the behaviour of this element type are compared with existing shell and solid elements implemented in the same program system. Hourglass resisting algorithms are reviewed and formulated, and parameter studies are carried out.

A new contact interface algorithm for dynamic analysis with explicit integration is presented. The development of the defence node algorithm permits contact constraints based on the Lagrange multiplier method to be introduced in dynamic analysis with explicit integration. Numerical tests show the good performance of the developed algorithms.

A new global search method for general contacting systems is developed and implemented in a computer program together with the above-mentioned contact interface algorithm. The concept of position codes for efficient global contact searching and the local search procedure used are presented. Numerical experiments are performed in order to examine the behaviour of the algorithms in different aspects.

References listed at the end of the dissertation:

materials with engineered microstructures, such as polymer composites and nanotube. Though the well-established finite element analysis (FEA) has the ability to analyze a small portion of such material, for the whole structure, the total degrees of freedom of a finite element model can easily exceed the bearable time in analysis or the capability of the best mainstream computers. To reduce the total degrees of freedom and save the computational efforts, an efficient way is to use a simpler and coarser mesh at the structure level with the micro level complexities captured by a homogenization method. Throughout the dissertation, the homogenization is carried on by variational asymptotic method which has been developed recently as the Variational Asymptotic Method for Unit Cell Homogenization (VAMUCH). This methodology is also expandable to the structure analysis as long as a representative structural element (RSE) can be obtained from structure. In the present research, the following problems are handled: (1) Maximizing the flexibility of choosing a RSE; (2) Bounding the effective properties of a random RSE; (3) Obtaining the equivalent plate stiffnesses for a corrugated plate from a RSE; (4) Extending the shell element of relative degree of freedom to analyze thin-walled RSE. These problems covered some important topics in homogenization theory. Firstly, the rules need to be followed when choosing a unit cell from a structure that can be homogenized. Secondly, for a randomly packed structure, the efficient way to predict effective material properties is to predict their bounds. Then, the composite material homogenization and the structural homogenization can be unified from a mathematical point of view, thus the repeating structure can be always simplified by the homogenization method. Lastly, the efficiency of analyzing thin-walled structures has been enhanced by the new type of shell element. In this research, the first two topics have been solved numerically through the finite element method under the framework of VAMUCH. The third one has been solved both analytically and numerically, and in the last, a new type of element has been implemented in VAMUCH to adapt the characteristics of a thin-walled problem. Numerous examples have demonstrated VAMUCH application and accuracy as a general-purpose analysis tool.

References listed at the end of the dissertation:


Paul Gerrard Duxbury, “Solution of elasto-plastic plate and shell problems using the generalized Galerkin method”, PhD Dissertation, Civil Engineering Department, Imperial College of Science and Technology, January 1988

ABSTRACT: This thesis describes the means of nonlinear structural analysis by microcomputer, whereby the machine replaces the analytical flow produced classically by hand. The automation of the analysis allows the full evaluation of the performance of Galerkin's method for the competitive solution of a specialized class of plate and shell problems.

A comprehensive program to follow the proposed routines was written and applied to a selection of plate and shell problems, including both material and geometric nonlinearities.

In addition, different aspects of nonlinear mechanics are examined. Considering material nonlinearity, methods which eliminate ‘drift’ from the yield surface and accurately integrate stresses through a shell thickness are proposed. For an elastic system, various aspects of structural stability are discussed and a method to solve for nonlinear bifurcation paths developed.

References listed at the end of the dissertation:
3 J.E. Harding and P.J. Dowling, Recent research on the behaviour of cylindrical shells in offshore structures, Conf. on Steel Structures, Budva, Yugoslavia, pp 317-338, (1986).
33. J. Kempner, Deformations and stresses caused in circular cylindrical shells by pipe attachments - Part VI, Derivation of generalized Donnell-type equations for circular cylindrical shells with application to line loads along the generatrices, KAPL Report, No 926 (1953).
ABSTRACT:
Mechanical Engineering, The University of British Columbia, Canada 1994


ABSTRACT: Peripheral milling of flexible components is a commonly used operation in the aerospace industry.
Aircraft wings, fuselage sections, jet engine compressors, turbine blades and a variety of mechanical components have flexible webs which must be finish machined using long slender end mills. Peripheral milling of very flexible plate structures made of titanium alloys is one of the most complex operations in the aerospace industry and it is investigated in this thesis.

Flexible plates and cutters deflect statically and dynamically due to periodically varying milling forces and self excited chatter vibrations. Static deflections of the plate and cutter cause dimensional form errors, whereas forced and chatter vibrations result in poor surface quality and chipping of the cutting edges. In this thesis, a comprehensive model of the peripheral milling of very flexible cantilever plates is presented. The plate and cutter structures are modeled by 8 node finite elements and an elastic beam, respectively. The cutting forces are shown to be very dependent on the magnitude of the plate and cutter deformations which are irregular along the helical end mill-plate contact. The interaction between the milling process and cutter-plate structures is modeled, and the milling forces, structural deformations and dimensional form errors left on the finish surface are accurately predicted by the simulation system developed in this study. A strategy, which constrains the maximum dimensional form errors caused by static deformations of plate and cutter by scheduling the feed along the tool path, is developed. The variation of the plate thickness due to machining and the partial disengagement of the plate and cutter due to excessive static deflections are considered in the model. The simulation system is proven in numerous peripheral milling experiments with both rigid blocks and very flexible cantilevered plates. . . (Cannot cut and paste the rest of the abstract…)

References listed at the end of the Dissertation:

H.F. Mahmood and S.H. Abed (Engineering and Manufacturing Staff, Ford Motor Co., Dearborn, Michigan, USA), “Computer aided analysis of thin walled structural components subjected to axial and bending crush loads”, Eighth International Specialty Conference on Cold-Formed Steel Structures, St. Louis, Missouri, USA, November 11-12, 1986

ABSTRACT: An interactive computer program "SECOLLAPSE" has been developed to assist the designer in selecting the most efficient structural component to meet automotive requirements for crash strength and energy management. The program predicts the strength characteristics and loading history of general, thin walled plate-components, subjected to axial and/or bending crush loads. In the program the component section is divided into
several sub-elements according to its shape. Each sub-element is analyzed for elastic buckling, maximum strength, fold size and mode of collapse. Elements strength characteristics are determined based on the boundary condition (degree of restraint) and the applied stress pattern. The analytical prediction shows good correlation with the test data.

References listed at the end of the paper:

Holm Altenbach (1) and Victor A. Eremeyev (2)
(1) Chair of Engineering Mechanics, Faculty of Mechanical Engineering, Otto-von-Guericke-Universita t Magdeburg, Magdeburg, Germany
(2) Faculty of Mechanical Engineering and Aeronautics, Rzeszów University of Technology, Rzeszów, Podkarpackie, Poland

"Thin-walled structural elements: Classification, classical and advanced theories, new applications", Publisher and date are not given in the pdf file; the most recent reference is dated 2016. Perhaps this is a chapter in a book.

ABSTRACT: Thin structures were existing from the ancient time. From observations of the nature the people understood that thinner means lighter, but stiffness and stability problems arose. This was the starting point for the elaboration of theories analyzing these structures. At that time applications were limited to civil engineering. At present they are used in aerospace engineering as basic elements. Such structures are applied as a model of analysis in other branches too, e.g. mechanical engineering. With the necessity to substitute classical material by new (advanced) materials - instead of steel or concrete, now laminates, foams, nano-films, biological membranes, etc. are used. The new trends in applications demand improvements of the theoretical foundations of the plate and shell theories, since new effects (for example, transverse shear or surface effects) must be taken into account. This contribution is mainly an introduction to the CISM-Course SHELL-LIKE STRUCTURES: ADVANCED THEORIES AND APPLICATIONS. After some introduction to the history some examples concerning new applications are discussed. After that main directions in the theory of plates and shells are presented. Finally, various advanced theories are briefly introduced. Other advanced theories are presented in the following chapter.

References listed at the end of the paper:
H. Altenbach, V.A. Eremeyev, and N.F. Morozov. Linear theory of shells taking into account surface stresses. Doklady Physics,
INTRODUCTION: A structure can be classified as "thin-walled" if its thickness is much smaller than its other dimensions. In general, thin-walled structures possess a very high in-plane stiffness while their out-of-plane stiffness is very low. This property makes thin-walled structures very suitable for two purposes. Firstly, if the structure is designed such that the loading assesses mainly the in-plane stiffness, load-carrying constructions with very high stiffness-to-mass ratios can be achieved. Due to this property, thin-walled structures are used extensively in building and civil engineering constructions, aircraft, aerospace, shipbuilding and other industries. Secondly, the out-of-plane flexibility property of thin-walled structures allows to make mechanisms with relative large displacements while staying in the elastic domain. Applications can, for example, be encountered in suspension systems [138], deployable structures [125] and in Micro-Electro-Mechanical-Systems [114; 115].

The design of thin-walled structures encompasses a number of challenges. Firstly, thin-walled structures under compressive loading may become unstable, that is they buckle. Buckling often occurs at stresses much lower than the yield stress making the buckling strength one of the key design criteria. Secondly, thin-walled structures may be sensitive to geometrical imperfections (small deviations from the nominal shape) and loading imperfections. This can result in significant reductions of the maximum load carrying capacity of the imperfect structure with respect to the perfect one. Finally, out-of-plane displacements can rapidly become very large (in comparison with the thickness of the structure) resulting in the fact that geometrical nonlinearities can no longer be neglected during the analysis.

Although there are still some open issues, the analysis of the (nonlinear) response and buckling of thin-walled structured subjected to static loading (i.e. the situation in which transient inertia and damping forces may be neglected) is well established in engineering science [66]. However, in practise thin-walled structures are often subjected not only to a static load but also to a dynamic load. The resistance of structures liable to buckling, to withstand timedependent loading is addressed as the dynamic stability of these structures. The term dynamic stability will be further elucidated in Section 2.2. Now, two examples of dynamically loaded thin-walled structures will be discussed.

The first example comes from aerospace engineering and considers the case where a thin-walled structure acts as a (light-weight) load-carrying construction. The Vega is an expendable launch vehicle (ELV), used to place satellites into an orbit around the Earth, see Fig. 1.1. The satellite (the pay load) is placed in the top of the ELV and in four steps the vehicle is brought into the atmosphere. During each step, one stage of the ELV is ignited and after its fuel is burned it is separated from the rest of the vehicle using pyrotechnic charges. The first and second stage of the Vega are interconnected using a conical thin-walled interstage, see Fig. 1.2. The interstage has a maximum diameter of approximately 3 [m] and is constructed from curved aluminium panels with a thickness of approximately 6 [mm] in combination with ring stiffeners for extra stability [134]. A simplification of the mechanical loading of the interstage during the launch is shown in Fig. 1.3, i.e. the structure carries a rigid top mass (resembling the mass of the upper part of the launch vehicle) while being subjected to a base acceleration (resembling the longitudinal acceleration of the launch vehicle). During a typical launch, the longitudinal acceleration shows various static levels (with peak values up to 5.5 · g, where g = 9.81 [m/s²] denotes the gravitation constant) with on top significant dynamic fluctuations (order 1 · g) and shocks [9; 137]. The combination of the base acceleration and the top mass results in a (time-varying) compressive loading of the thin-walled interstage. Consequently, dynamic buckling of the interstage, but obviously also of other parts, is one of main issues during the design of such a launcher.

The next example illustrates how the (out-of-plane) flexibility property of thin-walled structures can be exploited to realize a flexible mechanism for adaptive optics on micro scale. In Fig. 1.4, a 3D self assembled

microplate suspended in two buckled beams is depicted [115]. The microplate has size 380 × 250 [μm] and can be electrostatically actuated using electrodes buried underneath the microplate. Before assembly, the structure is planar. Then, by using scratch drive actuators (SDA), the beams are forced to buckle and locked using a self-locking mechanism to make the buckled state permanent. This forces the microplate to lift out of the substrate plane, creating enough space for large rotations of the microplate. The buckled beams do not only lift the microplate but also act as elastic torsional hinges. In this manner, actuation of the microplate can be achieved with rotations up to ±15 degrees, while remaining in the elastic domain of the used material. During operation, the microplate is controlled to follow high speed prescribed motions, resulting in both torsional and transversal dynamic loading of thin buckled beams.

To obtain competitive designs for dynamically loaded thin-walled structures such as discussed above, it is vital to be able to understand, predict, and eventually optimize the dynamic stability behaviour of the structure. However, design strategies and fast (pre-)design tools for thin-walled structures under dynamic loading are still lacking. This can be partially explained by the involved computational complexity of the dynamic stability analysis, especially since in such analyses geometrical nonlinearities should be taken into account. Furthermore, in general time-dependent loads are described by multiple parameters (i.e. multi-parameter studies must be performed) and a wide variety in possible time-dependent loading types can be considered, like for example shock/impact loading, step loading, periodic loading or stochastic loading. Furthermore, although already many theoretical studies have been performed regarding dynamically loaded thin-walled structures [15; 77; 121], experimental validation of these results is scarce. Based on these observations, the objectives of this thesis are formulated in the next subsection.

**OBJECTIVE:** The research objective of this thesis is to develop (fast) modelling and analysis tools which give insight in the behaviour of dynamically loaded thin-walled structures. To illustrate and to test the abilities of the developed tools, a number of case studies are examined. The tools are developed for structures with a relatively simple geometry. The geometric simplicity of the structures allows to derive models with a relatively low number of degrees of freedom which are, therefore, very suitable for extensive parameter studies (as essential during the design process of a thin-walled structure). These models are symbolically derived via an energy based approach, using analytical expressions for the undeformed and deformed structural geometry. This approach has been implemented in a generic manner in a symbolic manipulation software package, such that model variations can be easily performed. For the analyses, both nonlinear static and nonlinear dynamic responses will be computed using numerical techniques in combination with the derived nonlinear models. The combination of the symbolic derivation of the model and the numerical techniques to obtain the solutions, is called a semi-analytical approach. Using this semi-analytical approach, the buckling of four structures due to both quasi-static loads and time-dependent loads (i.e. shock loading and harmonic loading) are thoroughly studied. These studies will include investigation of the effect of several parameter variations and the effect of small deviations from the nominal geometry. For validation, the semi-analytical results will initially be compared with results obtained from computationally much more demanding FEM analyses. However, more important, for two cases the semi-analytical results will also be compared with experimentally obtained results. For this purpose, a dedicated experimental setup will be realized.

References listed at the end of the dissertation:


due to the exact geometry description with NURBS, curvatures can be evaluated directly on the surface. Shell is mainly determined by its geometry and therefore a good geometric description is essential. Furthermore, functions. NURBS

In this thesis, the isogeometric analysis with the goal of merging design and analysis into one model by using a unified geometric representation. NURBS (Non-Uniform Rational B-Splines) are the most widespread technology in today’s CAD modeling tools and therefore are adopted as basis functions for analysis.

In this thesis, the isogeometric concept is applied to the analysis and shape optimization of shell structures. A new, rotation-free shell element is developed, using the Kirchhoff-Love shell theory and NURBS as basis functions. NURBS-based analysis provides advantages especially for shells, since the structural behavior of a shell is mainly determined by its geometry and therefore a good geometric description is essential. Furthermore, due to the exact geometry description with NURBS, curvatures can be evaluated directly on the surface without
rotational degrees of freedom or nodal directors.

Different examples show the good performance and accuracy of the method, for geometrically linear and nonlinear problems. Aspects concerning boundary conditions and the treatment of multiple patch structures are investigated, and solutions are proposed which allow the use of this method for a broad variety of problems. Furthermore, the developed shell formulation proves as very well suited for a direct integration into a CAD model, which is also realized in a commercial CAD software. The practical application of this integrated method for different examples also reveals problems and limitations of the present approach, which are discussed subsequently. Another goal of this thesis is to extend the isogeometric concept to shape optimization. After a brief review of shape optimization using CAD-based or FE-based design models, isogeometric shape optimization is introduced as a combination of both existing approaches which enhances flexibility in choosing the design space.

In the context of a cooperation project, the developed structural formulation is integrated into a fluid-structure interaction (FSI) environment and is applied to the three-dimensional FSI simulation of a wind turbine blade rotating in the air flow. This example shows the relevance of this method to large industrial applications.

References listed at the end of the dissertation:


Azhar Mahmood Nasir, “Axisymmetric shell structures for multi-use”, PhD Dissertation, School of Civil Engineering, Queensland University of Technology (QUT), Brisbane, Australia, March 2002

ABSTRACT: Shell structures find use in many fields of engineering, notably structural, mechanical, aerospace and nuclear-reactor disciplines. Axisymmetric shell structures are used as dome type of roofs, hyperbolic cooling towers, silos for storage of grain, oil and industrial chemicals and water tanks. Despite their thin walls, strength is derived due to the curvature. The generally high strength-to-weight ratio of the shell form, combined with its inherent stiffness, has formed the basis of this vast application. With the advent in computation technology, the finite element method and optimisation techniques, structural engineers have extremely versatile tools for the optimum design of such structures.

Optimisation of shell structures can result not only in improved designs, but also in a large saving of material. The finite element method being a general numerical procedure that could be used to treat any shell problem to any desired degree of accuracy, requires several runs in order to obtain a complete picture of the effect of one parameter on the shell structure. This redesign / re-analysis cycle has been achieved via structural optimisation in the present research, and MSC/NASTRAN (a commercially available finite element code) has been used in this context for volume optimisation of axisymmetric shell structures under axisymmetric and non-axisymmetric loading conditions.

The parametric study of different axisymmetric shell structures has revealed that the hyperbolic shape is the most economical solution of shells of revolution. To establish this, axisymmetric loading; self-weight and hydrostatic pressure, and non-axisymmetric loading; wind pressure and earthquake dynamic forces have been modelled on graphical pre and post processor (PATRAN) and analysis has been performed on two finite element codes (ABAQUS and NASTRAN), numerical model verification studies are performed, and optimum material volume required in the walls of cylindrical, conical, parabolic and hyperbolic forms of axisymmetric shell structures are evaluated and reviewed. Free vibration and transient earthquake analysis of hyperbolic shells have been performed once it was established that hyperbolic shape is the most economical under all possible loading conditions. Effect of important parameters of hyperbolic shell structures; shell wall thickness, height and curvature, have been evaluated and empirical relationships have been developed to estimate an approximate value of the lowest (first) natural frequency of vibration.

The outcome of this thesis has been the generation of new research information on performance characteristics of axisymmetric shell structures that will facilitate improved designs of shells with better choice of shapes and enhanced levels of economy and performance.

Publications from this work:
Australasian Finite Element Conference, Melbourne, Australia.


References listed at the end of the paper:


Ce Liang, “Analysis of crashworthiness of the dimpled thin-walled structures”, PhD Dissertation, University of Sussex (US), December 2017

ABSTRACT: Thin-walled structures are often used as kinetic energy absorbers in vehicular systems and infrastructure designs. In such applications, high specific energy absorption is usually desirable, because it is beneficial for weight reduction. The dimpling cold-roll metal forming process introduces dimpled geometry and increases the strength of sheet metal. This thesis aims to investigate the energy absorption characteristics of the dimpled thin-walled structures.

A finite element (FE) modelling analysis was performed using ANSYS Explicit Dynamics solver, to predict the response of dimpled structures to dynamic and quasi-static loads. A series of experimental tests were conducted and the FE method was validated through comparing the numerical and experimental results. To understand the response of the dimpled structural components to axial crushing loads, numerical simulations were performed. A parametric study on a key cold-roll forming parameter “forming depth” was carried out to evaluate its effects on the dimpled geometry and material properties. Through the parametric study, manufacturing parameters for the cold-roll forming process were suggested to improve yield strength and energy absorption performance of dimpled steel components. It was shown that the specific energy absorption can be increased by up to 16% after optimizing the forming depth.

To take the most advantage of the dimpled geometry, multi-layer dimpled thin-walled columns were analysed. The interlocking mechanism of dimpled plates were investigated and an empirical model was proposed to describe the interaction between dimpled plates. It was shown that a considerable amount of energy can be absorbed through the interaction between dimpled walls. The behaviour of dimpled columns under lateral impact loads was also investigated. It was revealed that the introduced dimpled geometry contributes to reducing the peak impact force without sacrificing the energy absorption capacity. However, this is only valid when at least one end of the dimpled thin-walled column is fully restrained.

References listed at the end of the dissertation:


[41] Lam K, Behdinan K, Cleghorn W. A material and gauge thickness sensitivity analysis on the NVH and crashworthiness of
normal and shear stress components are of notable importance in many engineering applications, and therefore

ABSTRACT: Conference on Composite Materials, Seville, Spain, 22–26 June 2014

D. Pastorino (1), A. Blazquez (1), J.A. Reinoso (2) and F. Paris (1)

(1) Grupo de Elasticidad y Resistencia de Materiales, ETS de Ingeniería, Universidad de Sevilla
(2) Institut für Statik und Dynamik, Leibniz Universität Hannover, Germany

“Composite plates modeling strategies for the estimation of transverse stresses”, ECCM16 – 16th European Conference on Composite Materials, Seville, Spain, 22-26 June 2014

ABSTRACT: The development of mechanical models that incorporate accurate estimations of the transverse normal and shear stress components are of notable importance in many engineering applications, and therefore
it has attracted the interest of the research community along the last decades. This is the case of debonding and delamination of composite laminates, in which these mechanical actions play a crucial role in the initiation and propagation of these damage mechanisms. In this contribution, the accuracy levels of some numerical techniques that are used to compute these stress components are assessed. Geometrically linear and non-linear benchmark problems are solved using such techniques, whose results are compared between them.

References listed at the end of the paper:


ABSTRACT: The paper presents the results of an experimental and numerical investigation of the deformation process of duraluminium plates under the action of a shock wave formed as a result of the explosion of a condensed explosive. The character of the deformation and destruction of the plate fixed along the perimeter is determined. It is shown that the plate is deformed according to the "envelope" scheme. The residual plastic deformation of the plate is determined. The shock wave load is described by semi-empirical dependences. The results of the calculations coincide with the experimental data.

References listed at the end of the paper:
18 M. B. Altman, Industrial deformable, sintered and cast aluminum alloys

ABSTRACT: Cold-formed thin-walled sections are prone to local buckling caused by residual stresses, geometrical imperfections and inconsistency of material properties. We present a real case of buckling failure and conduct a numerical and experimental study aimed to identify methods capable of predicting such failures. It is important because designers of structures are getting more FEA-oriented and tend to avoid lengthy procedures of cold-formed structures design. Currently adopted methods are complicated and require patience and caution from a designer which is reasonable in case of the most important structural members but not necessarily so in ordinary design. Since it is important, we offer an insight into several FEA and manual methods which were sufficient to predict the failure while remaining fairly simple. Using a non-uniform partial safety factor was still necessary. We hope that this paper will be of interest for people performing a lot of routine analyses and worrying about reliability of their computations.

References listed at the end of the paper:

3. Cold-Formed Steel Design Manual, American Iron and Steel Institute, 2013
14. Schafer BW, Pekoz T. Direct strength prediction of cold-formed steel members using numerical elastic buckling solutions. 14th International Specialty Conference on Cold-Formed Steel Structures. 1998;69-76.

ABSTRACT: In this study, geometrically nonlinear analysis of plate and shell structures is carried out by using a degenerated shell element. The present shell element is formulated by using the isogeometric concept. Reissner-Mindlin assumption is adopted in the element formulation where total Lagrange formulation is used. In particular, the positions of control points is consistently used to create the normal vector for the mapping between control points and associated points on real surface. The arc-length method is employed to handle the snap-through behaviour of shells. Several benchmark tests are tackled to verify the performance of the present shell element. From numerical tests, the present shell element can remove locking phenomena with the only use of refinement technique and it performs satisfactorily for both thin and thick plate and shell structures under geometrically nonlinear situations.

References listed at the end of the paper:


Jozef Havran, “Snap-through effect of a slender web and a shallow shell”, PhD Dissertation, Dept. of Structural Mechanics, Slovenska Technicka Univerzita V Bratislave (STU), Date not given

ABSTRACT: The term stability denotes an attribute of structure that can be characterized as an ability of the structure to remain in the equilibrium state. Stability of the bearing system is a crucial requirement when it comes to the safety of each building structure. In the presented work, the attention is paid to the analysis of an undesirable phenomenon of loss of stability. From the analysis of simple bar structures we gradually move to the stability analysis of planar structures (thin plates and shells). Among the substantial problems concerning the mechanism of stability loss of thin-walled structures belongs the snap-through of thin plate, of von Mises truss and of a shallow shell. Theoretical background of this phenomenon is analyzed in detail in this work. The geometrically nonlinear theory must be used to describe the post buckling effect of thin-walled structures. In the work, an incremental technique has been used (Euler) in combination with iteration procedures (Newton-Raphson). Effect of shape imperfections (called as initial imperfections) has been analyzed. In the primary analyses it was necessary to confirm the validity of some principles on mathematically simple models of bars. Subsequently, we proceeded with analysis of thin plates and shallow shells. In the case of plates loaded in compression, the post buckling behavior was analyzed. Our next objective was to investigate the stability problems of cylindrical shells and shells of translation. The above mentioned problems were examined using the computer software based on the Finite Element Method. The results of particular programs and computation approaches were analyzed and evaluated.

R.M. Gutkowski (1) , C.J. Chen (2) and J.A. Puckett (3)
(1) Department of Civil Engineering, Colorado State University, Fort Collins, Colorado 80523, USA  
(2) Civil Engineering Department, Chung-Cheng Institute of Technology, Tashi, Taiwan, Republic of China  
(3) Department of Civil Engineering, University of Wyoming, Laramie, Wyoming 82071, USA


ABSTRACT: A cubic B-spline finite strip method (BFSM) is developed to analyze thin plates in bending. The basic mathematical relationships are derived for a direct stiffness formulation using a series type strip displacement function. Longitudinal behavior is modeled by a spline series in which unequal spline spacing is permitted. This feature allows local refinement of the discretization near patch and concentrated loads. Accuracy and convergence vis-à-vis alternative methods are compared. These include various finite element models, the conventional finite strip method and the BFSM with equally spaced splines. Comparisons show comparable accuracy with improved convergence. Oscillatory convergence due to Gibb's phenomenon, evident in some of the models, is avoided in the BFSM.


ABSTRACT: The studies on the long-term stability of composite plates and shells under limited creep carried out mainly by the research associates of the Institute of Polymer Mechanics are reviewed. The statement of the stability problems is discussed, according to which a viscoelastic structural member can be regarded as stable if
a disturbance in the form of a small initial deflection asymptotically tends with time to a small constant value. In the case of stability, as evidenced by experiments, the increase in the axisymmetric components of the initial deflection, dominating in the early stage, die down with time. On the contrary, the amplitudes of nonaxisymmetric initial imperfections grow at an increasing velocity. Analytical investigations show that the initial imperfections, when expanded into Fourier series, have a spectrum of short- and long-term critical forces. The deflection components having a critical force exceeding the external load are damped out, whereas those having a smaller critical force increase infinitely. The accelerated growth in the deflection, after a time, leads to transient buckling of the shell into a new stable equilibrium form. The problems of optimization of the structure and geometry of thin-walled composite constructions, with constraints on their long-term stability and critical time, are discussed.

References listed at the end of the paper:

ABSTRACT: This paper deals with the design of steel plate elements of rectangular industria


ABSTRACT: This paper deals with the design of steel plate elements of rectangular industrial ducts. Because of the practical aspect ratios and the stiffener arrangements, such a plate element is often treated as a long plate (one way slab), fixed supported at the edges and subjected to transverse pressure. The design pressure and the deflection limit determine the plate thickness and the stiffener spacing. Current design practice considers the geometrical nonlinearity, however, uses the strength criterion of first yield. This investigation postulates that consideration of partial yielding of the plate may result in an economical design option, while meeting the
serviceability criterion. The study is based on nonlinear finite element analyses of long plates subjected to increasing transverse pressure. Dimensionless parameters that characterize the behavior of such plates were identified and varied in a parametric study. Based on these analyses, design equations have been established for plate thickness and for stiffener spacing corresponding to three different scenarios namely: 0%, 16.5%, and 33% of through thickness partial yielding of the plate. Results show that allowing for 16.5% yielding results in 50% increase in stiffener spacing, at the expense of about 40% increase in deflections. Partially yielding plates can satisfy the serviceability limits states and can lead to economical stiffened plate systems for large rectangular industrial ducts.

References listed at the end of the paper:
· 1 ADINA. 2009. ADINA 8.5 user manual. ADINA R & D Inc., Watertown, MA, USA.


ABSTRACT: Buckling and post-buckling are among the most important failure factors in thin walled structures. The load-carrying behavior of cylindrical thin-walled shell structures under external pressure load is strongly dependent upon the nature and magnitude of the initial imperfections. These imperfections are invariably caused by an assortment of manufacturing processes like installing or welding. One of the most important imperfections caused by welding that has been reported to have an essential detrimental effect on the buckling resistance of these shells under external pressure load is longitudinal imperfections. Buckling and post-buckling capacity of the shells depend on the H/R and t/ R ratios (H the height, R the radius and t the thickness of a cylindrical shell). The present work discusses the finiteelement models labeled as SS (Shallow Slim), DS (Deep Slim), ST (Shallow Thick) and DT (Deep Thick). The samples of first group are modified to include a line longitudinal imperfection, amplitudes of 0.5t, 1t, 2t, 3t, 4t and 8t in depth (t is the thickness of cylindrical shell). The results presented are in agreement with international codes and theories concerning buckling.

References listed at the end of the paper:


ABSTRACT: In this thesis both static and dynamic analyses of composite thin-walled structures are carried out. Most notably, the Dynamic Stiffness Method (DSM) has been extensively exploited to develop advanced formulations for plates and shells. In particular, the Dynamic Stiffness (DS) matrices have been developed for laminated composite plates and shells using Higher-order Shear Deformation Theory (HSDT) in order to investigate their free vibration behavior and buckling characteristics. First, the Governing Differential Equations (GDEs) of motion and associated natural Boundary Conditions (BCs) (Neumann-type) for the given displacement field are derived via Hamilton's principle for both composite plate and shell structures. In the case of composite plates, the DS matrices are formulated for both out-of-plane and in-plane deformations. The GDEs for each of the two cases are solved in Levy's form separately. Next the problems for both plates and shells are reduced to a system of ordinary differential equations which are then solved by using the classical exponential solution procedure.

Mart Heerschap, “Design of cut-outs in shell structures”, PhD dissertation, unknown university, 2018

ABSTRACT: Aircraft fuselages are inevitably weakened by a large number of cutouts. In particular large cut-outs in the pressure cabinet, like those for doors, remain highly fatigue sensitive. This is not only due to the fact that the cut-out causes a large stress concentration, but is also due to the use of the door in service. This considerably increases the chance of accidental damage. It is obvious, therefore, that the reinforcement around a cut-out must be designed with care. The large number of repair patches around doors and other large cut-outs, found on virtually all aircraft over a certain age, clearly shows that the currently used design methods are inadequate. An improved design method for cut-outs in pressurized aircraft fuselages is described in this thesis. The design aspect should be emphasized, because design is more than simply the availability of an appropriate analysis method. A design procedure may by definition include the sizing of the structure and, moreover, must provide the designer with sufficient information to understand its behaviour. The latter aspect is especially important, because this allows the designer to concentrate on the creative part of the design task. Reduction of the time taken in design is obviously important from an economical point of view. Besides economic...
advantages, reduction of the time taken in design is also important with respect to changes in design. A door together with its surrounding structure, is often redesigned to meet individual customer requirements and this redesign often has to be performed in a very short time. The design method presented in this thesis offers a procedure for the prediction and modification of the stresses around a cut-out by means of finite element analysis, optimization, sensitivity studies and "what-if" analysis. The design tool developed speeds up the design process by around an order of magnitude. The design method is applied to an existing aircraft and the results compared to experimental data. A parameter study is performed to identify the most effective members of the reinforcing structure.


ABSTRACT: An equivalent classical plate model of corrugated structures is derived using the variational asymptotic method. Starting from a thin shell theory, we carry out an asymptotic analysis of the strain energy in terms of the smallness of a single corrugation with respect to the characteristic length of macroscopic deformation of the corrugated structure. Without invoking any a priori assumptions, we obtained the complete set of analytical formulas for effective plate stiffnesses valid for both shallow and deep corrugations. These formulas can reproduce the well-known classical plate stiffnesses when the corrugated structure is degenerated to a flat plate. The extension-bending coupling stiffnesses are obtained the first time. The complete set of recovery relations are also derived for recovering the fields within the corrugated structure from the strains obtained in the equivalent plate analysis.

References listed at the end of the paper:
very useful results can be obtained. We concentrate on these.

We first develop the strong formulation for plates and present thei

two. The plates in three

plane stress. Plates in flexure are the two

analogous to that of rods. We consider both of these separately.

We consider both of these separately.

We first develop the strong formulation for plates and present their spectral forms. It turns out, however, that very few strong-form solutions are available for arbitrary BCs, but there is one class with periodic BCs where very useful results can be obtained. We concentrate on these.

ABSTRACT: (Cannot cut and paste it)


ABSTRACT: A plate is an extended body where one of the dimensions is substantially smaller than the other two. The plates in three-dimensional (3D) thin-walled structures (called shells and folded-plate structures) can support both in-plane and out-of-plane loading. Furthermore, because the plates are thin, they lend themselves to approximation – while the structure may be three-dimensional, the local behavior is two-dimensional under plane stress. Plates in flexure are the two-dimensional equivalent of beams, and classical plate theory is the equivalent of the Bernoulli-Euler beam theory, whereas the in-plane or membrane behavior of plates is analogous to that of rods. We consider both of these separately.

We first develop the strong formulation for plates and present their spectral forms. It turns out, however, that very few strong-form solutions are available for arbitrary BCs, but there is one class with periodic BCs where very useful results can be obtained. We concentrate on these.
Flexural Behavior of Flat Plates
We develop a thin-plate model (called classical plate theory) that does not take the transverse shear deformation into account – this is therefore the plate counterpart of the Bernoulli-Euler beam. We could develop a model (called the Mindlin plate theory) that takes the shear deformation into account; however, it is worth keeping in mind that if shear effects in the plate might be important, then the plate should be modeled using the 3D solid Hex20 element.

Fei Wang (1), Haoran Gong (1), Xi Chen (2) and C.Q. Chen (1)
(1) Department of Engineering Mechanics and Center for Nano and Micro Mechanics, AML, Tsinghua University, Beijing 100084, China
(2) Columbia Nanomechanics Research Center, Department of Earth and Environmental Engineering, Columbia University, New York, NY 10027, USA

“Folding to curved surfaces: A generalized design method and mechanics of origami-based cylindrical structures”. Scientific Reports, Vol. 6, Article ID 33312, 2016, doi: 10.1038/srep33312

ABSTRACT: Origami structures enrich the field of mechanical metamaterials with the ability to convert morphologically and systematically between two-dimensional (2D) thin sheets and three-dimensional (3D) spatial structures. In this study, an in-plane design method is proposed to approximate curved surfaces of interest with generalized Miura-ori units. Using this method, two combination types of crease lines are unified in one reprogrammable procedure, generating multiple types of cylindrical structures. Structural completeness conditions of the finite-thickness counterparts to the two types are also proposed. As an example of the design method, the kinematics and elastic properties of an origami-based circular cylindrical shell are analysed. The concept of Poisson’s ratio is extended to the cylindrical structures, demonstrating their auxetic property. An analytical model of rigid plates linked by elastic hinges, consistent with numerical simulations, is employed to describe the mechanical response of the structures. Under particular load patterns, the circular shells display novel mechanical behaviour such as snap-through and limiting folding positions. By analysing the geometry and mechanics of the origami structures, we extend the design space of mechanical metamaterials and provide a basis for their practical applications in science and engineering.

References listed at the end of the paper:

ABSTRACT: Folded plates are assemblies of flat plates rigidly connected together so as to make structural system capable of carrying loads. They provide an economical and aesthetically pleasing design. This Paper aims at studying the material used for folded plate structure, analysis of folded plate structure by finite element strip or computer programs.

References listed at the end of the paper:
5. Robeller C., Weinandy Y., Interlocking folded plate – integral mechanical attachment for structural wood panels. Int. Journal of...
ABSTRACT: Origami engineering, which is the practice of creating useful three-dimensional structures through folding and fold-like operations applied to initially two-dimensional entities, has the potential to impact several areas of design and manufacturing. In some instances, however, it may be impractical to apply external manipulations to produce the desired folds (e.g., as in remote applications such as space systems). In such cases, self-folding capabilities are valuable. A self-folding material or material system is one that can perform folding operations without manipulations from external forces. This work considers a concept for a self-folding material system. The system extends the 'programmable matter' concept and consists of an active, self-morphing sheet composed of two meshes of thermally actuated shape memory alloy (SMA) wire separated by a compliant passive layer. The geometric and power input parameters of the self-folding sheet are optimized to achieve the tightest local fold possible subject to stress and temperature constraints. The sheet folding performance considering folds at different angles relative to the orientation of the wire mesh is also analyzed. The optimization results show that a relatively low elastomer thickness is preferable to generate the tightest fold possible. The results also show that the self-folding sheet does not require large power inputs to achieve an optimal folding performance. It was shown that the self-folding sheet is capable of creating similar quality folds at different orientations.

Edwin A. Peraza-Hernandez (1,2), Darren J. Harti (1,3) and Richard J. Malak Jr. (2,3)
(1) Department of Aerospace Engineering, Texas A&M University, College Station, TX 77843, USA
(2) Design Systems Laboratory, Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843, USA
(3) Texas Institute for Intelligent Materials and Structures, Texas A&M University, College Station, TX 77843, USA


ABSTRACT: Four-fold-mechanisms, such as the Miura-Ori-pattern, and its possible combinations are investigated by completing the mathematical description of a thin paper model done by Haas [1], with influences resulting from the thickness of the plate material. Additionally, different planning and realisation factors are analysed, focusing particularly on the elasticity of the plate material, the folding pattern, the realistic simulation of the hinge position and its necessity of kinematical freedom, as well as the inner friction resistance, resulting from the deployment of the necessary drive mechanism. Possible combinations of single four-fold-mechanisms to larger patterns featuring these characteristics are investigated, taking into account the previously mentioned conditions for planning and realisation.


ABSTRACT: This paper deals with structural shape optimization of shells and folded plates using two-noded Mindlin-Reissner C(0) finite strips. The whole shape optimization process is carried out by integrating finite strip analysis, cubic spline shape definition, automatic mesh generation, sensitivity analysis and mathematical programming methods in an efficient way. Both thickness and shape variables defining the cross-section of the structure are considered. The objective is to minimize the strain energy with a constraint that the total material volume of the structure remains constant. It is observed that minimization of strain energy leads to optimum structures in which the deflections and stress resultants in the members are considerably reduced. This is illustrated using several examples. The relative contributions of the bending, membrane and shear strain energies are also monitored during the whole optimization process. It is found that most optimal shell and folded plate structures are membrane dominant.

1) Constitutive model of light-activated shape memory polymers (LASMP) and foldable structures by LASMP
2) Time-dependent electro-active plate/shell structures
3) Computational tool for simulating folding of compliant systems

Lorenzo Guiducci, John W.C. Dunlop and Peter Fratzl, “An introduction into the physics of self-folding thin structures”, Publisher and date not given in the pdf file; most recent reference is dated 2016

INTRODUCTION: Spontaneous folding of matter has long been the subject of disparate branches of research, from the earlier vitalistic view of Leibniz1 to the mathematical description of morphogenetic processes of D’Arcy Thompson.2 Today, scientific advancements have shown how folding is a common strategy adopted in biological systems to build up more and more complex structures – in proteins, from a peptide chain to a functional enzyme; in plants, from bud petals to a developed flower; in organisms, from layers of cells to diversified embryos. One might think that such folding processes require exceptionally complex biological machineries to orchestrate them. On the contrary, with this contribution, we will show that folding can result from remarkably simple processes – and equally applies to both natural and artificial systems. In the following we will introduce the reader to the necessary theoretical concepts that are needed to understand these phenomena, providing examples from the common experience enabling a more systematic understanding.

When we talk about self-folding3 thin structures we refer to a broad class of spontaneous shape changes (that is not caused by an external load) that occur in thin bodies. The adjective thin here means that a three-dimensional body has at least one dimension much smaller than the other; that is, a rod can be considered one-dimensional since it has two small dimensions; a plate instead is two-dimensional since it has one small dimension. In particular we will refer to bodies that can be considered two-dimensional, that is plates (which are flat) and shells (which are curved). As will become clear in section 1, the fact that plates (and shells) are thin is at the
base of the rich panorama of shape changes that are observed.
The goal of the present document is to provide an overview of some of the scientific literature dealing with shape changes in self-folding thin structures. Although these shape changes can be of a very different nature, size and origin – occurring in artificial as well as biological materials, and in systems that range from nanometer to centimeter sizes – all can be understood under some unifying concepts that will be introduced in the following. Thanks to our presentation, it becomes much easier to locate where research efforts have been focused until now and to identify new fields of interest that scientific research hasn’t addressed yet.

This document is organized as follows. In section 1 we introduce the reader to the basic concepts of the mechanics of a thin plate (the experienced reader can skip this part). In section 2 we will introduce many examples of self-folding systems, categorizing them on the base of how eigenstrains are distributed and oriented in the plate. In this section, we will discuss the folding (or more generally the morphing) of systems that: undergo confined expansion due to an attached elastic foundation (section 2.2); are subjected to the so-called edge growth (section 2.3); which change curvature (section 2.4). In section 3 we will give some concluding remarks on the present work.

References listed at the end of the paper:
displacements and stresses in the structures. Some parametric analysis is also presented.

ABSTRACT: Origami is an old art of paper folding. From mechanical point of view origami can be defined as a folded structure. In the present paper a comparative study of four origami inspired folded plate structures is presented. Longitudinal, facet, egg-box and Miura-ori origami modules are used for the analysis. The models are based on six-parameter shell theory with the use of the finite element method. Convergence analysis of each module is presented. Numerical study of roof folded plates in oriented to the comparison of maximal displacements and stresses in the structures. Some parametric analysis is also presented.

ABSTRACT: Folded Plates and spatial structures are adopted for construction of large span structures in which a large space is realized without columns as the structural components. In those cases, the structures are expected to resist against various design loads mainly through their extremely strong capability which can be acquired through in-plane or membrane stress resultants and this is just the reason by which they themselves stand for external loads without columns as their structural components in the large span structures. In civil engineering construction, folded plates are commonly used as roofing units. However, they are frequently subjected to dynamic loadings in their service life and hence, the knowledge of their dynamic behavior is important from the standpoint of analysis and design. To understand the performance and behavior of folded plate, the finite element modeling approach is a very important aspect. Finite Element Analysis is performed for both linear and non-linear problems to design and analysis evaluation situations. In this study the finite element modeling of multi bay cylindrical shell structures has been done to understand its performance during earthquake using SAP 2000 (version 14). The structure is idealized as an assemblage of thin constant thickness shell element with each element subdivided into 3 numbers of layers. The layered shell allows any number of layers to be defined in the thickness direction, each with an independent location, thickness, behavior, and material. This paper introduces the application of non-linear static and non-linear dynamic analysis of large-span RC spatial structure. In the present work an attempt has been made to convert the MDOF model of large span reinforced concrete shell structures into SDOF system using N2-method. With the help of this method, equivalent stiffness, mass and force can be obtained.

References listed at the end of the paper:


ABSTRACT: Folded plate structures should be redefined as form-resistant structures in which the folded-plate action is a combination of transverse and longitudinal beam action [1] p.264. The early generation of folded plate structure is marked with true folded plate structures. As the number and the variety of building form
increases, classification based on form took place and being developed. This leads to confusion and false interpretation of folded structures. The confusion is shown from building examples. Roofing with either steel or pre-stressed concrete trusses were classified as folded structures. Origami could lead to another confusion, because it could be applied either as a building structure or as a non-structural member, such as ceilings and awnings. Based on the case of Sydney Opera House, and on other misleading folded structure building examples, a conclusion to stop the usage of the term “folded structures” has been recommended. Another recommendation is to separate building form categories from building structure classification.

References listed at the end of the paper:


Virginia Agostiniani (1), Antonio DeSimone (2), Alessandro Lucantonio (2) and Danka Lucic (2)
(1) Computer Science Department, University of Verona, Strada le Grazie 15, 37134 Verona - Italy
ABSTRACT: We discuss self-folding of a thin sheet by using patterned hydrogel bilayers, which act as hinges connecting flat faces. Folding is actuated by heterogeneous swelling due to different cross-linking densities of the polymer network in the two layers. Our analysis is based on a dimensionally reduced plate model, obtained by applying a recently developed theory [1], which provides us with an explicit connection between (three-dimensional) material properties and the curvatures induced at the hinges. This connection offers a recipe for the fabrication and design of the bilayers, by providing the values of the cross-linking density of each layer that need to be imprinted during polymerization in order to produce a desired folded shape upon swelling.

References listed at the end of the paper:


ABSTRACT: The discrete-Kirchhoff Mindlin quadrilateral (DKMQ) element has recently been developed for analysis of composite laminated plates. This paper presents further development of the DKMQ for analysis of composite laminated folded plates. In this development, a local coordinate system is set up for each element at its centroid. The DKMQ stiffness matrix is superimposed with that of the standard four-node plane stress quadrilateral element to obtain a 24-by-24 folded plate stiffness matrix in the local coordinate system. To avoid singularity of the stiffness matrix, a small stiffness coefficient is added in the entries corresponding to the drilling degrees of freedom. The local stiffness matrix and force vector are then transformed to the global ones and assembled. The accuracy and convergence of the folded plate element are assessed using a number of numerical examples. The results show that the element is accurate and converge well to the reference solutions.

References listed at the end of the paper:


INTRODUCTION: Membranes stretched in tension are found in a variety of large gossamer space structures in order to meet the requirements of future space exploration missions, including the JWST shield, solar sails, and space inflatable antenna reflectors. The surface of these membrane structures should be as wrinkle free, and crease free as possible, especially for the solar sails and the inflatable antenna reflectors [1]. The wrinkle is defined as an elastic response of a membrane due to the localized buckling in the compressed areas. It has been well studied by using the membrane method [2,3] and the thin shell method [4-6]. Large membrane structures must be folded for packaging or stowing before launching. These folding processes may create some permanent creases. The crease is defined as an inelastic deformation of the membrane characterized by a sharp cusp. The membrane creasing has not been well studied but the interest is growing[7,8]. In this paper, the wrinkling behavior of a rectangular creased membrane under shearing is analyzed by using the Direct Perturb-Force method[6] to deeply understand the wrinkle-crease interactions. The effects of the crease location on the wrinkling are also analyzed in the end.

References listed at the end of the paper:


C. Wang, Z. Du, H. Tan and J. Xie (Center for Composite Material, Harbin Institute of Technology, Harbin, China), “Shearing-wrinkling behavior of creased rectangular membrane”, 13th International Conference on Composite Materials, No date given in the pdf file; the most recent reference is dated 2009

K.R. Unnikrishnan (1), C.O. Arun (2) and I.R. Praveen Krishna (1,2)
(1) Tata Consultancy Services Pune, India
(2) Indian Institute of Space Science and Technology

“Wrinkling analysis of pre-stressed membranes using element free Galerkin method”, Publisher and date not given in the pdf file; the most recent reference is dated 2015

ABSTRACT: In the current study, element free Galerkin method, a meshless method, is proposed for wrinkling
analysis of pre-stressed membranes. The mathematical model for studying wrinkling of pre-stressed membranes is derived by considering the bending stiffness, though it is negligible. Moving least approximation for deflection is constructed by considering three degrees of freedom per node. Essential boundary conditions are imposed using scaled transformation matrix method. Initially, compression induced wrinkling of a homogeneous thin plate without pre-stress is solved to validate the method and then a pre-stressed homogeneous membrane is analyzed for both compression induced and shear induced wrinkling. Capabilities of proposed method for membrane analysis is compared with that of finite element method (FEM). Comparative study on wrinkling analysis using EFGM and different FEM element types in a FEM package shows that, in lower modes both methods shows satisfying consistency in eigenvalues with respect to total of number of nodes, while at higher modes EFGM shows better consistency than FEM. Further the study is extended to wrinkling of non-homogeneous membranes subjected to linearly varying in-plane load. The results obtained from EFGM analysis is compared and found to be matching well with those available in literature.

References listed at the end of the paper:


ABSTRACT: This paper is concerned with an efficient algorithm for the wrinkling with finite strains of very thin structures made of hyperelastic material. In this work, the problem of wrinkling is solved by directly minimizing the total potential energy of the structure. The numerical solution is carried out by means of an iterative method such as the conjugate gradient algorithm. Although the proposed approach is theoretically equivalent to the traditional finite element method, it proves to be an attractive alternative which is particularly efficient for thin wrinkled structures.

References listed at the end of the paper:


ABSTRACT: Wrinkling of thin membranes has become a huge concern in aerospace engineering due to the widespread of membrane structures in aerospace applications. The wrinkling of these lightweight structures is often observed and deteriorates their surface accuracy. Being thought that surface accuracy is a fundamental requirement in the manipulation and design of the membranes, it is necessary to evaluate the wrinkling of these materials in order to control and mitigate the wrinkling phenomenon. In this work, a study of the wrinkling phenomenon in thin rectangular sheets subjected to uniaxial tension is presented, including the wrinkle profile, the stress field and several parameters that influence this phenomenon. First, experimental tests on specimens with different thicknesses and plane dimensions are performed. Using a tri-dimensional digital image correlation technique (VIC-3D), the images of a rectangular Kapton HN sheet in tension are captured to investigate the evolution of the wrinkles, in terms of amplitude and wavelength. Then, a numerical study using the commercial finite element package ABAQUS is made based on the physical model of the membrane, with the aim to assess the growth, the evolution and the characteristics of the wrinkles. For that, a buckling and geometrically nonlinear analyses of the membranes are performed, using thin-shell elements. After that, the numerical validation of the results is made through the comparison with the numerical solutions available in published literature as well as the comparison with the experimental data obtained in this dissertation. Finally, some concluding remarks and future developments are described.

References listed at the end of the thesis:


ABSTRACT: We present a new technique for simulating high resolution surface wrinkling deformations of composite objects consisting of a soft interior and a harder skin. We combine high resolution thin shells with coarse finite element lattices and define frequency based constraints that allow the formation of wrinkles with properties matching those predicted by the physical parameters of the composite object. Our two-way coupled model produces the expected wrinkling behavior without the computational expense of a large number of volumetric elements to model deformations under the surface. We use C1 quadratic shape functions for the interior deformations, allowing very coarse resolutions to model the overall global deformation efficiently, while avoiding visual artifacts of wrinkling at discretization boundaries. We demonstrate that our model produces wrinkle wavelengths that match both theoretical predictions and high resolution volumetric simulations. We also show example applications in simulating wrinkles on passive objects, such as furniture, and for wrinkles on faces in character animation.

References listed at the end of the paper:

IRVING, G., TERAN, J., AND FEDKIW, R. 2006. Tetrahedral and hexahedral invertible finite elements. Graph. Mod. 68, 2, 66–89.
This paper presents the development and evaluation of a wrinkling analysis procedure for anisotropic membrane. The procedure is based on a penalty-parameter modified material model and a nonlinear root finding to simulate the uniaxial stress state. The procedure was implemented in the ABAQUS finite element code as a user subroutine, and then applied to annular and square membranes. The wrinkling problems were also solved by shell element post-buckling analysis and the results were compared. The effect of anisotropy and unsymmetric loading on the wrinkling behavior was investigated.

References listed at the end of the paper:
ABSTRACT: Heterogeneous membrane with rigid elements has been extensively applied in flexible electronic packaging systems and in aerospace structures. Here, we study the surface wrinkling of such heterogeneous membrane. The characteristics of wrinkles related to the positions of rigid elements and stretching strain are investigated and the underlying mechanism is revealed. It is found that wrinkle patterns on the wrinkle pattern of the membrane. The characteristics of wrinkles related to the positions of rigid elements and stretching strain are investigated and the underlying mechanism is revealed. It is found that wrinkle patterns on the structural vibration behaviors are also summarized in detail in the end.

Dong Yan (1), Dongzhen Huangfu (2), Kai Zhan (1,3) and Gengkai Hu (1)
(1) School of Aerospace Engineering, Beijing Institute of Technology - Beijing 100081, China
(2) School of Mechatronical Engineering, Beijing Institute of Technology - Beijing 100081, China
(3) Key Laboratory of Autonomous Navigation and Control for Deep Space Exploration, Ministry of Industry and Information Technology, Beijing Institute of Technology - Beijing 100081, China

ABSTRACT: Heterogeneous membrane with rigid elements has been extensively applied in flexible electronic systems and in aerospace structures. Here, we study the surface wrinkling of such heterogeneous membrane. Experiment, theoretical analysis and numerical simulation are performed to quantify the effect of rigid elements on the wrinkling pattern of the membrane. The characteristics of wrinkles related to the positions of rigid elements and stretching strain are investigated and the underlying mechanism is revealed. It is found that wrinkle patterns can be tailored by varying the positions of the rigid elements to achieve desired functions. Our results can provide insightful ideas to understand the wrinkling phenomenon of heterogeneous membranes and create novel wrinkle patterns in a controllable way.

A. Libai (1) and J. G. Simmonds (2)
(1) Technion – Israel Institute of Technology, Haifa, Israel
(2) University of Virginia, USA

ABSTRACT: A membrane, the two-dimensional analog of a string, is a thin-walled body that can only carry internal forces tangent to its deformed shape. Thus, a membrane is either a shell so thin that it is, essentially,
incapable of supporting stress couples or else it is a shell with sensible bending stiffness but which is subject to a combination of external loads and boundary/initial conditions which produce negligible bending. If we wish to distinguish between these two models, we shall refer to the former as a true membrane and to the latter as a (solution-dependent) shell-membrane. True membranes model certain biological tissues, inflatables, soap bubbles, shells subject to very high pressure and very large strains, and the like; shell-membranes model regions of shells that cannot undergo (nearly) inextensional bending and which are not too close to geometric or material discontinuities such as crowns of toroidal shells, cracks, or shell boundaries. Moreover, true membranes cannot support compressive stresses and thus may wrinkle whereas shell-membranes can resist this type of instability. In various parts of Section V.S we looked at the membrane limit of the simplified, nonlinear, small-strain, axisymmetric Reissner equations. In Section V.T, we developed the general theory of aximembranes undergoing large strains and gave many examples and references. In this chapter, we develop the general theory of membranes, including the subtheory of wrinkling, a topic both mathematically challenging and of growing applicability to natural and manufactured objects.

Yihong Hong, (1,2), Wenjuan Yao (1) and Yan Xu (3)
(1) Department of Civil Engineering, Shanghai University, Shanghai 200072, China
(2) School of Architectural Engineering, Quzhou University, Zhejiang 324000, China
(3) School of Aeronautics and Astronautics, Zhejiang University, Hangzhou 310027, China


ABSTRACT: Al-polymer laminated membranes are widely used in large aerospace structures. When the laminated membranes are pressurized, wrinkles emerge, which have an important effect on the performance of the structures during operation. This paper describes the numerical simulation and experimental investigation of wrinkles in laminated membranes. The nonlinear postbuckling analysis method, based on laminated thin-shell elements, was used to simulate the onset, growth, and final configuration of wrinkles when laminated membranes are subjected to external loads. The simulations are conducted with the ANSYS finite element package. Changing regularities of number, wavelength, and range for the wrinkles during the onset and growth processes are investigated. The wrinkles of laminated membranes with different design parameters such as material selection, ply number, ply angle, and ply mode are predicted. Devices that can be used to clamp and load laminated membranes in several load cases were designed and developed. A 3D photogrammetry system was constructed to characterize wrinkling patterns of laminated membranes subjected to shear displacement loads. By comparing the results of numerical analysis and experimental results, the accuracy of the numerical analysis method was verified. This study work is expected to inform wrinkling simulation and shape control of aerospace laminated membrane structures.

References listed at the end of the paper:

ABSTRACT: The wrinkling characteristics of a rectangular graphene membrane under local tension are studied in this paper based on the continuum theory. The characteristics of the primary bifurcation and secondary wrinkling are studied to discover the physics of graphene wrinkling. The wrinkling geometry is predicted by a continuum theory model. The results reveal that the first wrinkle is formed at the primary bifurcation point. The non-uniform stretch-induced compressed effects, that originate from both the loaded portion and the clamped edges, buckle the graphene to form the first wrinkle. Secondary wrinkling is generated on the boundary of the wrinkled regions and the slack regions near the loaded portion in the post-wrinkling stage is the intrinsic nature of the wrinkling rupture and evolution of graphene. In addition, the length of the loaded portion and the aspect ratio of graphene have great effects on the wrinkling characteristics. These results are tremendously useful in understanding the intrinsic nature of the structural instability of graphene.


ABSTRACT: Wrinkling of thin membranes due to different in-plane loading and boundary conditions has drawn attention of researchers in structural engineering since the development of thin webs for early aircraft structures. More recently, prestressed lightweight membrane structures have been proposed for future space missions, for example solar sails, the next generation space telescope sunshield and space-based radar systems. These structures are often partially wrinkled during operation. The formation of wrinkles alters the load paths and the structural stiffness of the membranes. More importantly its occurrence degrades the surface accuracy of these structures, which is a key design parameter. This dissertation focuses on wrinkling of thin rectangular membranes subjected to uniaxial tension and investigates the onset and profiles of wrinkles using both experimental and numerical approaches. An optical method, which integrates fringe projection method with a uniaxial tension testbed, a LCD projector and a CCD camera, was developed in order to measure the full-field out-of-plane displacement of membranes, and an optical system was constructed including a uniaxial tension testbed, a LCD projector and a CCD camera. A series of uniaxial tensile tests were carried out on silicone rubber membranes of varying dimensions and aspect ratios in order to investigate the effect of geometric factors such as membrane dimension and aspect ratio on wrinkling onset; and a series of measurements were performed on each membrane at several desired strain levels to understand the evolution of the wrinkles, in particular wrinkle amplitude and wavelength. A numerical study was carried out using the commercial finite element software ABAQUS to further understand the important characteristics of wrinkling of thin membranes observed in the physical model. Geometrically nonlinear finite element models of membrane structures were constructed with thin-shell elements. A series of simulations were carried out for different membrane dimensions. The critical buckling load and buckling modes were predicted for each dimension using a pre-buckling eigenvalue analysis. The desirable buckling mode was selected and introduced into the structure as a geometric imperfection. The formation and growth of wrinkles were simulated in the post-buckling analysis. Finally, an idea of suppressing wrinkle instabilities of dielectric elastomer membranes using through-thickness electric field was proposed and verified in both experiment and numerical simulations.

References listed at the end of the dissertation:
The effects of these modeling strategies on the ability to attain converged nonlinear deformations has been a topic of study. The studies presented address the issues of mesh refinement and stress-concentration alleviation, and the effects of these modeling strategies on the ability to attain converged nonlinear deformations due to solar-sail membrane problems in order to model the out-of-plane deformations due to structural wrinkling. Whereas certain problems lend themselves to achieving converged nonlinear solutions that compare favorably with experimental observations, solutions to tensioned membranes exhibiting high stress concentrations have been difficult to obtain even with the best nonlinear finite element codes and advanced shell element technology. In this paper, two numerical studies are presented that pave the way to improving the modeling of this class of nonlinear problems. The studies address the issues of mesh refinement and stress-concentration alleviation, and the effects of these modeling strategies on the ability to attain converged nonlinear deformations due to


ABSTRACT: Geometrically nonlinear shell finite element analysis has recently been applied to solar-sail membrane problems in order to model the out-of-plane deformations due to structural wrinkling. Whereas certain problems lend themselves to achieving converged nonlinear solutions that compare favorably with experimental observations, solutions to tensioned membranes exhibiting high stress concentrations have been difficult to obtain even with the best nonlinear finite element codes and advanced shell element technology. In this paper, two numerical studies are presented that pave the way to improving the modeling of this class of nonlinear problems. The studies address the issues of mesh refinement and stress-concentration alleviation, and the effects of these modeling strategies on the ability to attain converged nonlinear deformations due to
wringling. The numerical studies demonstrate that excessive mesh refinement in the regions of stress concentration may be disadvantageous to achieving wrinkled equilibrium states, causing the nonlinear solution to lock in the membrane response mode, while totally discarding the very low-energy bending response that is necessary to cause wrinkling deformation patterns. An element-level, strain-energy density criterion is suggested for facilitating automated, adaptive mesh refinements specifically aimed at the modeling of thin-film membranes undergoing wrinkling deformations.

References listed at the end of the paper:


ABSTRACT: As research on the applications of high-precision membrane structures develops, wrinkling has become a popular topic. Here, we present a new wrinkle-wave model to describe wrinkles more accurately. First, the characteristics of wrinkle-waves that result from radial tension stress applied at the vertex of a triangular structure were analyzed. However, for polygonal structures under more than two tensions, the influence of the other vertexes should also be considered. Therefore, by introducing a load ratio, we constructed a wrinkle-wave model of a square membrane structure subjected to corner forces. This model is applicable to various loading cases and polygonal membrane structures. Comparison among the results of the finite element analysis, and the experimental and analytical results showed that the proposed model more accurately described the wrinkling details and solved the problem of convergence that is encountered during finite element analysis.

References listed at the end of the paper:


ABSTRACT: A method to describe the stress situation in a wrinkled membrane is presented. In this paper it will be shown that a special deformation tensor can be chosen which leads to the correct stress state of a membrane after wrinkling when it is substituted in the constitutive equation. The method can be used for anisotropic membranes in geometrically and physically nonlinear analysis. The case of simple shear and stretching of a membrane is considered to illustrate the potency of the method.


ABSTRACT: We consider the point indentation of a pressurized elastic shell. It has previously been shown that such a shell is subject to a wrinkling instability as the indentation depth is quasi-statically increased. Here we present detailed analysis of this wrinkling instability using a combination of analytical techniques and finite-element simulations. In particular, we study how the number of wrinkles observed at the onset of instability grows with increasing pressurization. We also study how, for fixed pressurization, the number of wrinkles changes both spatially and with increasing indentation depth beyond onset. This ‘Far from threshold’ analysis exploits the largeness of the wrinkle wavenumber that is observed at high pressurization and leads to quantitative differences with the standard ‘Near threshold’ stability analysis.

References listed at the end of the paper:
3 Reis PM. 2015 A perspective on the revival of structural (in) stability with novel opportunities for function: from buckliphobia to buckliphilia. J. Appl. Mech. 82, 111001. (doi:10.1115/1.4031456)
12 Fu YB, Ciarletta P. 2015 Buckling of a coated elastic half-space when the coating and substrate have similar material properties. Proc. R. Soc. A 471, 20140979. (doi:10.1098/rspa.2014.0979)
ABSTRACT: Thin solar sail membranes of very large span are being envisioned for near-term space missions. One major design issue that is inherent to these very flexible structures is the formation of wrinkling patterns. Structural wrinkles may deteriorate a solar sail’s performance and, in certain cases, structural integrity. In this paper, a geometrically nonlinear, updated Lagrangian shell formulation is employed using the ABAQUS finite element code to simulate the formation of wrinkled deformations in thin-film membranes. The restrictive assumptions of true membranes, i.e. Tension Field theory (TF), are not invoked. Two effective modeling strategies are introduced to facilitate convergent solutions of wrinkled equilibrium states. Several numerical studies are carried out, and the results are compared with recent experimental data. Good agreement is observed between the numerical simulations and experimental data.

References listed at the end of the paper:


ABSTRACT: High strength thin-walled concrete-filled steel tubular (CFST) slender beam-columns may undergo local and global buckling when subjected to biaxial loads, preloads or cyclic loading. The local buckling effects of steel tube walls under stress gradients have not been considered in existing numerical models for CFST slender beam-columns. This thesis presents a systematic development of new numerical models for the nonlinear inelastic analysis of thin-walled rectangular and circular CFST slender beam-columns incorporating the effects of local buckling, concrete confinement, geometric imperfections, preloads, high strength materials, second order and cyclic behavior. In the proposed numerical models, the inelastic behavior of column cross-sections is simulated using the accurate fiber element method. Accurate constitutive laws for confined concrete are implemented in the models. The effects of progressive local buckling are taken into account in the models by using effective width formulas. Axial load-moment-curvature relationships computed from the fiber analysis of sections are used in the column stability analysis to determine equilibrium states. Deflections caused by preloads on the steel tubes arising from the construction of upper floors are included in the analysis of CFST slender columns. Efficient computational algorithms based on the Müller’s method are developed to obtain nonlinear solutions. Analysis procedures are proposed for predicting load-deflection and axial load-moment interaction curves for CFST slender columns under axial load and uniaxial bending, biaxial loads, preloads or axial load and cyclic lateral loading. The numerical models developed are verified by comparisons of computer solutions with existing experimental results and then utilized to undertake extensive
parametric studies on the fundamental behavior of CFST slender columns covering a wide range of parameters. The numerical models are shown to be efficient computer simulation tools for designing safe and economical thin-walled CFST slender beam-columns with any steel and concrete strength grades. The thesis presents benchmark numerical results on the behavior of high strength thin-walled CFST slender beam-columns accounting for progressive local buckling effects. These results provide a better understanding of the fundamental behavior of CFST columns and are valuable to structural designers and composite code writers.

References listed at the end of the dissertation:


ACI (2011). Building code requirements for structural concrete and commentary. USA, American Concrete Institute (ACI).


ABSTRACT: (cannot cut and paste it)

Sudhir Kumar Kashyap (1), Sajal Kumar (2), Mousumi Mallick (1), Rudra Pratap Singh (1) and Manoranjan Verma (1)
(1) CSIR-Central Institute of Mining & Fuel Research , Barwa Road, Dhanbad -826015, INDIA
(2) Birsa Institute of Technology, Sindri, Dhanbad-828123, INDIA
“A comparative study between experimental and theoretical buckling load for hollow steel column”,
http://dx.doi.org/10.4314/ije.2018.v10i3.3

ABSTRACT: Hollow mild steel columns of same outer diameter and length but different wall thickness show
the buckling behavior in different manner in the fix-fix end condition. The behavior of the column is in good
agreement with Rankine’s formula. Additionally, there is a very strong relation between actual buckling load
and buckling load by Rankine’s formula. There is some difference between the theoretical and actual buckling
load which may be due to geometrical defect, crack generation, chemical composition and formation of
eccentricity. Columns show that the variation of differences between actual and theoretical buckling load with
respect to wall thickness is parabolic in nature.

References listed at the end of the paper:
Bhui R, Kalurkar L.G, 2014, Study of buckling behavior of beam and column subject to axial loading for various rolled I section ;
Bystrom J and Kuzmin L, 2013, Circular vs. triangular cross-section: Some thoughts about bending stiffness, downloaded at:
www.kuzmin.se/docs/buckling_of_ski_pole_2013.pdf, pp. 1-4
Eryilmaz A, Tarikatay M., Caskun SB and Basbiik M, 2013, Buckling of Euler column with a continuous elastic restraint via

ABSTRACT: This paper presents a new design approach for the stability design of thin-walled members. The proposed approach is based on the buckling modes and critical forces/moments determined by a linear buckling analysis performed on a regular shell finite element model. A fully automatic buckling mode identification technique is applied, by using the modal base functions of the newly proposed constrained finite strip method, where the various buckling types are separated by clearly defined mechanical criteria. The paper briefly summarizes the determination of modal base functions which then are used to approximate finite element displacement functions (i.e., buckling modes). The mode identification method provides the lowest critical values (forces or moments) to all the three characteristic buckling types: global, distortional and local, on the basis of which the buckling resistance can be calculated by using the design formulae of the direct strength method. The proposed new approach, which is potentially more general than any of the existing design approaches, is demonstrated on Z columns and beams with simple loading and boundary conditions. Critical values as well as resistances are calculated for some selected cases, the results are compared to those of another design method. The comparisons prove the applicability of the proposed procedure. Further research is necessary to extend the proposal for more general and more complex practical cases.

References listed at the end of the paper:
7. Schafer BW, Cold-formed steel behavior and design: analytical and numerical modeling of elements and members with longitudinal stiffeners, Cornell University, Ithaca, NY, USA, 1997, PhD thesis.
13. Schafer BW, Adány S, Buckling analysis of cold-formed steel members using CUFSM: conventional and constrained finite strip methods, Orlando, FL, USA, 2006. Eighteenth International Specialty Conference on Cold-Formed Steel Structures.
14. Casafont M, Marimon F, Pastor MM, Calculation of pure distortional elastic buckling loads of members subjected to compression...

ABSTRACT: This paper presents an experimental investigation of short cold-formed lipped channel columns compressed between pinned ends. The short columns are subjected to pure axial compressive loading. Twelve column specimens are tested and the columns are categorised into three groups, depending on the length and thickness. The buckling modes of failure that occurred include local buckling and distortional buckling. A comparison of the experimental results with the loads predicted by the South African standard for the design of cold-formed steelwork (SANS 10162-2) shows that the code is not conservative enough to cater for these columns.

References listed at the end of the paper:
AISI (American Iron and Steel Institute) 1996. Specification for the design of cold-formed steel structural members. Washington DC: AISI.
Carina Filipa Gomes Caldeira (Department of Civil Engineering, Architecture and Geo-Resources Superior Técnico, Universidade de Lisboa, Portugal), “Behavior and design of T-section thin-walled columns”, no publisher nor date given in the pdf file; the most recent references is dated 2014.

ABSTRACT: This work presents and discusses the buckling, post-buckling and ultimate behaviour of centrally compressed thin-walled T-sections members. It is firstly presented a brief literature review on recent studies involving this type of columns, and secondly the stability analysis of a wide range of members, with both ends fixed and different cross sections dimensions, obtain through GBTUL code, based on the Generalized Beam Theory - the study made possible to characterize the column buckling modes and select the dimensions, namely the length of the members. Then, the elastic and elasto-plastic post-buckling behaviours of short-to-intermediate columns with different values tensile stresses is analysed, using ABAQUS code. Finally, in a parametric study carried out to determine a wide range of ultimate load values, the quality of the Direct Strength Method (DSM) predictions to estimate the resistance of cold formed steel fixed-ended T section columns is assessed.

References listed at the end of the paper:

M. Macdonald 1, M.A.Heiyantuduwa2, D.K.Harrison3, R.Bailey4, J.Rhodes5
1,2,3,4 School of Engineering, Science & Design, Glasgow Caledonian University, Cowcaddens Road, Glasgow, G4 0BA, UK.
5 Department of Mechanical Engineering, University of Strathclyde, James Weir Building, 75 Montrose Street, Glasgow, G1 1XJ, UK.

ABSTRACT: A review of literature on the area of the behaviour of thin-walled cold-formed steel structural members was carried out with an emphasis on the phenomenon of web crippling of beam members. Web crippling is a common mode of failure experienced by web elements of thin-walled beams under concentrated loads or reactions. Most of the studies done on web crippling behaviour are experimental and based on compression testing of beams to determine the ultimate web crippling strength. It has been identified that the theoretical investigation of web crippling behaviour is rather complicated due to localised collapse behaviour. However, some attempts have been made to develop theoretically based models to predict web crippling behaviour, and to obtain better understanding of the failure modes. Different theoretical studies, especially on elastic and plastic behaviour of plate elements were investigated with the intention of developing an analytical model to describe web crippling behaviour. It was found that almost all of the design codes around the world make design recommendations to predict the load at which web crippling would occur, based on equations obtained from web crippling tests conducted by various researchers.

References listed at the end of the paper:
Beshara, B. & Schuster, R.M. 2000, "Web crippling of cold-formed steel C- and Z-sections", Fifteenth International Speciality Conference on Cold-Formed Steel Structures, pp. 23.
Setiyono, H. 1994, Web Crippling of Cold-Formed Plain Channel Steel Section Beams, Ph.D. Thesis, University of Strathclyde.
Winter, G. & Pian, R. H. J. 1946, Crushing Strength of Thin Steel Webs, Engineering Experiment Station, Cornell University.
Young, B. & Hancock, G.J. 2000, "Experimental investigation of cold-formed channels subjected to combined bending and web crippling", Fourth International Specialty Conference on Cold-Formed Steel Structures, pp. 71-90.
Young, B. & Hancock, G.J. 2000, "Tests and design of cold-formed unlipped channels subjected to web crippling", Fourth International Specialty Conference on Cold-Formed Steel Structures, pp. 43-69.
Young, B. & Hancock, G.J. 2000, "Web crippling behaviour of channels with flanges restrained", Fourth International Specialty Conference on Cold-Formed Steel Structures, pp. 91-104.
Young, B. & Hancock, G.J. 1998, "Web crippling behaviour of cold formed unlifted channels", Fourteenth International Specialty Conference on Cold-Formed Steel Structures, pp. 127-149.
Yu, W.W. 2000, Cold-Formed Steel Design, John Wiley & Sons, Inc.

ABSTRACT: The object of the research are short, thin-walled columns with an open top-hat cross section made of multilayer laminate. The walls of the investigated profiles are made of plate elements. The entire columns are subjected to uniform compression. A detailed analysis allowed us to determine critical forces and post-critical equilibrium paths. It is assumed that the columns are articulately supported on the edges forming their ends. The numerical investigation is performed by the finite element method. The study involves solving the problem of eigenvalue and the non-linear problem of stability of the structure. The numerical analysis is performed by the commercial simulation software ABAQUS. The numerical results are then validated experimentally. In the discussed cases, it is assumed that the material operates within a linearly-elastic range, and the non-linearity of the FEM model is due to large displacements.

References listed at the end of the paper:
Banat, D., Mania, R.J.: Comparison of failure criteria application for FML column buckling strength analysis. Compos. Struct. 140, 806–815 (2016)
Usage of cold formed steel structural components for buildings and structures is gaining popularity in India for a decade. Hot rolled steel member behaviour and design are well developed, whereas the cold formed steel member behaviour and design is not developed fully compared to the rest of the world. The Indian code for cold-formed steel design, IS 801 was revised during 1975, which is in line with 1968 edition of AISI standard. Bureau of Indian standards is in the process of revision of IS 801 to catch up with the latest developments and design methods with the other codes of practices in the world. As a background for the development of codal provisions, the design provisions developed in the various codes of practices have been reviewed and a comparative study has been carried out on design flexural strength of cold formed steel lipped channel sections. For this purpose, experimental results are collected from the literature. Based on the comparative study, direct strength method (DSM), which gives flexural strength closer to experimental results has been chosen for further parametric studies. There are several failure modes among which distortional buckling is one such failure mode that affects the strength of the section. In order to assess the influence of distortional buckling, a parametric study has been conducted by varying the lip depth, which is the influencing factor for distortional buckling strength. This paper presents the details of the studies carried out and the conclusions arrived.

References listed at the end of the paper:
1. Dinar C. and Pedro B.D., Coupled instabilities with distortional buckling in cold-formed steel lipped channel columns, Thin-Walled Structures, 49, 562–575 (2011)
5. AISI Standard – North American specification for the design of cold formed steel structural members (2007)
7. BS: 5950 part 5 - Code of practice for design for cold formed thin gauge sections (1998)
10. Direct Strength method of design AS/NZS 4600 –(2005) Australian/New Zealand standard
11. Moreyra and Pekoz., Experiments on lipped channel flexural members, 12th International specialty conference on cold formed

ABSTRACT: Beam-column elements are defined as structural members subjected to a combination of axial and bending forces. Lateral torsional buckling is one of the major failure modes in which beam-columns that are bent about its strong axis may buckle out of the plane by deflecting laterally and twisting. This study presents a compact closed-form equation that it can be used for calculating critical lateral torsional-buckling load of beam-columns with monosymmetric sections in the presence of a known axial load. Lateral-torsional buckling behavior of beam-columns subjected to constant axial force and various transverse load cases are investigated by using Ritz method in order to establish proposed equation. Lateral-torsional buckling loads calculated by presented formula are compared to finite element model results. ABAQUS software is utilized to generate finite element models of beam-columns. It is found out that lateral-torsional buckling load of beam-columns with monosymmetric sections can be determined by proposed equation and can be safely used in design.

References listed at the end of the paper:


ABSTRACT: In this paper, one investigates the local-plate, distortional and global buckling behavior of thin-walled steel beams subjected to non-uniform bending moment diagrams, i.e. under the presence of longitudinal stress gradients. One begins by deriving a novel formulation based on Generalized Beam Theory (GBT), which (i) can handle beams with arbitrary open cross-sections and (ii) incorporates all the effects stemming from the presence of longitudinally varying stress distributions. This formulation is numerically implemented by means of the finite element method: one (i) develops a GBT-based beam finite element, which accounts for the
stiffness reduction associated to applied longitudinal stresses with linear, quadratic and cubic variation, as well as to the ensuing shear stresses, and (ii) addresses the derivation of the equilibrium equation system that needs to be solved in the context of a GBT buckling analysis. Then, in order to illustrate the application and capabilities of the proposed GBT-based formulation and finite element implementation, one presents and discusses numerical results concerning (i) rectangular plates under longitudinally varying stresses and pure shear, (ii) I-section cantilevers subjected to uniform major axis bending, tip point loads and uniformly distributed loads, and (iii) simply supported lipped channel beams subjected to uniform major axis bending, mid-span point loads and uniformly distributed loads — by taking full advantage of the GBT modal nature, one is able to acquire an in-depth understanding on the influence of the longitudinal stress gradients and shear stresses on the beam local and global buckling behavior. For validation purposes, the GBT results are compared with values either (i) yielded by shell finite element analyses, performed in the code ANSYS, or (ii) reported in the literature. Finally, the computational efficiency of the proposed GBT-based beam finite element is briefly assessed.


INTRODUCTION:
The beam has for many years been an important part of civil engineering structures. Successful design of structures involving beam elements requires a well-developed description of the beam behavior. This has been recognized by researchers and during the last century great emphasis has been given towards the establishment of linear as well as nonlinear beam theories. A review of some of the literature connected to beam theories is presented in Section 1.1. Driven by economic incentives such as increasing relative cost for materials, by the development of high-strength materials, and by the advancement in structural analysis and design, the trend has been towards the design and construction of increasingly more slender and flexible structures. An important component in this progress is the thin-walled beam. The double symmetric thin-walled beam has been used for many years while the use of thin-walled beams with arbitrary cross-sections is relatively recent. Using more slender and more flexible structures makes the stability problem essential in the design process. The stability behavior of symmetric beams, such as I- and H-profiles, has been examined for many years and leading to a general solution procedure where the stability failure is determined by considering an ideal structure. Possible precritical deformations are hereby neglected. In case of beam and frame structures with non-symmetric cross-sections the precritical deformations may be significant leading to a more complex behavior of the structure. This implies that the critical behavior is more complicated as for the symmetric structure. A rational utilization of these profiles therefore necessitates a detailed description of the stability problem. A theory is developed for beams of arbitrary shape, (Chapter 2). The beam is represented by a curve with a local set of base vectors fixed to the cross-section at each point of the curve. The generalized displacements are the translation vector for the curve and the rotation vector for the cross-sections. The equilibrium equations for the beam are reformulated as a virtual work equation, and this defines three strain components and three curvature components. The two shear strain components describe the difference between the tangent vector of the curve and the normal vector to the cross-section. It is important for a systematic derivation of the equations that all three rotation components are preserved as independent displacement parameters. If desired the Bernoulli hypothesis concerning the normality of the cross-sections can be introduced in the final equations. The warping effect, characteristic of thin-walled beams, is treated separately in order to preserve the generality. The general theory is specialised to stability analysis by considering a prebuckled/initial state, with prebuckling curvatures and stresses, and a neighbouring postbuckled state, (Chapter 3). The effect of prebuckling deformation is considered consistently by using the equilibrium equations of the initial state. Specialising the theory to thin-walled beams requires the appropriate constitutive equations. This is the subject of Chapter 4. A small strain deformation measure expressed by the generalized deformations is introduced and by energy principles the constitutive equations are developed. A brief discussion of energy principles is presented in Chapter 5 where also the transition from virtual work to potential energy or vice versa for the present formulation is considered. An example of the possibilities of the present formulation in a numerical context is given by the development of a two node beam element, (Chapter 6). The strain deformations are assumed negligible while the curvature contributions are retained in the formulation. This leads to a formulation in terms of the rotation components only. A link between displacements and rotations is obtained by introducing the zero strain condition via the
Lagrange Multiplier method. A mixed formulation is hereby obtained where linear shape functions can be used. This chapter serves as an introduction to the development of the incremental updated element considered in Chapter 8. Analytical stability analysis can be performed in a manageable way by some minor modifications of the general formulation, (Chapter 7). Neglecting strain deformations leads to a formulation expressed entirely in terms of the three rotation components. An asymptotic buckling and postbuckling theory is developed by means of a perturbation method. The asymptotic postbuckling behavior of a straight column in axial compression is considered for arbitrary cross-section parameters. The theory is also illustrated by analysing buckling and postbuckling of the beam in pure bending. The format of the results for this case are used to discuss the relation of the present general theory to previously published theories for simply curved beams. Further the governing parameters describing the initial postbuckling behavior are determined. Finally on the basis of the previous chapters a numerical formulation of the nonlinear stability problem is obtained in Chapter 8. The performance of the incremental updated Lagrangian two node hybrid element developed, is discussed by considering four canonical problems. The results strongly indicate that initial deformations and non-symmetric properties are essential for a proper determination of the critical load.


ABSTRACT: The paper deals with linear (eigen-buckling) and nonlinear buckling and post buckling analysis of thin-walled profiles made of FML type layered material. Considered profiles of open cross-section are subjected to axial compression. The analysis is performed with application of analytical and numerical method which results are compared with laboratory experiment. This multi-way approach gives the opportunity to improve both analytical and numerical models and solution methods which have been applied in our research team, with respect to current experiment results.

References listed at the end of the paper:


ABSTRACT: The finite element method is employed for the flexural-torsional linear buckling analysis of beams of arbitrarily shaped composite cross-section taking into account generalized warping (shear lag effects due to both flexure and torsion). The contacting materials, that constitute the composite cross section, may include a finite number of holes. A compressive axial load is applied to the beam. The influence of nonuniform warping is considered by the usage of one independent warping parameter for each warping type, i.e. shear warping in each direction and primary as well as secondary torsional warping, multiplied by the respective warping function. The calculation of the four aforementioned warping functions is implemented by the solution of a corresponding boundary value problem (longitudinal local equilibrium equation). The resulting stress field
is corrected through a shear stress correction. The equations are formulated with reference to the independent warping parameters additionally to the displacement and rotation components.

References listed at the end of the paper:
[29] Schardt, R., Verallgemeinerte Technische Biegetheorie, Springer Verlag, Berlin, Germany, 1989 (German).
Shahabeddin Torabian, Baofeng Zheng and Benjamin W. Schafer, "Development of a New Beam-Column Design Method for Cold-Formed Steel Lipped Channel Members" (2014). 22nd International Specialty Conference on Cold-Formed Steel Structures, St. Louis, Missouri, USA, November 5-6, 2014, https://scholarsmine.mst.edu/isccss/22iccfss/session04/1

ABSTRACT: The structural strength of cold-formed steel lipped channels under combined axial force and biaxial bending moments has been predicted by geometric and material nonlinear collapse analyses performed in ABAQUS and compared to both current, and a newly proposed, beam-column design method. The ABAQUS analyses utilizes a validated modeling protocol calibrated against previous testing by the authors, and including residual stresses and strains, and geometric imperfections; as well as, appropriate cross-section dimensions, member length, and boundary conditions. A total of 75 different lipped channel cross-sections have been selected and the capacity of the beam-column member has been examined under 127 combinations of actions in...
the P-M\textsubscript{1}-M\textsubscript{2} space (axial load, P, and major-axis, M\textsubscript{1}, and minor-axis, M\textsubscript{2}, bending moments). The results have been used to evaluate the current beam-column design method and validate a new Direct Strength Method (DSM) approach for cold-formed steel beam-columns. The newly proposed method provides means to incorporate more realistic stability analyses of cross-sections under the applied actions, where the current design methods include only a linear prediction of the combined actions using “column strength” and “beam strength” as anchor points. Correspondingly, the reliability of both current and newly proposed methods has been evaluated. The newly proposed extensions to the Direct Strength Method show a potential to realize a sizeable strength increase in many situations, and follow the overall trends in the data (P-M\textsubscript{1}-M\textsubscript{2} surface) well; however, additional advancement is needed to realize the complete benefits predicted in the finite element models.

References listed at the end of the paper:

- Pekoz, T. (1986). Development of a unified approach to the design of cold-formed steel members. In Eighth International Specialty Conference on Cold-Formed Steel Structures (pp. 77–84). St. Louis, MO.
- Yiu, F., & Pekoz, T. (2000). Design of Cold-Formed Steel Plain Channels. In Fifteenth International Specialty Conference on Cold-Formed Steel Structures (pp. 13–22). St. Louis, MO.

Sreedhar Kalavagunta\textsuperscript{1}, Sivakumar Naganathan\textsuperscript{2} and Kamal Nasharuddin Bin Mustapha\textsuperscript{3}

\textsuperscript{1} Bentley Systems (Singapore) Pvt. Ltd. 30 Raffles Place, #12-02/30, Chevron House, Singapore;

\textsuperscript{2} Civil Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000, Kajang, Selangor, Malaysia;

\textsuperscript{3} Civil Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000, Kajang, Selangor, Malaysia;

“Experimental study of axially compressed cold formed steel channel columns”, Indian Journal of Science and Technology, Vol. 6, No. 4, April 2013

ABSTRACT: Analysis and design of axially compressed cold formed steel channel section presented in this paper was conducted through experimental study, design based on British standards and North American
Specification for the design of cold-formed steel structural members. More than 18 laboratory experiments were undertaken first on these steel channel columns under axial compression. A series of parametric studies were also carried out by varying the thickness and column length. All of these columns failed by local and distortional buckling. The test results were compared with American (AISI-2007) and British Standards (BS5950-Part5) for the design of cold-formed steel structural members. The details of this investigation and the outcomes are presented in this paper.

References listed at the end of the paper:
16. Schafer B W (2006). Designing Cold-Formed Steel using the Direct Strength Method, 18th International Specialty Conference on Cold-Formed Steel Structures, Orlando, Florida.


ABSTRACT: A column is a vertical compression member designed to transmit compressive loading. It is generally seen that when a slender member is loaded in compression, it will bow sideways or buckle, and if the load is then increased further the column will eventually fail in bending. Buckling is a mode of failure that is mainly observed in compression members due to structural instability. A pretwisted column has its strong flexural plane weakened and its weak flexural plane strengthened, leading to a favourable effect on buckling strength of the pretwisted column. A linear buckling analysis study was conducted for boxed and unboxed sections for columns with varying twist angles to study the effect of twist angle variation on improvement in buckling capacity. The studies reviewed that buckling capacity increased up to an optimum twist angle value
and further reduced. It was found that pretwisting is effective to increase the buckling capacity of columns.

References listed at the end of the paper:


ABSTRACT: This thesis presents a theoretical study into the behaviour of thin-walled metal tubes that are filled with elastic material. The study has considered the behaviour and design of concrete-filled steel columns by analysing the effect of the combined actions of axial compression and bending on closed stainless steel cross-sections with a concrete infill as well as the elastic buckling of square, circular and elliptical thin-walled steel tubes, when filled with elastic material. The elastic local buckling of a rectangular plate having four edges clamped and subjected to in-plane linearly varying uniaxial loading with and without juxtaposition with a rigid infill has also been studied. Concrete-filled composite columns find widespread use globally in engineering structures because of their optimal strength and ease of construction. Enhancing the strength of filled columns by utilising newer materials such as stainless steel or shape memory alloys for the skin of the cross-section of the column will increase the construction cost of the column. In order to circumvent this increased construction cost, or to minimise it, the metal skin should be as thin as possible. Members with thin-walled cross-section are prone to lateral torsional buckling, and in particular they are prone to local buckling, with the latter buckling mode playing an important role in the strength of a composite column with a concrete infill. The local buckling coefficient is enhanced by the provision of a rigid concrete infill, and efficient design must make use of this fact to minimise the cost of the skin. The initial portions of this thesis demonstrate the beneficial effects that the rigid concrete core has on the overall strength, and also on the local buckling behaviour of thin-walled metal tubes. The local buckling of the metal skin has been modelled in this thesis by using a Ritz-based energy method. In bi-lateral and uni-lateral buckling studies of rectangular plates, a more general trigonometric function has been selected by application of boundary conditions to the chosen shape function, with these boundary conditions being implemented to make the chosen shape function satisfy the edge conditions for the problem under consideration. The restraining medium is modelled as a tensionless foundation and this restraint condition is introduced through a penalty method formulation. Extensive comparative, convergence, and parametric studies have been carried out by considering a wide range of uni-laterally constrained plates. Following a concise review of the available literature, techniques for analysing the elastic local buckling of thin-walled square tubes, fully filled with elastic materials and subjected to concentric uni-axial compression, are formulated by means of a simple stiffness approach and a proper Ritz-based technique. This method is then extended to account for the local buckling of thin-walled circular and elliptical cylinders with elastic infill. By
representation of a proper trigonometric displacement function in the formulation which is capable of incorporating the effects of the penetration zone in a harmonic form, in addition to satisfying all the necessary boundary conditions, it is shown that the buckling solution reduces to a dimensionless representation for which the relevant geometrical and material properties that govern the local buckling coefficient can be identified. It was found that the provision of lightweight and low density infill is functional and attractive with respect to an increase in the efficacy of the restraint. A comparison was made, and good agreement was found to exist, between the results obtained from this study and results that are available in the literature. Finally, a strength to weight index is introduced that quantifies the enhancement in the local buckling coefficient for a number of materials with a wide range of stiffness and density. This index has potential applications for optimal design in aerospace and other specialized engineering applications.

Papers generated from this dissertation:

References listed at the end of the dissertation:
Euler, L. (1744) Additamentum I de curvis elasticis, methodus inveniendi lineas curvas maximi minimivi proprietate gaudentes. IN: Opera Omnia I, Bouquet, Lausanne. 231-297.


Research, 63(1), 37-44.


Lundquist, E. E. & Stowell, E. Z. (1942a) Critical compressive stress for flat rectangular plates supported along all edges and elastically restrained against rotation along the unloaded edges. NACA-TR-733, National Advisory Committee for Aeronautics.


Smith, S. T., Bradford, M. A. & Oehlers, D. J. (1999d) Numerical convergence of simple and orthogonal polynomials for the


ABSTRACT: Lateral buckling of a laminated composite beam with I-section is studied. A general analytical model applicable to the lateral buckling of a I-section composite beam subjected to various types of loadings is developed. This model is based on the classical lamination theory, and accounts for the material coupling for arbitrary laminate stacking sequence configuration and various boundary conditions. The effects of the location of applied loading on the buckling capacity are also included in the analysis. A displacement-based one-dimensional finite element model is developed to predict critical loads and corresponding buckling modes for a thin-walled composite beam with arbitrary boundary conditions. Numerical results are obtained for thin-walled angle-ply laminated composites under central point load, uniformly-distributed load, and pure bending. The effects of fiber orientation, location of applied load, and types of loads on the critical buckling loads are parametrically studied.

Andréa Gonçalves Rodrigues das Dôres (1), Dinar Camotim (2), Pedro Borges Dinis (3) and Marcilio Sousa da Rocha Freitas (4)
(1) Engenheira Civil Ouro Preto - Minas Gerais - Brasil
(2) Catedrático Universidade de Lisboa Instituto Superior Técnico, DECivil Lisboa - Portugal
(3) Auxiliar Universidade de Lisboa Instituto Superior Técnico, DECivil Lisboa – Portugal
(4) Titular Universidade Federal de Ouro Preto - UFOP Escola de Minas Departamento de Engenharia Civil Ouro Preto - Minas Gerais - Brasil


ABSTRACT: This article reports the results of an investigation on the effects of internal moments on the vibration behavior of thin-walled steel members. The analyses are based on the Generalized Beam Theory (GBT), a thin-walled bar theory accounting for cross-section in-plane deformations - its main distinctive feature is the representation of the member deformed configuration by means of a linear combination of cross-section
deformation modes, multiplied by their longitudinal amplitude functions. The study concerns a simply supported T-section (with unequal flanges) members exhibiting a wide range of lengths and subjected to uniform internal moment diagrams - their magnitudes are specified as percentages of the corresponding critical buckling values. After providing a brief overview of the main concepts and procedures involved in performing a GBT-based structural analysis, the vibration behavior of load-free and loaded T-section members is addressed - the influence of the applied loadings is assessed in terms of (i) the fundamental frequency difference and (ii) the change in the corresponding vibration mode shape. For validation purposes, some GBT results are compared with values yielded by shell finite element analysis performed in the codeABAQUS (Simulia, 2008).

References listed at the end of the paper:


Demao Yang, “Compression stability of high strength steel sections with low strain-hardening”, PhD dissertation, School of Civil and Mining Engineering, University of Sydney, Australia, 2003

**ABSTRACT:** Thin-walled steel sections made from high strength thin cold-reduced G550 steel to Australian Standard AS 1397-1993 under compression are investigated experimentally and theoretically in this thesis. This thesis describes three series of compression tests performed on box-section stub columns, box-section long columns and lipped channel section columns cold-formed from high strength steel plates in 0.42 mm or 0.60 mm thickness with nominal yield stress of 550 MPa. The tests presented in this thesis formed part of an Australian Research Council research project entitled "Compression Stability of High Strength Steel Sections with Low Strain-Hardening". For the fix-ended stub column tests, a total of 94 lipped-square and hexagonal section stub columns were tested to study the influence of low strain hardening of G550 steel on the compressive section capacities of the column members. For the pin-ended long column tests, a total of 28 box-section columns were tested to study the stability of members with sections which undergo local instability at loads significantly less than the ultimate loads. For the fix-ended lipped channel section columns, a total of 21 stub and long columns were tested to study the failure resulting from local and distortional buckling with interaction between the modes. A numerical simulation on the three series of tests using the commercial finite element computer program ABAQUS is also presented as part of this thesis. The post-buckling behaviour of thin-walled compression members is investigated. The effect of changing variables, such as geometric imperfections and end boundary conditions is also investigated. The ABAQUS analysis gives accurate simulations of the tests and is in good agreement with the experimental results. Theoretical studies using finite strip methods are presented in this thesis to investigate the buckling behaviour of cold-formed members in compression. The theoretical studies provide valuable information on the local and distortional buckling stresses for use in the interaction buckling studies. The finite strip models used are the semi-analytical and spline models. As expected from the stub columns tests, the greatest effect of low strain hardening was for the stockier sections where material properties play an important role. For the more slender sections where elastic local buckling and post-local buckling are more important, the effect of low strain hardening does not appear to be as significant. The pin-ended and fix-ended long column tests show that interaction, which is between local and overall buckling in the box sections, and between local and distortional buckling in the open channel sections, has a significant effect on their member capacities. The results of the successful column tests and ABAQUS simulation have been compared with the design procedures in the Australian/New Zealand Standard for Cold-Formed Steel Structures (AS/NZS 4600) and the North American Specification for Cold-Formed Steel Structural Members prepared by the American Iron and Steel Institute. The stub column tests show that the current design rules give too conservative predictions on the compressive section capacities of the column members; whereas the long column tests show that the current column design rules are unconservative if used in their current form for G550 steel. Three design proposals are presented in this thesis to account for the effects of high strength thin steels on the section and member capacities.

**Fifteen papers generated from this dissertation:**

1. Compression Tests of Box-shaped Cold-Reduced High Strength Steel Sections, Proceedings, 6th Pacific Structural Steel Conference, Beijing, October, 2001, Seismological Press (Yang and Hancock)
2. Stability and Ductility of Thin-High Strength G550 Steel Members and Connections, Keynote paper, Proceedings of the 3rd International Conference on Thin-Walled Structures, Krakow, Poland, (published as Thin-Walled Structures-Advances and Developments-Elsevier 2001) (also published in Thin-Walled Structures Vol. 41, 2003.) (Rogers, Yang, Hancock)
3. Compression Tests of Cold-Reduced High Strength Steel Stub Columns, Proceedings, 16th International Specialty Conference on Cold-Formed Steel Structures in Orlando, October, 2002 (Yang and Hancock)
4. Compression Tests of Cold-Reduced High Strength Steel Long Columns., Proceedings, 16th International Specialty Conference on Cold-Formed Steel Structures in Orlando, October, 2002 (Yang, Hancock and Rasmussen)
5. The Behaviour of High Strength G550 Steel Sections as Used in Residential Construction, Keynote paper, Proceedings, 2nd
International Symposium on Steel Structures, Seoul Korea, November, 2002 (Hancock, Rogers and Yang)
6. Stability of High Strength G550 Steel Compression Members, Keynote paper, Proceedings of the 3rd International Conference on Advances in Steel Structures, Hong Kong, December, 2002 (Yang and Hancock)
7. Compression Tests of Cold-Reduced High Strength Steel Channel Columns Failing in the Distortional Mode, Proceedings of the 5th International Conference on Steel and Aluminium Structures (ICSA) & 7th International Conference on Steel Concrete Composite Structures (ASSCCS03), Sydney, June, 2003 (Yang and Hancock)
8. Compression Tests of Cold-Reduced High Strength Steel Stub Columns, University of Sydney, Department of Civil Engineering, Research Report R815, 2002 (Yang and Hancock)
9. Compression Tests of Cold-Reduced High Strength Steel Long Columns, University of Sydney, Department of Civil Engineering, Research Report R816, 2002 (Yang, Hancock and Rasmussen)
10. Compression Tests of Cold-Reduced High Strength Steel Channel Columns failing in the Distortional Mode, University of Sydney, Department of Civil Engineering, Research Report R825, 2003 (Yang and Hancock)
11. Compression Tests of Cold-Reduced High Strength Steel Stub Columns, (accepted for publication in ASCE) (Yang and Hancock)
12. Compression Tests of Cold-Reduced High Strength Steel Long Columns, (accepted for publication in ASCE) (Yang, Hancock and Rasmussen)
13. Compression Tests of Cold-Reduced High Strength Steel Channel Columns failing in the Interaction between Local and Distortional Modes, (accepted for publication in ASCE) (Yang and Hancock)
15. Numerical Simulations of High-Strength Steel Box-Shape & Channel Columns, Proceedings, 17th International Specialty Conference on Cold-Formed Steel Structures in Orlando, November, 2004 (will be submitted) (Yang and Hancock)

References listed at the end of the dissertation:

Macadam J.N., Brockenbrough R.L., Laboube R.A. and Pkoz T. and Schneider E.J. (1988), Low strain hardening ductile steel cold formed members, Proceedings of the 9th International Specialty Conference on Cold-Formed Steel Structures, Missouri-Rolla, USA, 459-487.


Papangelis, J.P. and Hancock, G.J. THIN-WALL 2.0 (1998), Centre for Advanced Structural Engineering, Department of Civil Engineering, University of Sydney, Australia.

Parks M.B., Santaputra C. and Yu W.W. (1986). Local buckling of curved elements, Proceedings of the 8th Int. Specialty Conference on Cold-Formed Steel Structures, Missouri-Rolla, USA, 277-294.


Pkoz T. (1986b). “Development of a unified approach to the design of cold-formed steel members”, Proceedings of the 8th Int. Specialty Conference on Cold-Formed Steel Structures, Missouri-Rolla, Nov. 11-12.


Rogers, C.A. and Hancock, G.J. (1997b). "Bolted connection tests of thin G550 and G300 sheet steels" Research Report, R749, Department of Civil Engineering, University of Sydney, Australia.


Schafer B.W. (1997). “Cold-formed steel behaviour and design: analytical and numerical modeling of elements and members with


Wilkinson T. and Hancock G.J. (1999). “Finite element analysis of plastic bending of cold formed rectangular hollow section beams”, Research Report, R792, Department of Civil engineering, University of Sydney, Australia (also published as “Predicting the rotation capacity of cold-formed RHS beams using finite element analysis” in Journal of Constructional Steel Research, Vol 58, 1455-1471, 2002).


Iraj H.P. Mamaghani (Department of Civil Engineering, University of North Dakota, Grand Forks, USA), “Seismic design and retrofit of thin-walled steel tubular columns”, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6, 2004, Paper No. 271

ABSTRACT: This paper deals with seismic design and retrofit of thin-walled steel tubular columns supporting highway bridge superstructures. The basic characteristics of the thin-walled steel tubular columns are noted and the importance of various retrofit techniques in improving strength and ductility capacity of such structures is explained. A seismic design method for ultimate strength and ductility evaluation of the retrofitted, thin-walled, steel tubular beam-columns is presented. The application of the method is demonstrated by comparing the computed strength and ductility of some cantilever columns with test results. The method is applicable for both the design of new and retrofitting of existing thin-walled steel tubular columns. The effects of some important parameters such as width-to-thickness ratio, column slenderness ratio, height of infill concrete, residual stress, arrangement of additional longitudinal stiffeners and energy absorption segment on the ultimate strength and ductility of thin-walled steel tubular columns are presented and discussed.

References listed at the end of the paper:


Usami, T., Interim Guidelines and New Technologies for Seismic Design of Steel Structures, Committee on New Technology for
ABSTRACT:

In this work, non-uniform steel members with or without initial geometrical or loading imperfections, that are loaded by axial forces applied concentrically or eccentrically and by concentrated moments applied at the ends or at intermediate points, are studied. More specifically, steel members with varying cross-sections, tapered or stepped or members consisting by two different tapered parts are considered. The formulation presented in this work is based on solving the governing equation of the problem through a numerical method where the eigenshapes of the member are employed. A failure plasticity criterion is introduced for members especially the short ones that will never reach the elastic critical buckling load. Although only the simply supported beam-column case is studied herein, it is obvious that the method can be extended to multi-span beams and frames, by employing the corresponding eigenshapes. Useful diagrams are presented for both the critical buckling loads and the equilibrium paths showing the influence of the main characteristics of the beam-column.

References listed at the end of the paper:
Nahla K. Hassan (1) and Ayman S. Mosallam (2)

(1) Ain Shams University, Cairo, Egypt
(2) University of California, Irvine, Irvine, California, USA

“Buckling and ultimate failure of thin-walled pultruded composite columns”, Polymers and Polymer Composites, Vol. 12, No. 6, 2004

ABSTRACT: This paper presents the results of an investigation on the buckling behavior of concentrically loaded thin-walled pultruded fiber reinforced polymer (PFRP) composite columns. Both open- and closed-web columns were evaluated. Finite element (FE) analysis and theoretical predictions are presented and correlated with experimental data. Good agreement between theoretical, analytical and experimental results was achieved. The paper also presents design guidelines to determine the bending stiffness and the critical buckling load for pultruded composite columns. In addition, a discussion on the axial strength of unidirectional PFRP columns and identification of different modes of failure are presented.

References listed at the end of the paper:

Benjamin W. Schafer (Dept. of Civil Engineering, Johns Hopkins University, Baltimore, MD, USA),
“Distortional buckling of cold-formed steel columns”. Final Report to the American Iron and Steel Institute: Washington (DC). 2000; Appendix A to that report:
Benjamin Schafer and Gregory Hancock, “A detailed history of distortional buckling of columns”
ABSTRACT: Research in the behavior of cold-formed steel columns spans approximately fifty years. Through that time distortional buckling, under many different names, has come in and out of the spotlight. This brief account highlights the major experimental work in cold-formed steel column research. Theoretical trends are also briefly mentioned, particularly as they relate to distortional buckling. Though distortional buckling in beams and columns is intimately tied together an attempt is made to focus only on the column research.

References listed at the end of the appendix:
A parametric study was then performed using the numerical model and interaction diagrams for the investigated and strength of thin structures. The model considers both the material and geometric nonlinearities. The model results were first verified against some of the currently available experimental results. A parametric study was then performed using the numerical model and interaction diagrams for the investigated beam-columns have been presented. The effects of the web depth-to-thickness ratio, flange outstand-to-thickness ratio and bending moment-to-normal force ratio on the ultimate strength of thin-walled I-section
beam-columns were scrutinized. The interaction equations adopted for beam columns design by the NAS
(North American Specifications for the design of cold formed steel structural members) have been critically
reviewed. An equation for the buckling coefficient which considers the interaction between local buckling of
the flange and the web of a thin-walled I-section beam-column has been proposed.

L. Pesic, D. Lane and G. Turkalj (Department of Engineering Mechanics, Faculty of Engineering, University of
Rijeka, Vukovarska, Rijeka), “Non-linear thermal buckling analysis of thin-walled beam structures”,

ABSTRACT: The paper presents an algorithm for thermal buckling analysis of thin-walled beam-type
structures. One-dimensional finite element is employed under assumptions of large displacements, large rotation
effects but small strains. Stability analysis is performed in load deflection manner using co-rotational
formulation. The cross-section mid-line contour is assumed to remain not deformed in its own plane and the
shear strains of middle surface are neglected. The material properties of the beam are temperature-dependent.

Results are validated on test examples.

References listed at the end of the paper:

Li Bai, “Interactive buckling in thin-walled I-section struts, PhD dissertation, Dept. of Civil and Environmental Engineering, Imperial College London, May 2014

ABSTRACT: Compression members, made from slender metallic plate elements, are prone to a wide range of
different elastic instability phenomena. A thin-walled I-section strut, made from a linear elastic material, can
suffer from the nonlinear interaction between a global (Euler) buckling mode, and a local flange plate buckling mode. The interactive buckling behaviour is usually much more unstable than when the modes are triggered individually and hence significantly reduces the load-carrying capacity of real struts. The current work focuses on such a problem using an analytical approach, the methodology of which has been well established in previous works on sandwich struts and I-section beams. An analytical model that describes the interactive buckling of a thin-walled I-section strut under pure compression based on variational principles is presented. Analytical formulations combining the Rayleigh–Ritz method and continuous displacement functions are presented to derive a series of systems that comprise differential and integral equilibrium equations for the structural component. Solving the systems of equations with numerical continuation reveals progressive cellular buckling (or snaking) arising from the nonlinear interaction between the weakly stable global buckling mode and the strongly stable local buckling mode. The resulting behaviour is highly unstable and when the model is extended to include geometric imperfections it compares excellently with some recently published experiments. Imperfection sensitivity studies reveal high sensitivity to both global and local imperfection types. The worst forms of local imperfection are identified in terms of the initial wavelength, amplitude and degree of localization. The effect of the varying rigidity of the joint of the section web and flanges is also studied and a rapid erosion of the cellular buckling response is revealed with increasing rigidity of the flange–web joint. A shell-based nonlinear finite element model is presented, primarily for validation purposes. The results from the analytical and finite element models show a good comparison, particularly for higher rigidities of the flange–web joint. A parametric study is conducted for two limiting cases, where the flange–web joint is assumed to be fully pinned or fully rigid. For a chosen set of geometries, the most undesirable interactive region is identified for both global and local slendernesses, in terms of the strut length and the flange width respectively. Practical implications are discussed in terms of the idealized buckling design curve. An analytical framework for the structural analysis of the thin-walled I-section struts that exhibit the nonlinear interaction of a global and a local buckling mode, including cellular buckling, has therefore been established.

References listed at the end of the dissertation:


Wadee, M. A. 2000. Effects of periodic and localized imperfections on struts on nonlinear foundations and compression sandwich

ABSTRACT: This paper deals with a theoretical and a numerical analysis of tapered beam-columns subjected to a bending moment and an axial force. A standard FEM code COSMOS/M has been used for a numerical estimation of a critical load multiplier. It has been assumed that the critical force of an axially loaded tapered column could be calculated in an analogous way as for uniform member just with an additional correction factor $\eta$. Similarly, a critical bending moment of the tapered column subjected to a pure bending could be determined by using a correction factor $\mu$. A large number of simulations carried out within a wide range of the ratios of second moments of area allowed to determine the proper values of these two factors. For practical engineers, solution of such kind of problems can be easier when an equivalent cross-sectional height $h_{eq}$ is used.

References listed at the end of the paper:

ABSTRACT: This article is the first part of a review of recent research in buckling analysis of thin-walled structures. It covers fundamental developments in new methods of analysis and their applications. The second part of the review will be published in April 1999 and will focus on numerical developments based mainly on the finite element and finite strip methods, and applied research on specific types of thin-walled structures, including stiffened panels, girders, shear panels and coldformed structural members.

A.H. Salem (1), A.A. El-Serwi (1), M.M. Korashy (1) and E.Y. Sayed_Ahmed (2)
(1) Structural Engineering Department, Ain Shams University El-Sarayat Street, Abbasia, Cairo, Egypt
(2) Civil Eng. Dept., University of Qatar (on leave from Struct. Eng. Dept., Ain Shams University) P.O. Box 2713, Doha, Qatar


ABSTRACT: A finite element model which considers both the material and geometric nonlinearities is adopted to investigate the behavior of thin-walled I-section beam-columns. The model results were first verified against some of the currently available experimental results. A parametric study was then performed using the numerical model. Interaction diagrams for the studied beam-columns have been presented. The influences of the web depth-to-thickness ratio, flange outstand-to-thickness ratio and bending moment-to-normal force ratio on the ultimate strength of the investigated beam-columns were scrutinized. The interaction equations currently used by the AISI-1996 and the ECP specifications for beam-columns have been critically reviewed. A proposed design method for thin-walled I-section beam-columns has been proposed.

References listed at the end of the paper:
REFERENCES LISTED AT THE END OF THE DISSERTATION:

12. AISI “American Iron and Steel Institute, Cold-Formed Steel Design Manual”, Milwaukee, Wisconsin 1996.


ABSTRACT: A fully nonlinear theory of a three-dimensional thin-walled beam, in arbitrary rectangular coordinates with the pole of the sectorial area at an arbitrary point and the origin of the sectorial area at an arbitrary point of the beam section, is developed to incorporate transverse shear, torsion-induced warping, and local-buckling-induced cross-section distortion. Based on a geometrically-exact description of the kinematics of deformation, this theory allows large deformation and large overall motion with a general out-of-plane warping function and a general in-plane distortion function. The present theory can exactly reduce to the classical Vlasov theory for vanishing shearing and cross-section distortion in the case of small deformation. The nonlinear weak form of the governing equations of equilibrium is constructed and the linearization of the weak form is derived. A finite element code is developed to implement this generalized thin-walled beam element. The results given by the post-buckling analysis are compared with numerical and/or experimental results to investigate the local buckling effect on the member behavior.

References listed at the end of the dissertation:

Cold-Formed Steel


[80] Yu, F. (2001). Design of Cold-Formed Steel Plain Channels, Progress Report: Project No CF9501, Department of Civil Engineering, Cornell University


ABSTRACT: This paper presents a performance-based analysis (PBA) technique based on fiber element formulations for the nonlinear analysis and performance-based design of thin-walled concrete-filled steel tubular (CFST) beam-columns with local buckling effects. Geometric imperfections, residual stresses and strain hardening of steel tubes and confined concrete models are considered in the PBA technique. Initial local buckling and effective strength/width formulas are incorporated in the PBA program to account for local buckling effects. The progressive local buckling of a thin-walled steel tube filled with concrete is simulated by gradually redistributing normal stresses within the steel tube walls. Performance indices are proposed to quantify the section, axial ductility and curvature ductility performance of thin-walled CFST beam-columns under axial load and biaxial bending. Efficient secant algorithms are developed to iterate the depth and orientation of the neutral axis in a thin-walled CFST beam-column section to satisfy equilibrium conditions. The analysis algorithms for thin-walled CFST beam-columns under axial load and uni- and biaxial bending are presented. The PBA program can efficiently generate axial load–strain curves, moment–curvature curves and axial load–moment strength interaction diagrams for thin-walled CFST beam-columns under biaxial loads. The proposed PBA technique allows the designer to analyze and design thin-walled CFST beam-columns made of compact or non-compact steel tubes with any strength grades and normal and high-strength concrete. The verification and applications of the PBA program are given in a companion paper.


ABSTRACT: Use of thin-walled steel sections in structures represents a trend further in the exploitation of structural form from its early ponderousness to the present day's trend towards tenuity. In the past seventy years, extensive experimental and analytical research has been carried out to examine the behavior of thin-walled
structures containing openings. The experimental results have not been fully utilized by other researchers. As part of this review, an endeavor is made to cluster the experimental and analytical results with particular importance on plates, beams and plate girders and compression members and cellular structures containing perforations as an elucidative database using a handy spreadsheet program written in Visual Basic.


ABSTRACT: This paper is concerned with the application of the direct strength method to equal angle section beam-columns with locally unstable legs. In contrast to existing design methods, which independently determine the compression and bending capacities and use an interaction equation to combine these, the direct strength method determines the elastic local buckling stress for the actual stress distribution resulting from the combined action of compression and bending, and incorporates the elastic buckling stress into a direct strength equation for beam-columns. In applying the method to equal leg angles, the torsional buckling mode is ignored when determining the overall buckling capacities, since it is accounted for through the local buckling mode, and the shift of the effective centroid is incorporated as an additional loading eccentricity. The shift in the effective centroid resulting from local buckling is determined from the actual stress distribution, as obtained using Stowell’s classical solution, in place of an effective cross section. The predicted strengths are conservative compared to tests on slender equal angle columns, and are shown to accurately predict the variation in load with applied loading eccentricity.

Benjamin W. Schafer, “Cold-formed steel structures around the world: A review of recent advances in applications, analysis and design”, Steel Construction, 2011; (4) 3, https://doi.org/10.1002/stco.201110019

ABSTRACT: The objective of this paper is to provide a brief review of recent (over approximately the last five years) advances in the application, analysis and design of cold-formed steel structures. Attention here is focused on load-bearing cold-formed steel structures; as opposed to secondary systems, curtain walls, etc. Cold-formed steel applications continue to advance in three primary categories: framing, metal buildings, and racks. Examples largely derived from the author’s experiences in North America are used to illustrate the applications. The behaviour of cold-formed steel structures can be complicated due to the thin-walled nature of the sections; thus, analysis advances are required. Recent work in Generalized Beam Theory and the constrained Finite Strip Method demonstrate that, at least when it comes to thin-walled members, significant advances in structural analysis are still possible and desirable. Design of cold-formed steel structures continues to see significant improvements and refinements. Recent efforts related to the Direct Strength Method of design are highlighted, including novel extensions from the member to the system level. Finally, similar to many other areas of structural engineering, seismic engineering has motivated notable advances in applications, analysis, and design. For cold-formed steel structures these advances are reviewed to demonstrate current progress and future directions in this important area.

References listed at the end of the paper:


[32] Li, Z., Schafer, B. W.: Buckling analysis of cold-formed steel members with general boundary conditions using CUFSM: Conventional and constrained finite strip methods, 2010.


Zbigniew Kolakowski (1) and Andrześ Teter (2)
(1) Department of Strength of Materials, Lodz University of Technology, Lodz, Poland
(2) Department of Applied Mechanics, Lublin University of Technology, Lublin, Poland


ABSTRACT: A review of papers that investigate the static and dynamic coupled buckling and post-buckling behaviour of thin-walled structures is carried out. The problem of static coupled buckling is sufficiently well-recognized. The analysis of dynamic interactive buckling is limited in practice to columns, single plates and shells. The applications of finite element method (FEM) or/and analytical-numerical method (ANM) to solve interaction buckling problems are on-going. In Poland, the team of scientists from the Department of Strength of Materials, Lodz University of Technology and co-workers developed the analytical-numerical method. This method allows to determine static buckling stresses, natural frequencies, coefficients of the equation describing the post-buckling equilibrium path and dynamic response of the plate structure subjected to compression load and/or bending moment. Using the dynamic buckling criteria, it is possible to determine the dynamic critical load. They presented a lot of interesting results for problems of the static and dynamic coupled buckling of thin-walled plate structures with complex shapes of cross-sections, including an interaction of component plates. The most important advantage of presented analytical-numerical method is that it enables to describe all buckling
modes and the post-buckling behaviours of thin-walled columns made of different materials. Thin isotropic, orthotropic or laminate structures were considered.

References listed at the end of the paper:

ABSTRACT: A new analytical model has been developed for a study of the response of thin-walled beam-columns having doubly symmetric cross sections. The novel features of the model are that: (1) It incorporates the interaction of overall buckling/bending with two companion local modes; (2) it accounts for the phenomenon of amplitude modulation; and (3) it can model any set of realistic end conditions. These features are a result of an innovative combination of the finite strip and finite element techniques. The model has been tested for numerical convergence and against the available results on square box columns. A small number of examples have been studied. These relate to the performance of eccentrically loaded columns and single story frames. Also, the vital necessity of considering amplitude modulation in thin-walled beam columns has been brought out.


ABSTRACT: Features of the phenomenon of interactive buckling of thin-walled columns are briefly reviewed. The theoretical results are compared with the recent test results from University of Sydney and earlier results from Cornell University. The agreement is very good indeed. The role of imperfections in producing scatter in the prediction of the ultimate capacity of the columns is illustrated. Design procedures, one developed at Cornell University in the seventies and the other recommended by the new American Iron and Steel Institute Code, are examined in the light of the new results. In order to account for the interaction of plate elements, it is suggested that exact local critical stress be used in the effective width formula. To obtain a reliable and safe estimate of the column strength, it is proposed that the collapse load given by the design methods be multiplied by an appropriate factor. This factor must be a function of the key parameters governing the problem. A statistically derived expression for this factor is also suggested.

ABSTRACT: Many review articles were published on free vibration and buckling of laminated composites, sandwich plates, and shells. The present article reviews the literature on the buckling and free vibration analysis of shear deformable isotropic and laminated composite sandwich plates and shells using various methods available for plates in the past few decades. Various theories, finite element modeling, and experimentations have been reported for the analysis of sandwich plates and shells. Few papers on functionally graded material plates, plates with smart skin (electrorheological, magnetorheological, and piezoelectric), and also viscoelastic materials were also reviewed. The scope for future research on sandwich plates and shells was also accessed.


ABSTRACT: This paper presents the state of art in the field of composite shells with focus on stress analysis, buckling and post-buckling responses under mechanical and thermal loading. Many researchers have investigated the buckling and post-buckling responses of cylindrical, conical, spherical, thin and thick composite shells with single and doubly curved shells under mechanical and thermal loading. From the literature it can be inferred that hydrostatic pressure, axial compression and thermal environment influence the buckling behavior of laminated composite shell significantly. An effort is taken to review the research on buckling and post-buckling responses of cylindrical and conical shaped shells under mechanical and thermal loading and their behavior during buckling and post-buckling conditions.


ABSTRACT: The paper is devoted to cold-formed thin-walled channel beams with open or closed flanges. The global–local buckling and optimization of these beams are described. The review includes simple analytical description and calculations, numerical analysis, and the laboratory tests of selected beams. The buckling problems for flanges and webs of thin-walled beams are described in detail. Additionally, an objective comparison of the beams of different cross sections is presented. A quality measure of thin-walled beams is proposed. Comparison of selected thin-walled beams with use of the quality measure is presented in figures.


ABSTRACT: Thin films deposited on substrates are usually submitted to large residual compression stresses, causing delamination and buckling of the film into various patterns. The present study is focused on the different equilibria arising on strip-shaped delaminated areas. The three most common types of buckling patterns observed on such strips are known as the straight-sided wrinkles, bubble pattern, and telephone cord blisters. The stability of those equilibria as a function of the two stress components of the loading is investigated. The Föppl–Von Karman model for elastic plates is used for theoretical aspects. The post-critical equilibrium paths of the buckling patterns are investigated numerically by means of the finite-element method. The substrate is assumed to be rigid and the contact to be frictionless. The equilibrium solutions can be classified into families of homologous equilibria allowing the identification of dimensionless parameters for the study of stability. A mapping of the different stable post-critical equilibria is given. It is shown that the straight-sided wrinkles and the bubbles are associated with anisotropy of stresses and/or of elastic properties, whereas the telephone cords are stable at high isotropic stresses. The morphological transitions are experimentally evidenced by in situ atomic force microscopy observations of a nickel 50–nm-thick film under stress.

References listed at the end of the paper:

ABSTRACT: Tubular construction is synonymous with modern architecture. The familiar range of tubular sections – square, rectangular and circular hollow sections – has been recently extended to include elliptical hollow sections (EHSs). Due to differing flexural rigidities about the two principal axes, these new sections combine the elegance of circular hollow sections with the improved structural efficiency in bending of rectangular hollow sections. Following the introduction of structural steel EHSs, a number of investigations into their structural response have been carried out. This paper presents a state-of-the-art review of recent research on EHSs together with a sample of practical applications. The paper addresses fundamental research on elastic local buckling and post-buckling, cross-section classification, response in shear, member instabilities, connections and the behaviour of concrete-filled EHSs. Details of full-scale testing and numerical modelling studies are described, and the generation of statistically validated structural design rules, suitable for incorporation into international design codes, is outlined.

References listed at the end of the paper:

Chan TM and Gardner L (2009b) Structural behaviour of elliptical hollow sections under combined actions. Proceedings of the 6th International Conference on Advances in Steel Structures, Hong Kong, China, 253–260.
EN 10210-2 (2006) Hot finished structural hollow sections of non-alloy and fine grain steels – Part 2: Tolerances, dimensions and
sectional properties. CEN.
Paxton R, Editor (1990) 100 years of the Forth Bridge. Thomas Telford.

ABSTRACT: The enabling emerging technologies such as nanotechnology increased the demand for small-size devices. The proper understanding of the nonclassical behavior of nanostructures is key for the design of these devices. As a result, the static and dynamic behavior of nanoscale beam structures has received a great attention in the past few years. This review aims at directing the light to research work concerned with bending, buckling, vibrations, and wave propagation of nanobeams modeled according to the nonlocal elasticity theory of Eringen. Due to the large body of references found in the literature, the authors chose to briefly present the key findings and challenges and direct light to possible future work. This review does not intersect with recent relevant reviews, which reflects its significance to readers.


ABSTRACT: Buckling behavior of tubulars inside wellbores is the major subject of many articles. This paper presents a general overview on most of the material available in the literature on the subject and also comments on the different, and sometimes conflicting solutions presented in various works. Different aspects of the phenomenon are discussed including sinusoidal (lateral) and helical buckling and influence of torque.


ABSTRACT: Theoretical models and experimental data for buried tube buckling are reviewed, and linear buckling solutions based on the elastic continuum model for the ground are selected as being most suitable for the design of buried flexible metal tubes. An examination of both theory and experiment confirms that maximum rather than average hoop thrust should be used to characterize the loads in the buried structure. Various scalar correction factors are recommended for use in calibrating the preferred buckling theory so that it can be used in the design of buried flexible tubes.


ABSTRACT: As technology continues towards smaller, thinner and lighter devices, more stringent demands are placed on thin polymer films as diffusion barriers, dielectric coatings, electronic packaging and so on. Therefore, there is a growing need for testing platforms to rapidly determine the mechanical properties of thin polymer films and coatings. We introduce here an elegant, efficient measurement method that yields the elastic moduli of nanoscale polymer films in a rapid and quantitative manner without the need for expensive equipment or material-specific modelling. The technique exploits a buckling instability that occurs in bilayers consisting of a stiff, thin film coated onto a relatively soft, thick substrate. Using the spacing of these highly periodic wrinkles, we calculate the film’s elastic modulus by applying well-established buckling mechanics. We successfully apply this new measurement platform to several systems displaying a wide range of thicknesses (nanometre to micrometre) and moduli (MPa to GPa).

References listed at the end of the paper:

fluctuations of elastic sheets such as graphene and evaluate their effect on the effective bending stiffness at

31. Huang, E.
32. Hedstrom, J. A.

35. Lenhart, J. L.
36. Volksen, W.

Fatemeh Ahmadpoor (1), Peng Wang (2), Rui Huang (2), Pradeep Sharma (1,3)
(1) Department of Mechanical Engineering, University of Houston, Houston, TX 77204, USA
(2) Department of Aerospace Engineering and Engineering mechanics, University of Texas, Austin, TX 78712, USA
(3) Department of Physics, University of Houston, Houston, TX 77204, USA


ABSTRACT: The study of statistical mechanics of thermal fluctuations of graphene—the prototypical two-dimensional material—is rendered rather complicated due to the necessity of accounting for geometric deformation nonlinearity. Unlike fluid membranes such as lipid bilayers, coupling of stretching and flexural modes in solid membranes like graphene leads to a highly anharmonic elastic Hamiltonian. Existing treatments draw heavily on analogies in the high-energy physics literature and are hard to extend or modify in the typical contexts that permeate materials, mechanics and some of the condensed matter physics literature. In this study, using a variational perturbation method, we present a “mechanics-oriented” treatment of the thermal fluctuations of elastic sheets such as graphene and evaluate their effect on the effective bending stiffness at
finite temperatures. In particular, we explore the size, pre-strain and temperature dependency of the out-of-plane fluctuations, and demonstrate how an elastic sheet becomes effectively stiffer at larger sizes. Our derivations provide a transparent approach that can be extended to include multi-field couplings and anisotropy for other 2D materials. To reconcile our analytical results with atomistic considerations, we also perform molecular dynamics simulations on graphene and contrast the obtained results and physical insights with those in the literature.

References listed at the end of the paper:


ABSTRACT: Two buckling modes have been observed in thin films: buckle delamination and wrinkling. This letter identifies the conditions for selecting the favored buckling modes for elastic films on elastic substrates. Transition from one buckling mode to another is predicted as the stiffness ratio between the substrate and the film or is predicted for variation of the stiffness ratio between the substrate and the film or variation of the interfacial defect size. The theoretical results are demonstrated experimentally by observing the coexistence of both buckling modes and mode transition in one film-substrate system.

References listed at the end of the paper:


Haixia Mei, Yaoyu Pang, Se Hyuk Im and Rui Huang (Department of Aerospace Engineering and Engineering Mechanics, University of Texas at Austin, Texas), “Fracture, delamination, and buckling of elastic thin films on compliant substrates”, Paper from conference that is not identified in the pdf file, June 2008, DOI: 10.1109/ITHERM.2008.4544345 · Source: IEEE Xplore

ABSTRACT: A series of studies have been conducted for mechanical behavior of elastic thin films on compliant substrates. Under tension, the film may fracture by growing channel cracks. The driving force for channel cracking (i.e., the energy release rate) increases significantly for compliant substrates. Moreover, channel cracking may be accompanied by interfacial delamination. For a film on a relatively compliant substrate, a critical interface toughness is predicted, which separates stable and unstable delamination. For a film on a relatively stiff substrate, however, a channel crack grows with no delamination when the interface toughness is greater than a critical value. An effective energy release rate for the steady-state growth of a channel crack is defined to account for the influence of interfacial delamination on both the fracture driving force and the resistance, which can be significantly higher than the energy release rate assuming no delamination. Alternatively, when the film is under compression, it tends to buckle. Two buckling modes have been observed, one with interfacial delamination (i.e., buckle-delamination) and the other without delamination (i.e., wrinkling). By comparing the critical stresses for the onset of buckling, we give a criterion for the
selection of the buckling modes, which depends on the stiffness ratio between the film and the substrate as well as the interface defects. A general conclusion from these studies is that, whether tension or compression, the interfacial properties are critical in controlling the morphology and failure of elastic thin films on compliant substrates.

References listed at the end of the paper:
ABSTRACT: This paper develops a model for evolving wrinkles in a bilayer thin film consisting of an elastic layer and a viscoelastic layer. The elastic layer is subjected to a compressive residual stress and is modeled by the nonlinear von Karman plate theory. A thin layer approximation is developed for the viscoelastic layer. The stability of the bilayer and the evolution of wrinkles are studied first by a linear perturbation analysis and then numerically. Three stages of the wrinkle evolution are identified: initial growth of the fastest growing mode, intermediate growth with mode transition, and, finally, an equilibrium wrinkle state. DOI: 10.1115/1.2043191.

References listed at the end of the paper:

ABSTRACT: The unique lattice structure and properties of graphene have drawn tremendous interests recently. By combining continuum and atomistic approaches, this paper investigates the mechanical properties of single-atom-layer graphene sheets. A theoretical framework of nonlinear continuum mechanics is developed for graphene under both in-plane and bending deformation. Atomistic simulations are carried out to deduce the effective mechanical properties. It is found that graphene becomes highly nonlinear and anisotropic under finite-strain uniaxial stretch, and coupling between stretch and shear occurs except for stretching in the zigzag and armchair directions. The theoretical strength (fracture strain and fracture stress) of perfect graphene lattice also varies with the chiral direction of graphene and properties of graphene have drawn tremendous interests recently. By combining continuum and atomistic approaches, this paper investigates the mechanical properties of single-atom-layer graphene sheets. A theoretical framework of nonlinear continuum mechanics is developed for graphene under both in-plane and bending deformation. Atomistic simulations are carried out to deduce the effective mechanical properties. It is found that graphene becomes highly nonlinear and anisotropic under finite-strain uniaxial stretch, and coupling between stretch and shear occurs except for stretching in the zigzag and armchair directions. The theoretical strength (fracture strain and fracture stress) of perfect graphene lattice also varies with the chiral direction of uniaxial stretch. By rolling graphene sheets into cylindrical tubes of various radii, the bending modulus of graphene is obtained. Buckling of graphene ribbons under uniaxial compression is simulated and the critical strain for the onset of buckling is compared to a linear buckling analysis.

References listed at the end of the paper:


ABSTRACT: This paper presents a bilayer model to account for surface effects on the wrinkling of ultrathin polymer films. Assuming a surface layer of finite thickness, effects of surface properties on the critical strain, the equilibrium wavelength, and the wrinkle amplitude are discussed in comparison with conventional analysis. Experimental measurements of wrinkling in polymer films with thickness ranging from 200 nm to 5 nm are conducted. The bilayer model provides a consistent understanding of the experiments that deviate from conventional analysis for thickness less than 30 nm. A set of empirical surface properties is deduced from the experimental data.

References listed at the end of the paper:


ABSTRACT: The nonlinear mechanical response of monolayer graphene on polyethylene terephthalate (PET) is characterised using in-situ Raman spectroscopy and atomic force microscopy. While interfacial stress transfer leads to tension in graphene as the PET substrate is stretched, retraction of the substrate during unloading imposes compression in the graphene. Two interfacial failure mechanisms, shear sliding under tension and buckling under compression, are identified. Using a nonlinear shear-lag model, the interfacial shear strength is found to range between 0.46 and 0.69 MPa. The critical strain for onset of interfacial sliding is ~0.3%, while the maximum strain that can be transferred to graphene ranges from 1.2% to 1.6% depending on the interfacial shear strength and graphene size. Beyond a critical compressive strain of around ~0.7%, buckling ridges are observed after unloading. The results from this work provide valuable insight and design guidelines for a broad spectrum of applications of graphene and other 2D nanomaterials, such as flexible and stretchable electronics, strain sensing, and nanocomposites.

References listed at the end of the paper:

simulations only for relatively small rippling amplitudes but can be extended to account for the anharmonic
buckling instability is predicted at a critical compressive strain that depends on both the temperature and the
with increasing temperature. Moreover, the effect of a biaxial
energy are predicted simultaneously and compared with molecular dynamics (MD) simulations. While the
substrate at 0 K. The rippling amplitude, the equilibrium average separation, and the average interaction
interactions between monolayer graphene and a rigid
substrate could considerably suppress thermal rippling. On the
thermal fluctuations at 0 K. The rippling amplitude, the equilibrium average separation, and the average interaction
substrate, assuming a generic form of van der Waals interactions between graphene and substrate at T = 0 K. The rippling amplitude, the equilibrium average separation, and the average interaction
energy are predicted simultaneously and compared with molecular dynamics (MD) simulations. While the
amplitude of thermal rippling is reduced by adhesive interactions, the entropic contribution leads to an effective
repulsion. As a result, the equilibrium average separation increases and the effective adhesion energy decreases with increasing temperature. Moreover, the effect of a biaxial pre-strain in graphene is considered, and a buckling instability is predicted at a critical compressive strain that depends on both the temperature and the adhesive interactions. Limited by the harmonic approximations, the theoretical predictions agree with MD simulations only for relatively small rippling amplitudes but can be extended to account for the anharmonic

Peng Wang (1), Wei Gao (2) and Rui Huang (1)
(1) Department of Aerospace Engineering and Engineering Mechanics, University of Texas, Austin, TX, USA
(2) Department of Mechanical Engineering, Northwestern University, Evanston, IL, USA

“Entropic effects of thermal rippling on van der Waals interactions between monolayer graphene and a rigid substrate”, Journal of Applied Physics, November 2015, DOI: 10.1063/1.4941987

ABSTRACT: Graphene monolayer, with extremely low flexural stiffness, displays spontaneous rippling due to
termperature. When a graphene membrane is placed on a solid substrate, the adhesive interactions between graphene and the substrate could considerably suppress thermal rippling. On the other hand, the statistical nature of thermal rippling adds an entropic contribution to the graphene-substrate interactions. In this paper we present a statistical mechanics analysis on thermal rippling of monolayer graphene supported on a rigid substrate, assuming a generic form of van der Waals interactions between graphene and substrate at T = 0 K. The rippling amplitude, the equilibrium average separation, and the average interaction energy are predicted simultaneously and compared with molecular dynamics (MD) simulations. While the amplitude of thermal rippling is reduced by adhesive interactions, the entropic contribution leads to an effective repulsion. As a result, the equilibrium average separation increases and the effective adhesion energy decreases with increasing temperature. Moreover, the effect of a biaxial pre-strain in graphene is considered, and a buckling instability is predicted at a critical compressive strain that depends on both the temperature and the adhesive interactions. Limited by the harmonic approximations, the theoretical predictions agree with MD simulations only for relatively small rippling amplitudes but can be extended to account for the anharmonic

effects.

References listed at the end of the paper:


Subject to a compressive membrane force, a solid film on a liquid layer may form wrinkles. The three-dimensional analysis, which accounts for substrate bending and interfacial forces, is performed using analytic and numerical methods. We show that the wrinkling of thin films is a collective phenomenon, and that it is controlled by a dimensionless number called the ‘wrinkling length’. The wrinkling length is inversely proportional to the square root of the film thickness, and it determines the wavelength of the wrinkles. The analytical theory is confirmed by atomistic simulations, and by experiments on thin films of different materials. The wrinkling instability is similar to the buckling of a column under compressive force. However, the wrinkling length of thin films is much smaller than the radius of curvature of the substrate. This suggests that the wrinkling of thin films is a unique phenomenon that is not observed in the buckling of columns.

ABSTRACT: A compressively strained elastic film bonded to a viscous layer can form wrinkles. The present study provides a theoretical model for the wrinkling process. The elastic film is modeled with the nonlinear theory of a thin plate subject to in-plane and out-of-plane loads. The flow of the viscous layer is modeled with the theory of lubrication. The interface between the elastic film and the viscous layer is assumed to be perfect with no slipping or debonding. A set of partial differential equations evolves the deflection and the in-plane displacements as functions of time. A linear stability analysis identifies the critical wave number, below which the elastic film is unstable and the wrinkles can grow. For any fixed wave number less than the critical wave number, the wrinkles reach a kinetically constrained equilibrium configuration, in which the stress is partially relaxed in the elastic film and the viscous layer stops flowing. Numerical simulations reveal rich dynamics of the system with many unstable equilibrium configurations.

References listed at the end of the paper:

Deji Akinwande 1, Christopher J. Brennan 1, J. Scott Bunch 2, Philip Egberts 3, Jonathan R. Felts 4, Huajian Gao 5, Rui Huang 6, Joon-Seok Kim 1, Teng Li 7, Yao Li 8, Kenneth M. Liechti 6, Nanshu Lu 6, Harold S. Park 2, Evan J. Reed 9, Peng Wang 6, Boris I. Yakobson 10, Teng Zhang 11, Yong-Wei Zhang 12, Yao Zhou 9, Yong Zhu 13

1 Department of Electrical and Computer Engineering, University of Texas at Austin, Austin, Texas 78712, USA
2 Department of Mechanical Engineering, Boston University, Boston, MA 02215, USA
3 Department of Mechanical and Manufacturing Engineering, University of Calgary, 40 Research Place NW, Calgary, AB T2L 1Y6 Canada
4 Department of Mechanical Engineering, Texas A&M University, College Station, Texas, 77843 USA
5 School of Engineering, Brown University, Providence, RI 02912, USA
6 Department of Aerospace Engineering & Engineering Mechanics, University of Texas at Austin, Austin, Texas 78712, USA
7 Department of Mechanical Engineering, University of Maryland, College Park, MD 20742, USA
8 Department of Applied Physics, Stanford University, Stanford, CA 94305, USA
9 Department of Material Science and Engineering, Stanford University, Stanford, CA 94305, USA
10 Department of Materials Science & NanoEngineering, Department of Chemistry, and the Richard E. Smalley Institute, Rice University, Houston, Texas 77005, USA
ABSTRACT: Since the first successful synthesis of graphene just over a decade ago, a variety of two-dimensional (2D) materials (e.g., transition metal-dichalcogenides, hexagonal boron-nitride, etc.) have been discovered. Among the many unique and attractive properties of 2D materials, mechanical properties play important roles in manufacturing, integration and performance for their potential applications. Mechanics is indispensable in the study of mechanical properties, both experimentally and theoretically. The coupling between the mechanical and other physical properties (thermal, electronic, optical) is also of great interest in exploring novel applications, where mechanics has to be combined with condensed matter physics to establish a scalable theoretical framework. Moreover, mechanical interactions between 2D materials and various substrate materials are essential for integrated device applications of 2D materials, for which the mechanics of interfaces (adhesion and friction) has to be developed for the 2D materials. Here we review recent theoretical and experimental works related to mechanics and mechanical properties of 2D materials. While graphene is the most studied 2D material to date, we expect continual growth of interest in the mechanics of other 2D materials beyond graphene.

References listed at the end of the paper:

56 Lindsay, L. and D.A. Broio, Optimized Tersoff and Brenner empirical potential parameters for lattice dynamics and phonon


142 Song, Z., et al., Defect-detriment to graphene strength is concealed by local probe: the topological and geometrical effects. ACS Nano, 2014. 9: p. 401-408.
110: p. 266801.
249 Kim, J.-S., et al., High pressure Raman study of layered Mo0.5W0.5S2 ternary compound. 2D Materials, 2016. 3: p. 025003.
1079-1092.


Qi, J., et al., The possibility of chemically inert, graphene-based all-Carbon electronic devices with 0.8 eV gap. ACS Nano, 2011. 5: p. 3475-3482.


Tian, B., et al., Photothermally enhanced photodynamic therapy delivered by nano-graphene oxide. ACS Nano, 2011. 5: p. 7000-
ABSTRACT: Swell-induced surface instability has been observed experimentally in rubbers and gels. Here we present a theoretical model that predicts the critical condition along with a characteristic wavelength for swell-induced surface instability in substrate-confined hydrogel layers. The effect of surface tension is found to be critical in suppressing short-wavelength modes of instability, while the substrate confinement suppresses long-wavelength modes. Together, an intermediate wavelength is selected at a critical swelling ratio for the onset of surface instability. Both the critical swelling ratio and the characteristic wavelength depend on the initial thickness of the hydrogel layer as well as other material properties of the hydrogel. It is found that the hydrogel layer becomes increasingly stable as the initial layer thickness decreases. A critical thickness is predicted, below which the hydrogel layer swells homogeneously and remains stable at the equilibrium state.

References listed at the end of the paper:

9 J. Kim, J. Yoon and R. C. Hayward, Nat. Mater., 2010, 9, 159–164.

S.H. Im and R. Huang, “Morphological instability and kinetics of an elastic film on a viscoelastic layer”, Chapter in a book that is unidentified in the pdf file; the most recent reference is dated 2004

ABSTRACT: This paper develops a theoretical model for wrinkling of an elastic film on a viscoelastic layer. The film is elastic and subjected to a compressive residual strain. The viscoelastic layer is sandwiched between the film and a rigid substrate. The nonlinear von Karman plate theory is employed to model the film, and a thin-layer approximation is adopted for the viscoelastic layer. The stability of the system and the kinetics of structural evolution are studied first by a linear perturbation analysis and then by numerical simulations, both for plane strain deformation only. Three stages of evolution are identified: initial growth of the fastest growing mode, intermediate growth with mode transition, and finally an equilibrium wrinkled state. The results qualitatively agree with experimental observations of wrinkling in metal/polymer bilayer films.

References listed at the end of the chapter:

Rui Huang (Department of Aerospace Engineering and Engineering Mechanics, University of Texas at Austin, TX, USA), “A Kinetics Approach to Surface Wrinkling of Elastic Thin Films”, No publisher or date given in the pdf file; the most recent reference is dated 2011

ABSTRACT: Complex wrinkle patterns have been observed in various thin film systems, typically with integrated hard and soft materials for various applications as well as in nature. The underlying mechanism of wrinkling has been generally understood as a stress-driven instability. On an elastic substrate, equilibrium and energetics set the critical condition and select the wrinkle wavelength and amplitude. On a viscous substrate, wrinkles grow over time and kinetics select the fastest growing mode. Moreover, on a viscoelastic substrate, both energetics and kinetics play important roles in determining the critical condition, the growth rate, and wrinkle patterns. The dynamics of wrinkling, while analogous to other phase ordering phenomena, is rich and distinct under the effects of stress and film-substrate interactions. In this chapter, a kinetics approach is presented for wrinkling of isotropic and anisotropic elastic films on viscoelastic substrates. Analytic solutions are obtained by a linear perturbation analysis and a nonlinear energy minimization method, which predict the kinetics of wrinkle growth at the early stage and the equilibrium states at the long-time limit, respectively. In between, a power-law coarsening of the wrinkle wavelength is predicted by a scaling analysis. Furthermore, the kinetics approach enables numerical simulations that demonstrate emergence and transition of diverse wrinkle patterns (ordered and disordered) under various conditions.

References listed at the end of the paper:
Thin films bonded to compliant substrates often develop wrinkles when subjected to an applied or inherent compressive stress. This paper presents a bilayer model to account for surface effects on the wrinkling of ultrathin solid films. Assuming a surface layer of finite thickness, effects of surface properties on the critical strain, the equilibrium wavelength, and the wrinkle amplitude are discussed in comparison with conventional analysis. We apply this model to explain experimental observations of wrinkling in thin polymer films. The measured wrinkle wavelengths and amplitudes deviate from conventional analysis for ultrathin films with thickness less than 30 nm. The bilayer model provides a consistent understanding of the observed deviations, based on which a set of material properties for the surface and the bulk of the polymer films are deduced from the experimental data.
analyses show a significant shear compressive strain lower than previous solutions for both wrinkling and buckle eigenvalue analysis. For an intermediate delamination size, a missing delamination crack, the critical strain for the onset of buckling instability is predicted by finite element normal traction at the interface and interfacial force. In comparison with a nonlinear finite element analysis, an approximate formula is derived to estimate the interfacial force.

Recent experiments have observed that concomitant wrinkling and buckle instability. Two commonly observed buckling modes, buckle and delamination, exist and co-evolve. In this paper, by analytical and finite element methods, we present a study on concomitant wrinkling and delamination. Post-buckling analyses show a significant shear-lag effect with an effective load transfer length three orders of magnitude.

Haixia Mei, Chad M. Landis and Rui Huang (Department of Aerospace Engineering and Engineering Mechanics, University of Texas, Austin, TX 78712, USA), “Concomitant wrinkling and buckle-delamination of elastic thin films on compliant substrates,” Mechanics of Materials Vol. 43, No. 11, pp 627-642, November 2011, https://doi.org/10.1016/j.mechmat.2011.08.003

ABSTRACT: Compressing a thin elastic film attached to a thick compliant substrate can lead to buckling instability. Two commonly observed buckling modes, buckle-delamination and wrinkling, have each been analyzed separately in previous studies. Recent experiments have observed that the two modes can co-exist and co-evolve. In this paper, by analytical and finite element methods, we present a study on concomitant wrinkling and buckle-delamination for an elastic film on a highly compliant substrate. First, without delamination, we present an analytical solution for wrinkling that takes into account the effect of Poisson’s ratio of the substrate. In comparison with a nonlinear finite element analysis, an approximate formula is derived to estimate the normal traction at the interface and to predict initiation of wrinkle-induced delamination. Next, with a pre-existing delamination crack, the critical strain for the onset of buckling instability is predicted by finite element eigenvalue analysis. For an intermediate delamination size, a mixed buckling mode is predicted with the critical compressive strain lower than previous solutions for both wrinkling and buckle-delamination. Post-buckling analyses show a significant shear-lag effect with an effective load transfer length three orders of magnitude.
greater than the film thickness. Finally, concomitant wrinkling and buckle-delamination is simulated to illustrate the interaction between the two buckling modes, and the results are discussed in view of failure mechanisms and applications in thin film metrology.

References listed at the end of the paper:

ABSTRACT: Distributed actuators offer spatially distributed actuations and they are usually effective to multiple modes of a continuum. Spatially filtered distributed vibration controls of a laminated cylindrical shell and a piezoelectric shell are investigated, and their control effectivenesses are evaluated in this study. In general, there are two control actions, the in-plane membrane control forces and the counteracting control moments, induced by the distributed actuator in the laminated shell. There is only an in-plane circumferential control force in the piezoelectric shell. Analyses suggest that in either case the control actions are effective in odd natural modes and ineffective in even modes. Spatially filtered control effectiveness and active damping of both shells are studied.

References listed at the end of the paper:


ABSTRACT: Shallow paraboloidal shells of revolution are common components for reflectors, mirrors, etc. This study is to investigate the micro-control actions and distributed control effectiveness of precision
paraboloidal shell structures laminated with segmented actuator patches. Mathematical models and governing equations of the paraboloidal shells laminated with distributed actuator layers segmented into patches are presented first, followed by formulations of distributed control forces and micro-control actions including meridional/circumferential membrane and bending control components based on an assumed mode shape function and the Taylor series expansion. Distributed control forces, patch sizes, actuator locations, micro-control actions, and normalized control authorities of a shallow paraboloidal shell are then analyzed in a case study. Analysis indicates that 1) the control forces, and membrane/bending components are mode and location dependent, 2) the meridional/circumferential membrane control actions dominate the overall control effect, 3) there are optimal actuator locations resulting in the maximal control effects at the minimal control cost for each natural mode. The analytical results provide generic design guidelines for actuator placement on precision shallow paraboloidal shell structures.

References listed at the end of the paper:


ABSTRACT: Adaptive structures with controllable geometries and shapes are rather useful in many engineering applications, such as adaptive wings, variable focus mirrors, adaptive machines, micro-electromechanical systems, etc. Dynamics and feedback control effectiveness of adaptive shells whose curvatures are actively controlled and continuously changed are evaluated. An adaptive piezoelectric laminated cylindrical shell composite with continuous curvature changes is studied, and its natural frequencies and controlled damping ratios are evaluated. The curvature change of the adaptive shell starts from an open shallow shell (300) and ends with a deep cylindrical shell (360°). Dynamic characteristics and control effectiveness (via the proportional velocity feedback) of this series of shells are investigated and compared at every 30° curvature change. Analytical solutions suggest that the lower modes are sensitive to curvature changes and the higher modes are relatively insensitive.

References listed at the end of the paper:


Horn-Sen Tzou, Mike S. Lih and Gregory Hickey, “Distributed modal signal of thin paraboloidal shells”, Submitted to Internation Union of Theoretical and Applied Mechanics, IUTAM2000, Symposium on Smart Structures and Structural Systems, Magdeburg, Germany, September 26-29, 2000

ABSTRACT: Flexible paraboloidal shell of revolution is considered one of the most difficult geometry among all shell and non-shell structures, such as spherical shells, cylindrical shells, conical shells, plates, rings, beams, etc. Often space structures and civil structures are designed based on the paraboloidal shell, because of its functionality, beauty, and strength. Static and dynamic vibration analyses of these paraboloidal shells have been investigated analytically, numerically or experimentally over the years. However, due to its complexity, analytical solutions and experimental data are still scarce and only limited to simple boundary conditions. Thus, numerical (finite element) technique becomes popular and useful in engineering design and applications. This paper is to present (analytical) assumed solution technique and to evaluate distributed sensing characteristics - modal voltages - of paraboloidal shells laminated with distributed piezoelectric layers.

References listed at the end of the paper:


ABSTRACT: Optical membrane mirrors are promising key components for future space telescopes. Due to their ultra-thin and high flexible properties, the surfaces of these membrane mirrors are susceptible to temperature variations. Therefore adaptive shape control of the mirror is essential to maintain the surface precision and to ensure its working performance. However, researches on modeling and control of membrane mirrors under thermal loads are sparse in open literatures. A 0.2 m diameter scale model of a polyimide membrane mirror is developed in this study. Three Polyvinylidene fluoride (PVDF) patches are laminated on the non-reflective side of the membrane mirror to serve as in-plane actuators. A new mathematical model of the piezoelectric actuated membrane mirror in multiple fields, (i.e., thermal, mechanical, and electrical field) is established, with which dynamic and static behaviors of the mirror can be analyzed. A closed-loop membrane mirror shape control system is set up and a surface shape control method based on an influence function matrix of the mirror is then investigated. Several experiments including surface displacement tracking and thermal deformation alleviation are performed. The deviations range from 15 μm to 20 μm are eliminated within 0.1 s and the residual deformation is controlled to micron level, which demonstrates the effectiveness of the proposed membrane shape control strategy and shows a satisfactory real-time performance. The proposed research provides a technological support and instruction for shape control of optical membrane mirrors.

References listed at the end of the paper:


ABSTRACT: In this study, a thin cylindrical shell is actively controlled by photostrictive patches which can produce photodeformation strains under the illumination of ultraviolet lights. Governing equations of the cylindrical shell laminated with the photostrictive actuators oriented in the circumferential direction are established. With the uniform illumination and the alternate illumination schemes, the bending control effect and the membrane control effect of the new actuator configuration are analyzed and evaluated with respect to the curvature angles of the cylindrical shell. Considering the multi-field coupling behavior of the photo-strictive actuators, two types of control algorithms with constant light intensity and variable light intensity are adopted. Using the two control algorithms, time histories of the transverse displacement, control light intensity, photo-induced electric field, temperature, and control force are presented. The results of time history analysis show that the constant light intensity control provides better control performance as compared with the variable light intensity control. Based on the configuration of two paired actuators, both the uniform illumination and the
alternate illumination schemes are analyzed and compared. The alternate illumination scheme improves the modal control effects to some modes which are decided by the actuator configuration and the mode shapes of the cylindrical shell.

References listed at the end of the paper:
Uchino, K. 1990. ‘‘Photostrictive Actuator,’’ In: IEEE Ultrasonics Symposium, 4 7 December, Honolulu, HI, pp.721 723.

ABSTRACT: Parabolic cylindrical shell panel is useful in the aerospace. Light-activated shape memory polymer is a novel kind of smart materials. It is capable of offering a non-contact control way at the room temperature. In this study, the parabolic cylindrical shell panel laminated with light-activated shape memory polymer actuators is analyzed. First, the dynamic equations of the parabolic cylindrical shell panel coupled with light-activated shape memory polymer actuators are established; the modal control force of light-activated shape memory polymer actuators is derived with the modal expansion method. Then, the strain variation of light-activated shape memory polymer actuators is modeled based on the chemical kinetics. Furthermore, Young’s modulus of light-activated shape memory polymer actuators is measured through the biaxial tension experiments. The strain variation of light-activated shape memory polymer actuator with initial strain is also measured. The established strain model is validated by the experimental data of strain variation. In this case study, the snap-back control effects of the first four modes, that is, the (1,3), (1,4), (2,4), and (2,5) modes are evaluated. The study shows light-activated shape memory polymer actuators are effective to control the vibration of parabolic cylindrical shell panels. Light-activated shape memory polymer actuators have potential applications for the vibration control of double-curvature shells.

References listed at the end of the paper:


ABSTRACT: The converse flexoelectric effect, i.e., the polarization (or electric field) gradient-induced internal stress (or strain), can be utilized to actuate and control flexible structures. This study focuses on the microscopic actuation behavior and effectiveness of a flexoelectric actuator patch laminated on an elastic ring shell. An atomic force microscope (AFM) probe is placed on the upper surface of the flexoelectric patch to induce an inhomogeneous electric field resulting in internal stresses of the actuator patch. The flexoelectric stress-induced membrane control force and bending control moment regulate the ring vibration and their actuation mechanics, i.e., transverse and circumferential control actions, are, respectively, studied. For the transverse direction, the electric field gradient quickly decays along the ring thickness, resulting in a nonuniform transverse distribution of the induced stress, and this distribution profile is not influenced by the actuator thickness. The flexoelectric-induced circumferential membrane control force and bending control moment resemble the Dirac delta functions at the AFM contact point. The flexo-electric actuation can be regarded as a localized drastic bending to the ring. To evaluate the actuation effect, dynamic responses and controllable displacements of the elastic ring with flexoelectric actuations are analyzed with respect to design parameters, such as the flexoelectric patch thickness, AFM probe radius, ring thickness, and ring radius.

References listed at the end of the paper:

ABSTRACT: An open parabolic cylindrical shell panel plays a key role in radial signal collection, reflection, and/or transmission applied to radar antennas, space reflectors, solar collectors, etc. Active vibration control can suppress unexpected fluctuation and maintain its precision surface and operations. This study aims to investigate the distributed active actuation behavior of adaptive open parabolic cylindrical shell panels using piezoelectric actuator patches. Dynamic equations of parabolic cylindrical shells laminated with piezoelectric actuator patches are presented first. Then, the actuator induced modal control force is defined based on a newly derived mode shape function. As the actuator area varies due to the curvature change, the normalized actuation effectiveness (i.e., modal control force per unit actuator area) is further evaluated. When the actuator area shrinks to infinitesimal, the expression of microscopic local modal control force is obtained. The total control force and its three components exhibit distinct characteristics with respect to shell geometries, modes, and actuator properties. Analyses suggest that the control force contributed by the membrane force component dominates the total actuation effect. The bending-contributed component increases with the corresponding mode number, while the membrane-contributed component decreases. Actuation effectiveness of two shell geometries, from shallow to deep, and actuator sizes are evaluated. Analysis of optimal actuator locations reveals that actuators placed at the maximal shell curvature are more effective and maximize the control effects.

References listed at the end of the paper:
Thus, the flexoelectric effect could provide an effective alternative for structural sensing. Vibrations. For a flexible structure, the flexoelectric signal is much more prominent than the piezoelectric one for sensing of bending vibrations. Sensing capabilities of these two materials and mechanisms are compared with respect to ring thickness, sensor thickness, and ring radius in case studies. Results show that the piezoelectric sensing signal appears to be sensitive for both bending-dominant and membrane-dominant vibrations, while the flexoelectric signal is much more prominent than the piezoelectric one for sensing of bending-dominant vibrations. For a flexible structure performing transverse vibration, the bending behavior is usually dominant. Thus, the flexoelectric effect could provide an effective alternative for structural sensing.


ABSTRACT: Piezoelectric materials have been widely used for structural sensing due to the linear electromechanical coupling effect. Flexoelectricity, generally existing in all dielectrics, describes the linear inhomogeneous electromechanical coupling phenomena. Previous studies have shown that the direct flexoelectric effect is sensitive to the bending deformation. This study focuses on comparison and differences between two sensing mechanisms, that is, the flexoelectric and the piezoelectric effects, and explores their distinctive characteristics and potential applications. Based on the direct flexoelectric/ piezoelectric effects, flexoelectric/piezoelectric materials treated as flexoelectric/piezoelectric sensors are applied to two ring models with identical dimensions. The mathematical models of thin elastic rings laminated with flexoelectric/piezoelectric sensors are established. Open-circuit sensing signals are derived for further evaluation and comparison. Sensing capabilities of these two materials and mechanisms are compared with respect to ring thickness, sensor thickness, and ring radius in case studies. Results show that the piezoelectric sensing signal appears to be sensitive for both bending-dominant and membrane-dominant vibrations, while the flexoelectric signal is much more prominent than the piezoelectric one for sensing of bending-dominant vibrations. For a flexible structure performing transverse vibration, the bending behavior is usually dominant. Thus, the flexoelectric effect could provide an effective alternative for structural sensing.
Iran

ABSTRACT: In this paper, free and forced vibration of simply-supported Single-walled carbon nanotube is investigated under the moving nanoparticle by considering nonlocal cylindrical shell model. To validate the theoretical results, modal analysis of nanotube is conducted using ANSYS commercial software. Excellent agreement is exhibited between the results of two different methods. Furthermore, the dynamic response of SWCNT under moving nanoparticle is also studied. It is assumed that the nanoparticle travels along the center of nanotube with constant velocity and the van der Waals force between CNT and particle is taken into account. The dynamic response of the SWCNT under the influence of C60 particle obtained using dynamic Green’s function and modal expansion. The obtained results show that the nonlocal scale effect decreases the natural frequency and dynamic displacement of the CNT.

References listed at the end of the paper:
procedure is compared favorably with experimental results and those obtained using a numerical finite element method. A literature review reveals that beam functions are used extensively as an approximation for simply supported boundary conditions. The accuracy of the resonance frequencies obtained using the approximate method are also investigated by comparing results with those of the exact analysis. Part II presents effects of different parameters on mode shapes and natural frequencies of circular cylindrical shells.

References listed at the end of the paper:


ABSTRACT: In order to study the free vibration of simply supported circular cylindrical shells, a semi-analytical procedure is discussed in detail. In this technique, beam function is used as an approximation for simply supported boundary conditions. A literature review reveals that beam functions are used extensively in predicting natural frequencies of shells. Since this method does not involve with boundary condition equations, there is no need to deal with intense calculations. Hence, it is important to check the accuracy of this approximate technique. So this method was applied to ten different shell theories: 1) Donnell-Mushtari, 2) Love-Timoshenko, 3) Arnold-Warburton, 4) Houghton-Johns, 5) Flugge-Byrne-Lur’ye, 6) Reissner-Naghd-Berry, 7) Sanders, 8) Vlasov, 9) Kennard-Simplified and 10) Soedel. The approximate procedure was compared favorably with experimental results. Finally, variations and influences of length, radius and thickness were studied on amplitude ratios.

References listed at the end of the paper:


Liu, J. C. (1), Zhang, Y. Q. (1,2) and Fan, L. F. (3)
(1) College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310058, PR China
(2) State Key Laboratory of Mechanical Structural Strength and Vibration, Xi'an Jiaotong University, Xi'an 710049, PR China
(3) College of Architecture and Civil Engineering, Beijing University of Technology, Beijing 100084, PR China
https://doi.org/10.1016/j.physleta.2017.01.056

ABSTRACT: The general equation for transverse vibration of double-viscoelastic-FGM-nanoplate system with viscoelastic Pasternak medium in between and each nanoplate subjected to in-plane edge loads is formulated on the basis of the Eringen's nonlocal elastic theory and the Kelvin model. The factors of the structural damping, medium damping, small size effect, loading ratio, and Winkler modulus and shear modulus of the medium are incorporated in the formulation. Based on the Navier's method, the analytical solutions for vibrational frequency and buckling load of the system with simply supported boundary conditions are obtained. The influences of these factors on vibrational frequency and buckling load of the system are discussed. It is demonstrated that the vibrational frequency of the system for the out-of-phase vibration is dependent upon the structural damping, small size effect and viscoelastic Pasternak medium, whereas the vibrational frequency for the in-phase vibration is independent of the viscoelastic Pasternak medium. While the buckling load of the system for the in-phase buckling case has nothing to do with the viscoelastic Pasternak medium, the buckling load for the out-of-phase case is related to the small size effect, loading ratio and Pasternak medium.

ABSTRACT: In this paper, the effect of humidity conditions on thermal buckling analysis of graphene system contained two layers under different boundary conditions is investigated. The two-variable shear deformation plate theory is employed with the nonlocal continuum theory to deduce the governing stability equations. These equations are solved analytically to obtain the thermal buckling of the nanoplate system with simply supported, clamped and free boundary conditions. The present system of double-layered graphene sheets is composed from two sheets of graphene joined together by an elastic medium and hedged by two-parameter foundations. The external foundations are modeled as Winkler–Pasternak model. Two characteristic types of thermal buckling are considered: synchronous and asynchronous modes of buckling. The temperature rise and moisture concentration are assumed as a fixed, linear or nonlinear function of $z$ (along the thickness direction). For the validation of the formulations, the present results are compared with those published in the references. Furthermore, the influences of the nonlocal parameter, humidity and other parameters on thermal buckling of double-layered graphene system are all discussed.


ABSTRACT: The free vibration analysis of symmetrically laminated composite circular plates with curvilinear fibers is performed using the first-order shear deformation theory along with a curved hierarchical square finite element. The blending function method is used to describe accurately the geometry of the circular plate. The hierarchical shape functions are constructed from Legendre orthogonal polynomials. The element stiffness and mass matrices are integrated numerically by means of the Gauss-Legendre quadrature. The equations of motion are derived using Lagrange's method. Results for the fundamental frequency are obtained for clamped and soft simply supported laminated composite circular plates with E-glass, graphite, and boron curvilinear fibers in epoxy matrices. The element is validated by means of the convergence test and comparison with published data for isotropic and laminated composite circular plates with rectilinear fibers. Contour plots of frequency as a function of fiber orientation angles for laminated composite circular plates with curvilinear fibers are presented. The fiber material and boundary conditions are shown to influence the distribution of frequency throughout the design space. Frequency curves as a function of fiber orientation angles for the first five modes of laminated composite circular plates with curvilinear fibers are also presented. They reveal that none of the first five modes of clamped and soft simply supported laminates is affected by crossing but modes 3 and 4 of clamped graphite/epoxy and boron/epoxy laminates are affected by veering.


ABSTRACT: A skew $p$-element is developed for the nonlinear free vibration of variable stiffness symmetric skew laminates. The governing equations are based on thin plate theory and Von Karman strains. The fundamental frequencies and normal modes are computed for fully clamped edge conditions. The equations of motion are derived using Lagrange's method. By employing the harmonic balance method, the transformation from time to frequency domain is facilitated. The nonlinear equations are solved using the iterative technique known as the linearized updated mode method. The numerical results are validated with the help of convergence tests and comparisons with published data. New results are presented for variable stiffness symmetric skew laminates with different fiber configurations showing the effects of variation in skew angle on frequency, normal mode, and degree of hardening.


ABSTRACT: This paper introduces a model for strengthening slender reinforced concrete columns. The proposed technique aims at controlling second order lateral deflections using longitudinal high-modulus bonded reinforcement, thereby altering the loading path to intercept the axial load-moment (P-M) interaction curve at a higher axial capacity. With the availability of high- and ultra-high-modulus carbon fiber reinforced polymer (CFRP) plates, this approach should be quite efficient according to Euler’s buckling rule, in which, column strength is stiffness-controlled. This approach is different from the classical transverse wrapping method for confinement; a technique that achieves strengthening by enlarging the (P-M) diagram in the compression-
controlled region. The proposed model accounts for concrete nonlinearity in compression, cracking in tension, steel rebar plasticity, and certainly geometric nonlinearity, in addition to the possibility of premature CFRP debonding failure in tension and the lower CFRP strength in compression than tension. The model is validated against experimental results and used in a parametric study to assess the effects of slenderness ratio $\lambda$, axial load initial eccentricity ratio $e_0/h$, and CFRP reinforcement ratio $\zeta_f$, and modulus $E_f$. It was shown that strength gain increases from 17 to 30% as $\lambda$ increases from 20 to 120, when a very small $\zeta_f$ of 0.5% is used. A range of 0.1 to 1% for $\zeta_f$ results in a 4 to 41% strength gain, while a range of 100 to 500 GPa for $E_f$ results in a 5 to 26% gain. As $e_0/h$ increases from 0.05 to 0.6, the gain increases from 17 to 90%.

M.R. Bambach (Dept. of Civil Engineering, Monash University, Australia), “Unified element and section approach to design of cold-formed steel structures”, ASCE Journal of Structural Engineering, Vol. 136, No. 4, April 2010

ABSTRACT: Slender open-section cold-formed steel members that contain flanges with edge stiffeners may buckle in different modes and with mode interactions. The element design approach (effective width method) has been shown to produce unconservative capacity predictions for a particular class of such members. This paper presents a modification to the effective width method derived from an investigation of the fundamental behavior of edge stiffened flange elements and sections that contain them. The modified element design approach is validated against the results of 913 compression and bending members collected from the literature, where all section and member buckling modes and interactions were evident. A section design approach is also presented which is directly in line with the element approach. The unified element and section approach is shown to provide accurate and reliable design solutions for cold-formed steel compression and flexural members. Proposals for the North American specification for cold-formed steel structures are presented.


ABSTRACT: This chapter summarises recent research on the strengthening of thin-walled steel structures with fibre-reinforced polymers. The focus is on steel square hollow sections strengthened with carbon fibre-reinforced polymer. An extensive series of experiments with a wide range of thin-walled steel section geometries where the exterior surfaces of the tube walls were strengthened with bonded carbon fibres, is discussed. Experiments were performed under quasi-static axial compression to investigate strengthening with regards to elastic buckling and compression strength, and under axial impact to investigate strengthening with regards to dynamic axial crushing and associated crushworthiness indicators. Design models are developed and compared with the experimental results, and optimisation is discussed.

M. Reza Eslami (Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran), “Buckling of Spherical Shells”, a chapter in Buckling and Postbuckling of Beams, Plates, and Shells by M. Reza Eslami, Springer, 2018, pp 465-537

ABSTRACT: Spherical shells, as part of structural systems, are frequently used in many structural design problems. This type of shells is capable to stand high internal or external pressures and is especially quite stable under external pressures. The behavior of deep spherical shells, in particular, under external pressure is quite unique and the bifurcation load is far from expectation. Ancient spherical domes with wide spans in historic buildings is a good example of such structure to show its remarkable stability feature. Spherical shells used in the industrial applications are exposed to different types of mechanical or thermal loads. Under these circumstances, it is necessary to predict the critical mechanical and/or thermal buckling loads of spherical shells. Closed form solutions for the buckling loads are valuable tools for designer in the design stage. This chapter presents the methods to calculate critical buckling temperatures or pressures in spherical shell made of isotropic and functionally graded materials for both perfect and imperfect shells.

References listed at the end of the chapter:

ABSTRACT: Structural stability is one, or the most design driving criterion for aerospace structures. The accurate prediction of the various forms of buckling becomes especially important when seeking a minimum weight design. The grid-stiffened structures, with the isogrid and orthogrid being the most popular forms, provide a large design space to investigate, but also exhibit a complex behaviour in terms of structural stability. This paper focuses on buckling of the panel as a whole by presenting and comparing semi-analytical methods for global and panel buckling, where the latter takes the discrete nature of the stiffening structure into account. Results are presented for parameter studies of the composite cylindrical grid-stiffened shell including mechanical effects from panel curvature, stiffener eccentricity, and material orthotropy. The results show panel buckling to occur at significantly lower loads compared to global buckling, with a magnitude depending on the very specific geometry and kind of applied loads.

References listed at the end of the paper:
M.P. Nemeth and M.M. Mikulas, Simple Formulas and Results for Buckling-Resistance and Stiffness Design of Compression-Loaded


ABSTRACT: Optimal design of stiffened laminated composite cylinder of symmetric and balanced layup with isogrid form stiffeners is investigated and presented. The isogrid stiffened cylinder is subjected to uniform compressive load. In the optimization for the maximum buckling load, the panel skin laminate stacking sequence and stiffener configuration are chosen as design variables. A smeared model is employed in the buckling analysis of the stiffened composite cylinder. A new variant of particle swarm intelligence algorithm, using multiple swarms, built with quantum and dynamically reconfigurable features is developed and employed in the present investigations. The optimization is carried out using the proposed multi swarm based quantum particle swarm optimisation (PSO) algorithm, taking into consideration of the ply contiguous constraint. An optimal layup of the skin and stiffener configuration has also been obtained by using the proposed dynamic quantum PSO algorithm. Comparisons have been made with quantum PSO, cooperative quantum PSO, multi swarm based hybrid PSO, the newly developed multi swarm versions of quantum PSO and cooperative quantum PSO algorithms. Studies clearly indicate that multi swarm version of quantum PSO algorithms are more consistent and also reliable in providing optimal solutions. The methods presented in this paper will be applicable in general to the design of laminate composite structures.

References listed at the end of the paper:
REFERENCES listed at the end of the paper: (Cannot cut and paste them)

ABSTRACT: The buckling problem of stiffened plate panels under longitudinal compression is studied. The fundamental and practical aspects of the artificial neural networks are demonstrated and a view of their structures, topology and strengths is presented. The application of the neural network to the problem of buckling and ultimate strength of stiffened plates is explored. Two-hidden layer backpropagation neural network has been used to predict the crossover, local and overall buckling behaviour of the stiffened plates. The effects of the parameters, such as the number of nodes in the input layer, output layer and hidden layer, the pre-process (normalization) of the training patterns, the weight-factors initialization and the selection of the learning rate and momentum coefficient, on the behaviour of the neural network have been investigated. Both the gradient descent (GD) backpropagation algorithm and the conjugate gradient (CG) algorithm have been used and the latter is found to improve the performance (small Mean Square Error) of the neural network model. After training, the generalization of the neural network was tested by the patterns not included in the training patterns. Two structures of networks are worked out as follow:a) The configuration 5:22:13:3 is used to predict the crossover, local and overall buckling stresses of stiffened plates under uniaxial compression.b) The configuration 5:22:13:1 is used to predict the ultimate strength of stiffened plates. Also the shear buckling stress of plate girder is predicted using the same configuration. The neural network model was trained based on experimental results of other researches. The developed neural network is applied to investigate the behaviour of plate girders. The shear buckling stresses are assessed. It is found that normalizing the input and target values of training patterns using zero-mean normalization method reduces the training time. Gaussian weight-factor distribution with range (±1) is found to give a minimum mean square error (MSE) in comparison with other ranges. In addition, the effective values for learning rate and momentum coefficient are (0.3) and (0.6) respectively, and the configuration (22:13) for hidden layer is proved to be very efficient. Plates stiffened by T-type stiffeners are found to have higher values (20% and 25%) of buckling and ultimate strengths in comparison with those having flat and angle types stiffeners. The values of shear buckling stresses of plate girder which predicted by neural network model are greater than the values permitted by the Indian code.

References listed at the end of the paper:


Hughes, O.F., and Ghosh, B., "Improved Prediction of Simultaneous Local and Overall Buckling of Stiffened Panels", communicated for publication in Thin-Walled Structures.


Rizwan Sabir (1), Abid Ali Khan (1), Hassan Junaid (1), Qasim Zeeshan (1) and Yousaf ? (2)
(1) Department of Aeronautics and Astronautics, Institute of Space Technology, Islamabad, Pakistan
(2) Department of Mechanical Engineering, PIEAS, Islamabad, Pakistan


ABSTRACT: Optimization catches application in every field of engineering and science. The procedure of optimization is based on selection of best solution from a group of probable candidates such that the selected response is superior to the others in certain characteristics. Design optimization follows the procedure whereby nominated set of input design variables is automatically modified through an algorithm to acquire outputs that are more desired. High-speed computers, clusters, and workstations reduces human efforts to solve the high fidelity models. The optimization procedure of methodical and concurrent gathering of preferred functions is known as ‘Multi-Objective Optimization (MDO) or Vector Optimization’. This paper discusses different proposed optimization techniques for the buckling of Iso-grid structures from 2005 to 2012. These structures may be fabricated out of simple metals or composites. An Iso-grid panel is a face sheet or a plate with integral stiffening ribs of triangular shape and the structure acts like an isotropic material.

References listed at the end of the paper:

[7] W. Akla, A. El-Sabbagha, A. Bazb, Optimization of the static and dynamic characteristics of plates with isogrid stiffeners, a Design and Production Engineering Department, MD 20742, USA Received 9 July 2007; received in revised form 7 January 2008; accepted 7 January 2008

ABSTRACT: A summary of a NASA design analysis and test program on the buckling of large-scale, integrally-stiffened metallic cylinders is presented. The test article designs were developed based on proposed NASA launch vehicle cylinder designs and span a significant portion of the design space. Various loading conditions were applied to the cylinders and include different combinations of axial compression, bending, and internal pressure loads that simulate typical launch vehicle loading scenarios. The data gathered from this test program is being used to develop and validate new analysis-based knockdown factors and design guidelines for these stiffened metallic cylinders. In this paper, the test article designs and fabrication methods are described along with the test facilities and instrumentation. Selected test and finite element analysis results are presented and compared and are used to illustrate the typical response characteristics of the stiffened metallic cylinders considered. Overall, good qualitative agreement is found, however, several discrepancies in the results were
identified across several of the tests. The discrepancies were investigated thoroughly and can be attributed to variations in the as-built skin and stiffener geometry, variations in the measured geometric imperfection, and modeling assumptions associated with the boundary conditions, and loading imperfections. Based on these findings, several refinements were made to the finite element models which significantly improved the correlation between the test and analysis results. These modeling refinements are described and the updated analysis results are presented.

References listed at the end of the paper:


ABSTRACT: Grid-stiffened composite structures, where the skin is stiffened by a lattice of stiffeners, not only allow for significant reduction in structural weight but are also competitive in terms of structural stability and damage tolerance compared with sandwich composite structures. As the development of Automated Fiber Placement (AFP) technology matures, integrated construction of skin and stiffeners is easily manufacturable. Optimization of grid-stiffened structures is needed to fully take advantage of the expanded design possibilities. In this paper, a steering/curved stiffener layout is optimized for grid-stiffened composite structures in order to enhance the structural buckling resistance. A homogenization method is used to calculate the equivalent material properties. Global and local buckling loads are determined by a global/local coupled strategy. A linear variation of stiffener angles is assumed resulting in the formation of a locally rhombic lattice pattern by the stiffeners. Moreover, manufacturing constraints are considered in the optimization by setting a lower bound on the stiffener spacing. Since the calculation is implemented on an equivalent model with a fixed mesh, it is possible to use a gradient-based optimization algorithm. A comparison between the performance of grid-stiffened composite structures with curved stiffeners, with straight stiffeners, and with variable-stiffness skins with curved fibers, reveals the potential of curved stiffener configurations in improving structural efficiency.

References listed at the end of the paper:

An aircraft is a light weight air breathing semi-monocoque complex aerostructure comprising of longerons, bulkheads, stiffeners, stringers, legs, bolts and joints, ribs and other special forms of structures. In its service, it has to sustain mainly aerodynamic, structural, propulsive, fatigue and impact loads. Even though the load carrying agents are the stiffening materials, the loads are firstly faced by the aircraft skin in the form of
shear loads and later on transferred to the stiffening structures inside. These loads give rise to bending, buckling, shear, torsion and warping effects in different magnitudes on the semi-mococque structures. The implementation of the stiffened panel structure can be found inside the fuselage, wings and horizontal and vertical stabilizers of an aircraft. While in operation, an aircraft must resist all the loads said above in all kinds of mission profiles, that is from passenger, cargo, military, reconnaissance to combat situations with varying load spectrum. So it becomes very important and necessary to analyse an aircraft stiffened panel structure subjected to assumed static structural loads and dynamic (modal) loads.

References listed at the end of the paper:
Composite Steel Plate Shear Wall (CSPSW), which is used as the lateral resisting system in tall buildings.

ABSTRACT: Isogrid stiffened structures with a higher specific strength and stiffness due to their lightweight properties are composed of thin outer skin and repetitive equilateral triangular grid stiffeners. These grid stiffeners become isotropic in the plane of the structure and metallic isogrid stiffened structures are still used in an aerospace field such as launch vehicle payload fairings, inter stage adapter rings and fuel tanks. In order to produce these structures, a most of thick metal plate becomes cutoffs while remaining panel with stiffeners and both ends of the panel are welded to each other. This process needs long lead time and a high cost. Therefore we developed an integral molding method of CFRP isogrid cylindrical shells by using a filament winding apparatus [1] and a silicon rubber mold [2] (see Figs. 1 and 2) and performed the uniaxial compression test for the CFRP isogrid cylindrical shells. In this paper, the reinforcement effect of isogrid stiffeners on the compressive strength of CFRP cylindrical shell are shown in Table 1. Maximum compressive loads of CFRP isogrid shell are larger than the total loads of the CFRP shell without the isogrid and the isogrid shell alone. Next, formulations of linear and nonlinear analyses for CFRP isogrid cylindrical shells by using FEM code of ANSYS are presented and the uniaxial compression test of CFRP isogrid cylindrical shells are also shown. After the results of linear and nonlinear buckling analyses are compared with those of experiments of the CFRP isogrid cylindrical shells, an agreement of both results are shown in Table 2. Furthermore, an optimum design of CFRP cylindrical shell under the compression load is also demonstrated. In the optimum problem, three design parameters, such as an orientation angle of cylindrical shell, the width and thickness of isogrid stiffeners are selected among the many design parameters and their optimum value are searched for decreasing the weight of CFRP isogrid shell subjected the constrain of some value of buckling load by the response surface method (RSM) combined with movingleastsquares(MLS).

References listed at the end of the paper:


Goichi Ben, Naomi Kishitani and Yuuta Mochizuki (Department of Mechanical Engineering, College of Industrial Technology, Nihon University, Chiba, Japan), “Buckling analysis and optimum design of CFRP isogrid cylindrical shells”, 16th International Conference on Composite Structures (ICCS16), A.J.M. Ferreira (Editor), Porto, 2011

SUMMARY: The results of linear and nonlinear buckling analyses by FEM are compared with those of uniaxial compression test of the CFRP isogrid cylindrical shells and an agreement of both results is obtained. Furthermore, an optimum design of CFRP cylindrical shell under the compression load is also demonstrated.

ABSTRACT: Isogrid stiffened structures with a higher specific strength and stiffness due to their lightweight properties are composed of thin outer skin and repetitive equilateral triangular grid stiffeners. These grid stiffeners become isotropic in the plane of the structure and metallic isogrid stiffened structures are still used in an aerospace field such as launch vehicle payload fairings, inter stage adapter rings and fuel tanks. In order to produce these structures, a most of thick metal plate becomes cutoffs while remaining panel with stiffeners and both ends of the panel are welded to each other. This process needs long lead time and a high cost. Therefore we developed an integral molding method of CFRP isogrid cylindrical shells by using a filament winding apparatus [1] and a silicon rubber mold [2] (see Figs. 1 and 2) and performed the uniaxial compression test for the CFRP isogrid cylindrical shells. In this paper, the reinforcement effect of isogrid stiffeners on the compressive strength of CFRP cylindrical shell are shown in Table 1. Maximum compressive loads of CFRP isogrid shell are larger than the total loads of the CFRP shell without the isogrid and the isogrid shell alone. Next, formulations of linear and nonlinear analyses for CFRP isogrid cylindrical shells by using FEM code of ANSYS are presented and the uniaxial compression test of CFRP isogrid cylindrical shells are also shown. After the results of linear and nonlinear buckling analyses are compared with those of experiments of the CFRP isogrid cylindrical shells, an agreement of both results are shown in Table 2. Furthermore, an optimum design of CFRP cylindrical shell under the uniaxial compression is also demonstrated. In the optimum problem, three design parameters, such as an orientation angle of cylindrical shell, the width and thickness of isogrid stiffeners are selected among the many design parameters and their optimum value are searched for decreasing the weight of CFRP isogrid shell subjected the constrain of some value of buckling load by the response surface method (RSM) combined with movingleastsquares(MLS).

References listed at the end of the paper:


A. Arabzade, H. Moharami and A. Ayazi (Department of Civil and Environmental Engineering, School of Engineering, Tarbiat Modares University, Tehran, P.O. Box 14115-397, Iran), “Local elastic buckling coefficients of steel plates in composite steel plate shear walls”, Scientia Iranica, Vol. 18, No. 1, pp 9-15, February 2011

ABSTRACT: The system of a steel plate bolted to a Reinforced Concrete (RC) shear wall goes by the name of a ‘Composite Steel Plate Shear Wall’ (CSPSW), which is used as the lateral resisting system in tall buildings. In
this system, the steel plate buckles under medium-strong earthquakes, which may lead to instability. However, the buckling load of steel plates is usually a limited criterion for the design of CSPSW. This paper reports a series of experiments on CSPSW. The experiments were used to investigate the buckling load of a steel plate bolted to one side of a high strength reinforced concrete panel. Furthermore, theoretical modeling, based on energy methods, was used to obtain the elastic buckling coefficients of steel plates with various aspect ratios under shear loading. The results were presented in graphical and tabular forms showing good agreement of theoretical modeling with experimental results. The elastic buckling coefficients can be used for determination of the number of bolts or the spacing between the bolts.

References listed at the end of the paper:
1 Astaneh-Asl, A., Experimental and analytical studies of composite (steel–concrete) shear walls, Research Project, Sponsored by the National Science Foundation, Department of Civil and Env. Engrg., Univ. of California, Berkeley, 1998–2001.
5 H.D. Wright, Buckling of plates in contact with a rigid medium. The Structural Engineer, 71(12) (1993), pp. 209-215
10 B. Uy, H.D. Wright, M.A. Bradford, Combined axial and flexural strength of profiled composite walled, Structures & Buildings, 146 (2) (2001), pp. 129-130
14 ACI Committee 318-08. Building Code Requirements for Structural Concrete and Commentary. American Concrete Institute (2008)


ABSTRACT: This paper describes the fabrication and testing of the composite isogrid stiffened cylinder. The purpose of the axial compression test was to identify various failure modes that are present in the structures such as rib crippling, skin (pocket) buckling, and general instability. The rib buckling was found to be the critical failure mode for the isogrid cylinder. The isogrid cylinder has been demonstrated to be tolerant to structural damage due to the multiplicity of load paths. The cylinder continued to resist compression loading even after one or more ribs had fractured. The imperfections to the cylinder resulted in reduced buckling resistance but this problem can be overcome by advancement in the manufacturing methods.

Hao Wu (1), Changlian Lai (2), Fangfang Sun (2), Ming Li (2), Bin Ji (3), Weiyi Wei (4), Debo Liu (4), Xi Zhang (4), and Hualin Fan (2,3,4)
(1) State Key Laboratory for Disaster Prevention & Mitigation of Explosion & Impact, PLA University of Science and Technology, Nanjing, China
(2) Research Center of Lightweight Structures and Intelligent Manufacturing, State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
(3) Aerospace System Engineering Shanghai, Shanghai 201108, China
(4) China Academy of Launch Vehicle Technology, Beijing 100076, China

ABSTRACT: To get strong, stiff and light cylindrical shell, carbon fiber reinforced hierarchical orthogrid stiffened cylinders are designed and fabricated. The cylinder is stiffened by two-scale orthogrid. The primary orthogrid has thick and high ribs and contains several sub-orthogrid cells whose rib is much thinner and lower. The primary orthogrid stiffens the bending rigidity of the cylinder to resist the global instability while the sub-orthogrid stiffens the bending rigidity of the skin enclosed by the primary orthogrid to resist local buckling. The cylinder is fabricated by filament winding method based on a silicone rubber mandrel with hierarchical grooves. Axial compression tests are performed to reveal the failure modes. With hierarchical stiffeners, the cylinder fails at skin fracture and has high specific strength. The cylinder will fail at end crushing if the end of the cylinder is not thickened. Global instability and local buckling are well restricted by the hierarchical stiffeners.


ABSTRACT: In launch vehicle structures, for withstanding buckling failures due to the compressive loads and external pressure, integrally stiffened shell structures (waffle and isogrid shell structures) are employed. This paper discusses about the design of cylindrical and conical shaped isogrid structures subjected to axial compression and the external pressure and the effect of variation of design parameters like height of the triangle, skin thickness, rib width, rib depth etc. on the buckling load capacity. First, theoretical computation of the buckling load factor has been carried out using design equations for isogrid structure. A near optimum configuration is arrived at, which results in minimum equivalent weight thickness and positive margins of safety. By using inhouse software FEAST, a parametric modeling tool has been developed for modeling isogrid and waffle shell structures. Static analysis, buckling analysis and free vibration analysis have been carried out for both structures using FEAST software. By comparing the results, isogrid structures have less static displacement and more buckling load factor when compared with waffle structure.

References listed at the end of the paper:

Emad Zolqadr, “Buckling of spherical concrete shells”, Master’s thesis, Dept. of Civil Engineering, Ryerson University, Toronto, Ontario, Canada, 2017

ABSTRACT: This study is focused on the buckling behavior of spherical concrete shells (domes) under different loading conditions. The background of analytical analysis and recommended equations for calculation of design buckling pressure for spherical shells are discussed in this study. The finite element (FE) method is used to study the linear and nonlinear response of spherical concrete shells under different vertical and horizontal load combination buckling analysis. The effect of different domes support conditions are considered and investigated in this study. Several dome configurations with different geometry specifications are used in this study to attain reliable results. The resulted buckling pressures from linear FE analysis for all the cases are close to the analytical equations for elastic behavior of spherical shells. The results of this study show that geometric nonlinearity widely affects the buckling resistance of the spherical shells. The effect of horizontal loads due to horizontal component of earthquake is not currently considered in the recommended equation by The American Concrete Institute (ACI) to design spherical concrete shells against buckling. However, the
results of this study show that horizontal loads have a major effect on buckling pressure and it could not be ignored.

References listed at the end of the thesis:
- Huang, Nai-Chen, “Unsymmetrical Buckling of Thin Shallow Spherical Shells,” Division of Engineering and Applied Physics, Harvard University, Cambridge, Massachusetts, 1963


ABSTRACT: The steel stiffened segment in a steel–concrete connection joint is critical to the load capability of the cable-stayed bridge with hybrid girders. The research focused on the improvement of steel stiffened segments by investigating their failure reasons, mechanical behavior, and transmission efficiency. In order to achieve that, both the experiments and finite-element (FE) analysis of three classical types of stiffened segments subjected to axial compression were conducted, and FE results were consistent with test data. Effects of element sizes, geometric imperfections, and residual stresses were considered in FE models, and proper values for the imperfections were suggested. With refined models, transmission efficiency and stress concentration of three types of steel stiffened segments have been investigated. Segments with a U-shaped stiffener inserted T-stiffener and U-shaped stiffener circumscribed double T-stiffener are suggested for better force transmission and less local stress concentration. Furthermore, parameter studies on two suggested types above are carried out. Results show that the vertical plate could be thinning when the condition of stability is satisfied. Proper thickness of the vertical plate in a single T-stiffener and proper spacing between vertical plates in a double T-stiffener are given.


ABSTRACT: Ranging from agriculture to food processing, from mining to industrial processing, all these sectors have a need for the temporary storage of (dry) powdered, granular, and bulk materials between different stages of all kinds of manufacturing processes and between manufacturing process and transportation, or vice versa. Silos are therefore the perfect solution to meet this need, because they can easily store large volumes on a relatively limited floor space. Frequently, silos have a circular platform and are placed in elevated position. The latter can be achieved by a limited number of discrete equidistant supports around the barrel circumference. However, in such cases, large loads have to be transferred to the limited number of supports, causing locally high axial compressive stress concentrations, and consequently premature failure due to plastic yielding and/or elastic buckling (depending on the thickness of the silo wall). A possible answer to avoid these problems is to provide a partial-height U-shaped longitudinal stiffener above each support. Such stiffeners allow for a more gradual load transfer to the supports, increasing the maximum failure load. This paper aims to map the influence of the dimensions of such longitudinal stiffeners (i.e. the parameters of the cross-section and the height) on the failure behaviour of thick-walled silos. All results and findings are based on geometrically and materially non-linear analyses or GMNA performed with finite element software. The simulations indicate that correctly, for thick-walled silos, failure will always occur by (elasto-)plastic yielding. Depending on the longitudinal stiffener cross-section, the location of failure will occur in the stiffened zone of the silo just above the supports for silos.
with stiffeners with a small cross-section, whereas for stiffeners with larger cross-sections, failure occurs in the unstiffened zone just above the terminations of the stiffeners. In addition, the stiffener width in circumferential and radial direction have respectively an advantageous and a disadvantageous influence on the failure load. Finally, the stiffener height only has a positive impact on the failure load when failure occurs in the unstiffened silo wall. This can be addressed to the distribution of the supporting force over the entire circumference with higher stiffeners.


ABSTRACT: This work uses different finite element approaches to the free vibration analysis of reinforced shell structures, and a simplified model of a typical launcher with two boosters is used as an example. The results obtained using a refined one-dimensional (1D) beam model are compared to those obtained with commercial finite element software. The 1D models that are used in the present work are based on the Carrera Unified Formulation (CUF), which assumes a variable kinematic displacement field over the cross-sections of the beam. Two different sets of polynomials that correspond to Taylor (TE) or Lagrange (LE) expansions were used. The analyses focused on three reinforced structures: a stiffened panel, a reinforced cylinder and the complete structure of the launcher. The frequencies and natural modes obtained using one-dimensional models are compared to those obtained from classical finite element analysis. The classical FE models were built using a beam-shell or solid elements, and the results indicate that the refined beam models can in fact be used to investigate the behavior of very complex reinforced structures. These models can predict the shell-like modes that are typical of thin-walled structures that cannot be detected using classical beam models. The refined 1D models used in the present work provide results that are as accurate as those from solid FE models, but the 1D models have a much lower computational cost.

References listed at the end of the paper:

PARTIAL ARTICLE: Anyone designing high-performance cylindrical and conical-shell structures invariably wants to balance strength and low weight, along with several other characteristics including lowest-cost manufacturing. FEA and CAD software provide one way to shape complex forms, but these general-purpose programs work best when applied to a wider variety engineered structures and tasks.

Often hard-to-implement analysis methods may provide some assistance designing the cylindrical and conical shell structures traditionally found in aerospace products, such as rockets and launch vehicles. But these methods may not work equally well, if at all, designing structures that could be, for example, load carrying vacuum vessels or any thin-wall structure.

Software for shell structures: One particular program, Shell Structures Tools (SST), has been in development 40 years and addresses the lightweight, high-strength requirements, and more. Its start menu makes it easy to type in design requirements, and results are easy to understand and use in a format similar to Web pages. The software unifies design, manufacturing, and analysis based on classical, empirical, and FEA methods. It comprehensively and quickly produces a design along with production plans for the structure.

Shell structures designed by the software can be isogrid, waffle, monocoque, sandwich, honeycomb, or ring or stringer-rib stiffened. Several variations of those are possible. For example, sandwich structures can have fluted cores, honeycomb can have proprietary Hexcel cores, ribs can be stiffened with flanges and various skin-and-stringers can be used for shell stiffening.

When designing each structure, the software calls upon particular empirical, classical, and finite-element methods to size, analyze, and optimize about 11 characteristics the structures commonly need. This brief introduction to the software gives an idea of what designers would provide and what the software returns. The Start Menu box outlines typical inputs needed to design and analyze a shell. The inputs for about 10 categories typically include the shell geometry such as the large and small ID for a cone, and a length. If the shell includes cutouts such as round portholes, designers supply porthole diameters and locations, and whether or not the structure will include load-bearing doors (a yes or no selection). Local loads can be applied to the shell several ways such as, normal loads and bending moments.

Users select the construction material, which can include metals, composites, and their adhesives. Depending on the material, designers may have to supply material properties at temperature. For a complete list of the input criteria see http://www.machinedesign.com/md/images/SST-START-MENU-MD1.xls.

The software lops time off design work several ways. For instance, its unformatted inputs means users need not supply a CAD model. The dimensions typed into the Start Menu, actually an Excel spreadsheet, give enough information to get things started. Users are also asked to supply edge conditions, external loads, needed safety factors, structural configurations, identify critical-failure modes, modal-response requirements, construction methods, requirements for trade-offs, and tolerances for manufacturing and structural analysis.

Using runtime files, the software generates a best design and presents results in a Web site. Results are globally modified so users might, for example, adjust the manufacturing tolerances once and the software finds all calculations that use them before recalculating. The design is complete and comprehensive for the supplied loads the first time SST produces an output.
It is not difficult to run the software but it is preferable that my firm return to clients results to the spreadsheet Start Menu submitted by clients. Hence, the first turn-around may take a day or two. But after the program generates runtime files, iterations on the original design can be a matter of minutes. . . . (More is available but not reproduced here in order to save space.)

Jinliang Song (1,2), Quansheng Sun (1), Shengmin Luo (2), Sanjay R. Arwade (2), Simos Gerasimidis (2), Yi Guo (3) and Guoping Shang (2)
(1) Department of Civil Engineering, Northeast Forestry University, Harbin 150040, China
(2) Department of Civil and Environmental Engineering, University of Massachusetts Amherst, Amherst, MA 01003, USA
(3) Diamond Offshore Drilling, Inc., Houston, TX 77094, USA

ABSTRACT: This paper presents an integrated experimental and computational study of the compression behavior of individual thin-walled metallic hollow spheres (MHS) with patterned distributions of microporosity. Quasi-static compression testing, including purely elastic loading, was conducted on two groups of individual MHS with two different sizes to examine the entire deformation process as well as the purely elastic response. Three-dimensional finite element modeling was then performed to investigate the effects of different microporosity distribution patterns on the MHS compression behavior and to understand the pertinent deformation and failure mechanisms. Results show that the Young's modulus and collapse stress of individual MHS with a uniform microporosity distribution decrease nonlinearly with porosity, which follows the same power-law functions developed for the porous wall material. For other patterned (i.e., vertical, horizontal, and random) distributions of microporosity involving localized weak wall sections, buckling commences at the weak sections, generating “buckling lines”, followed by buckling failure along these adjacent or converged “buckling lines”. Moreover, among the “buckling lines” generate some hinges that contribute to the increased load-bearing capability during the densification process. These findings can shed lights on the design, manufacturing, and modeling of individual MHS and MHS-based materials with specifically tailored engineering performance.


ABSTRACT: The results of FEM calculations of stability of thin–walled spherical shells are presented. A static and dynamic stability analysis was conducted. Hemispherical shells and spherical caps with various dilation angles, subjected to external pressure, were considered. For each shell calculated, various boundary conditions of support were analyzed: joint, fixed and elastically fixed support. In the calculations, an axisymmetric and random discretization of the model was accounted for. As a result of the calculations conducted for static loads, values of upper critical pressures and buckling modes of the shells were obtained. The results were presented for various shell thicknesses. The FEM solutions were compared to the available results obtained with analytical and numerical methods, showing a good conformity. Dynamic calculations were conducted for a triangular pulse load. On the basis of the Budiansky–Roth dynamic criterion of stability loss, values of upper dynamic critical pressures were obtained. Shell buckling modes were determined as well.

References listed at the end of the paper:

ABSTRACT: For a cylindrical intersecting-latticed-three-dimensional-beam-system (ILTDBS) reticulated mega-structure braced with single-layer latticed membranous shell substructures, the formation method, form parameters and support styles are first studied in this paper. And a program, which can automatically generate the form of the structure, is developed. Then the geometrically nonlinear mechanical model and stability analysis program are developed, and the stabilities of the structure are investigated. The structural ultimate bearing capacities and buckling modes including overall buckling and local buckling are studied in detail by parametric analyses. And the laws of determination of various parameters of the structure with different spans on the critical state between local and overall buckling are obtained. The work will provide guidance in theory for practical applications of this kind of structure.

Bo Wang (1), Siyuan Bao (1,2), Sandra Vinnikova (1), Pravarsha Ghanta (1) and Shuodao Wang (1)
(1) School of Mechanical and Aerospace Engineering, Oklahoma State University, Stillwater, OK 74078, USA
(2) School of Civil Engineering, University of Science and Technology of Suzhou, Suzhou 215011, China


ABSTRACT: In the last decade, stretchable electronics evolved as a class of novel systems that have electronic performances equal to established semiconductor technologies, but can be stretched, compressed, and twisted like a rubber band. The compliance and stretchability of these electronics allow them to conform and mount to soft, elastic biological organs and tissues, thereby providing attractive opportunities in health care and biosensing. Majority of stretchable electronic systems use an elastomeric substrate to carry an ultrathin circuit mesh that consists of sparsely distributed stiff, thin-film electronic components interconnected by various forms of stretchable metal strips or low-dimension materials. During the fabrication processes and application of stretchable electronics, the thin-film components or nanomaterials undergo different kinds of in-plane deformation that often leads to out-of-plane or lateral buckling, in-surface buckling, or a combination of all. A lot of creative concepts and ideas have been developed to control and harness buckling behaviors, commonly regarded as pervasive occurrences in structural designs, to facilitate fabrication of stretchable structures, or to enhance stretchability. This paper provides a brief review of recent progresses on buckling analysis in stretchable electronics. Detailed buckling mechanics reveals important correlations between the geometric/material properties and system performance (e.g., mechanical robustness, deformability, structural architecture, and control). These mechanics models and analysis provide insights to design and optimize stretchable electronics for a wide range of important applications.

References listed at the end of the paper:


ABSTRACT: A Generalized Beam Theory (GBT) approach is derived that performs automated, quantitative modal decomposition of thin-walled members with an open cross-section. The technique extracts modal amplitudes and modal participation factors from any 3D displacement field, for example from finite element analysis or point clouds measured in the lab during a test to collapse. Thin-walled members exhibit deformation that can be represented as combinations of cross-sectional and global buckling modes. It is useful to quantitatively decompose these modes for strength prediction and design code development. Conventionally, buckling mode participation has been determined by visual inspection. This process is subjective and tedious since the person conducting the inspection is often dealing with many models or experiments. Taking advantage of GBT kinematics, the proposed method distinguishes itself by using only the GBT cross-section deformation modes instead of member-wise basis functions. The method is by nature applicable to different boundary and loading conditions without recalculating of basis functions. The mechanics are formulated to show that the method is supported by GBT kinematic assumptions, which ensures its general applicability. The approach is implemented in a Graphical User Interface (GUI) that accepts a thin-walled member 3D displacement field as input and then calculates modal participation factors, i.e., for member local, distortional, and global (Euler) buckling.

References listed at the end of the paper:
Nedelcu, M., and Cucu, H. L. (2014). “Buckling modes identification from FEA of thin-walled members using only GBT cross-sectional deformation modes.” Thin-Walled Structures, Coupled Instabilities in Metal Structures, 81, 150–158.

ABSTRACT: Failure in cold-formed steel beams is generally initiated by one of three instabilities: local, distortional, or lateral-torsional buckling. For cold-formed steel joists, purlins, or girts, when the compression flange is not restrained by attachment to sheathing or paneling, distortional buckling may be the predominant failure mode. Experimental results on cold-formed steel beams with unrestrained compression flanges are scarce. Therefore a series of distortional buckling tests on cold-formed steel C and Z sections in bending was conducted to establish the capacity in distortional buckling failures. Test details were selected to allow distortional buckling to form, but restrict lateral-torsional buckling to the extent possible. These distortional buckling tests also provide a direct comparison against the local buckling tests previously performed by the writers. As expected, large strength reductions are observed in the tested specimens when distortional buckling initiated the failure instead of local buckling. U.S., Canadian, and joint North American standards for design, which are known to primarily focus on local buckling, provided unconservative predictions of the observed strength. The Australian/New Zealand Standard and the direct strength method, which provide explicit methods for calculating the capacity in the distortional buckling mode, provided reasonably accurate and reliable predictions.


INTRODUCTION: Japan is in a seismically active area and experiences many damaging earthquakes with loss of life. In 1995, the Hyogoken-Nanbu earthquake caused major destruction in Kobe City and in 2011 the Great Eastern Japan earthquake and tsunami caused major destruction in the Pacific coast areas of northeastern Japan. Additionally, recent relatively less destructive earthquakes include the 2003 Tokachi-Oki earthquake, the 2004 Niigataken Chuetsu earthquake, the 2005 Miyagi-oki earthquake, the 2007 Noto-Hanto earthquake, and the 2007 Niigataken Chuetsu-Oki earthquake. In particular, the Great Eastern Japan, Noto-Hanto, Miyagi-oki, and Niigataken-Chuetsu-Oki earthquakes occurred near nuclear power facilities and have been accompanied by enhanced public concern for seismic safety of nuclear plants. Within the Japanese national government, the Nuclear Safety Commission revised the Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities (Nuclear Safety Commission of Japan, 2006) in 2006. This revised Regulatory Guide required seismic safety design of buildings, structures and equipment for larger seismic motions. In addition, seismic probabilistic safety assessment (seismic PSA) (American Nuclear Society, 2007; Atomic Energy Society of Japan, 2007) was urged, for which accurate evaluation techniques for seismic response of equipment installed in the nuclear power plants were needed. Large cylindrical liquid storage tanks in nuclear power plants are classified as equipment requiring high seismic safety because many are containers storing cooling water used in normal plant operation and in accidents. Their seismic evaluation is done on the basis of the Technical Codes for Aseismic Design of Nuclear Power Plants (Japan Electric Association [JEA], 2008) published by the Japan Electric Association. The seismic evaluation methods used in the conventional seismic design of the tanks (Kanagawa Prefecture, 2002; High Pressure Gas Safety Institute of Japan [KHK], 2003; Architectural Institute of Japan [AIJ], 2010) such as the Technical Codes examine the bending vibration mode (beam-type vibration) which mainly affects the seismic resistance of the tanks, but they do not consider high order vibration modes (oval-type vibration) which are excited in the tank wall by large vibrations and cause oscillation patterns that look like petals of a flower. Therefore, it is necessary to reveal the influence of oval-type vibration on vibration characteristics and seismic safety and to consider the vibration in the seismic design of the tanks (Japan Society of Civil Engineers, 1989). However, research on oval-type vibration has only been of academic interest,
including reports on fluid-structure interaction which causes oval-type vibration (Japan Society of Mechanical Engineers, 2003) and nonlinear behavior of oval-type vibration (Chiba, 1993). Though analysis techniques such as finite element methods are available as seismic evaluation methods at present, numerical seismic analysis of the tanks considering oval-type vibration has not been established because advanced techniques such as fluid-structure interaction analysis and nonlinear dynamic structure analysis are needed to simulate the oval-type vibration behavior. In addition, capacity to resist buckling is an important evaluation item in seismic design of cylindrical liquid storage tanks. Buckling is a dangerous mode for tanks which drastically lowers their structural strength (proof force) and collapses their geometries. In the ultimate buckled state and post-buckling, the cylindrical liquid storage tanks are deformed largely and display nonlinear inelastic behavior. Therefore, it is desirable to take into account the nonlinear inelastic dynamic behavior when evaluating seismic safety of the tanks. The conventional seismic design of tanks (Kanagawa Prefecture, 2002; KHK, 2003; JEA, 2008; AIJ, 2010) uses evaluation equations for static buckling derived from static buckling tests and the assumption of a linear response. However, the evaluation equations have not been validated sufficiently from the viewpoint of the dynamic liquid pressure effect in tanks subjected to seismic motions. Though a few dynamic experiments and development of numerical methods for buckling of cylindrical liquid storage tanks were done in the past, the developed numerical methods could simulate the experimental results only qualitatively (Fujita et al., 1992; Toyoda et al., 1997). As described above, the conventional seismic design assumes linear behavior of the tanks and does not include nonlinear behavior in post-buckling. However, it is necessary to develop accurate seismic response analysis methods for the cylindrical liquid storage tanks to ensure seismic safety and conduct accurate seismic PSA for mega earthquakes. Therefore, an accurate dynamic analysis method to evaluate dynamic nonlinear behavior of the cylindrical liquid storage tanks subjected to seismic motions was proposed and validated by the dynamic experiment in this chapter. The research was done for the liquid storage tanks installed in nuclear power plants such as refueling water tanks and condensate water tanks. In this chapter, previous studies are overviewed and then sequential research findings on the dynamic analysis method are summarized. First, the seismic damage modes of the cylindrical liquid storage tanks are explained briefly. Especially buckling modes caused by earthquakes are introduced. Secondly, the vibration behavior of the tanks is explained. Thirdly, previous studies are overviewed with regard to vibration characteristics and seismic evaluations. Special focus is given to the seismic response analysis and dynamic buckling evaluation. Fourthly, research studies concerned with oval-type vibration are summarized. Finally, the author’s study regarding dynamic nonlinear analysis method for seismic response of the cylindrical liquid storage tanks is described and the method is shown to be suitable for actual tanks based on comparison with experimental results.

References listed at the end of the paper:


ABSTRACT: A review is made of the development of methods used to examine the response of steel frame structures to statically applied loads. The various possible alternatives in terms of rigor and complexity are defined and key effects — especially the role of connections — discussed. Both multistorey and low-rise frames are considered. A section of the paper contrasts the relative lack of attention paid to a number of “neglected features” with the plethora of publications devoted to the analysis of 2-dimensional, bare steel, rigid jointed structures.


ABSTRACT: Frames are possibly the most common forms of man-made engineering structures. They are formed by joining one-dimensional members together. Since the early work of Euler, engineers started to realize that the strength of a member under compression does not only depend on the material yield stress, but also on the Young’s modulus of elasticity. The introduction of steel material and other metals makes the consideration more important because of their relatively slender dimensions. From the vision of the current computer age, this paper is addressed to a review and summary of the work conducted on the non-linear analysis and design of steel frames in the past few decades.


ABSTRACT: The system-based design of steel structures using advanced analysis leads to a more efficient structural design process and achieves a more uniform level of structural system reliability. The main impediment to adopting this method in practical applications is the apparent difficulty in assigning an
appropriate resistance factor to structural systems. In this paper, the reliability assessment and derivation of system resistance factors for a series of 3D low-to-mid-rise steel frames are presented, taking into account the inherent uncertainties in material and geometric properties, and the model uncertainty of advanced analysis. Braced and unbraced (sway) frames with regular and irregular configurations are analysed under gravity loads and the system resistance factors are derived for different target reliability levels. The frames are selected to provide different system failure modes such as sway instability and/or member failure. Recommendations are made for the appropriate target reliabilities and associated system resistance factors for use in designing 3D steel frames at system level by advanced analysis.

References listed at the end of the paper:
INTRODUCTION: Taking into account the stiffness and inertia forces, dynamic behaviour of structures can be investigated. Dynamic investigation usually starts with an example of free vibration. It means to evaluate the natural frequency. The simplest stability problem of structures is buckling of a column. This problem can be arranged preparing the equilibrium conditions on a deformed structure. In general, however, for the evaluation of the stability problems strains should be evaluated for a deformed differential element what means to apply geometric non-linear theory.
Combination of dynamics and stability yields in a lot of problems: dynamic buckling, dynamic post buckling behaviour, parametric resonance, etc. Introduction example – vibration of a column loaded in compression is simple but its investigation still represents a lot of problems.
The natural frequency can be measured by using rather simple equipment. The comparison of frequencies measured experimentally and evaluated numerically is the basis of non-destructive methods for investigation of structure properties. Generally, it can be said that in structural design stability effects have to be taken into consideration. These two ideas are the reason for our investigation of the combination of vibration and stability.
Leonard Euler was probably the first scientist who had analyzed stability problems. The former solutions are supposed to be the linear stability. It means that we suppose an ideal structure. The differences between theory and reality inspired researchers to search for more accurate models. Especially the slender web as the main part of thin-walled structure has significant post-buckling reserves and it is necessary to accept a geometric non-linear theory for their description. The problem of the vibration of the non-linear system was formulated by Bolotin [2]. Burgreen [3] analysed the problem of the vibration of an imperfect column in early 50's. Some valuable results have been achieved by Volmir [7]. Combination of dynamics and stability is still a subject of research all over the world.

References listed at the end of the paper:
San Francisco, 1994.)
References listed at the end of the paper:

46 W. Ding, Y. Yang, Y. Zhao, S. Jiang, Y. Cao, Well-defined orthogonal surface wrinkles directed by the wrinkled boundary. Langmuir 9, 3720–3726 (2013).


ABSTRACT: In this paper, we report a novel nanoscale wrinkle-structure fabrication process using fluorocarbon plasma on poly(dimethylsiloxane) (PDMS) and Solaris membranes. Wrinkles with wavelengths of hundreds of nanometers were obtained on these two materials, showing that the fabrication process was universally applicable. By varying the plasma-treating time, the wavelength of the wrinkle structure could be controlled. Highly transparent membranes with wrinkle patterns were obtained when the plasma-treating time was <125s. The transmittances of these membranes were >90% in the visible region, making it difficult to distinguish them from a flat membrane. The deposited fluorocarbon polymer also dramatically reduced the surface energy, which allowed us to replicate the wrinkle pattern with high precision onto other membranes without any surfactant coating. The combined advantages of high electron affinity and high transparency enabled the fabricated membrane to improve the performance of a triboelectric nanogenerator. This nanoscale, single-step, and universal wrinkle-pattern fabrication process, with the functionality of high transparency and ultra-low surface energy, shows an attractive potential for future applications in micro- and nanodevices, especially in transparent energy harvesters.

References listed at the end of the paper:
REFERENCES listed at the end of the paper:


4 Wu, N.; Pease, L.F., III; Russel, W.B. Toward large-scale alignment of electrohydrodynamic patterning of thin polymer films. Adv.

Marta Palacios-Cuesta (1), Aitziber L. Cortajarena (2), Olga Garcia (1) and Juan Rodriguez-Hernandez (1)

(1) Department of Chemistry and Properties of Polymers, Instituto de Ciencia y Tecnologia de Polímeros-Consejo Superior de Investigaciones Científicas (ICTP-CSIC), Juan de la Cierva 3, 28006 Madrid, Spain
(2) Instituto Madrileño de Estudios Avanzados en Nanociencia (IMDEA-Nanociencia), Cantoblanco, 28049 Madrid, Spain


ABSTRACT: The generation of nano-microstructured surfaces is a current challenge in polymer science. The fabrication of such surfaces has been accomplished mainly following two different alternatives i.e., by adapting techniques, such as molding (embossing) or nano/microimprinting, or by developing novel techniques including laser ablation, soft lithography or laser scanning. Surface instabilities have been recently highlighted as a promising alternative to induce surface features. In particular, wrinkles have been extensively explored for this purpose. Herein, we describe the preparation of wrinkled interfaces by confining a photosensitive monomeric mixture composed of monofunctional monomer and a crosslinking agent within a substrate and a cover. The wrinkling characteristics can be controlled by the monomer mixture and the experimental conditions employed for the photopolymerization. More interestingly, incorporation within the material of a functional copolymer allowed us to vary the surface chemical composition while maintaining the surface structure. For that purpose we incorporated either a fluorinated copolymer that enhanced the surface hydrophobicity of the wrinkled interface or an acrylic acid containing copolymer that increased the hydrophilicity of the wrinkled surface. Finally, the role of the hydrophobicity on the bacterial surface adhesion will be tested by using Staphylococcus aureus.


Phys substrates form in the vicinity of positive disclinations. In free positive Gaussian curvature, whereas negative disclinations give rise to negative curvature. Here, we present a

ABSTRACT: Emergent three-dimensional structure. Standard lore dictates that positive disclinations are associated with positive Gaussian curvature, whereas negative disclinations give rise to negative curvature. Here, we present a diblock copolymer system exhibiting a striped columnar phase that preferentially forms wrinkles perpendicular to the underlying stripes. In free-standing films this wrinkling behavior induces negative Gaussian curvature to form in the vicinity of positive disclinations.

References listed at the end of the paper:


Elisabetta A. Matsumoto (1,2), Daniel A. Vega (3), Aldo D. Pezzutti (3), Nicolás A. García (3), Paul M. Chaikin (4), and Richard A. Register (5)

(1) Princeton Center for Theoretical Science, Princeton University, Princeton, NJ 08544
(2) John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138
(3) Instituto de Física del Sur, Consejo Nacional de Investigaciones Científicas y Técnicas, Universidad Nacional del Sur, 8000 Bahía Blanca, Argentina
(4) Center for Soft Condensed Matter Research and Department of Physics, New York University, New York, NY 10003
(5) Department of Chemical and Biological Engineering and Princeton Institute for the Science and Technology of Materials, Princeton University, Princeton, NJ 08544

“Wrinkles and splay conspire to give positive disclinations negative curvature”, Proceedings of the National Academy of Sciences of the USA (PNAS), Vol. 112, No. 41, 12639-12644, September 29, 2015, https://doi.org/10.1073/pnas.1514379112

SIGNIFICANCE: Diblock copolymers, polymers made by covalently bonding two otherwise immiscible polymers together, are prized for their robust ability to self-assemble into highly ordered geometric structures. Likewise, there has been recent interest in the ability to control the global geometry of a surface, merely by modifying its local microstructure. Here, we take advantage of the defect structure arising from a slow annealing of a thin film of cylinder-forming diblock copolymers as a means of guiding the geometry of an emergent three-dimensional structure.

ABSTRACT: Recently, there has been renewed interest in the coupling between geometry and topological defects in crystalline and striped systems. Standard lore dictates that positive disclinations are associated with positive Gaussian curvature, whereas negative disclinations give rise to negative curvature. Here, we present a diblock copolymer system exhibiting a striped columnar phase that preferentially forms wrinkles perpendicular to the underlying stripes. In free-standing films this wrinkling behavior induces negative Gaussian curvature to form in the vicinity of positive disclinations.

ABSTRACT: A non-Euclidean plate is a thin elastic object whose intrinsic geometry is not flat and hence has residual stresses arising from being embedded in three dimensional space. Recently, there has been interest in using localized swelling to induce residual stresses that shape flat objects into desired three dimensional structures. A fundamental question is whether we can use the mathematical theory of non-Euclidean plates to deduce the three dimensional configuration of the swelling sheet given the exact knowledge of the imposed geometry. We present and summarize the results of recent mathematical studies on non-Euclidean plates with imposed constant negative Gaussian curvature in both annular and disc geometries. We show in the Föppl–von Kármán approximation to the elastic energy there are only two types of global minimizers – flat and saddle shaped deformations – with localized regions of stretching near the boundary of the domain. We also show that there exist n-wave local minimizers that closely resemble experimental observations and have additional regions of stretching near lines of inflection. Furthermore, in the Kirchhoff approximation to the elastic energy, we show that there exists exact isometric immersions with periodic profiles. The number of waves in these configurations is set by the condition that the bending energy remains finite and grows approximately exponentially with the radius of the annulus. For large radii, these shape are energetically favorable over saddle shapes and could explain why wavy shapes are selected in crochet models of the hyperbolic plane. The predicted morphologies however differ from what is observed in experiments on hydrogel disks highlighting the need for further theoretical studies.

Sanjib C. Chowdhury, Bazle Z. (GAMA) Haque and John W. Gillespie Jr. [Center for Composite Materials (UD-CCM), University of Delaware, Newark, DE 19716, USA], “Molecular simulations of the carbon nanotubes intramolecular junctions under mechanical loading”, Computational Materials Science, Vol. 82, pp 503-509, 2014

ABSTRACT: In this paper, mechanical responses of the carbon nanotubes (CNTs) intramolecular junctions (IMJs) under three generic modes of mechanical loadings – tension, compression, and torsion have been studied using molecular dynamics simulations. (5,5)-(10,0), (7,7)-(14,0), (10,10)-(20,0) armchair–zigzag and (8,0)-(6,0) zigzag–zigzag IMJs have been simulated by connecting two constituent CNTs with pentagon and heptagon
rings. Classical molecular dynamics based on the velocity-Verlet algorithm has been used to solve the
Newtonian equation of motion and carbon–carbon interaction in the CNT has been modeled by the Brenner
potential. Mechanical properties, particularly stiffness and maximum force/torque and failure modes for
different loading conditions are studied. Simulation results show that stiffness of the IMJ falls between those of
the constituent CNTs. Compressive failure load of the IMJ is lower than either of the constituent CNTs.
However, failure loads and damage modes of the IMJs under tensile and torsional loadings depend on the
transition region in the IMJs.

References listed at the end of the paper:


ABSTRACT: A general minimum-weight cylindrical structural layout for the support of any combination of axial and torsional loading has been developed. The principal intention in this work is to provide a test case for 3-dimensional numerical topological optimization. It is anticipated that the solution may present a challenge, since for the small angular spacing of the truss elements the internal radial force component is always of the order of magnitude of the angular spacing for any arbitrary selected pair of helix families. Moreover for a wide range of solutions slender members are an essential part of the topology. A novel finite element topology optimization procedure is presented based on the application of Beta probability density and cumulative distribution functions. The procedure utilizes a family of Beta functions which provide a smooth transition from a uniform to a bi-modal density distribution, with constant probability mean to conserve constant mass.

References listed at the end of the paper:
References listed at the end of the paper:

M. Rezaiee-Pajand and R. Naserian (Dept. of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran), “Using more accurate strain for three-dimensional truss analysis”, Asian Journal of Civil Engineering (BHRC) Vol. 17, No. 1, pp 107-126, 2016

ABSTRACT: Instead of the usual neglecting, this study takes advantage of the second-order axial strain terms in the elastic constitutive equation of three-dimensional truss. This leads to higher-order terms on the resulting unbalanced force and on its corresponding tangent stiffness. The finite element procedure and updated Lagrangian descriptions are utilized with the new stiffness matrix. Furthermore, governing equilibrium equations are solved by using cylindrical arc-length approach. The validity of the proposed algorithm is checked by numerical examples. The outcomes indicate that the authors’ formulation possesses the ability to trace the equilibrium path completely. Moreover, the obtained answers are identical with the exact results of other researchers.

References listed at the end of the paper:


ABSTRACT: Availability of block-type syntactic foam buoyancy units has facilitated a range of underwater activities otherwise deemed as impossible, e.g., dive to the bottom of the oceans in 2012. But buoyancy units which require a vessel-type configuration still remain a subject of research. High specific properties, resistance to degradation in water, and flexible fabrication methods become valuable factors when underwater applications are considered. Light weight is critical for submersibles as this leads to increased pay-load and to enlarged operational envelope. All of that points towards the use of composite materials.

In this context the Chapter deals with the strength, buckling and structural optimization of externally pressurized bowed-out cylinders, domed end closures onto cylinders, and toroidal shells of closed cross-section subjected to hydrostatic external pressure. It is assumed that shells are from Carbon Fibre Reinforced Plastics (CFRPs). The work is primarily numerical but some details about the manufacture, testing and analyses of filament wound and draped CFRP heads carried out at Liverpool University are provided. The issues regarding the sensitivity of buckling pressures to the initial geometric imperfections, First Ply Failure, and the Last Ply Failure are also discussed.

References listed at the end of the paper:


P. Espinasse, Deepsea pilot sms mining system for harsh environments, In Proc. of the ASME Conf. on Ocean, Offshore and Arctic Engineering, Shanghai, China, OMAE-20477, pp. 1-6 (2010).


J. Blachut, Buckling of externally pressurised barrelled shells: a comparison of experiment and theory, Int. J. Pressure Vessels and
ABSTRACT: Postbuckling behavior of three-dimensional (3D) braided rectangular plates subjected to biaxial compression is presented. The 3D braided composite may be treated as a cell system, and the geometry of each cell is deeply dependent on its position in the cross section of the plate. Based on Reddy’s higher-order shear deformation plate theory and general von Kármán–type equations that include the initial geometric imperfection of the plate, a perturbation technique is employed to determine postbuckling equilibrium paths of 3D braided rectangular plates. The results reveal that the geometric and physical properties have a significant effect on the postbuckling behavior of braided composite plates.
Qingyuan Chen and Pizhong Qiao (State Key Laboratory of Ocean Engineering and School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China), “Post-buckling behavior of imperfect laminated composite plates with rotationally-restrained edges”, Composite Structures, Vol. 125, pp 117-126, July 2015, https://doi.org/10.1016/j.compstruct.2015.01.043

ABSTRACT: The nonlinear governing equations of rotationally-restrained laminated composite plates with imperfection are presented by the Galerkin method, and they are solved by employing the Newton–Raphson method for the post-buckling analysis. The considered laminates are symmetric, and they are loaded in pure in-plane shear or combined in-plane shear and compression. The deformation shape function of the restrained plates is obtained through a linear combination of vibration eigenfunctions of simply supported and clamped beams along either the longitudinal or transverse direction of plates. The validity study shows that the presented method is effective for performing the nonlinear analysis of laminates with all four edges elastically-restrained against rotation. A parametric study is conducted to evaluate the effect of rotational spring stiffness, material properties, and fiber orientation under pure in-plane shear as well as the loading ratio under combined shear and compression on the nonlinear static and post-buckling behavior of rotationally-restrained laminates. The proposed solution for nonlinear static analysis of rotationally-restrained composite plates with imperfection is accurate and effective, as demonstrated by the comparisons with the predictions by the finite element analysis, and combined with the discrete plate analysis technique, it can be potentially applied to post-buckling analysis of FRP structural shapes.


ABSTRACT: Geometric imperfections have a significant effect on both buckling and strength capacities of structural members. It is essential to accurately measure the geometric imperfections for finite element simulation especially for thin-walled sections. This paper presents the procedure to measure and incorporate geometric imperfections into finite element models using ABAQS software package with the focus of attention for cold-rolled aluminium sections. Laser scanners are firstly used to measure geometric imperfections along high-precision tracks while recording the distances to corresponding points on the surface of specimen. The measurement lines are located around the cross-section. Subsequently, a MATLAB code is developed to incorporate the measured imperfection magnitudes into a perfect mesh of the finite element model. The Fourier series approximation is used in the longitudinal direction along measurement lines while the linear interpolation is used for flanges, lips and web in the transverse direction.

References listed at the end of the paper:


Young, B.: The behaviour and design of cold-formed channel columns. Dissertation, University of Sydney (1997)

Zhao, X., Schafer, B.W.: Laser scanning to develop three-dimensional fields for the precise geometry of cold-formed steel members. Recent research and development in cold-formed steel design and construction (2014)


Zhao, X., Schafer, B.W.: Measured geometric imperfections for Cee, Zee, and built-up cold-formed steel members. In: Jwei-Wen Yu

ABSTRACT: Enumeration search method (ESM) checks all possible combinations of design variables in a bottom-up approach until it finds the global optimum solution for the design conditions. In this paper an optimum design of a multilayered laminated plate made of unidirectional fibre reinforced polymer (FRP) composite subject to uniaxial compression is sought. ESM together with classical laminated plate theory (CLPT) has been used to find the lightest laminate for maximizing the buckling load capable of providing structural stability for a set target uniaxial compression load. The choice of the design variables is limited to 4 possible fibres orientation angles (0, 90, -45, +45) and the sequence of the laminate, making the problem an integer programming. Experimental and finite element analyses were used to verify the optimum solution. It has been shown that the exhaustive enumeration search method is a powerful tool for finding the global optimum design.

References listed at the end of the paper:
[22] Park W.J., An optimal design of simple symmetric laminates under the first py failure criterion, J. Compos. Mater., 1982, 16,

ABSTRACT: The local buckling capacity of fire exposed thin-walled steel cross sections is affected by the reduction in strength and stiffness due to elevated temperatures and the amplitude of the initial local imperfections. Several researchers have proposed design methods to calculate the capacity of the plates (i.e. web and flanges) that compose these steel members at elevated temperatures, but they used different shapes of steel plates (sides ratio a/b) and different amplitudes of local imperfections. This variability in hypotheses happens because there is no clear provision defining the numerical modeling procedure for fire design of steel plates in the codes (European or US). According to the theory of perfect plates, the critical load depends of the shape of the rectangular plate (e.g. the sides ratio a/b) and the corresponding buckling mode (number of half waves), the boundary and the loading conditions. This paper reviews the existing code provisions and compares the existing design models and their assumptions for thin-walled steel cross sections. Elements of the theory of perfect plates are presented. Parametric finite element analyses are then conducted on isolated steel plates at elevated temperatures to investigate the effect of the plate shape (a/b ratio) and imperfections (amplitude and number of half wave lengths). From the analysis, the governing parameter will be estimated (a/b vs imperfections) for simulation of isolated flanges and webs. Finally, recommendations for the numerical modeling of steel plates at elevated temperatures are proposed.

References listed at the end of the paper:

ABSTRACT: The nonlinear vibrations of Single-Walled Carbon Nanotubes are analysed. The Sanders-Koiter elastic shell theory is applied in order to obtain the elastic strain energy and kinetic energy. The carbon nanotube deformation is described in terms of longitudinal, circumferential and radial displacement fields. The theory considers geometric nonlinearities due to large amplitude of vibration. The displacement fields are expanded by means of a double series based on harmonic functions for the circumferential variable and Chebyshev polynomials for the longitudinal variable. The Rayleigh-Ritz method is applied to obtain approximate natural frequencies and mode shapes. Free boundary conditions are considered. In the nonlinear analysis, the three displacement fields are re-expanded by using approximate eigenfunctions. An energy approach based on the Lagrange equations is considered in order to obtain a set of nonlinear ordinary differential equations. The total energy distribution of the shell is studied by considering combinations of different vibration modes. The effect of the conjugate modes is analysed.


ABSTRACT: This paper presents a comprehensive study of the lateral compressive response of hexagonal honeycomb panels from the initial elastic regime to a fully crushed state. Expanded aluminum alloy honeycomb panels with a cell size of 9.53 mm, a relative density of 0.026, and a height of 15.9 mm are laterally compressed quasi-statically between rigid platens under displacement control. The cells buckle elastically and collapse at a higher stress due to inelastic action. Deformation then first localizes at mid-height and the cells crush by progressive formation of folds; associated with each fold family is a stress undulation. The response densifies when the whole panel height is consumed by folds. The buckling and crushing events are simulated numerically using finite element models involving periodic domains of a single or several characteristic cells. The models idealize the microstructure as polygonal, with double walls in one direction. The nonlinear behavior is initiated by elastic buckling while inelastic collapse that leads to the localization observed in the experiments occurs at a significantly higher load. The collapse stress is found to be mildly sensitive to various problem imperfections. The subsequent folding can be reproduced numerically using periodic domains but requires a fine mesh capable of capturing the complexity of the folds. The calculated crushing response is shown to better resemble measured ones when a 4 x 4 cell domain is used. However, the average crushing stress can be captured with engineering accuracy even from a single cell domain.

References listed at the end of the paper:


Y. Chen, Z.-Y. Zhang, Y. Wang, H. Hua, Crush dynamics of square honeycomb thin rubber wall, Thin-Walled Struct., 47 (2009), pp. 1447-1456
Aluminum films 150 nm thick have been deposited on polymethylmethacrylate (PMMA) substrates by a magnetron sputtering process. Parallel straight-sided wrinkles are induced by axial compression. The evolution from straight-sided to 'telephone-cord' wrinkles is experimentally investigated using optical microscopy. Finite element modeling of instability is introduced for analyzing the secondary bifurcation or buckling of straight-sided wrinkles. Imperfections based on a random combination of buckling eigenmodes are introduced in the finite element method (FEM) analysis to take into account secondary bifurcation. Because the perturbation of the imperfection is totally random and small, it is a more realistic approach for taking into account the roughness and flatness of the film. Moreover, the perturbation method can be applied more widely in some complex patterns of telephone-cord wrinkles. Good agreement is found between experimental observation and FEM calculations.
Buwaneth Yasara Dharmadasa (1,2), H.M.Y.C. Mallikarachchi (2) and Francisco Lopez Jimeniz (1)
(1) University of Colorado, Boulder, Colorado, 80309, USA
(2) University of Moratuwa, Katubedda, Sri Lanka


ABSTRACT: Novel designs for solar sails and star shades make use of thin films with large surface areas packed into finite volumes by introducing origami-like fold patterns. Predicting the deployed shape, deployment dynamics and mechanical stability of these structures requires an accurate modeling of the mechanical properties of the folds, instead of assuming perfect hinges like in rigid foldable origami. We have performed experiments in thin films with a single crease to investigate the underlying mechanics and characterize the mechanical properties of the fold. A parametric study was conducted on folding a Kapton film, showing that the neutral angle after folding can be rationalized as a function of the parameters in the folding process, but it evolves over time due to viscoelastic effects. Additionally, a framework has been established to quantify the hinge stiffness of a fold by its moment - angle relationship, showing a linear relationship regardless of the neutral angle. Finally an analytic model has been proposed by combining the hinge stiffness along with Elastica theories to predict the deflected shapes of folded thin films.

References listed at the end of the paper:
Fan Xu (1) and Michel Potier-Ferry (2)
(1) Institute of Mechanics and Computational Engineering, Department of Aeronautics and Astronautics, Fudan University, 220 Handan Road, Shanghai, 200433, P. R. China
(2) Laboratoire d’Etude des Microstructures et de Mécanique des Matériaux, LEM3, UMR CNRS 7239, Université de Lorraine, 7 Rue Félix Savart, 57073 Metz Cedex 03, France

“Quantitative predictions of diverse wrinkling patterns in film/substrate systems”, Scientific Reports, Vol. 7, Article number 18081, 2017

ABSTRACT: A basic characteristic of stiff film/soft substrate systems is their ability to experience large deformation under compressive stresses, which inevitably leads to formation of patterns on the surface. Such pattern formation is the result of loss of stability and symmetry breaking. Knowledge on how such instabilities arise and evolve is essential to describe, understand, predict, and ultimately to design complex functional materials and structures, for example the fabrication of stretchable electronic devices and micro/nano-scale surface patterning control. In this paper, quantitative predictions of various instability pattern formations and evolutions, which involve highly nonlinear deformation and multiple bifurcations, will be presented based on advanced mechanical models and methods, from planar to curved geometry. The results can provide further insight into fundamental understanding in a whole view of a variety of surface patterning morphology and imply a potential way to facilitate the design of functional materials and structures by quantitatively harnessing surface instabilities.

References listed at the end of the paper:

ABSTRACT: Experiments on aluminum tubes with varying D/t ratios and their finite element simulation have been performed to study their collapse mechanism as well as the load compression and the energy absorption responses. Convergence studies with respect to model parameters like load step size, mesh density and boundary conditions have been established. Dependence of deformation characteristics and energy absorption response on boundary conditions (end fixity), geometrical parameter- D/t ratio, and material parameters - yield strength and tangent modulus, have been studied. Transition of deformation mode shapes from axisymmetric concertina mode to non axisymmetric diamond pattern owing to tube wall thickness eccentricity under perfectly axisymmetric tube end conditions has been simulated. Validation and comparison of numerical solution with the experimental results have been carried out.

References listed at the end of the paper:


Dorin Radu (1), Aleksander Sedmak (2), Simon Sedmak (2) and Momcao Dunjic (2)

(1) University of Transylvania, Faculty of Civil Engineering, Brașov, Romania
(2) University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia


ABSTRACT: In accordance with EN1993-1-1, in the definition of element classes, the tubular cross section
elements are considered as class 3 for cross section that respects the relation: \( d/t \leq 90e^2 \). If for any cross section this relation is not satisfied, the norm is not valid and the cross section is classified as a curved thin walled element – shell element. Thus the design is done according to EN 1993-1-6 normative. The paper presents some aspects regarding the shell design for a case study – a 30 m tall billboard pillar. The designing process is detailed in regard to the used analysis and the ultimate limit states checking. Considering the high stress concentration in the area of the segment joints, design of welded joints is also presented. The Finite Element Method (FEM) is applied as well, showing results in agreement with analytical ones.

References listed at the end of the paper:


ABSTRACT: The connection of a local support to an elevated cylindrical metal silo shell is a long-standing difficult problem in shell analysis, and most designs are based on simple ideas using past experiences of successes and failures. Smaller silo structures are often supported on local brackets attached to the side of the shell, but very few investigations of the behavior or strength of such an arrangement have ever been made. This paper presents an outline description of the behavior of a cylindrical steel shell that is discretely supported on several brackets, each rigidly connected to a stiff column or floor. The linear, materially nonlinear, geometrically nonlinear, and bifurcation behaviors of the shell under these conditions are outlined. In this problem the prebuckling deformations, bifurcation mode, and plastic collapse mode are each local. This configuration presents some interesting questions concerning the relative importance of geometric nonlinearity and geometric imperfections. The problem is recommended to advanced shell analysts as a benchmark test of their analysis and interpretation techniques.

References listed at the end of the paper:


ABSTRACT: Imposing curvature on crystalline sheets, such as 2D packings of colloids or proteins, or covalently bonded graphene leads to distinct types of structural instabilities. The first type involves the proliferation of localized defects that disrupt the crystalline order without affecting the imposed shape, whereas the second type consists of elastic modes, such as wrinkles and crumples, which deform the shape and also are common in amorphous polymer sheets. Here, we propose a profound link between these types of patterns, encapsulated in a universal, compression-free stress field, which is determined solely by the macroscale confining conditions. This “stress universality” principle and a few of its immediate consequences are borne out by studying a circular crystalline patch bound to a deformable spherical substrate, in which the two distinct patterns become, respectively, radial chains of dislocations (called “scars”) and radial wrinkles. The simplicity of this set-up allows us to characterize the morphologies and evaluate the energies of both patterns, from which we construct a phase diagram that predicts a wrinkle–scar transition in confined crystalline sheets at a critical value of the substrate stiffness. The construction of a unified theoretical framework that bridges inelastic crystalline defects and elastic deformations opens unique research directions. Beyond the potential use of this concept for finding energy-optimizing packings in curved topographies, the possibility of transforming defects into shape deformations that retain the crystalline structure may be valuable for a broad range of material applications, such as manipulations of graphene’s electronic structure.

References listed at the end of the paper:
ABSTRACT: At present molecular dynamics (MD) simulations are the major tools used to investigate the mechanical behaviour of fullerenes. In this study, the energy changes of three fullerene balls, C60, C80 and C180, under uniform inflation/deflation and axial tension/compression, are investigated using the second-generation Brenner potential. The energy changes can be precisely described by a cubic function of the inflation/deflation strain or tension/compression deflection. A spherical shell, the continuum model of the fullerene balls, is established and analysed by means of non-linear elasticity theory. The results of calculations using this model are in good agreement with those of MD simulations. A regular non-perturbative model for wrinkling in highly bendable sheets. Phys Rev E Stat Nonlin Soft Matter Phys 85(6 Pt 2):066115.


References listed at the end of the paper:

https://doi.org/10.3390/app8112238.

ABSTRACT: This paper investigates the postbuckling and free vibration response of geometrically imperfect multilayer nanobeams. The beam is assumed to be subjected to a pre-stress compressive load due to the manufacturing and its ends are kept at a fixed distance in space. The small-size effect is modeled according to the nonlocal elasticity differential model of Eringen within the nonlinear Bernoulli-Euler beam theory. The constitutive equations relating the stress resultants to the cross-section stiffness constants for a nonlocal multilayer beam are developed. The governing nonlinear equation of motion is derived and then manipulated to be given in terms of only the lateral displacement. The static problem is solved for the buckling load and the postbuckling deflection in terms of three parameters: Imperfection amplitude, size, and lamination. A closed-form solution for the buckling load in terms of all of the beam parameters is developed. With the presence of imperfection and size effects, it has been shown that the buckling load can be either less or greater than the Euler buckling load. Moreover, the free vibration in the pre and postbuckling domains are investigated for the first five modes. Numerical results show that the effects of imperfection, the nonlocal parameter, and layup on buckling loads and natural frequencies of the nanobeams are significant.

References listed at the end of the paper:
Wu, J.S.; Lin, F.T.; Shaw, H.J. Free in-plane vibration analysis of a curved beam (arch) with arbitrary various concentrated elements.
Abstract: A study of imperfect cylindrical steel tubes under global bending and varying support conditions, (1) Institute for Infrastructure and Environment, University of Edinburgh, UK

Oluwole K. Fajuyitan (1), Adam J. Sadowski (1) and J. Michael Rotter (2)
8 Karl Friedrich Gauss

SUMMARY: The paper presents the findings of a computational study into the effect of different support conditions. The study aims to understand the behavior of imperfect cylindrical steel tubes under global bending and varying support conditions. The research focuses on the structural stability and the influence of support configurations on the tubes' performance. The results highlight the importance of considering imperfections in the design of such structures to ensure safety and efficiency.

References

Olukwele K. Fajuyitan (1), Adam J. Sadowski (1) and J. Michael Rotter (2)
1 (1) Department of Civil and Environmental Engineering, Imperial College London, UK
2 (2) Institute for Infrastructure and Environment, University of Edinburgh, UK

"A study of imperfect cylindrical steel tubes under global bending and varying support conditions", Eighth International Conference on Advances in Steel Structures, Lisbon, Portugal, July 22-24, 2015

ABSTRACT: This paper presents the findings of a computational study into the effect of different support conditions on the behavior of imperfect cylindrical steel tubes under global bending. The research focuses on understanding the structural stability and the influence of support configurations on the tubes' performance. The results highlight the importance of considering imperfections in the design of such structures to ensure safety and efficiency.
conditions and geometric imperfections on the nonlinear elastic stability of tubular members of varying length under global bending. Using the finite element analysis software ABAQUS, the tubular member was modelled as an isotropic thin-walled cylindrical steel shell and subjected to a uniform bending moment distribution. The classical elastic critical buckling moment, the linear bifurcation moment and the nonlinear buckling moment were computed and the imperfection sensitivity under the linear buckling eigenmode was examined. The study demonstrates that the support conditions at the edges have a significant effect on the predicted buckling moment for short tubes, but that this influence vanishes for longer tubes. The effect of initial geometric imperfections on the nonlinear buckling strength was found to be sensitive to the tube length. The strength of longer tubes was much reduced, but in shorter ones, the effect was neutral or mildly beneficial. Overall, tubular members under global bending do not appear to be as imperfection-sensitive as those under uniform axial compression.

References listed at the end of the paper:
Harri Katajisto (1), Petri Kere (2) and Mikko Lyly (3)
(1) Componeering Inc., Itamerenkatu 8, FI-00180 Helsinki
(2) KONE Corporation, P.O. Box 677, FI-05801 Hyvinkää
(3) ABB Oy, P.O. Box 186, FI-00381 Helsinki


ABSTRACT: The laminated composite lay-up design typically involves trade-offs between material selection, thickness of the layer, orientation of the layers, and the stacking sequence. Finding the right structural concept early in the design process leaves resources for the detailed design. Many structural members made of laminated composite materials have the form of thin walled cylindrical shells that are prone to buckling. Thus it is desirable to find structural designs that satisfy global requirements for structural stability early in the design phases. In this work, thin-walled cylindrical composite shells under different loading conditions have been studied for structural stability. The simulation is performed with a shell facet model implemented in the ESAComp software. Preliminary design tools for structural stability of thin-walled cylindrical composite shells are demonstrated and discussed.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: Rigid-foldable structures are foldable surfaces consisting of rigid panels and hinges, thus can be used for wide variety of deployable structures without relying on flexible materials. In this paper, we present a family of rigid-foldable collapsible cylindrical polyhedra which is of great interest of structural engineering field. The symmetry operations in order to synthesize the cylindrical structures and their space filling tessellation are shown.

References listed at the end of the paper:

Lyubomir A. Zdravkov (Department of Metal, Wood and Plastic Structures, University of Architecture, Civil Engineering and Geodesy (UACEG), Sofia 1046, Bulgaria), “Necessary height of the vertical stiffeners in steel silos on discrete supports”, Challenge Journal of Structural Mechanics, Vol. 4, No. 4, pp 153-158, 2018

ABSTRACT: The steel silos are interesting complex facilities. In order to ensure unloading of whole amount of stored product by gravity, the steel silos are often placed on supporting frame structure. Values of stresses in the joints between the thin walled shell and supporting frame elements are very high. It can causes local loss of stability in the shell. To prevent its local buckling, many designers put stiffening elements above the supports. Here the question is how high should be the stiffening elements? The right solution is that they should reach that level till which the values of the meridional normal stresses above the supports and in the middle between them are equalized. Under this level the cylindrical shell will be considered as a ring beam, stiffened by elements above the supports. Above it, the cylinder can be calculated as continuously supported shell. But where is this level? A lot of researchers worked on values and way of distribution of normal meridional stresses above the supports of the cylindrical shells. As a result of their efforts are determined critical height Hcr of the shell and the ideal position H1 of intermediate stiffening ring. But these heights are considerably different between each other. To which of them our vertical stiffening elements should achieve?

References listed at the end of the paper:

ANSYS 17 (2016). Ansys Inc. Canonsburg, PA, USA.
Topkaya C, Rotter JM (2011b). Stiffness of silo supporting ring beams resting on discrete supports. 6th International Conference on Thin-Walled Structures, Timisoara, Romania.

A.V. Lopatin (1,2), E.V. Morozov (3) and A.V. Shatov (1)
1) Department of Aerospace Engineering, Siberian State University of Science and Technology, Krasnoyarsk, Russia
2) Institute of Computational Technologies, Siberian Branch of Russian Academy of Sciences, Krasnoyarsk, Russia
3) School of Engineering and Information Technology, University of New South Wales at the Australian Defence Force Academy, Canberra, Australia
“Buckling and vibration of composite lattice elliptical cylindrical shells”, Journal of Materials Design and
ABSTRACT: An approach to the finite element study of the buckling and dynamic behaviour of composite lattice cylindrical shells with elliptical cross sections is presented in this paper. The lattice shells are modelled as three-dimensional frame structures composed of curvilinear ribs using beam finite elements. A specialised algorithm is developed to generate the finite element model of the lattice shells based on multiple use of the repeating unit cell of the composite lattice structure. Using this model, the buckling behaviour of the shells subjected to axial loading and transverse bending are investigated. Fundamental frequencies of axial and transverse vibrations of the shells with a massive rigid disk attached to their ends are determined based on the modelling approach proposed in this work. The effects of parameters of the lattice structure on the values of critical buckling loads, buckling and vibration mode shapes, and the fundamental frequencies are examined using parametric analyses. Based on the computations, the angles of orientation of helical ribs delivering maximum critical loads and fundamental frequencies are identified. The results of this study can be applied to the design of the composite tubular bodies of spacecraft made in the form of cylindrical lattice shells with elliptical cross sections.

References listed at the end of the paper:


ABSTRACT: In this paper, experimental investigation of two new structural design solutions with the aim of improving crashworthiness characteristics of cylindrical metal tubes is performed. In the first design method, a rigid steel ring is press-fitted on top of circular aluminum tubes. When this arrangement of dissipating energy is...
subjected to axial compression, the rigid ring is driven into the cylindrical tube and expands its top area; then, plastic folds start shaping along the rest of the tube length as the compression of the structure continues. In the second design method, wide grooves are cut from the outer surface of steel thick-walled circular tubes. In fact, this method converts thick-walled tubes into several thin-walled tubes of shorter length, being assembled together coaxially. When this energy absorbing device is subjected to axial compression, plastic deformation occurs within the space of each wide groove, and thick portions control and stabilize collapsing of the whole structure. In the present study, several specimens of each developed design methods with various geometric parameters are prepared and compressed quasi-statistically. Also, some ordinary tubes of the same size of these specimens are compressed axially to investigate efficiency of the presented structural solutions in energy absorption applications. Experimental results show the significant efficiency of the presented design methods in improving crashworthiness characteristics and collapse modes of circular tubes under axial loading.

References listed at the end of the paper:
Shell structures are usually formed from concrete, steel and nowadays also from many others materials. Steel is typically used in the structures of chimneys, reservoirs, silos, pipelines, etc. Unlike concrete shells, steel shells are regularly stiffened with the help of longitudinal and/or ring stiffeners. The authors of this paper investigated steel cylindrical shells and their stiffening with the use of ring stiffeners. The more complete the stiffening, the more closely the shell will act to beam theory, and the calculations will be much easier.

References listed at the end of the paper:


ABSTRACT: Shell structures are usually formed from concrete, steel and nowadays also from many others materials. Steel is typically used in the structures of chimneys, reservoirs, silos, pipelines, etc. Unlike concrete shells, steel shells are regularly stiffened with the help of longitudinal and/or ring stiffeners. The authors of this paper investigated steel cylindrical shells and their stiffening with the use of ring stiffeners. The more complete the stiffening, the more closely the shell will act to beam theory, and the calculations will be much easier.
However, this would make realization of the structure more expensive and more laborious. The target of the study is to find the limits of ring stiffeners for cylindrical shells. Adequate stiffeners will eliminate semi-bending action of the shells in such way that the shell structures can be analyzed with the use of numerical models of the struts (e.g., by beam theory) without significant divergences from reality. Recommendations are made for the design of ring stiffeners, especially for the distances between stiffeners and for their bending stiffness.

References listed at the end of the paper:

ABSTRACT: Inflatable structures offer the potential of compactly stowing lightweight structures, which assume a fully deployed state in space. An important category of space inflatables are cylindrical booms, which may form the structural members of trusses or the support structure for solar sails. Two critical and interdependent aspects of designing inflatable cylindrical booms for space applications are i) packaging methods that enable compact stowage and ensure reliable deployment, and ii) rigidization techniques that provide long-term structural rigidity after deployment. The vast literature in these two fields is summarized to establish the state of the art.

References listed at the end of the paper:


ABSTRACT: The study investigates the behaviour of short, thin-walled laminated C-columns under eccentric compression. The tested columns are simple-supported. The effect of load inaccuracy on the critical and post-
critical (local buckling) states is examined. A numerical analysis by the finite element method and experimental tests on a test stand are performed. The samples were produced from a carbon-epoxy prepreg by the autoclave technique. The experimental tests rest on the assumption that compressive loads are 1.5 higher than the theoretical critical force. Numerical modelling is performed using the commercial software package ABAQUS®. The critical load is determined by solving an eigen problem using the Subspace algorithm. The experimental critical loads are determined based on post-buckling paths. The numerical and experimental results show high agreement, thus demonstrating a significant effect of load inaccuracy on the critical load corresponding to the column’s local buckling.

References listed at the end of the paper:

A. Teter and Z. Kołakowski, Composite Structures 95, 28-34, (2013).


ABSTRACT: An investigation on triggering mechanisms for the birdcaging failure mode of flexible pipes, used in offshore oil and gas production, is carried out. From previous experimental observations, a conjecture is made: the local axisymmetric instability of the external plastic layer, caused by the high radial loading which is internally applied due to the helical armor wires tendency to expand when the pipe is subjected to compression, would be this trigger. A simple instability onset criterion for the external plastic layer, namely, the polymer
intrinsic yielding limit stress, is proposed and assessed, analytically, numerically and experimentally for HDPE tubes. Then, previous birdcaging experimental observations are investigated further, focusing on the flexible pipe external plastic layer, to assess the proposed criterion. Strong evidences of validity are obtained.


ABSTRACT: Design models for local buckling of fire-exposed aluminum sections are currently lacking. Based on analyses with validated finite-element models, this paper investigates local buckling of extruded sections with stress-strain relationships representative for fire-exposed aluminum alloys. Due to the fact that these stress-strain relationships are more curved than at ambient temperature, existing design models developed for ambient temperature cannot be used for fire design. This paper presents a new design model for local buckling under fire conditions. The study concludes that the local buckling resistance decreases less fast than the plastic capacity at increasing temperature. This is mainly due to the fact that the ratio between the modulus of elasticity and the 0.2% proof stress increases with increasing temperature for structural aluminum alloys.


ABSTRACT: Steel silo failure is not a sporadic event in the industrial field. Sometimes the failure involves only a shell deformation that does not affect the structural integrity of the overall silos. In other cases, failure involves complete collapse of the structure that could affect the people's safety. In general three major causes of silo failure are identified: design errors, construction errors, and utilization errors. In this study, a buckling failure of the real silos used in a thermal power plant to store a granular solid material (limestone) is analysed. It has long been recognized that the buckling failure of the silos is due mainly to the eccentric discharge of its stored solid. The main reason for this kind of failure is due to the difficulty, in the design phase, to characterize the pressure distribution caused by eccentric solids flow (funnelling). In the present study, the pressures caused by eccentric discharge are characterized using the new rules of the European Standard EN 1991-4 that defines the “Actions in Silos and Tanks”. Using this new improved description of unsymmetrical pressures, it is now possible to perform relatively realistic calculations relating to this common but complicated shell buckling condition. The paper explores the structural behaviour leading to buckling during eccentric discharge and proposes a possible reinforcement design of the silos to minimize this kind of problems following the approach given in the European Standard EN 1993-1-6 “Strength and Stability of Shell Structures”.


ABSTRACT: In the presented work, the compressive behavior of circular cylinders, having certain size ratios and containing a notch with various configurations, was investigated through experimental and numerical studies. Nonlinear finite element analysis, using ABAQUS software, was conducted to evaluate the ultimate strength of the cylinders. The results were compared to those observed experimentally. The comparison of the numerical and experimental results showed that the nonlinear analysis results were more accurate than those established based on a linear analysis. The study also focuses on the deformed shape and stress distribution of the critical region in a notched cylinder for further consideration, e.g. repairing purposes.

References listed at the end of the paper:
1 J.K. Paik, et al., Ultimate strength of notched plate elements under axial compression or tension, Thin-Walled Structures, 43 (2005), pp. 237-272
2 R. Brighenti, Buckling of notched thin-plates under tension or compression, Thin-Walled Structures, 43 (2005), pp. 209-224
3 R. Brighenti, Numerical buckling analysis of compressed or tensioned notched thin plates, Engineering Structures, 27 (2005), pp. 265-276
4 M.S. El Naschite, A branching solution for the local buckling of a circumferentially notched cylindrical shells, International Journal of Mechanical Sciences, 16 (1974), pp. 689-697
References listed at the end of the paper:  

5 H.E. Estekanchi, A. Vafai, **On the buckling of cylindrical shells with through notches under axial loading.** Thin-Walled Structures, 35 (1999), pp. 255-274  
6 M. Javidruzzi, et al., **Vibration, buckling and dynamic stability of notched cylindrical shells.** Thin-Walled Structures, 42 (2004), pp. 79-99  
7 A. Vaziri, H.E. Estekanchi. **Buckling of notched cylindrical thin shells under combined internal pressure and axial compression.** Thin-Walled Structures, 44 (2006), pp. 141-151  
10 J.F. Jullien, A. Limam, **Effects of openings of the buckling of cylindrical shells subjected to axial compression.** Thin-Walled Structures, 42 (2004), pp. 79-99  
11 H. Han, et al., **Numerical and experimental investigations of the response of aluminum cylinders with a cutout subject to axial compression.** Thin-Walled Structures, 44 (2006), pp. 254-270  
14 J.G. Teng, Y.M. Hu, **Behaviour of FRP-jacketed circular steel tubes and cylindrical shells under axial compression.** Construction and Building Materials, 21 (2007), pp. 827-838  
15 Y. Liu, M.L. Day, **Bending collapse of thin-walled circular tubes and computational application.** Thin-Walled Structures, 46 (2008), pp. 442-450

Xingyou Yao (1,2)  
(1) Nanchang Institute of Technology, Jiangxi Province Key Laboratory of Hydraulic and Civil Engineering Infrastructure Security, Nanchang, Jiangxi, 330099, P.R. China  
(2) Tongji University, Department of building Engineering, Shanghai, 200092, P.R. China  
“Experiment and design method on cold-formed thin-walled steel lipped channel columns with slotted web holes under axial compression”, The Open Civil Engineering Journal, Vol. 11, pp 244-257, 2017  
ABSTRACT: Cold-formed steel structural sections used in the walls of residential buildings and agricultural facilities are commonly C-shaped sections with web holes. These holes located in the web of sections can alter the elastic stiffness and the ultimate strength of a structural member. The objective of this paper is to study the buckling mode and load-carrying capacity of cold-formed thin-walled steel column with slotted web holes. Compression tests were conducted on 26 intermediate length columns with and without holes. The tested compressive members included four different kinds of holes. For each specimen, a shell finite element Eigen-buckling analysis and nonlinear analysis were also conducted. The influence of the slotted web hole on local and distortional buckling response had also been studied. The comparison on ultimate strength between test results and calculated results using Chinese cold-formed steel specification GB50018-2002, North American cold-formed steel specification AISI S100-2016, and nonlinear Finite Element method was made. Test results showed that the distortional buckling occurred for intermediate columns with slotted holes and the ultimate strength of columns with holes was less than that of columns without holes. The ultimate strength of columns decreased with the increase in transverse width of hole in the cross-section of member. The Finite element analysis results showed that the web holes could influence on the elastic buckling stress of columns. The shell finite element could be used to model the buckling modes and analysis the ultimate strength of members with slotted web holes. The calculated ultimate strength shows that results predicted with AISI S100-2016 and analyzed using finite element method are close to test results. The calculated results using Chinese code are higher than the test results because Chinese code has no provision to calculate the ultimate strength of members with slotted The calculated method for cold-formed thin-walled steel columns with slotted web holes are proposed based on effective width method in Chinese code. The results calculated using the proposed method show good agreement with test results and can be used in engineering design for some specific cold-formed steel columns with slotted web holes studied in this paper.  
References listed at the end of the paper:  
In-field post-earthquake performance observations of winery facilities in the Marlborough region, New Zealand, were documented following the 14 November 2016 Kaikōura earthquake and subsequent aftershocks. Observations presented and discussed herein include land damage to vineyards and the performance of winery building facilities, legged and flat-bedded storage tanks, barrel racking systems, and catwalks. A range of winery facilities were instrumented with tri-axial accelerometers to capture seismic excitations during aftershocks, with the specific aim to instrument different storage tanks having varying capacities and support systems to better understand the dynamic performance and actual forces experienced up the height of the tanks during an earthquake, with preliminary results reported herein.

References listed at the end of the paper:
ABSTRACT: The purpose of this work is to detail some methodologies applied for analysis of the seismic behaviour of existing bottom supported storage tanks and pipelines, under predominantly horizontal seismic actions. Developments on the established finite element method (FEM), permitted to analyse tanks and their liquid contents by two possible approaches: Ritz method coupled with FEM applied to an analytical solution of the tank-liquid system; FEM of the full system by modelling the liquid as a degenerated solid. Both formulations permit to determine seismic response envelopes. Further, some considerations on active control of cylinders by piezoceramic stacks of actuators are outlined, for potential uses in pipelines and tube-like structures.

References listed at the end of the paper:
Evaluation in Civil Engineering, Department of Civil Engineering, FEUP, Porto, 5th July 2000, (in Portuguese).


K. Athiannan (1) and R. Palaninathan (2)

(1) Structural Mechanics Section, Reactor Engineering Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, India

(2) Department of Applied Mechanics, Indian Institute of Technology – Madras, Chennai, India


ABSTRACT: This paper presents experimental studies on buckling of cylindrical shell models under axial and transverse shear loads. Tests are carried out using an experimental facility specially designed, fabricated and installed, with provision for in-situ measurement of the initial geometric imperfections. The shell models are made by rolling and seam welding process and hence are expected to have imperfections more or less of a kind similar to that of real shell structures. The present work thus differs from most of the earlier investigations. The measured maximum imperfections \( \delta_{\text{max}} \) are of the order of plus or minus \( 3t \) \( (t = \text{thickness}) \). The buckling loads obtained experimentally are compared with the numerical buckling values obtained through finite element method (FEM). In the case of axial buckling, the imperfect geometry is obtained in four ways and in the case of transverse shear buckling, the FE modelling of imperfect geometry is done in two ways. The initial geometric imperfections affect the load carrying capacity. The load reduction is considerable in the case of axial compression and is marginal in the case of transverse shear buckling. Comparisons between experimental buckling loads under axial compression, reveal that the extent of imperfection, rather than its maximum value, in a specimen influences the failure load. Buckling tests under transverse shear are conducted with and without axial constraints. While differences in experimental loads are seen to exist between the two conditions, the numerical values are almost equal. The buckling modes are different, and the experimentally observed and numerically predicted values are in complete disagreement.

References listed at the end of the paper:
ABAQUS FE: User’s manual, version 5a5, Commercial Software Package Habitt, Karlsson & Sorensen Inc., 1080, Main street, Pawtucket, Rhode Island, 02860–4867, USA


Gerard G 1956 Compressive and torsional buckling of thin-wall cylinders in the yield region. National Advisory Committee for Aeronautics (NACA), Tech Note 3726


Lee L H N 1962 Inelastic buckling of initially imperfect cylindrical shells subject to axial compression. J. Aerosp. Sci. 29: 87–95
Lundquist E E 1933 Strength tests of thin-walled duralumin cylinders in compression. NACA Report No. 473
Lundquist E E 1935 Strength tests of thin-walled duralumin cylinders in combined transverse shear and bending. NACA Report No. 523
Saito K, Matsuura S, Nakajima M 2001 Shear-bending buckling tests of relatively thin-walled cylindrical shells. Trans. 16th Int. Conf. on Structural Mechanics in Reactor Technology, Washington D.C., USA, August, Division J, Paper No. 1527
Tennyson R C 1964 Buckling of circular cylindrical shells in axial compression. AIAA J. 2: 1351–1353
Waechtel N, Jullien J F, Lefermann P 1984 Experimental studies on the instability of cylindrical shells with initial geometric imperfections. In Recent advances in nuclear component testing and theoretical studies on buckling (ed.) G Baylac pp 33–42

Jian Zhang (1), Minglu Wang (1), Weicheng Cui (2), Fang Wang (2), Zhengdao Hua (1), Wenxian Tang (3)
(1) School of Mechanical Engineering, Jiangsu University of Science and Technology, Zhenjiang, China
(2) Shanghai Engineering Research Center of Hadal Science and Technology, Shanghai Ocean University, Shanghai, China
(3) Jiangsu Provincial Key Laboratory of Advanced Manufacturing for Marine Mechanical Equipment, Jiangsu University of Science and Technology, Zhenjiang, China
ABSTRACT: This paper is devoted to a further investigation on a range of externally pressurised egg-shaped pressure hulls. Hulls are 2.561 m long, 1.767 m wide, and have uniform wall thickness varying from 10 to 80 mm with 5 mm increment. Series of numerical simulations and laboratory scale experiments are performed to systematically study the buckling of egg-shaped pressure hulls, along with the effect of wall thickness on the buckling. Volume and mass equivalent spherical pressure hulls are also proposed to make a like-for-like comparison with egg-shaped pressure hulls. The results show that egg-shaped pressure hulls seem to be applicable to deep sea manned/unmanned submersibles, especially to full ocean depth ones (11,000 m). Also, deep pressure hulls tend to buckle in an elastic–plastic regime, which is strongly affected by the wall thickness. References listed at the end of the paper:
The list of references is similar to that given in the next paper.

ABSTRACT: This study focused on the buckling of stainless steel spherical caps under uniform external pressure. Caps with a circular arc meridian have a nominal base diameter of 146 mm, nominal uniform wall thickness of 1 mm and nominal height of 37 mm. Six nominally identical laboratory-scale caps were fabricated, measured precisely and tested slowly. The buckling performances of such caps were studied experimentally and numerically, and the results show good agreement with each other. Furthermore, the buckling of 13 mass-equivalent caps of various heights were numerically analysed to identify the cap with the best load-carrying capacity. The results suggest that a spherical cap with height-to-base diameter ratio of 0.274 supports the
highest buckling load. Such a cap can be applied as an end-closure for cylindrical pressure hulls or as a manhole cover for manned cabins in deep-sea vehicles.

References listed at the end of the paper:

ABSTRACT: Thin spherical pressure hulls are used as a human occupancy in deep water applications. DNV and other standards specify the imperfection allowed for pressure hulls. Numerical analyses are carried out to find the buckling pressure for both perfect and imperfect thin spherical pressure hulls, considering the geometric and material non-linearities. It is observed that there is a huge variation in the elastic and inelastic buckling pressure in perfect spherical pressure hulls. Moreover, if the manufacturing imperfections are considered in the inelastic numerical analysis, still there is a reduction in the buckling pressure. Design criteria, for deep water pressure hulls, is that both buckling pressure and yield pressure must be greater than the design pressure. In the elastic analysis, if \( t/D > 0.006 \) buckling pressure is always greater than the yield pressure whereas in the inelastic analysis, the buckling pressure is falling below the yield pressure for all \( t/D \) ratios. Hence, inelastic numerical analysis with manufacturing imperfection has to considered in the design of deep water spherical pressure hulls of manned submersibles.

References listed at the end of the paper:

1 C.T. Ross, Pressure Vessels: External Pressure Technology, Elsevier (2011)
5 L. Gannon, Submarine Pressure Hull Collapse Considering Corrosion and Penetrations (No. DRDC-ATLANTIC-TM-2010-246), Defence Research and Development Atlantic Dartmouth, Canada (2010)
7 Pan B., Cui W., Mar. Struct., 23 (3) (2010), pp. 227-240
14 Du Q., Cui W., Proceedings of the 2016 OCEANS, Shanghai (2016), pp. 1-7, 10.1109/OCEANSAP.2016.7485455
20 R. Zoelly Über ein Knickungsproblem an der Kugelschale
Thesis (1915)
21 DNV, Rules for Certification/Classification of Submersibles, Det Norske Veritas, Norway (1988), p. 64

ABSTRACT: Civil Engineering thin cylindrical shells such as silos and tanks are normally subjected to axial compression that arises from a stored solid, wind, earthquake, self-weight or roof loads. The walls of these shells are very thin, generally of the order of 6 to 25 mm, and massively less than the radius, which is typically 5 to 30 m. They are thus very thin shell structures, like those of rockets, spacecraft, motor vehicles and aircraft. The commonest failure mode is elastic buckling under axial compression. It has long been known that the buckling strength of a thin cylindrical shell under axial compression is very sensitive to tiny deviations of geometry, reducing the buckling strength to perhaps 10 or 20% of the value for the perfect structure. A normal internal pressure usually accompanies the axial compression, caused by stored granular solids or fluids. At relatively low pressures, the elastic buckling strength under axial compression rises, but an elastic-plastic buckling phenomenon intervenes at higher pressures, causing a dramatic decrease in buckling resistance associated with an elephant’s foot collapse mode. To construct such large shells, the fabrication technique is generally the assembly of many rolled plates or panels, joined by short longitudinal welds and continuous circumferential welds. The process of welding produces a distinctive geometric imperfection form at each weld joint, which in turn is extremely detrimental to the shell axial buckling carrying capacity. The strength may be further reduced by slight misalignments between adjacent panels, or in bolted construction, by vertical and horizontal lap splices. Due to the pattern of loading, both the axial compression and internal pressure increase progressively down the wall. Accordingly, practical construction usually uses a stepped wall, formed from panels of uniform thickness, but with larger thicknesses at lower levels. Since the loading varies smoothly, but each panel has constant thickness, the critical location for buckling lies at the base of a panel. But the greater thickness of the lower panel can usefully enhance the buckling strength of the critical panel above it. This thesis presents an extensive computational study that examines all the above influences, divided into chapters that are outlined here. A full exploration of the effect of the cylinder length on the perfect and imperfect elastic buckling strength is presented in Chapter 3. In Chapter 4, the elastic-plastic buckling resistance of imperfect cylinders is described, including strain hardening. These lead to many capacity curves, for which the key parameters are extracted. The effect of internal pressure on the buckling resistance of imperfect elastic cylinders is explored in Chapter 5. Chapter 6 studies the effect of high pressures that produce elastic-plastic elephant’s foot buckling at circumferential welds in imperfect shells. Next, a step change in plate thickness is studied in Chapter 7 for imperfect butt jointed cylinders with and without the internal pressure. Chapter 8 presents an exploration of the effect of plate misalignments at a circumferential joint, as well as the full misalignment of a circumferential lap joint in bolted construction. These are investigated in both the elastic and elastic-plastic domains. The entire thesis is conceived in the context of EN 1993-1-6 (2007) and the ECCS Recommendations on Shell Buckling (2008). This research has shown significant weaknesses in both the concepts and the detailed rules of these standards. Many conditions are found where either the standard is unnecessarily conservative, or its safety margin may be too low. Thus, some new provisions are proposed for each of the above practical problems. These are expected to provide useful knowledge for the design of such structures against buckling in the future.


ABSTRACT: The present study investigates the non-linear behavior of spherical shells under the influence of static circular ring loads. It is assumed that the material is isotropic and linearly elastic. The differential equations comprising the equilibrium equations, constitutive laws and kinematic equations are converted into non-linear algebraic equations by employing the method of finite differences. Respective non-linear algebraic equations are solved numerically by using the Newton–Raphson Method. The curves pertaining to the circular ring load versus the deflection at the application point of the ring load and the circular ring load versus the deflection at the apical point of the shell are plotted and compared for various shell radius/thickness ratios and parallel circle radii values.

References listed at the end of the paper:
References listed at the end of the paper:

95 Kumar D, Paulsen JD, Russell TP, Menon N. 2018. Science 359:775–778
107 Pak I. 2006. Preprint, Department of Mathematics, MIT (math.mit.edu/pak/papers/pillow4)
123 Amstad E. 2017. ACS Macro Lett. 6:841–847
INTRODUCTION: As indicated by the title, we will discuss Ruga (1) and thin films (2, 3). For “Ruga”, I directly borrowed the opening introduction from previous Journal club “The Ruga mechanics” organized by Dr. Mazen Diab, Dr. Ruike Zhao and Prof. Kyung-Suk Kim. “The ‘ruga’, a Latin term, means a single state of various corrugated material configurations, which form diverse 2D-patterns on solid surfaces, interfaces and in thin films. Typical ruga configurations include large-amplitude wrinkles, creases, folds, ridges, wrinklons, crinkles and crumles.” Thin films are ubiquitous in nature and engineering structures, from nanoscale graphene films to millimeter scale polymer films, from centimeter scale clothes to kilometer space balloon and floating ice sheet (Fig. 1). In this club discussion, we will focus on the intersection between thin films and mechanics of ruga configurations, which definitely is only a subset of the thin film mechanics and ruga mechanics. Further, this discussion is motivated by our recent collaboration on instability of floating thin films with Dr. Joseph Paulsen in Physics department at Syracuse University. Therefore, I will start from the wrinkling, crumpling, and folding in thin films floating on water surfaces and use them as representative examples to explore the nonlinear coupling of gravity, surface tension, curvature, and bending deformation in determining various ruga patterns in general thin film structures.

References listed at the end of the blog:

ABSTRACT: The present paper deals with the buckling of a circular cylindrical shell under axial compression from the viewpoint of energy and the characteristics of deformation. It is shown first, both theoretically and experimentally, that the reason why the buckling of a cylindrical shell is quite different from that of a flat plate is attributable to the existence of a nearly developable surface far apart from the original cylindrical surface. Based upon this result, the experimental fact that the buckling is really not general but local, that is, that the buckled region is limited axially to a range of 1.5 times the wave length of the lobe, is explained by the theoretical result that the minimum buckling load is smaller in the local buckling than in the general buckling case.


ABSTRACT: The applications of membranes are increasing rapidly in various fields of engineering and science. The geometric, material, force and contact non-linearities complicate their analysis, which increases the demand for computationally efficient methods and interpretation of counter-intuitive behaviours. To understand the complex behaviour of membrane structures, it is necessary to perform parametric studies of simple setups and understand their basic mechanical behaviour.

The first part of the present work studies the free and constrained inflation of circular and cylindrical membranes. The membranes are assumed to be in contact with a soft substrate, modelled as a linear spring distribution. Adhesive and frictionless contact conditions are considered during inflation, while only adhesive contact conditions are considered during deflation. For a circular membrane, peeling of the membrane during deflation is studied, and a numerical formulation of the energy release rate is proposed. The pre-stretch produces a stiffening effect for the circular membranes, and a softening effect for the cylindrical membranes, in the pre-limit zone.

The second part of the thesis discusses the instabilities observed for fluid containing cylindrical membranes. Limit points and bifurcation points are observed on primary equilibrium branches. The secondary branches emerge from bifurcation points, with their directions determined by eigenvectors corresponding to zero eigenvalues at the bifurcation point. Symmetry has major implications on stability analysis of the structures, and the relationship between eigenvalue analysis and symmetry is highlighted in this part of the thesis. The occurrence of critical points and the stability of equilibrium branches are determined by perturbation techniques. In the third part, wrinkling in the pressurized membranes is investigated, and robustness of the modified membrane theory and tension field theory is examined. The effect of boundary conditions, thickness variations, and inflating media on the wrinkling is investigated. It is observed that, with a relaxed strain energy formulation, the obtained equilibrium solutions are unstable due to the occurrence of pressure induced instabilities. These instabilities are not visible when axisymmetry is assumed or coarse discretizations in the wrinkling direction are used. A detailed analysis of pressure induced instabilities in the wrinkled membranes is described in the thesis.

References listed at the end of the first part (Overview) of the dissertation:


Jenkins, C., 2001 Gossamer spacecraft: Membrane and inflatable structures technology for space applications, Progress in Astronautics and Aeronautics, Virginia, USA.


ABSTRACT: Modelling of structural instability problems is considered for thin square membranes subjected to hydrostatic pressure, with a focus on the effects from symmetry conditions considered or neglected in the model. An analysis is performed through group-theoretical concepts of the symmetry aspects present in a flat membrane with one-sided pressure loading. The response of the membrane is described by its inherent differential eigensolutions, which are shown to be of five different types with respect to symmetry. A discussion is given on how boundary conditions must be introduced in order to catch all types of eigensolutions when modelling only a subdomain of the whole. Lacking symmetry in a FEM model of the whole domain is seen as a perturbation to the problem, and is shown to affect the calculated instability response, hiding or modifying instability modes. Numerical simulations verify and illustrate the analytical results, and further show the convergence with mesh fineness of different aspects of instability results.

References listed at the end of the paper:


ABSTRACT: This paper discusses the evaluation of instabilities on the quasi-static equilibrium path of fluid-loaded pre-stretched cylindrical membranes and the switching to a secondary branch at a bifurcation point. The membrane is represented by only the in-plane stress components, for which an incompressible, isotropic hyperelastic material model is assumed. The free inflation problem yields governing equations and boundary conditions, which are discretized by finite differences and solved by a Newton–Raphson method. An incremental arclength-cubic extrapolation method is used to find generalized equilibrium paths, with different parametrizations. Limit points and bifurcation points are observed on the equilibrium path when fluid level is seen as the controlling parameter. An eigen-mode injection method is employed to switch to a secondary equilibrium branch at the bifurcation point. A limit point with respect to fluid level is observed for a partially filled membrane when the aspect ratio (length/radius) is high, whereas for smaller aspect ratios, the limit point
with respect to fluid level is observed at over-filling. Pre-stretch is observed to have a stiffening effect in the pre-limit zone and a softening effect in the post-limit zone.

References listed at the end of the paper:

ABSTRACT: The paper describes how quasi-static, conservative instability problems can be analysed in a multi-parametric settings. The solution methods are seen as extensions to common incremental-iterative strategies, allowing the computations of subsets of equilibrium states which also fulfill some auxiliary conditions, e.g. criticality. A set of carefully chosen numerical examples demonstrates the versatility of the numerical procedures in performing sensitivity analyses for large scale structures.

References listed at the end of the paper:
always accompanied by buckling distortions where fusion welding is applied. Buckling distortions are more

ABSTRACT: Curie symmetry principle, the causality relation between the symmetry of the causes and the resultant effect, has often been invoked to infer the composite deformation history of geological bodies in the Earth’s crust. This principle provides a powerful constraint for predicting an unavailable past physical condition; the effects at the macroscopic level must be the same or higher symmetry than the intersection of the causes. However, in nonlinear phenomena, it is shown that the resultant effect selects a lower symmetry than the intersection of causes, which logically opposes the principle. Here, we introduce a symmetry breaking principle where the symmetry group of the effect is included in the intersection of the causes, and derive a new nonlinear phenomenological equation to formulate the symmetry breaking phenomena. The new principle suggests that the anisotropic pattern may not be necessary to consider the anisotropic causes or the multiple deformation history under nonlinear phenomena.

https://doi.org/10.1533/9781845690939.2.295

ABSTRACT: This chapter presents that manufacturing of sheet-metal-formed plates, panels, and shells are always accompanied by buckling distortions where fusion welding is applied. Buckling distortions are more
marked than other forms of welding distortions in thin-walled structural elements and they are the main troublesome problems in sheet metal fabrication. Recent progress in mathematical modeling and numerical simulation of welding phenomena offers researchers powerful tools for studying in more detail three-dimensional welding thermal and mechanical behaviors. Investigations in the field of innovative creation of new methods for welding distortion especially to prevent buckling are the world's most exciting and challenging subjects, involving many disciplines and industrial practice and process experiments. Those tools allow for the prediction of precise control of the abnormal temperature fields and therefore the abnormal thermal elastic-plastic cycles created by the possible combinations of the heat source–heat sink: multiple-source welding techniques. It is expected that a variety of coupled heat source–heat sink processes are feasible not only to control welding distortion, but also to produce defect-free specimens.


ABSTRACT: The industry in the fields of civil and mechanical engineering, and in particular of aerospace demands for significantly reduced development and operating costs. Reduction of structural weight at safe design is one avenue to achieve this objective. The running ESA (European Space Agency) study Probabilistic Aspects of Buckling Knock Down Factors – Tests and Analyses contributes to this goal by striving for an improved buckling knock-down factor (the ratio of buckling loads of imperfect and perfect structures) for unstiffened CFRP (carbon fiber reinforce plastics) cylindrical shells, and by validation of the linear and non-linear buckling simulations based on test results. DLR is acting as study contractor. The paper presents an overview about the DLR buckling tests, the measurement setup and the buckling simulations which are done so far, and gives an outlook to the results which are expected until the end of the running project.

References listed at the end of the paper:


ABSTRACT: A test method is described to experimentally investigate curved stiffened composite panels with respect to their buckling and post-buckling behavior up to collapse. The test method utilizes a new test rig with which stringer and frame stiffened curved panels can be tested under uniaxial compression loads, in-plane shear loads as well as a combination of both. During shear loading the panel is guided according to its radius. The whole test rig can be adjusted to cover a large range of geometric shell parameters. Results will be presented for

different stiffened composite panel designs. Effects of the chosen load introduction and the boundary conditions will be discussed, which have a considerable influence on the panel behavior. In addition, procedures and measurement techniques used during the tests will be explained. The findings confirm that the test method and in particular the new test rig is suitable to investigate representative stiffened structures under in-plane loading conditions relevant for stability analysis.

References listed at the end of the paper:

Alexander Kling, Jan Tessmer and Richard Degenhardt (DLR – Institute of Composite Structures and Adaptive Systems, Braunschweig, Germany), “Validation procedure for nonlinear analysis of stringer stiffened CFRP panels”, 25th International Congress of the Aeronautical Sciences (ICAS2006), Hamburg, 3-8 September 2006 ABSTRACT: The allowable load bearing capacity of undamaged thin-walled stringer stiffened carbon fibre reinforced plastic (CFRP) panels loaded in compression is currently limited by its buckling load. The extension to a novel stability design scenario - to permit postbuckling under ultimate load [1, 2] or even more progressive to move ultimate load close to collapse [3, 4] - requires validated simulation procedures for this highly nonlinear topic for fast tools in the early design phase up to numerical analysis within the certification process. Different aspects of the validation process with respect to experimental investigations, nonlinear FE analysis as well as the comparison on different levels of detail are highlighted.

References listed at the end of the paper:

Degenhardt R., Kling A., Rohwer K. (DLR, Institute of Composite Structures and Adaptive Systems, Braunschweig Germany), “Future Design Scenario for Composite Airframe Panels”, Proceedings of the 25th ICAS Congress, Hamburg, 3-8 September 2006 ABSTRACT: European aircraft industry demands for reduced development and operating costs, by 20% and 50% in the short and long term, respectively. Contributions to this aim are provided by the completed project POSICOSS and the running follow-up project COCOMAT, both supported by the European Commission. As an important contribution to cost reduction a decrease in structural weight can be reached by exploiting considerable reserves in primary fibre composite fuselage structures through an accurate and reliable simulation of postbuckling and collapse. The POSICOSS team developed fast procedures for postbuckling analysis of fibre composite stiffened panels, created comprehensive experimental data bases and derived design guidelines.
COCOMAT builds upon the POSICOSS results and considers in addition the simulation of collapse by taking degradation into account. The main objective is a future design scenario for composite stiffened panels which allows the exploiting of considerable reserves in primary fibre composite fuselage structures. The results comprise an extended experimental data base, degradation models, improved certification and design tools as well as design guidelines. The paper deals with the main objectives of the project COCOMAT, the general status of the progress as well as DLR’s first results.

References listed at the end of the paper:


ABSTRACT: European aircraft industry demands for reduced development and operating costs, by 20% and 50% in the short and long term, respectively. Contributions to this aim are provided by the completed project POSICOSS (5th FP) and the running follow-up project COCOMAT (6th FP), both supported by the European Commission. As an important contribution to cost reduction a decrease in structural weight can be reached by exploiting considerable reserves in primary fibre composite fuselage structures through an accurate and reliable simulation of postbuckling up to collapse. The POSICOSS team developed fast procedures for postbuckling analysis of stiffened fibre composite panels, created comprehensive experimental data bases and derived design guidelines. COCOMAT builds upon the POSICOSS results and considers in addition the simulation of collapse by taking degradation into account. The results comprise an extended experimental data base, degradation models, improved certification and design tools as well as design guidelines.

References listed at the end of the paper:

ABSTRACT: Statistical properties and phase transitions of semiflexible polymers on a soft elastic shell are investigated by using a molecular dynamics (MD) simulation method. The phase diagram of adsorbed semiflexible polymers depends on the bending energy of the elastic shell and the binding energy between polymers and the elastic shell. The ordered regular pentagons of polymers are observed at a moderate adhesive strength and bending energy. At the same time, the shape of the soft elastic shell can be controlled easily by adjusting the chain length of adsorbed polymers, which is helpful for the regulation and reshaping of membranes in the micrometre range or smaller sizes.

Kangjian Wang (1), Man Zhou (1,2), Mostafa Fahmi Hassanein (3), Jitao Zhong (4), Hanshan Ding (1) and Lin An (5)

(1) School of Civil Engineering, Southeast University, Nanjing, China
(2) School of Civil Engineering, Central South University, Changsha, China
(3) Department of Structural Engineering, Faculty of Engineering, Tanta University, Tanta, Egypt
(4) College of Civil Engineering and Architecture, Shandong University of Science and Technology, Qingdao, China
(5) Department of Civil Earth Resources Engineering, Kyoto University, Kyoto, Japan

“Study on Elastic Global Shear Buckling of Curved Girders with Corrugated Steel Webs: Theoretical Analysis and FE Modelling”, Applied Sciences, Vol. 8, 2457, DOI: 10.3390/app8122457

ABSTRACT: Despite the construction of several curved prestressed concrete girder bridges with corrugated steel webs (CSWs) around the world, their shear behavior has seldom been investigated. Accordingly, this paper substitutes the lack of available information on the global elastic shear buckling of a plane curved corrugated steel web (PCCSW) in a curved girder. This is based on the equilibrium equations and geometric equations in the elastic theory of classical shells, combined with the constitutive relation of orthotropic shells. Currently, the global elastic shear buckling process of the PCCSW in a curved girder is studied, for the first time in literature, with an equivalent orthotropic open circular cylindrical shell (OOCCS) model. The governing differential equation of global elastic shear buckling of the PCCSW, as well as its buckling strength, is derived by considering the orthotropic characteristics of a corrugated steel web, the rational trigonometric displacement modes, Galerkin’s method and variational principles. Additionally, the accuracy of the proposed theoretical formula is verified by comparison with finite element (FE) results. Moreover, the expressions of the inner or outer folded angle and radius of curvature are given by the cosine theorem of the trigonometric function and inverse trigonometric function. Subsequently, parametric analysis of the shear buckling behavior of the PCCSW is carried out by considering the cases where the radius of curvature is constant or variable. This parametric analysis highlights the effects of web dimensions, height-to-thickness ratio, aspect ratios of longitudinal and inclined panels, corrugation height, curvature radius and folded angles on the elastic shear buckling strength. As a result, this study provides a theoretical reference for the design and application of composite curved girders with CSWs.

References listed at the end of the paper:


12 Barakat, S.; Mansouri, A.A.; Altoubat, S. Shear strength of steel beams with trapezoidal corrugated webs using regression analysis. Steel Compos. Struct. 2015, 18, 757–773


18 Hassanein, M.F.; Elkawas, A.A.; El Hadidy, A.M.; Elchalakani, M. Shear analysis and design of high-strength steel corrugated web girders for bridge design. Eng. Struct. 2017, 146, 18–33


26 Amani, M.; Edlund, B.L.O.; Alinia, M.M. Buckling and postbuckling behavior of unstiffened slender curved plates under uniform shear. Thin-Walled Struct. 2011, 49, 1017–1031.

27 Japan Society of Civil Engineers. Design Manual for PC Bridges with Corrugated Steel Webs; Research Committee for Hybrid Structure with Corrugated Steel Webs, Japan Society of Civil Engineers: Tokyo, Japan, 1998. (In Japanese)


34 Lei, Z.; Yang, G.; Chen, H. Comparative analysis on main material index of china and international composite girder bridge with corrugated steel web. World Constr. 2016, 5, 11–19.


ABSTRACT: By expanding the response of a cylindrical shell in truncated Fourier series, the nonlinear Donnell type shell equations for imperfect stiffened shells were reduced to a set of linear equations in the correction terms by Newton's method of quasilinearization. Solutions were obtained for isotropic and for ring and stringer stiffened shells. The amplitudes of the initial imperfections used in the analysis were calculated from the corresponding Imbert-Donnell imperfection models. The free parameters in this imperfection model were
obtained by least square fitting the harmonics of the experimentally measured initial imperfections. It was possible in all cases to achieve satisfactory correlation using only a few suitably chosen deflection and imperfection modes.

References listed at the end of the paper:


13 Singer, J., Personal Communication, 1968


ABSTRACT: An outline of methods for the analysis of elliptic and hyperbolic shell. roofs is given, incorporating brief descriptions of the membrane and bending theories, methods of solution of the governing differential equations, and experimental studies of model shells.

ABSTRACT: An experimental program to determine the response of thin-walled steel projectiles to the impact with concrete targets was recently conducted. The projectiles were fired against41-MPa concrete targets at an impact velocity of 290 m/s. This article contains an outline of the experimental program, an examination of the results of a typical test, and predictions of projectile deformation by classical shell theory and computational simulation. Classical shell analysis of the projectile indicated that the predicted impact loads would result in circumferential buckling. A computational simulation of a test was conducted with an impact/penetration model created by linking a rigid-body penetration trajectory code with a general-purpose finite element code. Scientific visualization of the resulting data revealed that circumferential buckling was induced by the impact conditions considered.

BACKGROUND: Investigations into the survivability of hardened structures due to impact by conventional air-delivered munitions such as air-delivered bombs, have focused on defeating the bomb by casing failure. A traditional method of hardening structures against attack by aerial bombs is to place a burster slab over the structure. The burster slab is designed to detonate or break up contact-fused bombs and withstand penetration and blast effect of tail-fused bombs (Department of the Army, 1986). A concrete burster slab design was recently evaluated to investigate the effect of construction joints on the penetration resistance of the slab. Subscale thin-walled projectiles (simulating general purpose bombs) were fired into sections of the burster slab within a velocity range of 276-298 m/s. The penetration experiments were conducted at the US Army Engineer Waterways Experiment Station (WES) Projectile Penetration Research Facility which accommodates large targets constructed under laboratory-controlled conditions (Frew et al., 1993). All projectiles broke up after partial penetration into the slab. This article presents a discussion of the test results, an analysis of the structural response of the projectile using classical shell theory, and an ABAQUS finite element simulation of the test (ABAQUS is available under license from Hibbitt, Karlsson, and Sorensen, Inc., 1989a,1989b, 1989c).

Nandan L. Nerurkar (1), L. Mahadevan (2), and Clifford J. Tabin (1)
(1) Department of Genetics, Harvard Medical School, Boston, MA 02115
(2) School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138
“BMP signaling controls buckling forces to modulate looping morphogenesis of the gut”, Proceedings of the National Academy of Sciences of the USA (PNAS) February 28, 2017 114 (9) 2277-2282,
https://doi.org/10.1073/pnas.1700307114
“BMP”= “Bone Morphogenetic Proteins”
SIGNIFICANCE: During embryogenesis, the dramatic transformation from a seemingly disorganized mass of cells into the fully patterned adult form necessitates stereotyped regulation of forces at the genetic and molecular level. Although great progress has been made in understanding how gene expression and signaling generate biological pattern, little is known about how molecular cues organize forces to sculpt physical patterns during development. The present work identifies BMP signaling as a key pathway in controlling looping of the small intestine, a process driven by mechanical buckling due to elongation of the intestine against the constraint of a neighboring tissue, the dorsal mesentery.

ABSTRACT: Looping of the initially straight embryonic gut tube is an essential aspect of intestinal morphogenesis, permitting proper placement of the lengthy small intestine within the confines of the body cavity. The formation of intestinal loops is highly stereotyped within a given species and results from differential-growth–driven mechanical buckling of the gut tube as it elongates against the constraint of a thin, elastic membranous tissue, the dorsal mesentery. Although the physics of this process has been studied, the underlying biology has not. Here, we show that BMP signaling plays a critical role in looping morphogenesis of the avian small intestine. We first exploited differences between chicken and zebra finch gut morphology to identify the BMP pathway as a promising candidate to regulate differential growth in the gut. Next, focusing on the developing chick small intestine, we determined that Bmp2 expressed in the dorsal mesentery establishes differential elongation rates between the gut tube and mesentery, thereby regulating the compressive forces that
buckle the gut tube into loops. Consequently, the number and tightness of loops in the chick small intestine can be increased or decreased directly by modulation of BMP activity in the small intestine. In addition to providing insight into the molecular mechanisms underlying intestinal development, our findings provide an example of how biochemical signals act on tissue-level mechanics to drive organogenesis, and suggest a possible mechanism by which they can be modulated to achieve distinct morphologies through evolution.

INTRODUCTION: Differential growth represents one of the core physical mechanisms driving morphogenesis throughout the vertebrate embryo. Investigations into the mechanics of differential growth have often illustrated key physical parameters (e.g., tissue stiffness, growth rates, and initial geometry) that determine the resultant tissue shape. Ultimately, however, these parameters must be under genetic control. However, at present, there are only a limited few examples of how developmental signals are integrated with downstream physical properties to shape the embryo. Here, we build on our detailed understanding of the physics of loop morphogenesis in the chick small intestine (1) to ask what molecular cues underlie this important physical transformation during gastrointestinal development.

Looping maximizes the absorptive capacity of the gut by allowing intestinal length to extend well beyond the linear length of the organism, while maintaining an ordered configuration in the body cavity. Errors in looping, such as malrotation of the gut, can result in obstruction of the bowel or strangulation of the abdominal circulation, a condition known as midgut volvulus (10). Among birth defects, intestinal malrotation is relatively common in newborns and can be fatal if left untreated (11, 12). Early during looping morphogenesis, the initially straight midgut forms a primary loop that extends into the yolk stalk (umbilicus in mammals). Subsequent loops continue to form outside the body cavity as the midgut elongates, until the looped intestine retracts into the body cavity before birth. Although the intestine continues to elongate, no further loops form after birth. The number and shape of intestinal loops are remarkably conserved within a given species (1, 10). In previous work, we demonstrated that this precisely stereotyped looping results from physical forces that arise due to elongation of the initially straight gut tube against the constraint of the dorsal mesentery, a thin membranous tissue that anchors the gut tube to the body wall (1). As the gut tube elongates, it stretches the mesentery, which in turn compresses the tube. As a result of these compressive forces, the gut tube buckles into a looped configuration. The curvature and wavelength of loops can be mathematically predicted from experimentally measured parameters describing geometry and stiffness of the tube and mesentery, and differential elongation between the two tissues (1). Equipped with an understanding of the physics involved, here we aim to elucidate the underlying signaling pathways that control intestinal looping in the chicken embryo.


ABSTRACT: More adaptable geometric form of offshore platforms, counting on the benefits of form-dominant design, is effective to encounter various environmental loads. Offshore triceratops is a new-generation offshore platform, whose conceptual design showed good degree-of-adaptability to ultra-deep-water conditions. Deck is partially isolated from the buoyant legs by ball joints by allowing transfer of partial displacements of buoyant legs to deck but restraining transfer of rotational responses. Prior to the suitability assessment of triceratops for ultra-deep waters, detailed dynamic analysis on the preliminary geometric form is necessary as a proof of validation for design applications. Current study discusses a detailed numeric analysis of triceratops at 2400 m water depth under regular and irregular waves; preliminary design of both buoyant legs and the deck is also presented. Buoyant Legs are designed as stiffened cylinders and the deck is designed as the integrated truss system. In compliant structures, the role of tethers is of paramount importance. Hence, the stress analysis and fatigue analysis of the tethers are also carried out to assess the service life of the structure. Presented study shall aid offshore engineers and contractors to understand suitability of triceratops, in terms of design and dynamic response behaviour.

References listed at the end of the paper:

ABSTRACT: Considering the effect of stress wave, the dynamic buckling of circular cylindrical shells under an axial step load is discussed using the classical shell theories and the state-space technique in the paper. Based on the Hamilton’s principle, the dynamic buckling governing equations of shells are derived and solved with the Rayleigh-Ritz method. If the linear homogeneous equations have a non-trivial solution, the determinant of the coefficient matrix must be equal to zero, so the expression of the critical load on the dynamic buckling is got. The relationship between the critical load and length is obtained by using MATLAB software. The influences of boundary conditions, thickness, the number of circumferential waves and the number of axial waves on the dynamic buckling loads are discussed based on numerical computation.

ABSTRACT: Shape optimization design is carried out in the paper aiming at the feature of openings on curved shells to enhance the structural stability and reduce the stress concentration. In order to make sure that the hole boundary curve are always located on the prescribed curved shell, the parametrical mapping method is employed to describe the hole boundary on the curved shells with shape design variables defined in the intrinsic reference domain. Then, different optimization models are established and the specific sensitivity is calculated for buckling optimization. Finally, it concludes from numerical examples that the structural stability and the
ABSTRACT: The instability of the testing equipment protective shell is one of the importance issues in the design of testing equipment. In order to analyze the protective shell to external shocks instability problem, the shell instability of empirical formula was used to calculate the critical buckling load and the linear buckling was analysed to compare the simulation results with theoretical values and the error in control range by using finite element method. The calculations show that the finite element method for buckling analysis to provide guidance for the design is feasible.

Zheng Yan, Fan Zhang, Jiechen Wang, Fei Liu, Xuelin Guo, Kewang Nan, Qing Lin, Mingye Gao, Dongqing Xiao, Yan Shi, Yitao Qiu, Haiwen Luan, Jung Hwan Kim, Yiqi Wang, Hongying Luo, Mengdi Han, Yongyang Huang, Yihui Zhang, and John A. Rogers, “Controlled Mechanical Buckling for Origami-Inspired Construction of 3D Microstructures in Advanced Materials”, Advanced Functional Materials, 2016, DOI: 10.1002/adfm.201

References listed at the end of the paper:


ABSTRACT: In this article a thermoplastic fuselage shell concept is discussed, featuring stingers in two directions; an orthogrid. State of the art composite fuselage shells use a lot of fasteners to integrate skin, stringers and frames. Using thermoplastic composites, this might change. Thermoplastics are very tough and have a high out of plane strength. This enables new stiffening and joining methods, without the use of fasteners.

References listed at the end of the paper:

1. Website www.tapasproject.nl


ABSTRACT: Often the parameters considered as constants in an optimization problem have some uncertainty and it is interesting to know how the optimum solution is modified when these values are changed. The only way to continue having the optimal solution is to perform a new optimization loop, but this may require a high computational effort if the optimization problem is large. However, there are several procedures to obtain the new optimal design, based on getting the sensitivities of design variables and objective function with respect to a fixed parameter. Most of these methods require obtaining second derivatives which has a significant computational cost. This paper uses the feasible direction-based technique updating the active constraints to obtain the approximate optimum design. This procedure only requires the first derivatives and it is noted that the updating set of active constraints improves the result, making possible a greater fixed parameter variation. This methodology is applied to an example of very common structural optimization problems in technical literature and to a real aircraft structure.

References listed at the end of the paper:

Berke L, Khot NS (1974) Use of optimally criteria methods for large scale systems. AGARD-LS-70
Rouse M, Ambur DR, Bodine J, Dopker B (1997) Evaluation of a composite sandwich fuselage side panel with damage and subjected to internal pressure. NASA Tech Memo 110309
ABSTRACT: A series of single-frame and single-stringer compression tests were conducted at NASA Langley Research Center on specimens harvested from a large panel built using the Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) concept. Different frame and stringer designs were used in fabrication of the PRSEUS panel. In this report, the details of the experimental testing of single-frame and single-stringer compression specimens are presented, as well as discussions on the performance of the various structural configurations included in the panel.

References listed at the end of the paper: 

R. Jayendiran (1), B.M. Nour (2) and A. Ruimi (1) 
(1) Mechanical Engineering Program, Texas A&M University at Qatar, Doha, Qatar 
(2) Weill Cornell Medical College at Qatar, Doha, Qatar


ABSTRACT: Aortic dissection (AD) is a serious medical condition characterized by a tear in the intima, the inner layer of the aortic walls. In such occurrence, blood is being diverted to the media (middle) layer and may result in patient death if not quickly attended. In the case where the diseased portion of the aorta needs to be replaced, one common surgical technique is to use a graft made of Dacron, a synthetic fabric. We investigate the response of a composite human aortic segment-Dacron graft structure subjected to blood flow using the three-dimensional fluid-structure-interaction (FSI) capability in Abaqus. We obtain stress and strain profiles in each of the three layers of the aortic walls as well as in the Dacron graft. Results are compared when elastic and hyperelastic models are used and when isotropy vs. anisotropy is assumed. The more complex case
(hyperelastic-anisotropy) is represented by the Holzapfel-Gasser-Ogden (HGO) model which also accounts for the orientation of the fibers present in the tissues. The fluid flow is taken as Newtonian, incompressible, pulsatile and turbulent. The simulation show that for all the cases, the von Mises stress distribution at aorta-Dacron interface is well below the ultimate strength of the aorta. No significant change in radial displacement at the interface of the two materials due to blood flow is observed. Computation cost is also addressed and results show that the hyperelastic-anisotropic model takes about three times longer to run than the elastic isotropic case. Trade-off between accuracy and computational cost has to be weighted.


ABSTRACT: The effect of pre-buckling nonlinearity on the bifurcation point of a conical shell is examined on the basis of three shell theories: Donnell’s, Sanders’ and Timoshenko’s. The eigenvalue problem is solved iteratively about the nonlinear equilibrium state up to the bifurcation point. A new algorithm is presented for the real buckling behavior, dispensing with the need to cover the entire nonlinear pattern. This algorithm is very important for structures characterized by a softening process, in which the pre-buckling nonlinearity depresses the buckling level relative to the classical one. The procedure involves nonlinear partial differential equations, which are separated into two sets (using the perturbation technique) for the pre-buckling and buckling states, respectively and solved with the variable expanded in Fourier series in the circumferential direction, and by finite differences in the axial direction. A general computer code was developed and used in studying the effect of the pre-buckling nonlinearity on the buckling level, of the shell under axial compression, in the context of the three shell theories.

References listed at the end of the paper:

J. Famili, Asymmetric buckling of finitely deformed conical shells, AIAA J., 3 (8) (1965), pp. 1456-1461
Y. Goldfeld, J. Arbocz, Buckling of laminated conical shells given the variations of the stiffness coefficients, AIAA J., 42 (3) (2004), pp. 642-649
I. Sheinman, Y. Goldfeld, Buckling of laminated cylindrical shell in terms of different theories and formulations, AIAA J., 39 (9) (2001), pp. 1773-1781
J. Singer, Buckling of circular conical shells under uniform axial compression, AIAA J., 3 (5) (1965), pp. 985-987

J. Michael T. Thompson, “Dynamical integrity: three decades of progress from macro to nano mechanics”,

Advanced School on Global Nonlinear Dynamics for Engineering Design and System Safety (Udine, 13–17 June, 2016). Lectures to be published by CISM and Springer

ABSTRACT: During the explosion of interest in applied nonlinear dynamics and chaos in the 1980s a key concept was quickly seen to be the concept of dynamically integrity which was required to cope with, for example, the erosion of basins of attraction by fractal incursions. Articles by Thompson and Soliman laid down the fundamentals ideas, but major contributions by Rega and Lenci established this integrity as a central issue in the design of (for example) structures in their inevitable dynamic environment. They extended and developed the various integrity measures and pioneered ways of controlling the basin erosion phenomenon: and applied the ideas to a wide range of mechanical problems. The present paper offers a review of this progress, highlighting key conceptual ideas and some of the more interesting applications.

References listed at the end of the paper:


Lond., A 432, 101-111.


ABSTRACT: Not only the geometrical imperfection induced by welding but also cutouts will influence the buckling of large-scale thin-walled steel cylindrical shell under wind loading. Based on the practical cylindrical shells of a desulphurizing absorption tower, in consideration of the correlation between welding induced imperfection and circular cutouts, the influence of cutout position on buckling of cylinder under wind loading is investigated by nonlinear finite element method. The results indicate that the buckling capacity varies slightly when the cutout position moves along meridional direction in the neighboring region of welding imperfection. The buckling capacity varies significantly when the cutout position moves circumferentially as the cutout is located in the welding imperfection. The buckling capacity reaches the minimum value as the cutout is located in the buckle center of cylindrical shells without cutout.

References listed at the end of the paper:

H.B. Chew (1), M.-W. Moon (2), K.R. Lee (2) and K.-S. Kim (1)
(1) School of Engineering, Brown University, Providence, RI 02912, USA
(2) Computational Science Center, Interdisciplinary Fusion Technology Division, Korea Institute of Science and Technology, Seoul 136-791, Korea

ABSTRACT: We report that a graphene sheet has an unusual mode of atomic-scale fracture owing to its structural peculiarity, i.e. single sheet of atoms. Unlike conventional bond-breaking tensile fracture, a graphene sheet can be cut by in-plane compression, which is able to eject a row of atoms out-of-plane. Our scale-bridging
molecular dynamics simulations and experiments reveal that this compressive atomic-sheet fracture is the critical precursor mechanism of cutting single-walled carbon nanotubes (SWCNTs) by sonication. The atomic-sheet fracture typically occurs within 200fs during the dynamic axial buckling of a SWCNT; the nanotube is loaded by local nanoscale flow drag of water molecules caused by the collapse of a microbubble during sonication. This is on the contrary to common speculations that the nanotubes would be cut in tension, or by high-temperature chemical reactions in ultrasonication processes. The compressive fracture mechanism clarifies previously unexplainable diameter-dependent cutting of the SWCNTs under sonication.

References listed at the end of the paper:


Rayleigh, L. 1917 On the pressure developed in a liquid during the collapse of a spherical cavity. Philos. Mag. 34, 94–98.


ABSTRACT: The buckling of an orthotropic composite cylindrical shell with variable thickness, subjected to a dynamic loading, is reported here. At first, the fundamental relations and Donnell type dynamic buckling equation of an orthotropic cylindrical shell with variable thickness have been obtained. Then, employing Galerkin’s method, these equations have been reduced to a time dependent differential equation with variable coefficients. Finally, for different initial conditions and approximation functions, applying the Ritz type variational method, analytical expression has been found for the dynamic factor. Using these results, the effect of the variations of the power of time in the external pressure expression, the loading parameter and the ratios of the Young’s moduli on the dynamic factor are studied numerically for the case when the thickness of the cylindrical shell varies as a power and exponential functions. It has been observed that these effects change the dynamic factor of the problem in the heading appreciably.

References listed at the end of the paper:
15 Ogibalov PM, Lomakin VA & Kishkin BP, Mechanics of polymers (Moscow State University, Moscow), 1975 (in Russian).

Rawa Hamed and M. Al-Kalali (Mechanical Dept., Middle Technical University-Institute of Technology), “Optimum buckling design of cylindrical stiffener shell under external hydrostatic pressure”, The Iraqi Journal for Mechanical and Materials Engineering, Vol. 18, No. 2, 2018,
https://doi.org/10.32852/ijqfmmme.Vol18.Iss2.91

ABSTRACT: This paper present an investigation of the collapse load in cylinder shell under uniform external hydrostatic pressure with optimum design using finite element method via ANSYS software. Twenty cases are studied inclusive stiffeners in longitudinal and ring stiffeners. Buckling mode shape is evaluated. This paper studied the optimum design generated by ANSYS for thick cylinder with external hydrostatic pressure. The primary goal of this paper was to identify the improvement in the design of cylindrical shell under hydrostatic pressure with and without Stiffeners (longitudinal and ring) with incorporative technique of an optimization into ANSYS software. The design elements in this research was: critical load, design variable (thickness of shell (TH), stiffener’s width (B) and stiffener’s height (HF)). The results obtained illustrated that the objective is minimized using technique of numerical optimization in ANSYS with optimum shell thickness and stiffener’s sizes. In all cases the design variables (thickness of shell) was thicker than the monocoque due to a shell’s thicker is essential to achieve the strength constraints. It can be
concluded that cases (17,18,19, and 20) have more than 90% of un-stiffened critical load. The ring stiffeners causes increasing buckling load than un-stiffened and longitudinal stiffened cylinder.


ABSTRACT: Non-destructive methods to estimate the actual buckling load in particularly for imperfection sensitive thin-walled structures, are of severe interest among many fields. Particular techniques for validation of structural limit state and numerical model predictions for large scale structures are getting momentum. The vibration correlation technique (VCT) allows to correlate the ultimate load our instability point with rapid decrement of self-frequency response. Nevertheless this technique is still under development for thin-walled shells and plates. The current research discusses an experimental verification of extended approach, using vibration correlation technique, for the prediction of actual buckling loads on unstiffened cylindrical shells loaded in axial compression. Validation study include two laminated composite cylinders which were manufactured and repeatedly loaded up to instability point. In order to characterize a correlation with the applied load, several initial natural frequencies and mode shapes were measured during tests by 3D laser scanner. Results demonstrate that proposed vibration correlation technique allows one to predict the experimental buckling load with high reliability, without actually reaching the instability point. Additional experimental tests and numerical models are currently under development to further validate the proposed approach to extended composite and metallic structures.

References listed at the end of the paper:

ABSTRACT: Even though the thermal buckling behavior of shells has been investigated for many years, until now the thermal buckling problem with temperature-dependent material properties still cannot be solved by the existing commercial finite element codes. Therefore, the conventional theoretical solution of the critical temperature rise of cylindrical shell with temperature-dependent material properties is first derived in this work. Then, an innovative numerical approach is developed by introducing the bisection method and a user subroutine of ANSYS to overcome the shortcoming of existing finite element codes. The results prove that the temperature-dependent material properties have a great negative influence on the ability of the thermal buckling resistance of the cylindrical shell. As a result, the subroutine of ANSYS developed in this work provides a convenient design method for engineers to avoid the complicated theoretical calculation.

Cornelia Doerich (Abertay University), Wesley Vanlaere (Ghent University), Guy Lagaee (Ghent University), J. Michael Rotter (The University of Edinburgh), “Stability of column-supported steel cylinders with engaged columns”, Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009, Valencia; Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures 28 September – 2 October 2009, Universidad Politecnica de Valencia, Spain [Alberto Domingo and Carlos Lazaro (editors.)]
ABSTRACT: Steel silos are often supported on a small number of columns to facilitate emptying operations. The connection between these columns and an elevated cylindrical metal silo shell is a long-standing difficult problem in shell analysis. The presence of local supports beneath a cylinder leads to stress concentrations in the cylindrical wall just above the supports, which can cause buckling or plastic collapse and consequently failure of the entire structure. Engaged columns produce a gentler introduction of the support forces into the cylindrical shell and cause a smoother stress distribution above the column termination. Engaged columns are therefore a very practical solution for local supports. In practice, smaller silo structures are often supported on engaged columns attached to the side of the shell, but very few investigations of the structural behaviour or the strength of such an arrangement have ever been made. In this paper, the structural behaviour of a cylinder supported on engaged columns is investigated, including the effects of geometric imperfections and geometric nonlinearity. The study is conducted using the requirements for computational evaluations set out in EN 1993-1-6 (2007) and using the finite element package ABAQUS. The columns are assumed to be flexurally and axially rigid to provide a clear scientific study of the failure behaviour of the cylinder under these conditions.

References listed at the end of the paper:

ABSTRACT: Advanced lightweight laminated composite shells are increasingly being introduced in designs of modern aerospace structures, for enhancing their structural efficiency and performance. They are susceptible to buckling when subjected to significant static and dynamic or time dependent loadings. Their strength as governed by buckling is affected by initial geometric imperfections, boundary conditions, lamina stacking sequence and load eccentricity. While numerous studies are available on the buckling and post buckling behaviour of isotropic shells and the effects of geometric imperfections, relatively few investigations have been undertaken on the laminated composite shells for dynamic loading conditions. The need to design shell structures that have to withstand time-dependent dynamic loads, sometimes quite severe, and thus may be susceptible to dynamic buckling is relatively new in aerospace structures. The term dynamic buckling refers to two different phenomena. One is associated with the response of the structure to the action of cyclic loads i.e.
vibration buckling, and the second one relates to the behaviour of structures subjected to pulse loads. The presence of imperfections may also adversely affect the buckling behaviour of the shells. This paper deals with a numerical study on the effect of different shell parameters and imperfections on the buckling behaviour of circular cylindrical composite shells under axial impact. Composite cylindrical shells with three different layups $[0^\circ/0^\circ/60^\circ/60^\circ]_S$, $[0^\circ/45^\circ/-45^\circ/0^\circ]_S$ and $[75^\circ/-75^\circ/75^\circ/-75^\circ]_S$, each having different length to radius ratios (L/R) and radius to thickness ratios (R/t) have been considered in this study.

References listed at the end of the paper:


ABSTRACT: This chapter is devoted to the stability behavior of thin cylindrical shells. The basic governing equations of thin circular cylindrical shells employing the Donnell theory with the von-Karman geometrical non-linearity are derived. The nonlinear strain-displacement relations, the nonlinear equilibrium equations, and the linear stability equations are derived employing the variational formulations. The cylindrical shell under uniform compressive axial load is considered and the buckling load is obtained and given by closed form solution. Thermal buckling of cylindrical shell made of FGM for the uniform temperature rise, linear radial temperature, and the nonlinear radial temperature are presented and the effect of piezo-control is examined. Buckling and postbuckling of thin cylindrical shells with piezo-control under thermal loads is discussed and the chapter concludes with the stability discussion of cylindrical shells on elastic foundation. The buckling loads of
cylindrical shells of isotropic/homogeneous material are derived by simply setting proper values for the power law index of the FG materials.

References listed at the end of the paper:

Critical buckling load of a cylindrical shell having an elliptical cut-out orientation had a positive influence in which the buckling load value increased too. For this reason, an increase in the buckling load value. Moreover, the study showed that increasing parameters such as shell thickness and cut-out location from mid-height of the cylindrical shell towards a fixed edge caused increase in the buckling load value. Moreover, the study showed that increasing parameters such as shell thickness and cut-out orientation have a positive influence in which the buckling load value increased too. For fast design purposes, an empirical numerical based regression formula was presented for the calculation of the critical buckling load of a cylindrical shell having an elliptical cut-out.


PARTIAL INTRODUCTION: The experimental setup is rudimentary. Pick up a piece of a spongy sleeve, of the kind commonly used to fit over water pipes for insulation. You need a stub about one meter long, which is useless stuff for pipe installers, so you can easily get it for free. Hold the tube at both ends with your hands and twist energetically while pulling apart. If the tube is soft enough, you will be able to give several turns before it coils up, as shown in Figure 2. We expect you to observe the pattern of Figure 1, as long as you succeed in keeping the axis of the tube straight: its cross sections, circular when unstressed, flatten into a quasi-oval form, whose aspect ratio is essentially constant along the tube and increases with twist in a markedly nonlinear way; the principal axes of the oval seem to whorl at a uniform rate dictated by the twist (the parameter your hands control). This pattern is quite insensitive to the way you grab and squeeze each end of the tube, provided you apply suitable end torques and forces. In this paper, we aim at the simplest rational model that reproduces and explains this behaviour.

References listed at the end of the paper:


Malezkadeh, P.; Setoodeh, A.R. Large deformation analysis of moderately thick laminated plates on nonlinear elastic foundations by DQM. Compos. Struct. 2007, 80, 569–579.


Viola, E.; Tornabene, F.; Fantuzzi, N.; Bacciochi, M. Numerical Investigation of Composite Materials with Inclusions and

ABSTRACT: Major advances in the buckling analysis of cylindrical shells have been achieved in the last two decades. Eurocode nowadays provides rules for tanks up to r/t = 5000. However, since only few literature has become available in the past, dealing specifically with very thin walled shells in the range between r/t = 1500 and r/t = 10000, code provisions either are quite conservative or, in case of r/t > 5000, do barely exist. Employing modern construction methods, close-to-perfect, very thin-walled shells can be built that are out of the scope of the design codes. Therefore, to achieve more economical designs and a better sustainability, sophisticated design tools have to be used.

In this paper, modifications and extensions of the current design procedure are proposed to overcome current limitations and drawbacks. A review of experiments with a special focus on cylinders with high r/t-ratios was conducted and modified lower bound approximation curves for the knock-down factor α deduced. They were checked against representative experiments from literature. Test results recalculated using an axisymmetric imperfection to explore their equivalent imperfection depth, proved that even small imperfections drastically reduce the buckling strength. Using a parametric study, the result range of α was extended up to r/t = 10000. The design proposal could be approved and an equation for the determination of an equivalent imperfection depth that relates the dependence of α to the imperfection depth and the r/t-ratio is proposed.

References listed at the end of the paper:

Simos Gerasimidis and Pedro Reis, “Shell Buckling”, date and publisher not given in the pdf file

ABSTRACT: The arena of shell buckling received great attention after the monumental development of a general theory on elastic buckling and post-buckling behavior by Koiter in 1945. For more than three decades, the literature on shell buckling flourished with investigations on imperfections sensitivity, minimum buckling loads and instability modes. Following this intense progress, the field entered a period of idleness, up until very recently. Today, 74 years after Koiter’s presentation, there is a strong resurgence of activity in studying the mechanics of shell buckling which is observed worldwide by numerous research efforts. With the rapid progress in new materials and computational and experimental technology, a breadth of exciting new ideas has revitalized the problem. This mini-symposium will provide a forum for discussing the most recent computational, theoretical and experimental findings in the area of shell buckling, as well as future research directions.


ABSTRACT: Purpose: The aim of the paper is to evaluate buckling instabilities behaviour of long curved thin shell. Both initially straight and curved tubes are investigated with numerical and experimental assessment methods, in the context of NPP applications with an illustrative example for IRIS LWR integrated Steam Generator (SG) tubes. Design/methodology/approach: In this study structural buckling response tube with combination effects of geometric imperfections as well as initially bent shape under external pressure load are investigated using a non linear finite element (MSC.MARC FEM code) formulation analysis. Moreover results are presented, extending the findings of previous research activity works, carried out at Pisa University, on thin walled metal specimen. Findings: The experiments were conducted on Inconel 690 test specimen tube. The comparison between numerical and experimental results, for the same geometry and loading conditions, shows a good agreement between the elastic-plastic finite-element predictions and the experimental data.

Research limitations/implications: The presented research results may be considered preliminary in the sense that it would be important to enlarge the statistical base of the results themselves, even if they are yet certainly meaningful to highlight the real problem, considering the relatively large variability of the geometrical imperfections and bending instabilities also in high quality production tubes.

Originality/value: From the point of view of the practical implication, besides the addressed problem general interest in industrial plant technology, it is worth to stress that straight and curved axis tubes are foreseen specifically in innovative nuclear reactors SG design.

References listed at the end of the paper:


INTRODUCTION: The centenary of the publication of Love’s paper ‘The small free vibrations and deformation of a thin elastic shell’ provides us with an opportunity of looking at the subject of shell structures from a long perspective.

Problems arising from the analysis and design of thin shell structures have stimulated urgent research more or less continuously over the last hundred years. In surveying this work we can take two different viewpoints. On the one hand we can concentrate on the manifold changes which have taken place during the period in the industrial fields of application, in experimental methods, in the refinement and development of the basic equations, and in the methods of solution. On the other hand we can consider those aspects of our subject which have changed relatively little over the period under review.

The first of these viewpoints is, of course, the more obvious. For we have seen the fields of application embrace in turn aircraft, submarines, power plant, spacecraft and various aspects of oil production, and extend to parachutes and other membranes; we have witnessed the development of increasingly sophisticated experimental techniques and instrumentation; we have seen the ascendancy of tensor notation; we have seen the development of theory for both geometrical and material non-linearity; and we have seen an almost complete revolution from algebraic to numerical methods of analysis in the past twenty-five years.

Although I shall touch on some aspects of this long procession of advances during this lecture, I have decided to focus attention mainly on some of the unchanging features of our subject. My reasons for taking this second viewpoint are threefold. First, it makes a more manageable subject for a single lecture: to do justice to the many changes that have taken place would require a whole course of lectures and indeed I am inadequate as a scholar for such a task. Second, this perspective helps to provide an answer to the question of how it is that the same kinds of problem have constantly recurred in our subject over the last hundred years, whereas other subjects—such as chemistry and biology—have altered out of all recognition in the same period. And third, it allows me the opportunity to consider at greater length the contribution which Love himself made to our field.

The layout of my lecture is as follows. First I shall sketch the salient points of the life of A.E.H. Love. Then I shall describe in some detail the nature of Love’s work on thin shells, the circumstances in which it came to be done, and the changes which gradually took place in his view of the subject. Next, I shall outline the advances made in the theory over the last hundred years, and describe briefly the present state of the subject. Lastly, I shall discuss various difficulties, as I see them, which were evident one hundred years ago and which survive to the present time.


ABSTRACT: This paper treats in detail the life and work of Otto Blumenthal, one of the most tragic figures of the 188 emigré mathematicians from Germany and the Nazi-occupied continent. Blumenthal, the first doctoral student of David Hilbert, was crucial in the publication and communication system of German mathematics between the two World Wars. There has been an unusual revival of interest in his mathematical work in the last three decades. Thus his work on orthogonal polynomials whose zeros are dense in intervals, called the Blumenthal theorem by T.S. Chihara (1972), lead to over two dozen recent papers in the field. The Blumenthal–Nevai theorem, with applications to scattering theory in physics, is one example. In modern work on Hilbert modular forms, increasingly being called Hilbert–Blumenthal modular forms, many recent papers even contain the word Blumenthal in their titles. This paper contains 212 references.

Addendum relating to the paper by Calladine and the paper about Blumenthal (written by Igor Andrianov)

It should be noticed that a development of mathematical physics in many cases has been motivated by TS problems, in particular we mean those problems associated asymptotical methods (AM). Recall, that a key (for singular asymptotics) concept of an edge effect occurred in the works of H. Lamb and A B. Basset in 1890, while concept of boundary layer occurred in Fluid Mechanics only in 1904 [1].
The classical papers by M.I. Vishik and L.A. Lyusternik are generalization of some results obtained earlier by A.L. Gol’denberg. On the other hand, TS problems associated with occurrence of high technology development of materials and constructions implied development of various homogenization procedures. Investigation of rods stability by Euler yielded a linearization procedure, whereas W.T. Koiter approach has strongly influenced an occurrence of today’s Catastrophe Theory.

Bolotin V.V. mentioned WKB OR BLUMENTHAL -SHTAERMAN APPROACH. Really, in Math Congress paper 1912 [2] BLUMENTHAL used method WKB … which proposed in quantum mechanics in 1926! (Šhtaerman used it in 1924).


K. Athiannan (1) and R. Palan Nathan (2)
(1) Structural Mechanics Section, Reactor Engineering Group, Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, India
(2) Department of Applied Mechanics, Indian Institute of Technology – Madras, Chennai 600 036, India

Experimental investigation on buckling of cylindrical shell under compression and transverse shear, Sadhana, vol. 29, 2004, Feb., 93-115

ABSTRACT: This paper presents experimental studies on buckling of cylindrical shell models under axial and transverse shear loads. Tests are carried out using an experimental facility specially designed, fabricated and installed, with provision for in-situ measurement of the initial geometric imperfections. The shell models are made by rolling and seam welding process and hence are expected to have imperfections more or less of a kind similar to that of real shell structures. The present work thus differs from most of the earlier investigations. The measured maximum imperfections $\delta_{\text{max}}$ are of the order of plus or minus 3t ($t =$ thickness). The buckling loads obtained experimentally are compared with the numerical buckling values obtained through finite element method (FEM). In the case of axial buckling, the imperfect geometry is obtained in four ways and in the case of transverse shear buckling, the FE modelling of imperfect geometry is done in two ways. The initial geometric imperfections affect the load carrying capacity. The load reduction is considerable in the case of axial compression and is marginal in the case of transverse shear buckling. Comparisons between experimental buckling loads under axial compression, reveal that the extent of imperfection, rather than its maximum value, in a specimen influences the failure load. Buckling tests under transverse shear are conducted with and without axial constraints. While differences in experimental loads are seen to exist between the two conditions, the numerical values are almost equal. The buckling modes are different, and the experimentally observed and numerically predicted values are in complete disagreement.

References listed at the end of the paper:
Gerard G 1956 Compressive and torsional buckling of thin-wall cylinders in the yield region. National Advisory Committee for Aeronautics (NACA), Tech Note 3726
Lee L H N 1962 Inelastic buckling of initially imperfect cylindrical shells subject to axial compression. J. Aerosp. Sci. 29: 87–95
Lundquist E E 1933 Strength tests of thin-walled duraluminum cylinders in compression. NACA Report No. 473

ABSTRACT: A review of the literature reveals that information regarding fundamental frequencies and mode shapes of shallow laminated composite hypar shells with practical civil engineering boundary conditions is not available. The present investigation aims to fill this gap by applying an eight-noded isoparametric shell element as the tool. Numerical experiments are carried out for different parametric variations including boundary conditions and stacking orders to obtain the fundamental frequencies and mode shapes. Some of the results are used for validating the correctness of the present approach by comparing with the existing benchmark, while the other results are studied meticulously to extract a set of meaningful conclusions regarding the free vibration characteristics of composite shallow hypar shells.

References listed at the end of the paper:
Liew, K. M. and Lim, C. W., 1995b, “Vibratory behavior of shallow conical shells by a global Ritz formulation,” Engineering
ABSTRACT: Current research issues in the development of efficient analysis models and their efficient numerical implementation for smart piezoelectric laminated structures are discussed in this paper. The improved zigzag theories with a layerwise quadratic variation of electric potential have emerged as the best compromise between accuracy and cost for hybrid composite, sandwich and FGM beams and plates. The concept of associating surface potentials to electric nodes and internal potentials to physical nodes is very effective in modeling the equipotential electroded surfaces. Unified formulations for shear and extension mode actuation, and modeling of piezoelectric composite actuators and sensors are discussed. Future challenge lies in developing efficient theories capable of predicting the interlaminar transverse shear stresses in hybrid laminates directly from the constitutive equations.

References listed at the end of the paper:


Bailey, T., Hubbard, J.E.: Distributed piezoelectric-polymer active vibration control of a cantilever beam. J. Guiding Control 8, 605–611 (1985)


Ishihara, M., Noda, N.: Piezothermoelastic analysis of a cross-ply laminate considering the effects of transverse shear and coupling. J.


Ilinca Stanciulescu (2005), Nonlinear finite element formulations and bifurcation analysis for structures undergoing large deformations, Ph.D. Dissertation, Department of Civil and Environmental Engineering, Duke University.

ABSTRACT: Nonlinear phenomena are common in structural and solid mechanics; in general, the corresponding system of equations cannot be solved analytically, and numerical techniques are necessary. Furthermore, bifurcations of the solution are frequent; they can appear either at the physical level (the system may have multiple equilibrium configurations), or at the numerical level (related to the algorithm utilized in calculating the solution). Unfortunately no algorithm can solve every nonlinear system, and most of the time the recovery of solutions needs alternative iterative techniques. This thesis is concerned with finite element formulations and solution techniques for structures undergoing large deformations. The two applications examined are the steady state frictional rolling of tires and the postbuckling analysis of slender structures.
A formulation for steady state rolling calculations is introduced, focusing on the inclusion of frictional sliding conditions between a rolling tire and a flat roadway. Algorithmically, it is seen that traditional return mapping strategies are often ineffective for this problem even when frictional solutions exist; accordingly, an approach utilizing a global stick predictor is proposed to recover solutions to the sliding contact problem. Numerical examples are presented, to demonstrate the effectiveness of the approach advocated. Difficulties associated with enforcing frictional conditions within such a framework are discussed. The interaction of frictional conditions with bifurcation phenomena is also studied in the case of adherent contact conditions. Such phenomena are observed in the context of multiple solutions of the discretized system, and are also manifested in the behavior of the iterative map used to solve the nonlinear algebraic system of equations.

Another example of bifurcation is the buckling of slender structures with direct application to solar sail booms. An interesting aspect in the boom design is that postbuckled configurations are not avoided as is usually the case in structural design; instead, they are sometimes encouraged. In this context, the understanding of the structural behavior after buckling is essential. Various structural systems and loadings appropriate for the boom modeling are examined here. Natural frequencies of vibration about highly–deflected equilibria are extracted, exposing the high sensitivity that these structures have to minor changes in the geometry and loading.

References listed at the end of the dissertation:

Euler, L. (1744). Methodus inveniendi lineas curvas maximi minimive proprietas gaudentes.

Wadee, M. A., Yiatsos, S., & Theofanous, M. 2010 (Department of Civil and Environmental Engineering, Imperial College of Science, Technology & Medicine, South Kensington Campus, London SW7 2AZ, UK), “Comparative studies of localized buckling in sandwich struts with different core bending models”, Int. J. Non-Linear Mech., 45(2), 111–120. DOI: 10.1016/j.ijnonlinmech.2009.10.001.

ABSTRACT: Analytical models with geometric nonlinearities accounting for interactions between local and global instability modes leading to localized buckling in sandwich struts are formulated. For the core material response, two increasingly sophisticated bending models are compared against each other: Timoshenko beam theory (TBT) and Reddy–Bickford beam theory (RBT). Numerical solutions of the analytical models are validated with the commercial finite element code Abaqus. It is found that there is a small but significant difference in the critical load between the two models and that the previously obtained solution slightly underestimates the linear buckling strength. More importantly, it is found that the RBT model predicts the onset of interactive buckling before the TBT model and, according to the results from the finite element study, matches the actual behaviour of a strut in both its initial and advanced post-buckling states with excellent correlation.

References listed at the end of the paper:

ABSTRACT: Structural hollow sections are predominantly square, rectangular or circular in profile. While square and circular hollow sections are often the most effective in resisting axial loads, rectangular hollow sections, with greater stiffness about one principal axis than the other, are generally more suitable in bending. Oval or elliptical hollow sections combine the aesthetic external profile of circular hollow sections with the suitability for resisting flexure of rectangular sections, whilst also retaining the inherent torsional stiffness offered by all tubular sections. This paper examines the structural response of recently introduced stainless steel OHS in bending and presents design recommendations. In-plane bending tests in the three-point configuration about both the major and minor axis were conducted. All tested specimens were cold-formed from Grade 1.4401 stainless steel and had an aspect ratio of approximately 1.5. The full moment-rotation responses of the specimens were recorded and have been presented herein. The tests were replicated numerically by means of non-linear FE analysis and parametric studies were performed to investigate the influence of key parameters, such as the aspect ratio and the cross-section slenderness, on the flexural response. Based on both the experimental and numerical results, structural design recommendations for stainless steel OHS in bending in accordance with Eurocode 3: Part 1.4 have been made.

References listed at the end of the paper:


Deployable structures for architectural applications – A short review

ABSTRACT: Deployable structures can provide a change in the geometric morphology of the envelope by contributing to making it adaptable to changing external climate factors, in order to improve the indoor climate performance of the building. They have the ability to transform themselves from a small, closed or stowed configuration to a much larger, open or deployed configuration being also known as erectable, expandable, extendible, developable or unfurlable structures. According to their structural system, deployable structures can be divided into four main groups: spatial bar structures consisting of hinged bars, foldable plate structures consisting of hinged plates, strut-cable (tensegrity) structures and membrane structures. In this paper a short review only on two of these groups of deployable structures for architectural applications will be presented.

References listed at the end of the paper:

[18] M. Kawaguchi, M. Abe, On some characteristics of pantadome system, IASS 2002: Lightweight Structures in Civil Engineering,

ABSTRACT: Aluminum shear panels can dissipate significant amount of energy through hysteresis provided strength deterioration due to buckling is avoided. A detailed experimental study of the inelastic behavior of the full-scale models of shear panels of 6063-O and 1100-O alloys of aluminum is conducted under slow cyclic loading of increasing displacement levels. The geometric parameters that determine buckling of the shear panels, such as web depth-to-thickness ratio, aspect ratio of panels, and number of panels, were varied among the specimens. Test results were used to predict the onset of buckling with proportionality factor f in Gerard’s formulation of inelastic buckling. Moreover, a logarithmic relationship between buckling stress and slenderness ratio of the panel was observed to predict experimental data closely. These relations can be further used to determine the geometry of shear panels, which will limit the inelastic web buckling at design shear strains. (DOI: 10.1115/1.2793135)

Ashwin Kumar and Dipti R. Sahoo (Dept. of Civil Engineering, Indian Institute of Technology Delhi, India), “Effect of brace configurations on the behavior of SCBFS under near-field earthquake”. EUROSTEEL 2014, September 10-12, 2014, Naples, Italy

PARTIAL INTRODUCTION: Special concentrically braced frames (SCBFs) are used as lateral force-resisting systems in steel structures located in the high seismic areas to resist lateral loads through the vertical concentric truss system. Compared to other lateral force resisting systems, this system can be cheaper and is easier to build if proper care is taken in designing and detailing. The braces act as fuses which dissipate the input seismic energy through the tension yielding and compression buckling. Thus, the axial deformation of the braces allows the system as a whole to have ample drift capacity to resist the lateral forces without any failure of gravity load-resisting members. Several parameters, such as, brace slenderness ratio, width-to-thickness ratio, size and detailing of gusset plate, brace configurations, etc. control the response of SCBFs under earthquake loading [e.g., 1-3].

References listed at the end of the paper:

P.C Ashwin Kumar, Dipti Ranjan Sahoo & Nitin Kumar (Dept. of Civil Engineering, Indian Institute of Technology Delhi, India), “Limiting slenderness ratio for hollow square braces in special concentrically braced frames”, Proceedings of the Tenth Pacific Conference on Earthquake Engineering Building an Earthquake-Resilient Pacific 6-8 November 2015, Sydney, Australia

ABSTRACT: Special concentrically braced frames (SCBFs) are commonly used to resist lateral forces in structures located in high-seismic regions. Steel braces undergo inelastic axial deformations and thus provides an adequate level of structural ductility and hysteretic energy dissipation capability to the frame under cyclic...
loading. Past studies have shown that the slenderness ratio and the width-to-thickness ratio of braces are primarily responsible for achieving enhanced seismic response in SCBFs. An increase in the brace slenderness ratio results in a reduction in its energy dissipation capacity along with a simultaneous increase in the ductility nearing its fracture. Since both energy dissipation capacity and ductility of braces are essential parameters in quantifying the seismic performance of SCBFs, there is a need of establishing the optimum range of brace slenderness ratio and width-to-thickness ratio. The main objective of this study is to find an optimum range as well as the lower limits of these parameters for braces of hollow square steel (HSS) sections. An extensive finite element (FE) parametric study has been conducted on a wide range of values of these parameters using a commercial software package ABAQUS. The FE models accounts for the inelastic hysteretic characteristics and the fracture behavior of braces. The results of simulation models matched very well with the past experimental results with respect to the performance points, namely, global buckling, local buckling, fracture initiation, complete fracture and ductility. Finally, the relationship between the lower limit of slenderness ratio and the width-to-thickness of square braces has been established based on the simulation results.

References listed at the end of the paper:

Nitin Kumar, P.C. Ashwin Kumar and Dipti Ranjan Sahoo (Civil Engineering, Indian Institute of Technology Delhi), “Optimum range of slenderness ratio for braces in special concentric braced frames”, Fifth Asia Conference on Earthquake Engineering, October 16-18, 2014
ABSTRACT: Special concentric braced frames (SCBFs) are commonly used to resist the lateral forces in structures located in high-seismic regions. Steel braces undergo inelastic axial deformations and thus provides an adequate level of structural ductility and hysteretic energy dissipation capability to the frame under cyclic loading. Past studies have shown that the slenderness ratio and the width-to-thickness ratio of braces are primarily responsible for achieving enhanced seismic response in SCBFs. An increase in the brace slenderness ratio results in a reduction in its energy dissipation capacity along with a simultaneous increase in the ductility nearing its fracture. Currently, no guidelines are available for the lower limit of slenderness ratio and since both energy dissipation capacity and ductility of braces are essential parameters in quantifying the enhanced seismic performance of SCBFs, there is a need of establishing the optimum range of brace slenderness ratio and width-to-thickness ratio. Therefore, the main objective of this study was to find an optimum range as well as the lower limits of these parameters. An extensive finite element (FE) parametric study has been conducted on a wide range of parameters of hollow circular braces using a commercial software package ABAQUS. A validated simulation model which had the inelastic characteristics of braces and the fracture behavior incorporated was created. The results of simulation models matched very well with the past experimental results with respect to the four performance points, namely, global buckling, local buckling, fracture initiation, and complete fracture. This model paved way for the parametric study which resulted in a deep understanding of the influence of structural parameters on the behavior of braces.

References listed at the end of the paper:

ABSTRACT: A hybrid brace having a buckling-inhibited axially yielding segment and a non-yielding elastic component over a dominant length in sequence can provide a balanced hysteretic response under cyclic loading condition. Braced frames equipped with such a composite brace can dissipate energy in-elastically without any degradation in the lateral strength and stiffness. The enhanced stiffness of the hybrid brace can assist in reducing the drift demands on buckling-restrained braced frame (BRBF) system under the seismic action. The present study is focused on the energy dissipation characteristics of the short length buckling-restrained braces (BRBs). A reduced scale model of the short length BRB has been tested under a gradually increasing reversed-cyclic loading. In order to simulate the behavior of BRB specimens analytically, finite element modelling of the specimen is carried out using a commercial software package ABAQUS CAE. The modeling of short length BRBs and analysis results are discussed in detail in this paper. The hysteretic response obtained from analysis matched well with the test results.

References listed at the end of the paper:


ABSTRACT: Buckling-restrained braced frames (BRBFs) are considered to be one of the efficient lateral force-resisting systems used in buildings located in the seismically active regions. Nearly symmetric hysteretic response of buckling-restrained braces (BRBs) in tension and compression due to the yielding of steel core plates helps the BRBFs to withstand the seismic excitations without causing any extensive damage to the primary frame members. However, BRBFs may exhibit the excessive post-earthquake residual drift response due to the low axial stiffness of BRBs under the strong ground motions. A reduction in the yielding core segments of BRBs results in the improved elastic and post-elastic axial stiffness of BRBs which may help in controlling the excessive residual drift response. This study is focussed on the analytical evaluation of hysteretic response of BRBs of varying lengths using finite element (FE) software. The results of FE study are further used to evaluate the inter-story and residual drift response of a 3-story braced frame fitted with BRBs of short core lengths (referred as SBRBF). Nonlinear dynamic analysis results of SBRBF are compared with the conventional BRBF and concentrically braced frame (CBF). It is concluded that the optimum reduction in yielding core lengths of BRBs can improve the overall seismic response of BRBFs with a reduction in the residual drift response.
This paper presents a study on the development of high-performance finite elements for geometrically nonlinear analysis of frame structures with curved members. Based on the geometrically exact beam theory, a highly efficient and accurate mixed finite element is developed. A new approach is proposed for constructing the independent internal force field by including major terms satisfying equilibrium conditions in the deformed configuration. An element-level equilibrium iteration procedure is employed for the condensation of element internal degrees of freedom during the nonlinear solution. Numerical results are presented to demonstrate the excellent performance of the element developed, and it is shown that even when each structural member is modelled with just one element, accurate solutions can still be achieved.

References listed at the end of the paper:
Alexander Düster, Ernst Rank and Barna Szabó
(1) Hamburg University of Technology, Hamburg, Germany
(2) Institute for Advanced Study, Technische Universität München, Munich, Germany
(3) Washington University, St. Louis, MO, USA


ABSTRACT: In the first part of this chapter the basic algorithmic structure and performance characteristics of the p-version of the finite element method are surveyed with reference to elliptic problems in solid mechanics. For this class of problems, the theoretical basis of the p-version is fully established, and a very substantial amount of engineering experience covering linear and nonlinear applications is available. It is shown that p-extensions on properly designed meshes make realization of exponential rates of convergence in practical computations possible and provide for the estimation and control of relative errors in terms of any quantity of interest. In the second part the p-version of the finite element method will be extended to a high-order fictitious domain approach, the finite cell method. Whereas the finite cell method inherits the advantages of the p-version with respect to accuracy and robustness, it relieves analysts from the necessity to generate finite element meshes. Thus, it strongly supports the analysis of problems with highly complicated geometry, for which meshing with finite elements would be very difficult. Given the growing demand for verified numerical solutions, the p-version of the finite element and finite cell methods are expected to play an increasingly important role.

References listed at the end of the paper:
Barthold FJ, Schmidt M and Stein E. Error indicators and mesh refinements for finite-element-computations of elastoplastic...


Gordon WJ and Hall ChA. Transfinite element methods: blending function interpolation over arbitrary curved element domains.


D. Schillinger, M. Ruess, N. Zander, Y. Bazilevs, A. Duester, and E. Rank. Small and large deformation analysis with the p- and b-spline versions of the Finite Cell Method. Computational Mechanics, 50(4):445–478, 2012. ABSTRACT: The Finite Cell Method (FCM) is an embedded domain method, which combines the fictitious domain approach with high-order finite elements, adaptive integration, and weak imposition of unfitted Dirichlet boundary conditions. For smooth problems, FCM has been shown to achieve exponential rates of convergence in energy norm, while its structured cell grid guarantees simple mesh generation irrespective of the geometric complexity involved. The present contribution first unhinges the FCM concept from a special high-order basis. Several benchmarks of linear elasticity and a complex proximal femur bone with inhomogeneous material demonstrate that for small deformation analysis, FCM works equally well with basis functions of the p-version of the finite element method or high-order B-splines. Turning to large deformation analysis, it is then illustrated that a straightforward geometrically nonlinear FCM formulation leads to the loss of uniqueness of the deformation map in the fictitious domain. Therefore, a modified FCM formulation is introduced, based on repeated deformation resetting, which assumes for the fictitious domain the deformation-free reference configuration after each Newton iteration. Numerical experiments show that this intervention allows for stable nonlinear FCM analysis, preserving the full range of advantages of linear elastic FCM, in particular exponential rates of convergence. Finally, the weak imposition of unfitted Dirichlet boundary conditions via the penalty method, the robustness of FCM under severe mesh distortion, and the large deformation analysis of a complex voxel-based metal foam are addressed.

References listed at the end of the paper:


We conclude our review by briefly discussing some key aspects for the efficient implementation of the finite cell method. We first provide a concise introduction to the basics of the finite cell method. We then summarize recent findings on the treatment of geometric nonlinearities for large deformation analysis, the weak enforcement of boundary conditions, and local refinement schemes. We also discuss the capabilities and advantages of the finite cell method with several challenging examples, e.g. the image-based analysis of foam-like structures, the patient-specific analysis of a human femur bone, the analysis of volumetric structures based on CAD boundary representations, and the isogeometric treatment of trimmed NURBS surfaces. We conclude our review by briefly discussing some key aspects for the efficient implementation of the finite cell method.
References listed at the end of the paper:

67 I. Harari and E. Shavelzon. Embedded kinematic boundary conditions for thin plate bending by Nitsche’s approach. International
131 E. Rank, S. Kollmannsberger, C. Sorger, and A. Duster. Shell finite cell method: a high order fictitious domain approach for


ABSTRACT: A new Mixed Cubic Zigzag Theory (CZT(m)) has been developed via the Reissner Mixed Variational Theorem. The assumed kinematic field postulates an in-plane displacement components piecewise cubic along the thickness and a smeared parabolic through-the-thickness distribution for the transverse displacement. The assumed transverse shear stresses profile derives from integration of the three-dimensional equilibrium equations whereas the normal stress pattern is assumed smeared cubic along the laminate thickness. The entire formulation is here developed and the governing equations derived are used to solve the bending problem of a rectangular simply-supported cross-ply plate subjected to a bi-sinusoidal transverse load. In order to assess the predictive capabilities of the CZT(m) model, results are compared with the exact three-dimensional elasticity solution.

References listed at the end of the paper:


References:

[29] NAFEMS (1992) : Introduction to non-linear finite element analysis. E. Hinton Editor. Published by NAFEMS
[79] SUMNER G. (1991) : 20 MN and 100 MN multi-actuators wide plate testing machines in the structural integrity centre of the
ABSTRACT: This paper presents the design optimization of diaphragms for a micro-shock tube-based drug delivery device. The function of the diaphragm is to impart the required velocity and direction to the loosely held drug particles on the diaphragm through van der Waals interaction. The finite element model-based studies involved diaphragms made up of copper, brass and aluminium. The study of the influence of material and geometric parameters serves as a vital tool in optimizing the magnitude and direction of velocity distribution on the diaphragm surface. Experiments carried out using a micro-shock tube validate the final deformed shape of the diaphragms determined from the finite element simulation. The diaphragm yields a maximum velocity of 335 m/s for which the maximum deviation of the velocity vector is 0.62 deg. Drug particles that travel to the destination target tissue are simulated using the estimated velocity distribution and angular deviation. Further, a theoretical model of penetration helps in the prediction of the drug particle penetration in the skin tissue like a target, which is found to be 0.126 mm. The design and calibration procedure of a micro-shock tube device to alter drug particle penetration considering the skin thickness and property are presented.

S. Narendar (1) and S. Gopalakrishnan (2)
(1) Defence Research and Development Laboratory, Kanchanbagh, Hyderabad-500 058, India.
(2) Computational Wave Mechanics Laboratory, Department of Aerospace Engineering, Indian Institute of Science, Bangalore-560 058, India.


ABSTRACT: This paper presents the effect of nonlocal scaling parameter on the coupled i.e., axial, flexural, shear and contraction, wave propagation in single-walled carbon nanotubes (SWCNTs). The axial and transverse motion of SWCNT is modeled based on first order shear deformation theory (FSDT) and thickness contraction. The governing equations are derived based on nonlocal constitutive relations and the wave dispersion analysis is also carried out. The studies shows that the nonlocal scale parameter introduces certain band gap region in all wave modes where no wave propagation occurs. This is manifested in the wavenumber plots as the region where the wavenumber tends to infinite or wave speed tends to zero. The frequency at which this phenomenon occurs is called the escape frequency. Explicit expressions are derived for cut-off and escape frequencies of all waves in SWCNT. It is also shown that the cut-off frequencies of shear and contraction mode are independent of the nonlocal scale parameter. The results provided in this article are new and are useful guidance for the study and design of the next generation of nanodevices that make use of the coupled wave propagation properties of single-walled carbon nanotubes.


ABSTRACT: This paper presents the design optimization of diaphragms for a micro-shock tube-based drug delivery device. The function of the diaphragm is to impart the required velocity and direction to the loosely held drug particles on the diaphragm through van der Waals interaction. The finite element model-based studies involved diaphragms made up of copper, brass and aluminium. The study of the influence of material and geometric parameters serves as a vital tool in optimizing the magnitude and direction of velocity distribution on the diaphragm surface. Experiments carried out using a micro-shock tube validate the final deformed shape of the diaphragms determined from the finite element simulation. The diaphragm yields a maximum velocity of 335 m/s for which the maximum deviation of the velocity vector is 0.62 deg. Drug particles that travel to the destination target tissue are simulated using the estimated velocity distribution and angular deviation. Further, a theoretical model of penetration helps in the prediction of the drug particle penetration in the skin tissue like a target, which is found to be 0.126 mm. The design and calibration procedure of a micro-shock tube device to alter drug particle penetration considering the skin thickness and property are presented.

Guangyong Sun (1,2), Guangyao Li (1), Shujuan Hou (1), Shiwei Zhou (2), Wei Li (2) and Qing Li (2)
(1) State Key Laboratory of Advanced Design and Manufacture for Vehicle Body, Hunan University, Changsha 410082, China
ABSTRACT: Foam-filled thin-wall structures have exhibited significant advantages in light weight and high energy absorption and been widely applied in automotive, aerospace, transportation and defence industries. Unlike existing uniform foam materials, this paper introduces functionally graded foam (FGF) fillers to fill thin-walled structures, aiming to improve crashworthiness. In this novel structure, the foam density varies throughout the depth in a certain gradient. Numerical simulations showed that gradient exponential parameter m that controls the variation of foam density has significant effect on system crashworthiness. In this study, the single and multiobjective particle swarm optimization methods are used to seek for optimal gradient, where response surface models are established to formulate specific energy absorption and peak crushing force. The results yielded from the optimizations indicate that the FGF material is superior to its uniform counterparts in overall crashworthiness. The data has considerable implication in design of FGF materials for optimizing structural crashworthiness.

References listed at the end of the paper:
functionally graded cylindrical shell resting on elastic foundation are discussed. In addition, the effects of the variations of different parameters of generalized power law distribution on steady-state responses of the structure is carried out to establish its very high accuracy and versatility. Effects presented in this paper. The fast rate of convergence of the method is demonstrated and comparison studies are carried out to establish its very high accuracy and versatility. Effects of stiffness of the foundation and variations of different parameters of generalized power-law distribution on steady-state responses of the functionally graded cylindrical shell resting on elastic foundation are discussed. In addition, the effects of the

ABSTRACT: This paper investigates the three-dimensional thermo-elastic deformation of cylindrical shells on two-parameter elastic foundations with continuously graded of volume fraction, subjected to thermal load. Suitable temperature and displacement functions that identically satisfy boundary conditions at the edges are used to reduce the equilibrium equations to a set of coupled ordinary differential equations with variable coefficients, which are solved by Generalized Differential Quadrature (GDQ) method. Results are presented for two-constituent isotropic and fiber-reinforced functionally graded cylindrical shells that have a smooth variation of volume fractions through the radial direction. Symmetric and asymmetric volume fraction profiles are presented in this paper. The fast rate of convergence of the method is demonstrated and comparison studies are carried out to establish its very high accuracy and versatility. Effects of stiffness of the foundation and variations of different parameters of generalized power-law distribution on steady-state responses of the functionally graded cylindrical shell resting on elastic foundation are discussed. In addition, the effects of the

References listed at the end of the paper:

C.H. Li (1), K.C. Tsai (2), J.T. Chang (2) and C.H. Lin (1)
(1) Building Engineering Division, National Center for Research on Earthquake Engineering, Taiwan
(2) Department of Civil Engineering, National Taiwan University, Taiwan

ABSTRACT: This research aimed to investigate the seismic behavior and design of the Coupled Steel Plate Shear Wall (C-SPSW). A prototype six-story C-SPSW building was designed based on the model building code. A 40% scale specimen was constructed as the bottom two-and-half-story substructure of the six-story C-SPSW prototype. The reduced scale sub-structural specimen was cyclically tested using the Multi-Axial Testing System (MATS) at the National Center for Research on Earthquake Engineering (NCREE). In addition to the cyclic lateral forces, the constant vertical loading and cyclic overturning moments were applied on the specimen simultaneously. The test results show that the C-SPSW specimen behaved in a ductile manner and dissipated significant amounts of hysteresis energy during the cyclic loadings. Finally, based on the experimental results, the implications in the capacity design for the bottom boundary column are discussed. A numerical simulation using finite element model was conducted. The analytical results quite match the overall and local experimental responses.


ABSTRACT: This paper investigates the three-dimensional thermo-elastic deformation of cylindrical shells on two-parameter elastic foundations with continuously graded of volume fraction, subjected to thermal load. Suitable temperature and displacement functions that identically satisfy boundary conditions at the edges are used to reduce the equilibrium equations to a set of coupled ordinary differential equations with variable coefficients, which are solved by Generalized Differential Quadrature (GDQ) method. Results are presented for two-constituent isotropic and fiber-reinforced functionally graded cylindrical shells that have a smooth variation of volume fractions through the radial direction. Symmetric and asymmetric volume fraction profiles are presented in this paper. The fast rate of convergence of the method is demonstrated and comparison studies are carried out to establish its very high accuracy and versatility. Effects of stiffness of the foundation and variations of different parameters of generalized power-law distribution on steady-state responses of the functionally graded cylindrical shell resting on elastic foundation are discussed. In addition, the effects of the
FGM configuration are studied by considering the mechanical entities of different FGM fiber-reinforced cylindrical shells resting on elastic foundation. Some results are presented for the first time and some important conclusions are drawn.

References listed at the end of the paper:

ABSTRACT: A computational model was developed to study the nonlinear steady state static response and free vibration of thin-walled carbon nanotubes/fiber/polymer laminated multiscale composite beams and blades. A set of nonlinear intrinsic equations describing the response of rotating cantilever composite beams undergoing large deformations was established. The main assumptions were small local strains and local rotations, large deflections and global rotations. Halpin–Tsu equations and fiber micromechanics were used to predict the bulk material properties of the multiscale nanocomposite. The carbon nanotubes (CNTs) were assumed to be uniformly distributed and randomly oriented through the epoxy resin matrix. Discretized by the Galerkin approximation, eigenvalues and vectors and nonlinear steady state static response of the nanocomposite. The carbon nanotubes (CNTs) were assumed to

References listed at the end of the paper:
ABSTRACT: This paper investigates the nonlinear analysis of energy harvesting from piezoelectric functionally graded carbon nanotube reinforced composite plates under combined thermal and mechanical loadings. The excitation, which derives from harmonically varying mechanical in-plane loading, results in parametric excitation. The governing equations of the piezoelectric functionally graded carbon nanotube reinforced composite plates are derived based on classical plate theory and von Karman geometric nonlinearity. The material properties of the nanocomposite plate are assumed to be graded in the thickness direction. The single-walled carbon nanotubes (SWCNTs) are assumed to be aligned, straight and have a uniform layout. The linear buckling and vibration behavior of the nanocomposite plates is obtained in the first step. Then, Galerkin’s method is employed to derive the nonlinear governing equations of the problem with cubic nonlinearities associated with mid-plane stretching. Periodic solutions are determined by using the Poincare –Lindstedt perturbation scheme with movable simply supported boundary conditions. The effects of temperature change, the volume fraction and the distribution pattern of the SWCNTs on the parametric resonance, in particular the amplitude of vibration and the average harvested power of the smart functionally graded carbon nanotube reinforced composite plates, are investigated through a detailed parametric study.

References listed at the end of the paper:

Kármán geometric nonpiezoelectric CNTRC plates are derived based on first order shear deformation plate theory (FSDT) and von varyng actuators voltage, results in both external and parametr

ABSTRACT: This paper deals with non-linear dynamic stability of initially imperfect piezoelectric functionally graded carbon nanotube-reinforced composite (FG-CNTRC) plates under a combined thermal and electrical loadings and interaction of parametric and external resonance. The excitation, which derives from harmonically varying actuators voltage, results in both external and parametric excitation. The governing equations of the piezoelectric CNTRC plates are derived based on first order shear deformation plate theory (FSDT) and von Kármán geometric nonlinearity. The material properties of FG-CNTRC plate are assumed to be graded in the...
thickness direction. The single-walled carbon nanotubes (SWCNTs) are assumed aligned, straight and a uniform layout. The linear buckling and vibration behavior of perfect and imperfect plates are obtained in the first step. Then, Galerkin's method is employed to derive the non-linear governing equations of the problem with quadratic and cubic non-linearities associated with mid-plane stretching. Periodic solutions and their stability are determined by using the harmonic balance method with simply supported boundary conditions. The effect of the applied voltage, temperature change, plate geometry, imperfection, the volume fraction and distribution pattern of the SWCNTs on the parametric resonance, in particular the positions and sizes of the instability regions of the smart CNTRC plates as well as amplitude of steady state vibration are investigated through a detailed parametric study.

References listed at the end of the paper:


M. Rafiee, S. Mareishi, M. Mohammadi, An investigation on primary resonance phenomena of elastic medium

ABSTRACT: In this paper, the geometrically nonlinear free and forced oscillations of simply supported single
walled carbon nanotubes (SWCNTs) are analytically investigated on the basis of the Euler–Bernoulli beam
theory. The nonlinear frequencies of SWCNTs with initial lateral displacement are discussed. Equations have
been solved using an exact method for free vibration and multiple times scales (MTS) method for forced
vibration and some analytical relations have been obtained for natural frequency of oscillations. The numerical
results reveal that the nonlinear free and forced vibration of nanotubes is effected significantly by both
surrounding elastic medium and CNT aspect ratio.

References listed at the end of the paper:
1 Ansari, R., Hemmatnezhad, M., Ramezannezhad, H., 2010. Application of HPM to the nonlinear vibrations of multiwalled carbon
Vibration 296, 746–756.
ABSTRACT: Cylindrical shells exhibit a dense frequency spectrum, especially near the lowest frequency range. In addition, due to the circumferential symmetry, several equal or nearly equal frequencies may occur, leading to a complex dynamic behavior. So, the aim of the present work is to investigate the dynamic behavior and stability of cylindrical shells under axial forcing with multiple equal or nearly equal natural frequencies. The shell is modelled using nonlinear governing equations of motion and using several tools of nonlinear dynamics, a detailed parametric analysis is conducted to clarify the influence of the internal resonances on the bifurcations, stability boundaries, nonlinear vibration modes and basin of attraction of the structure.

References listed at the end of the paper:
References listed at the end of the paper:
Slade Gellin and Ruy M.O. Pauletti, “Form finding of tensioned fabric cone structures using the natural force density method”, Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2010, November 8-12, 2010, Shanghai, China

**ABSTRACT:** This paper explores the form finding analysis of tensioned fabric cone structures using the natural force density method. Results of form-finding of axisymmetric cone structures indicate an agreement with previous work in the subject and offer great promise in approaching non-axisymmetric cone structures in future research.


**ABSTRACT:** The problem of the equilibrium shape of a membrane structure between two coaxial rings of identical elliptical shape separated by a specified distance with a fixed ratio between the meridional and circumferential stress is explored. The maximum separation between the rings for a given stress ratio is determined, as well as the associated reduction in cross-section at the mid-plane between the rings. Results are compared with those obtained for circular rings.

References listed at the end of the paper:

Ruy M.L. Pauletti (1) and Slade Gellin (2)
(1) Polytechnic School, University of São Paulo, São Paulo, Brazil
(2) Department of Engineering Technology, Buffalo State College, Buffalo NY US

“We the influence of cable sliding on the structural response of a large pneumatic envelope”, Proceedings of the International Association for Shell and Spatial Structures (IASS), 2015, Future Visions, 17-20 August 2015, Amsterdam, The Netherlands

**ABSTRACT:** This paper presents the formulations of a sliding-cable super-element and a membrane element capable of representing wrinkling, whose stiffness matrices are obtained through finite-differences, thus requiring the sole definition of force vectors. These formulations are then applied to the analysis of a large pneumatic membrane reinforced by cables, and the effects of adherent or sliding conditions on the system’s structural response are investigated.

References listed at the end of the paper:
ABSTRACT: This paper presents a further investigation into the energy absorbing behaviour of axially splitting and curling square mild steel and aluminium tubes. Both quasi-static and dynamic tests were conducted. A simple quasi-static kinematic model is developed which describes all the main features of the deformation process. It is assumed in this model that cracks start from the four corners and propagate along the axial direction due to continuous fracture/tearing. The free side plates so formed by cracks roll up into four curls with a constant radius. Formulas for the average crush force, curl radius, and the energy absorption are achieved by analysing the ‘far-field’ and ‘near-tip’ deformation events and the bending moment at the crack tip. This quasi-static model is also extended and used for dynamic cases to explore strain-rate effects in splitting square metal tubes. Solutions are presented and detailed comparisons are made between theoretical predictions and experimental results.

References listed at the end of the paper:
8 Grzebieta, R. H. An alternative method for determining the behaviour of round stocky tubes subjected to axial crush loads. Thin Wall. Struct., 1990A, 9, 66 – 89.

Sun, C., Liu, K., Lu, G.: Dynamic torsional buckling of multiwalled carbon nanotubes embedded in an elastic

ABSTRACT: In this paper the dynamic torsional buckling of multi-walled carbon nanotubes (MWNTs) embedded in an elastic medium is studied by using a continuum mechanics model. By introducing initial imperfections for MWNTs and applying the preferred mode analytical method, a buckling condition is derived for the buckling load and associated buckling mode. In particular, explicit expressions are obtained for embedded double-walled carbon nanotubes (DWNTs). Numerical results show that, for both the DWNTs and embedded DWNTs, the buckling form shifts from the lower buckling mode to the higher buckling mode with increasing the buckling load, but the buckling mode is invariable for a certain domain of the buckling load. It is also indicated that, the surrounding elastic medium generally has effect on the lower buckling mode of DWNTs only when compared with the corresponding one for individual DWNTs.

References listed at the end of the paper:


ABSTRACT: This paper is concerned with the load-carrying capacities of a circular sandwich panel with metallic foam core subjected to quasi-static pressure loading. The analysis is performed with a newly developed yield criterion for the sandwich cross section. The large deflection response is estimated by assuming a velocity field, which is defined based on the initial velocity field and the boundary condition. A finite element simulation has been performed to validate the analytical solution for the simply supported cases. Good agreement is found between the theoretical and finite element predictions for the load-deflection response.

References listed at the end of the paper:
2. A. Sawczuk, Mechanics and Plasticity of Structures (Ellis Horwood, Chichester, 1989).


ABSTRACT: This paper is concerned with the load-carrying capacities of a circular sandwich panel with metallic foam core subjected to quasi-static pressure loading. The analysis is performed with a newly developed yield criterion for the sandwich cross section. The large deflection response is estimated by assuming a velocity field, which is defined based on the initial velocity field and the boundary condition. A finite element simulation has been performed to validate the analytical solution for the simply supported cases. Good agreement is found between the theoretical and finite element predictions for the load-deflection response.

References listed at the end of the paper:

Feng Zhu (1), Guoxing Lu (2), Dong Ruan (3) and Zhihua Wang (4)
(1) Bioengineering Center, Wayne State University, Detroit, MI 48201, USA
(2) School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore 639798,
Singapore
(3) Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Hawthorn, VIC 3122,
Australia
(4) Institute of Applied Mechanics and Biomedical Engineering, Taiyuan University of Technology, Taiyuan
030024, China

“Plastic deformation, failure and energy absorption of sandwich structures with metallic cellular cores”,
International Journal of Protective Structures, Vol. 1, No. 4, 2010

ABSTRACT: Cellular metals with stochastic, 2D or 3D periodic microstructures can sustain large plastic
deformation at almost constant stress. Due to such excellent energy absorption capability, cellular metals are
very suited to be used as the core of sandwich structures, which have been applied widely to the areas of
aerospace and aeronautical design, the automotive manufacturing, and shipbuilding, as well as the defense and
nuclear industries. Although there is a great deal of research currently available related to the behaviour of
sandwich structures with metallic cellular core under various loading conditions, they are widely scattered in the
literature. This review paper brings together the latest developments in this important research area. Three types
of cellular metals, namely metal foams, honeycombs and prismatic materials and truss and textile based lattice
materials are considered. The responses of sandwich structure with such cores subjected to different loads, i.e.
quasi-static/low velocity compression and indentation, ballistic impact, high speed compression and blast
loading, are reviewed. The emphasis has been placed on their plastic deformation, failure and energy absorption
behaviours.

References listed at the end of the paper:
34. Qin QH and Wang TJ. An analytical solution for the large deflections of a slender sandwich beam with a metallic foam core under transverse loading by a flat punch. Composite Structures, 2009; 88: 509–518.
72. Queheililt DT, Murty Y and Wadley HNG. Mechanical properties of an extruded pyramidal lattice truss sandwich structure.


ABSTRACT: This paper reviews some topics related to the advances and applications of structural impact dynamics in recent years. Dynamic behavior of structural members including tubes, beams and plates under axial or transverse loading, and cellular materials and sandwich structures under impact or blast loading are summarized here. The research methodology involves experimental studies, theoretical modeling, as well as numerical simulations. However, as we mainly focus on the longer time dynamic responses of structures and cellular materials, studies of stress wave propagation and the material’s strain-rate sensitivity are not included. References listed at the end of the paper:


Jie Song, Yan Chen and Guoxing Lu (School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore), “Axial crushing of internally braced tubes”, 4th International Conference on Design and Analysis of Protective Structures, Jeju, Korea, June 2012
ABSTRACT: Thin-walled tubular structures are widely used as energy absorbing devices. For conventional tubes subject to axial crushing, they usually exhibit a high initial peak force and large fluctuation in the load-displacement curve. In the present study, internal braces were introduced to square and circular tubes to reduce the initial peak and subsequent fluctuation. Crushing test and FE simulation were performed on the internally-braced and conventional tubes that had the same mass. Good agreement between experimental and numerical results was observed. It is shown that tubes with internal braces have lower initial peak and more uniform crushing process than the conventional ones.

References listed at the end of the paper:

Shiqiang Li (1), Guoxing Lu (2), Zhihua Wang (1), Longmao Zhao (1) and Guiyi Wu (1)
(1) Institute of Applied Mechanics and Biomedical Engineering, Taiyuan University of Technology, Taiyuan, Shanxi 030024, China
(2) School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore 639798, Singapore


ABSTRACT: The LS-DYNA software was employed to analyze the dynamic responses of a sandwich cylindrical shell system under internal blast loading. The system consisted of metallic face sheets and graded aluminum tubular cores with different wall thicknesses. The response of this system was also compared with that of conventional ungraded ones. The dynamic response of graded cylindrical shells with a series of different core arrangements is reported in this paper. The deformation and blast resistance of the structures were discussed in detail, and the optimum sandwich configuration was obtained. The core layers, which had thickness-tapered arrangement from the inner to the outer layer, were favorable for the energy dissipation and the out face-sheet deflection. Finally, two new response types were defined based on the core compression consequence, which is unique to sandwich structures with graded cores.

References listed at the end of the paper:
Lu Guoxing, Rafea Dakhil Hussein and Dong Ruan, “Energy absorption in axial crushing of thin-walled tubes”, The 18th Conference of Automotive Safety Technology, Suzhou, China, August 2015

Abstract: Recently more attention has been paid to the energy absorption capability of novel structures against impact or blast loading. For conventional tubes subject to axial crushing, they usually exhibit a high initial peak force and large fluctuation in the load-displacement curve. This paper summarizes some recent studies of the behavior of several kinds of thin-walled tubes under axial compression.

References listed at the end of the paper:

Sicong Liu (2), Weilin Lv (1, 3), Yan Chen (1, 3) and Guoxing Lu (4)
(1) Key Laboratory of Mechanism Theory and Equipment Design of Ministry of Education, Tianjin University, Tianjin 300072, China
(2) School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798
(3) School of Mechanical Engineering, Tianjin University, Tianjin 300072, China
(4) Faculty of Science, Engineering and Technology, Swinburne University of Technology, Hawthorn Vic 3122, Australia


Abstract: Rigid origami inspires new design technology in deployable structures with large deployable ratio due to the property of flat foldability. In this paper we present a general kinematic model of rigid origami pattern and obtain a family of deployable prismatic structures. Basically, a 4-crease vertex rigid origami pattern can be presented as a spherical 4R linkage, and the multi-vertex patterns are the assemblies of spherical linkages. Thus, this prismatic origami structure is modelled as a closed loop of spherical 4R linkages, which includes all the possible deployable structures consisting of quadrilateral facets and 4-crease vertices. By solving the compatibility of the kinematic model, a new group of 2n-sided deployable prismatic structures with plane symmetric intersections is derived with multilayer, straight and curvy variations. The general design method for the 2n-sided multilayer deployable prismatic structures is proposed. All the deployable structures constructed with this method have one single degree of freedom, can be deployed and folded without stretching or twisting the facets, and have the compactly flat-folded configuration, which makes it have great potential in engineering applications.

References listed at the end of the paper:


[34] Li QM, Meng H. Attenuation or enhancement – a one-dimensional analysis on shock transmission in the solid phase of a cellular

ABSTRACT: In this study buckling analysis of solid rectangular plate made of porous material in undrained condition is investigated. The mechanical properties of plate are assumed to vary through the thickness direction. Distributing of the pores through the plate thickness are assumed to be the nonlinear nonsymmetric, nonlinear symmetric, and monotonous distribution. The effect of pores and pores distribution on critical buckling load of porous plate are studied. Effect of fluid compressibility on critical buckling load is investigated in the undrained condition. Also, effect of temperature on fluid compressibility for symmetric porous material plate, choosing a linear function, is examined. The results obtained for porous plates are verified with the known data in literature. References listed at the end of the paper:

[23] Bodaghi, M., and Saidi, A.R., "Levy-type Solution for Buckling Analysis of Thick Functionally Graded Rectangular Plates Based...
The finite element (FE) models have been verified by previous experimental results in terms of deformation pattern, stress-strain curve, and energy dissipation. The verified FE models have then been used in comprehensive numerical analysis of different aluminum honeycombs. Plateau stress, $\sigma_{pl}$, and dissipated energy ($E_t$ for indentation and $E_C$ for compression) have been calculated at different strain rates ranging from $10^2$ to $10^4$ s$^{-1}$. The effects of strain rate and t/l ratio on the plateau stress, dissipated energy, and tearing energy have been discussed. An empirical formula is proposed to describe the relationship between the tearing energy per unit fracture area, relative density, and strain rate for honeycombs. Moreover, it has been found that a generic formula can be used to describe the relationship between tearing energy per unit fracture area and relative density for both aluminum honeycombs and foams.

References listed at the end of the paper:

Jianjun Zhang (1,2), Guoxing Lu (1), Zihua Wang (2), Dong Runa (1), Amer Alomarah (1) and Yvonne Durandet (1)
(1) Faculty of Science, Engineering and Technology, Swinburne University of Technology, Hawthorn, VIC 3122, Australia
(2) Institute of Applied Mechanics and Biomedical Engineering, Taiyuan University of Technology, Taiyuan 030024, China


ABSTRACT: The present paper reports on the post-yield behaviors of an auxetic structure, honeycomb with representative re-entrant topology. Specimens were made of stainless steel and polymer, respectively. Quasi-static uniaxial tensile tests were conducted in the two principal directions, followed by simulations using the commercial code – ABAQUS 6.11-2. The deformation, tensile stress-strain curves and Poisson’s ratio were of interest. A good agreement was observed between the numerical simulations and the experimental results. Subsequently, the effect of cell wall thickness and initial cell angle was studied by means of finite element analysis. An analytical equation was also given for the yield stress of such materials under tension.

References listed at the end of the paper:

[16] X. Huang, S. Blackburn, Developing a new processing route to manufacture honeycomb ceramics with negative Poisson’s ratio, Key Eng Mater 206 (2001) 201–204.
ABSTRACT: Monolithic and sandwich structures have been widely used as energy absorption structures in military and civil engineering. This article reviews theoretical analyses of monolithic beams and plates subjected to static loading, impulsive loading and impact by a mass systematically. Experimental data collected from the literatures are compared with these theoretical results. In addition, the critical impulses for the failure of the monolithic structures are also reviewed. Furthermore, sandwich structures under quasi-static, low-velocity impact, high-velocity impact and blast loading, as well as their failure modes, are also summarized. The research methodology involves experimental investigations, theoretical analyses and numerical simulations. 

References listed at the end of the paper:


ABSTRACT: Monolithic and sandwich structures have been widely used as energy absorption structures in military and civil engineering. This article reviews theoretical analyses of monolithic beams and plates subjected to static loading, impulsive loading and impact by a mass systematically. Experimental data collected from the literatures are compared with these theoretical results. In addition, the critical impulses for the failure of the monolithic structures are also reviewed. Furthermore, sandwich structures under quasi-static, low-velocity impact, high-velocity impact and blast loading, as well as their failure modes, are also summarized. The research methodology involves experimental investigations, theoretical analyses and numerical simulations. References listed at the end of the paper:


Dahai Zhang (1,2,3), Guoxing Lu (2), Dong Ruan (2), Qingguo Fei (1,3) and Wenhui Duan (4)
(1) Institute of Aerospace Machinery and Dynamics, Southeast University, Nanjing 211189, China
(2) Faculty of Science, Engineering and Technology, Swinburne University of Technology, John Street, Hawthorn, VIC3122, Australia
(3) School of Mechanical Engineering, Southeast University, Nanjing 211189, China
(4) Department of Civil Engineering, Monash University, Clayton, VIC3800, Australia


ABSTRACT: The mechanical behavior of aluminum honeycombs subjected to quasi-static combined compression-shear loading was experimentally investigated. Two different deformation patterns were observed, deforming cell walls non-inclined (Mode I) and inclined (Mode II) respectively. For the first time, normal and shear forces of honeycombs deforming in Mode II were measured directly using a tri-axial load cell. It was found that the shear force behavior was very different for Modes I and II, with a negative shear force being observed for Mode II, which was not previously reported. Three aluminum hexagonal honeycombs with different cell configurations (cell size and wall thickness) were tested at two loading velocities of $5 \times 10^{-4}$ and $5 \times 10^{-3}$ m/s, three loading angles of 15°, 30° and 45°, in the two plane orientations, respectively. The effects of loading velocity, loading angle and loading plane were discussed in detail. An empirical model specifically

References listed at the end of the paper:


ABSTRACT: Aluminium honeycomb is a type of cellular material which has high strength to weight ratio and is a good energy absorber. They are used as structural components in various engineering applications.

Comprehensive study has been conducted on the compressive behavior of aluminium honeycombs. However, the research of aluminium honeycombs subjected to other type of loading, such as indentation, is still limited. In this paper, quasi-static and dynamic indentation tests were conducted to study the deformation and energy absorption of three types of HEXCELL aluminium honeycombs with different cell sizes and cell wall thicknesses. Quasi-static tests were conducted by using a universal MTS machine at velocities of 0.05 mm/s, 0.5 mm/s and 5 mm/s, respectively. Dynamic tests were conducted by using a high speed INSTRON machine at a velocity of 5 m/s. Force-displacement curves were plotted in which the total energy absorbed was calculated. The deformation of aluminium honeycombs in indentation tests includes the compression of honeycomb cells under the indenter and tearing of honeycomb cell walls along the indenter edges. The energy dissipated in compression and tearing were calculated and discussed. The effects of cell size, cell wall thickness and loading velocity or strain rate on the plateau stress and energy absorption were analyzed.

References listed at the end of the paper:


Partial Introduction: The problem on the stability of thin plates with a hole under tension at the macrolevel was considered previously in [1–3]. The plates lose stability because of the formation of zones of compressing stresses near the edges of holes. When calculating the deformation, stability, and failure of nanoscale objects, it is necessary also to take into account the surface effect. With decreasing geometrical sizes, the influence of this effect increases. The local loss of stability of a plate with circular nanohole under uniaxial tension was considered by A.O. Bochkarev and M.A. Grekov [4]. In this case, the surface stresses on the circular hole boundary, which define more exactly the known solution of the Kirsch problem for small hole sizes, were taken into account in the subcritical state. It is noted that taking into account the surface stresses at the hole edge results in a loss of stability of the plate under a smaller load than in the classical formulation. The value of the load decreases by 5–7%.

References listed at the end of the paper:


ABSTRACT: Sandwich cellular structure, associated with more excellent mechanical properties and physical characteristic, such as, panel ductility and high core compressibility, is widely used in aerospace, transportation, military equipment and civil infrastructure. Due to the special compression properties of functional graded cores, the graded sandwich structure presented more excellent impact resistance than the ungraded sandwich. This article presents the results of experimental, numerical investigation into the failure mode and dynamic plastic response of layered graded sandwich plate with layered honeycomb cores to air blast loading. The core arrangements (different core density) effects on the structure’s deformation behavior, energy absorption and impact resistance were mainly discussed. Three typical failure modes can be observed, that was, local deformation, global bending and penetration failure. Under specific loading conditions, the graded sandwich had more excellent impact resistant and energy absorption ratio, especially for the density-decreased core arrangement sandwich.

References listed at the end of the paper:


ABSTRACT: The dynamic response of circular sandwich panels with aluminium honeycomb and corrugated cores under projectile impact was investigated experimentally and numerically. Impulse loaded on the panel was controlled by projectile launching velocity and the deformation process of sandwich panels was recorded by a high-speed camera in the experiments. Typical deformation/failure modes of face-sheets and cores were obtained and analysed. The back face-sheet deflections and strain histories of face-sheets were measured and discussed. A parametric study was conducted by LS-DYNA 3D to analyse the effect of geometrical configuration on energy absorption mechanism and back face-sheet permanent deflection of circular sandwich
panels. The results indicated that the impact resistance of the structure was sensitive to geometrical configuration. Increasing face-sheet thickness and core relative density significantly improved sandwich structure impact resistance. Increasing foil thickness improved the panel impact resistance more efficiently than decreasing wall side length. The results have important reference value to guide engineering application of the sandwich structure subjected to impact loading.

References listed at the end of the paper: (See Part 2)

ABSTRACT: Loss of stability under uniaxial tension in an infinite plate with a circular inclusion made of another material is analyzed. The influence exerted by the elastic modulus of the inclusion on the critical load is examined. The minimum eigenvalue corresponding to the first critical load is found by applying the variational principle. The computations are performed in Maple and are compared with results obtained with the finite element method in ANSYS 13.1. The computations show that the instability modes are different when the inclusion is softer than the plate and when the inclusion is stiffer than the plate. As the Young’s modulus of the inclusion approaches that of the plate, the critical load increases substantially. When these moduli coincide, stability loss is not possible.

References listed at the end of the paper:


ABSTRACT: The present article focuses on the nonlinear finite element simulation and control of large amplitude vibrations of smart piezolaminated composite structures. Full geometrically nonlinear finite rotation strain–displacement relations and Reissner–Mindlin first-order shear deformation hypothesis to include the transverse shear effects are considered to derive the variational formulation. A quadratic variation of electric potential is assumed in transverse direction. An assumed natural strain method for the shear strains, an enhanced assumed strain method for the membrane strains and an enhanced assumed gradient method for the electric field is incorporated to improve the behavior of a four-node shell element. Numerical simulations presented in this article show the accurate prediction capabilities of the proposed method, especially for structures undergoing finite deformations and rotations, in comparison to the results obtained by simplified nonlinear models available in references and also with those obtained by using the C3D20RE solid element for piezoelectric layers in the Abaqus code.

References listed at the end of the paper:


ABSTRACT: An improved Fourier series method (IFSM) is applied to study the free and forced vibration characteristics of the moderately thick laminated composite rectangular plates on the elastic Winkler or Pasternak foundations which have elastic uniform supports and multipoints supports. The formulation is based on the first-order shear deformation theory (FSDT) and combined with artificial virtual spring technology and the plate-foundation interaction by establishing the two-parameter foundation model. Under the framework of this paper, the displacement and rotation functions are expressed as a double Fourier cosine series and two...
supplementary functions which have no relations to boundary conditions. The Rayleigh-Ritz technique is applied to solve all the series expansion coefficients. The accuracy of the results obtained by the present method is validated by being compared with the results of literatures and Finite Element Method (FEM). In this paper, some results are obtained by analyzing the varying parameters, such as different boundary conditions, the number of layers and points, the spring stiffness parameters, and foundation parameters, which can provide a benchmark for the future research.

References listed at the end of the paper:
[26] E. Bahmyari and M.R. Khedmati, “Vibration analysis of nonhomogeneous moderately thick plates with point supports resting on
[56] Q. Wang, F. Pang, B. Qin, and Q. Liang, “A unified formulation for free vibration of functionally graded carbon nanotube


ABSTRACT: This paper presents free vibration analysis of open and closed shells with arbitrary boundary conditions using a spectro-geometric-Ritz method. In this method, regardless of the boundary conditions, each of the displacement components of open and closed shells is represented simultaneously as a standard Fourier cosine series and several auxiliary functions. The auxiliary functions are introduced to accelerate the convergence of the series expansion and eliminate all the relevant discontinuities with the displacement and its derivatives at the boundaries. The boundary conditions are modeled using the spring stiffness technique. All the expansion coefficients are treated equally and independently as the generalized coordinates and determined using Rayleigh-Ritz method. By using this method, a unified vibration analysis model for the open and closed shells with arbitrary boundary conditions can be established without the need of changing either the equations of motion or the expression of the displacement components. The reliability and accuracy of the proposed method are validated with the FEM results and those from the literature.

References listed at the end of the paper:


ABSTRACT: In this work, we propose two prismatic piezoelectric solid–shell elements based on fully three-dimensional kinematics. For this purpose, we perform electromechanical coupling, which consists in adding an electrical degree of freedom to each node of the purely mechanics-based versions of these elements. To increase
efficiency, these geometrically three-dimensional elements are provided with some desirable shell features, such as a special direction, designated as the thickness, along which the integration points are located, while adopting a reduced integration rule in the other directions. To assess the performance of the proposed piezoelectric solid–shell elements, a variety of benchmark tests, both in static and vibration analysis, have been performed on multilayer structures ranging from simple beams to more complex structures involving geometric nonlinearities. Compared to conventional finite elements with the same kinematics, the evaluation results allow highlighting the higher performance of the newly developed solid–shell technology.

References listed at the end of the paper:


ABSTRACT: In this paper, the effect of the temperature change on the vibration frequency of mono-layer graphene sheet embedded in an elastic medium are studied. Using the nonlocal elasticity theory, the governing equations are derived for single-layered graphene sheets. Using Levy and Navier solutions, analytical frequency equations for single-layered graphene sheets are obtained. Using Levy solution, the frequency equation and mode shapes of orthotropic rectangular nanoplate are considered for three cases of boundary conditions. The obtained results are subsequently compared with valid result reported in the literature. The effects of the small scale, temperature change, different boundary conditions, Winkler and Pasternak foundations, material properties and aspect ratios on natural frequencies are investigated. It has been shown that the non-dimensional frequency decreases with increasing temperature change. The present analysis results can be used for the design of the next generation of nanodevices that make use of the thermal vibration properties of the nanoplates.

References listed at the end of the paper:


**ABSTRACT:** A newly developed theory for the analysis of tapered sandwich panels with laminated anisotropic facings is presented. Unlike sandwich panels of uniform depth, the response of tapered sandwich panels is counterintuitive. For example, prior studies have demonstrated that a tapered cantilever sandwich beam having constant dimensions at the clamped edge and subjected to a tip load has an optimum taper angle where the tip deflection is a minimum. The decrease in tip deflection with increasing taper angle, despite the reduction in core thickness, is due to the participation of the facings in resisting transverse shear loads. In the present work, we systematically develop a tapered sandwich theory that is simple to use, yet accurately predicts the stresses and deflection of both symmetric and nonsymmetric tapered sections. A novel feature of the analytical model is that the elastic rigidities of tapered sandwich composites are expressed in terms of the familiar A, B, and D matrices that are widely used to analyze the response of laminated plates and sandwich beams of uniform depth. It is shown that the stiffness matrix for a tapered sandwich member exhibits a total of 12 elastic couplings that are absent in sandwich beams of uniform depth. The analytical model predicts large interlaminar shear and normal stresses near the root of the tapered sandwich beam, which can cause delamination failure between the facings and the core. Numerical results obtained using the tapered sandwich theory and two-dimensional finite element models are in good agreement for several case studies.

**References listed at the end of the paper:**

ABSTRACT: In this study, critical buckling load analysis for first mode of layered functionally graded shell structures made of silicon nitride (Si3N4)/stainless steel (SUS304) systems is studied. The shell structures are considered as three layers and the layer positions are carried out according to L9 (3^3) orthogonal array. The mechanical properties of the layers are calculated according to a simple rule of mixture of composite materials. The mechanical properties of the layers is assumed to be control factors. Optimum layer levels are obtained using signal to noise (S/N) analysis. Significant layers and their percent contributions on the results are detected using analysis of variance (ANOVA). Maximum buckling load value is carried out based on different arrangements of optimum layer levels.

References listed at the end of the paper:


ABSTRACT: This work researches the stability of cylindrical and conical thin-walled tank shells from the basic level in view of both analysis and previous test results. Detailed discussions on failure modes, numerical simulations and re-investigation of test results have been made. The axisymmetric elastic-plastic buckling phenomena, buckling modes and strengths of meridionally compressed and internally pressurized perfect and imperfect cylindrical and conical shells have been investigated in detail. The effects of imperfection wavelength, location along the meridian, orientation, and amplitude of sinusoidal & local imperfections have been thoroughly studied. The worst possible combined effect of an edge restraint and an imperfection in destabilizing such shells has also been discussed. All results are represented and interpreted in such a way that they can easily be understood and used for design purposes. Simplified expressions are obtained for the prediction of axisymmetric elastic-plastic buckling strength of general thin-walled cylindrical and conical shells under the mentioned loading situations. Design recommendations have been proposed. Comparisons with and critical review of few previous research works have as well been thoroughly carried out.

Detailed investigation of the numerous Gent laboratory test results (obtained about 30 years ago at the Laboratory of Model Testing at Gent University, Belgium) on liquid-filled conical shells, shortly called LFC, that have been made in response to a structural disaster in Belgium along with detailed discussions, explanations, and conclusions have been done. Previous LFC-related research works on nonlinear simulation of liquid-filled conical shells with and without geometric imperfections have as well been discussed and few cases have been re-examined for confirmation and further studying purposes. Relevant explanations and conclusions have been given to the outcomes of those works. Moreover, the Belgium (1972) and Canada (1990) steel water tower failure cases have been carefully examined to check and compare their elastic buckling strengths with the applied loads during failure; and to check for any possible roles played by plasticity effects during the collapse.

Previous research works related to the collapse of the water towers have also been discussed. The notion of a “corresponding cylinder” of a liquid-filled conical shell has been introduced which behaves in exactly the same way as the LFC. Detailed and comprehensive investigation of this “corresponding cylinder” was then made with the simple outcome that the liquid-filled cone behaves like a “wet cylinder”, i.e. with respect to its axisymmetric deformation and buckling behavior.

References listed at the end of the paper:


ABSTRACT: In the present study, a simple four-variable trigonometric shear deformation theory considering the effects of transverse shear deformation and rotary inertia is evaluated for the free vibration analysis of antisymmetric laminated composite and soft core sandwich plates. The theory is displacement-based equivalent single-layer theory in which the in-plane displacements use trigonometric function in terms of thickness coordinate, for calculating out-of-plane shear strains. The number of unknown variables involved in the present theory is only four as against five or more than five in case of other higher order theories. The equations of motion are obtained using the principle of virtual work. A closed-form solution for equations of motion is obtained using the Navier’s solution technique. The effects of side-to-thickness ratio, modular ratio and fibre angle are critically assessed for several problems of laminated composite and sandwich plates. The natural frequencies obtained by using present theory are verified by comparing the results with those of other theories and exact elasticity solution wherever applicable.

References listed at the end of the paper:

22 Kant T and Manjunatha BS. An un-symmetric FRC laminate C3 finite element model with 12 degrees of freedom per node. Eng Comput 1988; 5: 300–308.
55 Thai HT and Vo TP. A new sinusoidal shear deformation theory for bending, buckling, and vibration of functionally graded plates.
ABSTRACT: Laminated composite and sandwich structures are lightweight structures that can be found in many diverse applications especially civil, mechanical and aerospace engineering. The rapid increase in the industrial use of these structures has necessitated the development of new theories that suitable for the bending, buckling and vibration analysis of composite structures. Many review articles are reported in the literature on laminated composite plates and shells in the last few decades. But, in the whole variety of literature very few review articles are available exclusively on laminated composite and sandwich beams. In this article, a critical review of literature on bending, buckling and free vibration analysis of shear deformable isotropic, laminated composite and sandwich beams based on equivalent single layer theories, layerwise theories, zig-zag theories and exact elasticity solution is presented. In addition to this, literature on finite element modeling of laminated and sandwich beams based on classical and refined theories is also reviewed. Finally, displacement fields of various equivalent single layer and layerwise theories are summarized in the present study for the reference of researchers in this area. This article cites 515 references and highlights, the possible scope for the future research on laminated composite and sandwich beams.

References listed at the end of the paper:
[23] Kruszewski ET. Effect of transverse shear and rotatory inertia on the natural frequency of a uniform beam. NACA Technical
Note 1909; 1949.


[151] Frostig Y, Shenhar Y. High-order bending of sandwich beams with a transversely flexible core and unsymmetrical laminated


[444] Kim N, Lee J. Exact solutions for stability and free vibration of thin-walled Timoshenko laminated beams under variable forces.


[454] Sokolinsky VS, Nutt SR. Consistent higher order dynamic equations for soft-core sandwich beams. AIAA J 2004;42(2).


Isaac Elishakoff (Department of Ocean and Mechanical Engineering, Florida Atlantic University, Boca Raton, FL 33431-0991), “JP Den Hartog about SP Timoshenko: Fifty years later”, Mathematics and Mechanix of
Solids, pp 1-8, 2018, DOI: 10.1177/1081286518792959

ABSTRACT: This study is devoted to Jacob Pieter Den Hartog’s views about Stephen Prokopovych Timoshenko. Both were outstanding contributors to the mechanics-based design of structures and machines. Additionally, both were refugees, who were running from hardships in their own countries. Den Hartog ran away from economic hardships that befell the Netherlands after World War I. Timoshenko escaped two Russian revolutions that took place in 1917, in addition to the takeover of Kiev by several armies, including foreign ones, and imminent Soviet rule in Ukraine. Their destinies led them to meet at the Westinghouse Electric Corporation in the USA. This study reviews two prime documents associated with their interaction. The first document is the newly discovered letter sent by Den Hartog to Timoshenko half a century ago, specifically, on the occasion of the latter’s 90th birthday in 1968. The second document is the review of the book As I Remember by SP Timoshenko that Den Hartog published in Science magazine, also in 1968. A complex interrelationship emerges between these two scientists. On the one hand, there is a tremendous appreciation felt by Den Hartog toward Timoshenko; on the other hand, one clearly observes Den Hartog’s disapproval of Timoshenko’s ingratitude to the USA, as expressed in Timoshenko’s autobiography, in numerous passages.

Yanqing Wang and Zhiyuan Zhang (Department of Mechanics, College of Sciences, Northeastern University, Shenyang 110819, China), “Non-local buckling analysis of functionally graded nanoporous metal foam nanoplates”, Coatings, Vol. 8, No. 11, 389, 2018

ABSTRACT: In this study, the buckling of functionally graded (FG) nanoporous metal foam nanoplates is investigated by combining the refined plate theory with the non-local elasticity theory. The refined plate theory takes into account transverse shear strains which vary quadratically through the thickness without considering the shear correction factor. Based on Eringen’s non-local differential constitutive relations, the equations of motion are derived from Hamilton’s principle. The analytical solutions for the buckling of FG nanoporous metal foam nanoplates are obtained via Navier’s method. Moreover, the effects of porosity distributions, porosity coefficient, small scale parameter, axial compression ratio, mode number, aspect ratio and length-to-thickness ratio on the buckling loads are discussed. In order to verify the validity of present analysis, the analytical results have been compared with other previous studies.

References listed at the end of the paper:
6 Catania, G.; Strozzi, M. Damping oriented design of thin-walled mechanical components by means multi-layer coating technology. Coatings 2018, 8, 73.
ABSTRACT: Sandwich beams and plates made of functionally graded materials are widely used in many
engineering industries. Therefore, several modeling techniques and solution methods have been proposed by many researchers for the accurate analysis of functionally graded sandwich structures. This article focuses on the review of research on modeling and analysis of functionally graded sandwich beams using elasticity theory, analytical methods, and numerical methods based on classical and refined shear deformation theories. This article cites 250 references and includes the important suggestions for the future research in the area of analysis of functionally graded sandwich beams.

References listed at the end of the paper:


ABSTRACT: In this work, a modelling strategy based on damage mechanics is presented for Nomex honeycomb core. Application to sandwich beams. The proposed approach is based on the experimental analysis presented by the authors in [1] and consists of the decoupled modelling of the buckling and collapse of cells for the HRH-78 Nomex honeycomb core with two damage parameters. The proposed approach shows good agreement with the experimental tests. The computational cost is low, proving the efficacy of this technique. This strategy may avoid using full 3D models that mimic the real shape and is a step toward a full compression/shear nonlinear model for honeycomb core.

References listed at the end of the paper:

Chien H. Thai (1,2), A.J.M. Ferreira (3), M. Abdel Wahab (4,5) and H. Nguyen-Yuan (6,7)
(1) Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, VietNam
(2) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, VietNam
(3) Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
(4) Institute of Research and Development, Duy Tan University, 03 Quang Trung, Da Nang, Viet Nam
(5) Soete Laboratory, Faculty of Engineering and Architecture, Ghent University, 9000, Ghent, Belgium
(6) Center for Interdisciplinary Research in Technology, Hutech University, Ho Chi Minh City, Viet Nam
(7) Department of Architectural Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul 05006, Republic of Korea

ABSTRACT: This paper presents a moving Kriging meshfree method based on a naturally stabilized nodal integration (NSNI) for bending, free vibration and buckling analyses of isotropic and sandwich functionally graded (FG) plates within the framework of higher order shear deformation theories. A key feature of present formulation is to develop a NSNI technique for the moving Kriging meshfree method. Using this scheme, the strains are directly evaluated at the same nodes as the direct nodal integration (DNI). Importantly, the computational approach alleviates instability solutions in the DNI and decreases significantly computational cost from using the traditional high-order Gauss quadrature. Being different from the stabilized conforming nodal integration (SCNI) scheme which uses the divergence theorem to evaluate the strains by boundary integrations, the NSNI adopts a naturally implicit gradient expansion. The NSNI is then integrated into the Galerkin weak form for deriving the discrete system equations. Due to satisfying Kronecker delta function property of moving Kriging integration (MKI) shape function, the enforcement of essential boundary conditions in the present method is similar to the finite element method. Through numerical examples, the effects of geometries, stiffness ratios, volume fraction and boundary conditions are studied to prove the efficiency of the present approach.

References listed at the end of the paper:
Andreas Apostolatos, Isogeometric analysis of thin-walled structures on multipatch surfaces in fluid-structure interaction”, PhD Thesis, Technical University of Munich, 2018

ABSTRACT: In this thesis, the Isogeometric Analysis (IGA) of thin-walled structures modelled by trimmed Non-Uniform Rational B-Spline (NURBS) multipatches and its application to partitioned Fluid-Structure Interaction (FSI) is detailed. The structural analysis spans from linear two-dimensional elasticity up to three-dimensional geometrically non-linear membrane and Kirchhoff-Love shell analysis. IGA is a modern numerical method for solving Boundary Value Problems (BVPs) which in contrast to the standard Finite Element Method (FEM) uses the exact geometric description of the problem. In the present work, special emphasis is put on the continuity of the solution between trimmed NURBS multipatch surfaces which are standard in Computer-Aided Design (CAD). In this way, no effort is spent in preparing the analysis model as opposed to meshing in standard FEM and smoother approximations of the unknown fields are enabled. The latter is critical for the approximation of problems with high variational index such as the Kirchhoff-Love shell problem. Additionally, surface coupled multi-physics problems such as FSI especially benefit from the smoothness of the solution provided by isogeometric structural analysis. Accordingly, Penalty, Lagrange Multipliers and Nitsche-type methods are detailed and elaborated for the multipatch coupling and the application of weak Dirichlet boundary conditions on such structural models. FSI simulation is of high importance for the prediction of the mutual interaction between a fluid flow and a flexible structure. Typically, the fluid and the structural problems are solved separately while the coupling conditions are satisfied in an iterative manner along their common interface. In this way, the independent use of suitable methods for the discretization of each physical field is enabled. To exploit the benefits of isogeometric structural analysis on multipatches in FSI, a novel isogeometric mortar-based mapping method for real world CAD geometries is elaborated and detailed. Accordingly, field transformations between low order discretized fluid surfaces and trimmed multipatch NURBS representations of the structural surfaces are enabled in order to satisfy the interface constraints. The thesis is complemented with numerical examples in a sequence of increasing complexity, thus extending isogeometric analysis of thin-walled structures on multipatch surfaces to multiphysics problems of the fluid-structure interaction type.

References listed at the end of the thesis:

ABSTRACT: Anisogrid structural elements offer significant advantages over conventional stringer-stiffened analogues due to an exceptional strength and stiffness of unidirectional composite ribs, which are used as the main load-bearing elements. The paper presents a numerical solution for buckling of a sandwich cylindrical shell with composite lattice core loaded with hydrostatic pressure. To model the buckling of the shell, the finite element method is used. A parametric analysis on the effect of the number of helical ribs and the orientation angle on the critical hydrostatic pressure is performed. It is revealed that the local, global or coupled buckling modes can be realized in the buckled shell depending on the geometric parameters of the lattice core structure. The parameters at which the shell provides the maximum mass efficiency are determined.

References listed at the end of the paper:

[13] Li Z M and Qiao P 2015 Buckling and postbuckling of anisotropic laminated cylindrical shells under combined external pressure.

The governing differential equations are derived based on the second Piola-Kirchhoff stress tensor and are reduced to a homogenous linear system of equations using differential quadrature method (DQM). The buckling pressures have been calculated for the shell with isotropic core and orthotropic face sheets with 0-degree orientation with respect to the hoop direction. Moreover, buckling pressure reduction parameter has been defined and computed for different imperfection parameters of face sheets and geometrical properties of sandwich shells. The results obtained in the present work are compared with finite element solutions and results reported in the literature and very good agreements have been observed. It is shown that the imperfections have higher effects on the buckling load of thick shells than thin ones. Likewise, it is found that the present method can capture the various geometrical imperfections observed during the manufacturing process or service life.

References listed at the end of the paper:


ABSTRACT: A new analytical solution is presented for functionally graded (FG) beams to investigate the bending behaviour under the hygro-thermo-mechanical loading using a new fifth order shear and normal deformation theory (FOSNDT). The material properties of the FG beam are varied along the thickness direction according to the power law index. In the present theory, a polynomial shape function is expanded up to fifth-order in terms of thickness coordinate to consider the effects of transverse shear and normal deformations. The present theory is free from the shear correction factor. Using the Navier’s solution technique the closed-form solution is obtained for simply supported FG beams. All the results are presented in non-dimensional form and validated it by developing the classical beam theory (CBT), first order shear deformation theory (FSDT by Mindlin) and third order shear deformation theory (TSDT by Reddy) considering the hygro-thermo-mechanical loading effects which is mostly missing in the literature. It is noticed that the presented FOSNDT is very simple and accurate to predict the bending behaviour of FG beams under linear and non-linear hygro-thermo-mechanical loadings.

References listed at the end of the paper:


References listed at the end of the paper:


Develop new guidelines for sandwich composite cylindrical, conical, and cylindrical composite shells. The buckling behaviour and imperfection sensitivity have to be fully understood in order to section sensitivity has to be fully understood in order to

I. Elishakoff, J. Kaplunov and E. Kaplunov, “Galerkin’s Method was not Developed by Ritz, Contrary to the Timoshenko’s Statement”, Chapter 5 in Andrei Abramian, Igor Andrianov and Valery Gaiko (Editors), Nonlinear Dynamics of Discrete and Continuous Systems, Springer, 2021, 276 pages

ABSTRACT: In the context of its title, this paper we discuss two letters sent to S. P. Timoshenko (1878–1972), as well as a letter of response sent by Timoshenko to Grigolyuk. B. G. Galerkin (1871–1945) is the author of the first letter to S. P. Timoshenko. Second letter to him is by E. I. Grigolyuk. The letters are concerned with the method known as the Galerkin method (in the West), or the Bubnov-Galerkin method or the Bubnov method (in Russia). The letters are fully reproduced here in English translation. Their originals in Russian language are stored at the Timoshenko Archive at Stanford University. The copies of the originals are also obtainable from the authors. Galerkin’s letter appears to be the only document until now where B. G. Galerkin relates to this method, apart from his 1915 paper. The author of the second letter is E. I. Grigolyuk (1923–2005). Grigolyuk suggests to Timoshenko to co-author a paper on the priority associated with the Galerkin method, claiming that it belongs solely to I. G. Bubnov (1872–1919). Although a joint paper by Timoshenko and Grigolyuk was never written, Timoshenko expressed an interest in such an endeavor. These correspondents, namely, B. G. Galerkin, S. P. Timoshenko, and E. I. Grigolyuk have made important contributions to theoretical and applied mechanics of the last century, and their interaction appears to be of interest to the mechanics community. This paper is devoted to their correspondence concerning the priority of authorship, that was questioned by both S. P. Timoshenko and E. I. Grigolyuk, albeit in a different manner.


ABSTRACT: Cylindrical shells and conical shells have been analysed and tested separately for the last decade. However, due to new manufacturing techniques and the use of composite material systems more complex structures can be made. By combining a cylindrical shell and a conical shell one structural component can be created: a cylindrical-conical shell. This is a potential design solution for launch vehicle structures, but there is limited research available about it. Not much is known about the buckling behaviour or imperfection sensitivity of these structures, especially not for sandwich composite shells. Moreover, there are no design guidelines for the buckling of sandwich composite cylindrical-conical shells. SP-8007 and SP-8019 are commonly used guidelines for the design of launch vehicle structures; however, these are only valid for cylindrical shells and conical shells separately. These guidelines also only address composite shells and do not account for sandwich composite shells. The buckling behaviour and imperfection sensitivity has to be fully understood in order to develop new guidelines for sandwich composite cylindrical, conical, and cylindrical-conical shells. Therefore,
the purpose of this research is to better understand the buckling behaviour and imperfection sensitivity of sandwich composite cylindrical, conical, and cylindrical-conical shells. The research focuses on using finite element analysis to study the buckling behavior and imperfection sensitivity of the shells. Models are created of the sandwich composite cylindrical shell, conical shell, and cylindrical-conical shell. Different modelling techniques are compared to find out how to represent a sandwich composite shell. This is done by performing an element study, a mesh convergence study, and a study on the analysis parameters. Moreover, the buckling behavior of the individual shells are compared with the buckling behavior of the combined structure. Different shell geometries such as height of the cone, angle of the cone, and radius of curvature at the transition are used for the comparison. To further investigate the difference between the shells, both linear and non-linear analyses are performed. A comparison is made between the buckling loads, mode shapes, and force-displacement graphs. To investigate the imperfection sensitivity of the different shells, axisymmetric and eigenmode imperfections are added using different amplitudes based on a percentage of the wall thickness.

From the results it could be observed that the buckling behavior of the sandwich composite cylindrical and conical shells without initial imperfections can be captured by both the eigenvalue analysis and the dynamic implicit analysis. However, for the sandwich composite cylindrical-conical shell the eigenvalue analysis is not able to accurately capture the highly non-linear behavior. This can be explained due to the large radial displacement happening at the transition area for the dynamic implicit analysis. The result of this is that the dynamic implicit analysis model is less stiff compared to the eigenvalue analysis model resulting in a lower buckling load. In order to investigate if the non-linear behavior at the interface (location where the conical shell intersects with the cylindrical shell) can be mitigated, a radius of curvature was added to the structure. This was done in order to create a smooth transition at the interface. From the results it could be seen that by adding a radius of curvature the difference between the eigenvalue analysis and dynamic analysis decreased. Moreover, a reinforcement was added to the structure to stiffen the structure at the interface. The results show that this indeed mitigates the non-linear behavior and can give a dynamic implicit buckling load close to the eigenvalue analysis buckling load. From these results it can be concluded that if the non-linear effects are mitigated, the eigenvalue analysis is able to give a buckling load prediction of the sandwich composite cylindrical-conical shell. Moreover, the imperfection sensitivities were compared for the different shells. A similar imperfection sensitivity to geometrical imperfections was observed for the cylindrical shell and conical shell. However, when looking at the imperfection sensitivity of the cylindrical-conical shell it could be seen that the shell is not as sensitive to geometrical imperfections. This can be explained by the fact that the behavior at the transition is dominating the buckling behavior of the whole structure. The results obtained from the thesis show the importance of the non-linear behavior at the transition for the sandwich composite cylindrical-conical shell. This means that for further research it is important that the non-linear effects are included when analysing such a structure.

References listed at the end of the thesis:

References listed at the end of the paper:


ABSTRACT: Protein microtubules are one of the most effective intracellular components. The microtubules structure is in a manner that their behaviour is similar to that of the orthotropic materials. Therefore, in this paper, size-dependent vibration of the anisotropic protein microtubule is studied. For this purpose, using a first shear deformable shell model and based on couple stress theory, new equations are developed for the dynamic behavior of anisotropic protein microtubule. After solving the governing equations of microtubule motion, the effects of cytoplasm environment, microtubule dimensions and its mechanical properties, and material length scale parameters on the natural frequency of microtubules are investigated.

References listed at the end of the paper:

1 Hawkins, T., Mirigian, M., Yasar, M. S., and Ross, J. L. Mechanics of microtubules, Journal of Biomechanics, 43 (1), 23–30,

46 Taj, M. and Zhang, J. Analysis of wave propagation in orthotropic microtubules embedded within elastic medium by Pasternak


Yuzhen Chen and Lihua Jin (Department of Mechanical and Aerospace Engineering, University of California, Los Angeles, CA 90095, USA), “From continuous to snapping-back buckling: A post-buckling analysis for hyperelastic columns under axial compression”, International Journal of Non-Linear Mechanics, Vol. 125, Article ID 103532, 2020

ABSTRACT: Since Euler’s elastica, buckling of straight columns under axial compression has been studied for more than 260 years. A low width-to-length ratio column typically buckles at a critical compressive strain on
the order of 1%, after which the compressive load continuously increases with the displacement. Here using a general continuum mechanics-based asymptotic post-buckling analysis in the framework of finite elasticity, we show that a straight hyperelastic column under axial compression exhibits complex buckling behavior. As its width- to-length ratio increases, the column can undergo transitions from continuous buckling, like the Euler buckling, to snapping-through buckling, and eventually to snapping-back buckling. The critical width-to-length ratios for the transitions of buckling modes are determined analytically. The effect of material compressibility on the buckling modes and their transitions is further investigated. Our study provides new insights into column buckling.

References listed at the end of the paper:

The 1729 book by Musschenbroek is entitled: "Physicae experimental et geometricae dissertations" and includes a section in Chapter 9 on Strength of Solids under the title, "Introductio ad cohaerentiam corporum firmorum". The studies on resistance of columns under compression are included in this chapter.

Luis A. Godoy (1) and Isaac Elishakoff (2)
(1) Institute of Advanced Studies in Engineering and Technology, Science Research Council of Argentina and National University of Cordoba, Cordoba, Argentina; and Department of Mechanical and Aerospace Engineering, West Virginia University, Morgantown, West Virginia, USA
(2) Department of Ocean and Mechanical Engineering, Florida Atlantic University, Boca Raton, Florida, USA

ABSTRACT: This paper concentrates on the work by Petrus van Musschenbroek published in 1729, constituting apparently the first study in the literature on column buckling. To understand the significance of Musschenbroek's contribution, we provide the combined personal, historic and scientific contexts in which he carried out his studies; he was the first researcher to deal with the failure of compressed elements as a new phenomenon. Most unfortunately, his name is not currently known except for a small circle of historians of science, whereas engineering students at present are told that buckling should be associated with the name of Leonhard Euler. We fully share the idea of Benvenuto stating that "Musschenbroek's experimental law is of considerable historical interest". The contributions in his 1729 book are shown not only to include his experimental work but Musschenbroek also devised a design procedure for column buckling. The 1729 book by Musschenbroek is entitled: "Physicae experimental et geometricae dissertations". This 1729 book contains a section in Chapter 9 on Strength of Solids under the title, "Introductio ad cohaerentiam corporum firmorum". The studies on resistance of columns under compression are included in this chapter.

Yangkun Du (1,2), Chaofeng Lue (3,4,5), Congshan Liu (3), Zilong Han (1), Jian Li (1), Weiqiu Chen (1,4,5), Shaoxing Qu (1,4,5) and Michel Destrade (1,2)
ABSTRACT: Initial residual stress is omnipresent in biological tissues and soft matter, and can affect growth-induced pattern selection significantly. Here we demonstrate this effect experimentally by letting soft tubes grow in the presence or absence of initial residual stress and by observing different growth pattern evolutions. These experiments motivate us to model the mechanisms at play when a growing bilayer tubular organ spontaneously displays buckling patterns on its inner surface. We demonstrate that not only differential growth, geometry and elasticity, but also initial residual stress distribution, exert a notable influence on these pattern phenomena. Prescribing an initial residual stress distribution offers an alternative or a more effective way to implement pattern selection for growable bio-tissues or soft matter. The results also show promise for the design of 4D bio-mimic printing protocols or for controlling hydrogel actuators.

References listed at the end of the paper:
ABSTRACT: This present paper concerned with the analytic modelling for vibration of the functionally graded (FG) plates resting on non-variable and variable two parameter elastic foundation, based on two-dimensional elasticity using higher shear deformation theory. Our present theory has four unknown, which mean that have less than other higher order and lower theory, and we denote do not require the factor of correction like the first shear deformation theory. The indeterminate integral are introduced in the fields of displacement, it is allowed to reduce the number from five unknown to only four variables. The elastic foundations are assumed a classical model of Winkler-Pasternak with uniform distribution stiffness of the Winkler coefficient (kw), or it is with variables distribution coefficient (kw). The variable’s stiffness of elastic foundation is supposed linear, parabolic and trigonometry along the length of functionally plate. The properties of the FG plates vary according to the thickness, following a simple distribution of the power law in terms of volume fractions of the constituents of the material. The equations of motions for natural frequency of the functionally graded plates resting on variables elastic foundation are derived using Hamilton principal. The government equations are resolved, with respect boundary condition for simply supported FG plate, employing Navier series solution. The extensive validation with other works found in the literature and our results are present in this work to demonstrate the efficient and accuracy of this analytic model to predict free vibration of FG plates, with and without the effect of variables elastic foundations.

References listed at the end of the paper:


https://doi.org/10.1061/(ASCE)EM.1943-7889.0000665.


https://doi.org/10.1016/j.ast.2016.05.009.


Winkler, E. (1867), Die Lehre von der Elasticitaet und Festigkeit, Prag Dominicus.


Perampalam Gatheeshgar (1), Keerthan Poologanathan (1), Shanmugananthan Gunalan (2), Brabha Nagaratnam (1), Konstantinos Daniel Tsavardidis (3) and Jun Ye (4)
(1) Dept. of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne, UK
(2) School of Engineering and Built Environment, Griffith University, Gold Coast, Australia
(3) School of Civil Engineering, University of Leeds, UK
(4) Dept. of Civil and Environmental Engineering, Imperial College London, UK

“Structural behaviour of optimised cold-formed steel beams”, Steel Construction – Design and Research, September 2019

ABSTRACT: Cold-formed steel (CFS) members have been significantly employed in light gauge steel buildings due to their inherent advantages. Optimising these CFS members in order to gain enhanced load bearing capacity will result in economical and efficient building solutions. This research presents the
investigation on the optimisation of CFS members subjected to flexural capacity and results. The optimisation procedure was performed using Particle Swarm Optimisation (PSO) method while the section moment capacity was determined based on the effective width method adopted in EN1993-1-3 (EC3). Theoretical and manufacturing constraints were incorporated while optimising the CFS cross-sections. In total, four CFS sections (Lipped Channel Beam (LCB), Optimised LCB, Folded-Flange and Super-Sigma) were considered including novel sections in the optimisation process. The section moment capacities of these sections were also obtained through non-linear Finite Element (FE) analysis and compared with the EC3 based optimised section moment capacities. Results show that compared to the commercially available LCB with the same amount of material, the novel CFS sections possess the highest section moment capacity enhancements up to 65%. In addition, the performance of these CFS sections subject to shear and web crippling actions were also investigated using non-linear FE analysis.

References listed at the end of the paper:
[27] American Iron and Steel Institute (AISI), Specifications for the cold-formed steel structural members, cold-formed steel design
mechanical loads but rather by the stimulus provided by a non-active origami structures.

Researchers have become interested in the use of components that are easy to manufacture (sheets, plates, etc.) into three-dimensional structures. More recently, researchers have become interested in the use of active materials that convert various forms of energy into mechanical work to produce the desired folding behavior in origami structures. Such structures are termed active origami structures and are capable of folding and/or unfolding without the application of external mechanical loads but rather by the stimulus provided by a non-mechanical field (thermal, chemical,

---

Edwin A. Peraza Hernandez, Darren J. Hartl and Dimitris C. Lagoudas (Department of Aerospace Engineering, Texas A&M University, College Station, USA, “Introduction to Active Origami Structures”. In: Active Origami, pp 1-53, Springer, Cham, 2019. https://doi.org/10.1007/978-3-319-91866-2_1

ABSTRACT: Origami, the ancient art of paper folding, has inspired the design and functionality of engineering structures for decades. The underlying principles of origami are very general, it takes two-dimensional components that are easy to manufacture (sheets, plates, etc.) into three-dimensional structures. More recently, researchers have become interested in the use of active materials that convert various forms of energy into mechanical work to produce the desired folding behavior in origami structures. Such structures are termed active origami structures and are capable of folding and/or unfolding without the application of external mechanical loads but rather by the stimulus provided by a non-mechanical field (thermal, chemical,
electromagnetic). This is advantageous for many areas including aerospace systems, underwater robotics, and small scale devices. In this chapter, we introduce the basic concepts and applications of origami structures in general and then focus on the description and classification of active origami structures. We finalize this chapter by reviewing existing design and simulation efforts applicable to origami structures for engineering applications.

References listed at the end of the paper:


162. Q. Ge, C.K. Dunn, H. J. Qi, M.L. Dunn, Active origami by 4D printing. Smart Mater. Struct. 23(9), 094007 (2014)


This paper investigates the free vibration and compressive buckling characteristics of functionally graded graphene nanoplatelets reinforced composite beams with open edge cracks. Materials, Vol. 12, 1412, 2019

ABSTRACT: This paper investigates the free vibration and compressive buckling characteristics of functionally graded graphene nanoplatelets reinforced composite (FG-GPLRC) beams containing open edge cracks by using the finite element method. The beam is a multilayer structure where the weight fraction of graphene nanoplatelets (GPLs) remains constant in each layer but varies along the thickness direction. The effective Young’s modulus of each GPLRC layer is determined by the modified Halpin-Tsai micromechanics model while its Poisson’s ratio and mass density are predicted according to the rule of mixture. The effects of GPLs distribution pattern, weight fraction, geometry, crack depth ratio (CDR), slenderness ratio as well as boundary conditions on the fundamental frequency and critical buckling load of the FG-GPLRC beam are studied in detail. It was found that distributing more GPLs on the top and bottom surfaces of the cracked FG-GPLRC beam provides the best reinforcing effect for improved vibrational and buckling performance. The fundamental frequency and critical buckling load are also considerably affected by the geometry and dimension of GPL nanofillers.

References listed at the end of the paper:


Yan, T.; Yang, J.; Kitipornchai, S. Nonlinear dynamic response of an edge-cracked functionally graded Timoshenko beam under

Tomaz P. Drumond, Marcelo Greco, Carlos A. Cimini Jr. and Eduardo B. Medeiro (Department of Structural Engineering, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil), “Evaluation of alternative materials in a wing fixed leading edge to support UAS impact”, Proceedings of the XL Ibero-Latin American Congress on Computational Methods in Engineering (XL CILAMCE), Natal/RN, Brazil, 11-14 November 2019

ABSTRACT: In aeronautics, the risk of an airborne impact between an aircraft and other elements such as birds, hails and other small vehicles must be evaluated. The impact of an Unmanned Aerial Systems (UAS), for example, can be more critical for an aircraft than a bird strike, as reported in a study published by the Federal Aviation Administration (FAA) in 2016. In order to make structures withstand impact with stiffer elements and minimize the increase in their weight, new aircrafts have to be reinforced with alternative materials. In the present paper, a commercial aircraft Wing Fixed Leading Edge (WFLE) reinforced with a triangular structure and other reinforced with sandwich structure made up of aluminum plies and a hexweb aluminum flexcore are subjected to an impact with an UAS. It will be verified if the lithium-ion battery from the small vehicle would penetrate into the airframe when the impact occurs at the airliner cruising speed. The UAS considered is a quadcopter configuration intended for recreational and commercial aerial photography with a 1.2 kg mass. The UAS components were proportionally increased in order to make the small vehicle to be similar to a 1.8kg bird prescribed in requirement FAR 25.571(e). The impact analyzes will be carried out using explicit finite element models of NASTRAN software. The HYPERMESH software will be used for generating finite elements mesh. The Lagrangian approach will be used to model the UAS and the WFLE. For strength analysis of WFLE skin elements will be adopted the Johnson-Cook failure model based on deformations.

References listed at the end of the paper:
J. Michael T. Thompson (1) and Lawrence N. Virgin (2)
(1) Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge CB3 0WA, UK
(2) School of Engineering, Duke University, Durham, NC 27708, USA


ABSTRACT: Nonlinear bifurcations and instabilities of autonomous nonconservative systems, mainly involving the fluid loading of a solid or structure, are reviewed and described in this accessible, pictorial overview. In contrast to the earlier papers in this series (focusing on the instability of elastic deformable systems, and low-order periodically-forced mechanical systems), we focus on a handful of case studies in which the loss of stability is primarily driven by nonconservative forces, i.e. path-dependent forces not associated with a potential. Many systems involving fluid-structure interaction can lose stability under changing conditions in which there is a net flow of energy from the fluid to the structure, sometimes resulting in growing oscillatory behavior. Again, the generic manifestations of instability typically occur within the framework of bifurcation theory. Progression is from simple local bifurcations to more complex global events, and all are related to instructive and intriguing applications. Hopf bifurcations are presented in the context of the galloping and flutter of cables and pipes. Next, Neimark bifurcations appear in aircraft applications involving the free-play fluttering of aerofoils and the wing rock of the Harrier jump-jet. Turning to ships in wind and waves, a homoclinic saddle connection governs the surfing and surf-riding of a vessel in stern seas, while an omega flow explosion can compromise the course-keeping of a passenger ferry in a side wind. Recent work on the dynamic step-buckling of a spherical shell illustrates the role of a center manifold, and the paper ends with a careful study of dissipation-generated instabilities, drawing on the historical struggles to understand the evolution of spinning liquid planets.

References listed at the end of the paper:


Edgars Labans and Chiara Bisagni (Delft University of Technology, Delft, Netherlands), “Buckling of 3D-printed cylindrical shells with corrugated surface”, AIAA SCI-Tech Meeting, January 2020 ABSTRACT: 3D-printing technology opens broad possibilities to manufacture structural shapes which could not be always possible by other methods. In the field of lightweight shells it allows to investigate structures with higher buckling loads than conventional shells. The buckling behavior of 3D-printed shells is studied in this
paper where the shape of the cylindrical shells is modified by adding corrugation in the axial or circumferential directions. The shells are characterized by the amplitude of the corrugation and the number of the sinusoidal waves. Their elastic mechanical behavior is analyzed up to the buckling load. The numerical analysis shows that the modified surface can significantly improve the buckling load and reduces the sensitivity towards geometric imperfections. Prototypes of the shells were manufactured and tested to validate the numerical model. Regardless the experimental scatter, the average buckling load of the optimized corrugated shell twice exceeds the buckling load of the reference circular shell. At the same time stiffness and mass of the shell remain the same.

References listed at the end of the paper:

Vibin John (1) and Ramesh Kumar Radhakrishna Reddiar (2)
(1) College of Engineering Trivandrum, Thiruvananthapuram, India, 695016
(2) Government Engineering College Barton Hill, Thiruvananthapuram, India, 695035

ABSTRACT: Analytical equation for critical buckling stress of metallic sandwich shell is derived based on well-known Nemeth’s analytical solution for buckling stress of composite monocoque cylindrical shell incorporating the bending rigidity for the sandwich construction. A good agreement for the predicted critical buckling load with finite element analysis result for different geometric parameters is achieved for a rigid core sandwich. Once critical buckling stress of a monocoque shell is obtained based on Nemeth’s solution, then for the sandwich shell the buckling stress can be predicted following a factor of 0.9 (hc/t).

References listed at the end of the paper:

Ebrahim Nazarimofrad (1) and Mehdi Barang (2)
(1) Department of Civil Engineering, Hamedan, Iran
(2) Department of Civil Engineering, Eslamshar, Iran


ABSTRACT: The objective of this paper is to assess the in-plane shear buckling of a steel foam sandwich panel that relies on elastic Pasternak foundation. The panel is a combination of solid steel face sheets and foamed steel cores. Foamed steel, that is steel with internal voids, provides enhanced bending rigidity and energy dissipation, and also, the potential to reduce local buckling. The Classic plate theory is employed where their governing equations are solved by the Rayleigh–Ritz method. Uniformly distributed in-plane shear loads are applied to the two opposite edges of the panel and all the four edges of the panel are simply supported. Finally, the effects of the panel parameters, such as the existence of a Pasternak foundation, aspect ratios, and central fraction of the steel foam core, are presented. The results showed that the optimum central fraction of the steel foam core would be 65%, so that the maximum critical shear buckling load has taken place.

References listed at the end of the paper:
ABSTRACT: The present research deals with post-buckling analysis of geometrically perfect/imperfect honeycomb core sandwich panels having graphene platelet (GPL) reinforced face sheets based on general higher order plate model. Honeycomb sandwich panels are often made of aluminum material having low weight but also low stiffness. Here, the application of GPL-reinforced nano-composites as face sheets of sandwich panels has been proposed to enhance their mechanical performance. GPL distributions are considered as uniform and linear models in the face sheets. GPL volume and weight fractions are incorporated to Halpin-Tsai modeling of a nano-composite material. Adopting a general higher order plate theory with five field variables, it is possible to satisfy shear deformation influences needless of adding correction factors. Based on Gibson technique, the hexagonal honeycomb core is equalized with a solid core. Post-buckling load of the sandwich panel has been analytically derived and it is showed that the obtained post-buckling load is dependent on the core thickness, face sheet thickness, cell wall thickness of the core, GPL dispersion in the face sheets and also geometrical imperfection.

Guanping Zou (1), Yuyang Wang (1), Qichao Xue (1,2) and Chunwei Zhang (2)
(1) College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin 150001, China
(2) Department of Civil Engineering, Qingdao University of Technology, Qingdao, China

ABSTRACT: This paper discusses a global buckling analysis approach for sandwich plates with stiffening ribs. The approach is based on theoretical study and is implemented by the finite element method (FEM). The equilibrium equation corresponding to critical global buckling of the sandwich plate with stiffening ribs under simple supported boundary condition is established by the energy method. The critical buckling solutions for a typical rectangular sandwich plate system (SPS) with a single stiffening rib in the longitudinal direction are then investigated while varying the potential influencing factors. The shear rigidity within the inner core exerts little effect on global buckling and can be neglected. An FEM study on elastic buckling was then conducted via ANSYS software. The advantages of the SPS were highlighted via its elastic eigenvalue buckling numerical analysis with multiple stiffeners. The ultimate buckling loads were computed similarly for different influential factors. Finally, an SPS specimen was tested in a compression test. The results showed that when the rib spacing is large, the local buckling of the plates in the grillage is controllable and the SPS is more resistant to both local and global buckling. The results based on our theoretical method agreed well with those of the FEM and experimental results.

References listed at the end of the paper:
ABAQUS and other works, showing a good agreement with each other. A parametric study is then carried out.

**ABSTRACT:** In this paper, a new analytical approach is developed for buckling of composite sandwich pipes with iso-grid core under uniform external lateral pressure. Firstly, the stiffness contributions of iso-grid cores are evaluated through the new force and moment effect analysis. Then, iso-grid core is transformed into a solid pipe, as the middle layer of the sandwich pipe. The outer, inner, and middle pipes are transformed into an equivalent single-walled pipe. Therefore, composite sandwich pipe with iso-grid core is equalized with a single-walled pipe of the same stiffness. The Rayleigh–Ritz energy method is used to calculate the critical buckling pressure of the composite sandwich pipes with iso-grid cores. The efficiency and accuracy of the presented approach are confirmed by comparing the analytical solutions with finite element results obtained from ABAQUS and other works, showing a good agreement with each other. A parametric study is then carried out.
to investigate the effect of the scale of the structure, outer and inner pipes ply stacking sequence, radius to total thickness ratio, stiffener to outer and inner pipe thicknesses ratio, and stiffener angle on the buckling of sandwich pipes. Finally, applications of the present approach were demonstrated for designing of tendons toward constant various structural applications such as offshore pipelines.

Baeem B. Al-Masoudy (1) and Laith K. Al-Hadithy (2)
(1) Directorate General of Electrical Transmission Projects, Baghdad, Iraq
(2) Civil Engineering Department, Al-Nahrain University, Baghdad, Iraq


ABSTRACT: Folded plates have attracted profound interest in recent years because of their economic advantages and architectural appearance. In particular, their basic structural response is indeed logical enough, explicit and simple although its required numerical computation procedure is, in a little bit, boring. This type of structures have gained increasing popularity and offers more advantages than more complex structures, such as cylindrical shells, arches and right folded plate frames. Similarly, the thin-walled cellular bridge decks can be treated as a multi-folded plates structure. This study produces an overall review of the historical development of the most popular methods utilized for analysis the folded plate structures which are offered with their applications and how these methods are developed gradually. Four common methods are chosen in this paper to show their highlights of references particularizing in analysis of the above mentioned types of structure; the folded plate elasticity method (FPEM), finite element method (FEM), finite strip method (FSM) and spline finite strip method (SFSM). This investigation covers the elastic behavior, and the experimental researches on the elastic reaction of folded plate structures.

References listed at the end of the paper:
277–287.


1–11.


[64] Wah-yuk Li 1988 Spline finite strip analysis of arbitrarily shaped plates and shells Ph.D. Thesis University of Hong Kong (Pokfulam: Hong Kong)


[70] Abdul-Razzak A 1987 Solution of simply supported and continuous box-girder bridges using higher order finite strip method M. Sc. Thesis (University of Musul: Iraq)


[75] Ng S F and Chen X 1993 Analysis of arbitrary mindlin plates or bridge decks by spline finite strip method Computers & Structures 54 111-118.


[77] Senthilvasan J, Thambiratnam D P and Brameld G H 1996 Dynamic response of curved box girder bridges Proc. 2nd Int. Conf. in Civil Engineering on Computer Application, Research and Practice Univ. of Bahrain (Manama: Bahrain)


Nikolai Kleinfeller (1), Joachim Bos (1) and Tobias Melz (2)

(1) System Reliability, Adaptive Structures, and Machine Acoustics SAM, TU Darmstadt, Germany

(2) Fraunhofer Institute for Structural Durability and System Reliability LBF, Germany


ABSTRACT: The STructural Intensity (STI) describes the energy flow of structure-borne sound within a vibrating structure. For complex structures, the STI is usually obtained from a finite element analysis. At the present time, if structures with arbitrary shapes are considered a measurement procedure for validation purposes is not sufficiently developed. For this reason, a measurement procedure for determining the STI of arbitrarily shaped thin-walled structures is developed within the framework of this research project. This paper deals with the measurement of the STI of a curved shell structure by means of 3D laser vibrometry. Therefore, a measurement procedure is set up that consists of measurement data acquisition, measurement data processing, and a general STI calculation. In this context, the challenges of the measurement procedure should be emphasized, if the structures are not flat but curved. In addition to the flexural vibrations, the extensional
vibrations must also be recorded simultaneously. In the case of curved structures, knowledge of the curvature properties is necessary in addition to the structural vibrations. Finally, the results are compared to the STI obtained from the virtual data of a finite element analysis.

References listed at the end of the paper:


ABSTRACT: Computational modal analysis is usually carried out without consideration of gravity forces. This is well motivated for many structures. However, the vibrational properties of thin-walled plane or shallow shell structures are very sensitive with respect to small modifications of the shell geometry and with respect to in-plane stress and reinforcement. One reason for these in-plane stresses and geometric modifications consists in gravity. This becomes an important issue when using test data obtained under the presence of gravity to update a simulation model where the influence of gravity is neglected. This study investigates the influence of gravity on the modal parameters of a thin rectangular plate and of a thin-walled cubic box. For that, different simulation models are used. While all of them utilize the finite element method, linear and non-linear approaches are
compared. The latter take into account geometrical nonlinearities due to large deformations and the influence of gravity induced stress.

References listed at the end of the paper:

received a major boost due to the popularity of the isogeometric concept [1], along with finite element methods using NURBS or B-Splines as shape functions. Here, one of the decisive features is a relatively easy control of polynomial degree and continuity of shape functions, facilitating discretization of problems for which the weak form has a variational index of 2 or larger, for instance, the classical Kirchhoff-Love thin shell model. Another, most often mentioned feature of isogeometric analysis is the use of “exact” geometry from CAD for computation. Own preliminary studies for buckling and wrinkling analyses of shells and membranes show, that isogeometric shell formulations may provide superior accuracy compared to standard shell finite elements in detecting both critical load levels and physical buckling or wrinkling patterns. That is, isogeometric shell formulations may require only a fractional amount of degrees of freedom for the same level of accuracy obtained with a fine finite element mesh. In this contribution, the reasons for this discrepancy are investigated in a systematic way, i. e., we study the influence of (exact) geometry, polynomial degree, smoothness/continuity and locking effects on the accuracy of results.

References listed at the end of the paper:


ABSTRACT: Global changes of cell shape under mechanical or osmotic external stresses are mostly controlled by the mechanics of the cortical actin cytoskeleton underlying the cell membrane. Some aspects of this process can be recapitulated in vitro on reconstituted actin-and-membrane systems. In this paper, we investigate how the mechanical properties of a branched actin network shell, polymerized at the surface of a liposome, control membrane shape when the volume is reduced. We observe a variety of membrane shapes depending on the actin thickness. Thin shells undergo buckling, characterized by a cup-shape deformation of the membrane that coincides with the one of the actin network. Thick shells produce membrane wrinkles, but do not deform their outer layer. For intermediate micrometer-thick shells, wrinkling of the membrane is observed, and the actin layer is slightly deformed. Confronting our experimental results with a theoretical description, we determine the transition between buckling and wrinkling depending on the thickness of the actin shell and the size of the liposome. We thus unveil the generic mechanism by which biomembranes are able to accommodate their shape against mechanical compression, through thickness adaptation of their cortical cytoskeleton.

References listed at the end of the paper:


Quasay A. Al-Kaseasbeh, “Hysteretic behavior of thin-walled steel tubular columns under constant axial force and cyclic lateral loading”, PhD Dissertation, University of North Dakota, May 2019

ABSTRACT: Thin-walled steel tubular bridge piers (column refers to “bridge pier” in the subsequent text) with either circular and square box cross sections are becoming an increasingly attractive choice as cantilever bridge piers in severe earthquake regions due to their architectural, structural and constructional advantages. However, thin-walled steel tubular columns are vulnerable to local buckling, global buckling or interaction between both under extreme loading events such as strong earthquakes. This buckling results in a significant strength and ductility degradation, which eventually leads to an early and full collapse of the thin-walled steel tubular columns. The work presented in this dissertation investigates the inelastic structural behavior of uniform and newly proposed graded-thickness thin-walled steel tubular circular and square box columns under a constant axial force as a superstructure dead load and uni/bidirectional cyclic lateral loading. First of all, the adopted finite element model (FEM) in ABAQUS/Standard version 6.14, which takes into account the effect of both material and geometric nonlinearities, is verified with the experimental results reported in the literature and
employed for the analysis. Second, the newly proposed graded-thickness column, with size and volume of material equivalent to the BB column, is evaluated under a constant axial force and uni/bidirectional cyclic lateral loading. The proposed graded-thickness column is proved to have significant improvements in the overall hysteretic behavior compared to its counterpart conventional uniform column. Then, the deterioration of the circular bidirectional cyclic loading path over the unidirectional path is emphasized. Finally, a comprehensive parametric study is carried out to investigate the effect of key design parameters including: radius-to-thickness ratio parameter (R_t), width-to-thickness ratio parameter (R_w), column slenderness ratio parameter (λ), magnitude of axial load (P/P_y), and number of loading cycles (N) on the overall hysteretic behavior of uniform and graded-thickness columns under a constant axial force and uni/bidirectional cyclic lateral loading. Subsequently, design formulae have been derived to predict the ultimate strength and ductility of both uniform and proposed graded-thickness columns.

References listed at the end of the dissertation:


The purpose of present study is to improve the application of GM approach for both beam-columns without intermediate lateral-torsional restraints and with these restraints. The results from the proposed GM are compared with those from Eurocode 3-1-1 interaction equations according to Method 1 and Method 2. A better consistency between the developed GM approach and the Eurocode's interaction equation approach than Eurocode 3 GM approach is observed.

References listed at the end of the paper:


M. A. Gizejowski, Z. Stachura, A consistent Ayrton-Perry approach for the flexural-torsional buckling resistance evaluation of steel I-section members, CEER, 2, 89-105 (2017)

Z. Stachura, M. A. Gizejowski, An alternative analytical-numerical procedure in Eurocode's design of steel members with discrete lateral and torsional in-span restraints [in Polish], ICEEA, 64, 471-486 (2017)


M. Nedelcu, Generalisation of the Ayrton-Perry formula for the global-distortional-local buckling of thin-walled members, Thin-Walled Struct., 118, 73-86 (2017)


F. Mohri, Ch. Bouzerira M. Potier-Ferry, Lateral buckling of thin-walled beam-column elements under combined axial and bending loads, Thin-Walled Struct., 46, 290-302 (2008).


Z. Stachura, M. A. Gizejowski, Partial factors in modelling of steel structures reliability according to Eurocodes, CEER, 16, 195-207 (2015)

Hong-Xia Shen (School of Civil Engineering, Xi’an University of Architecture and Technology, Xi’an, Shaanxi, China), “A new simple method for the strength of high-strength steel thin-walled box columns subjected to axial force and biaxial end moments”, Advances in Civil Engineering, Vol. 2019, Article ID 7495890, 16 pages, https://doi.org/10.1155/2019/7495890

ABSTRACT: The strength of Q460 steel welded thin-walled box columns under biaxial bending is investigated by an FE model. The numerical results, together with available experimental data, are compared with the American Specification ANSI/AISC 360-10. It shows that ANSI/AISC 360-10 provides a good estimate over a wide range of column slenderness ratios; but it severely underestimates the strengths of beam-columns with large slenderness ratios and slightly underestimates those of beam-columns made from HSS with fy=741MPa, and the calculation is more complicated because of using an effective width concept. Therefore, a simple and effective calculation method is proposed. Also, a comparison is made between the proposed formulas and the available experimental results. It shows that the proposed formulas can precisely evaluate the local-overall interactive buckling strength of HSS beam-columns and, in most cases, are also suitable for beam-columns fabricated from mild steels. The proposed formulas are simple and, meanwhile, achieve the same level of accuracy as ANSI/AISC 360-10.

References listed at the end of the paper:
ABSTRACT: The present paper deals with the interactive buckling of thin-walled lipped channel (LC) beams under the bending moment in the web plane when the shear lag phenomenon and distortional deformations are taken into account. A plate model (2D) was adopted for LC beams. The structures were assumed to be simply supported at the ends. A modal method of solution to the interactive buckling problem within Koiter’s asymptotic theory, using the semi-analytical method (SAM) and the transition matrix method, was applied. LC-beams, from short through medium-long via long to very long beams, were considered. The paper focuses on the influence of the secondary global buckling mode on the load carrying capacity for the steel LC-beams under bending.

References listed at the end of the paper:
Do-Min Kim, Soomin Choi, Gang-Won Jang, Yoon Young Kim, “Buckling analysis of thin-walled box beams under arbitrary loads with general boundary conditions using higher-order beam theory”, Journal of Mechanical Science and Technology, Vol. 33, No. 5, pp 2289-2305, May 2019

ABSTRACT: When a higher-order or generalized beam theory is used for the buckling analysis of thin-walled beams, the analysis accuracy critically depends on the number and shapes of the cross-sectional modes associated with warping and distortion. In the study, we propose to use the hierarchically-derived cross-sectional modes consistent with the higher-order beam theory for the analysis of pre-buckling stress and
buckling load. The proposed formulation is applicable to any box beams subjected to arbitrary loads and general boundary conditions. We demonstrate the effectiveness of the proposed method by performing buckling analyses for axial, bending, torsional, and general loadings. Length-to-height ratios of the beams are also varied from 1 to 100. If up to fifty cross-sectional and rigid-body modes are employed, the calculated buckling loads are found to match favorably those predicted by the shell finite element analysis. In that a unified buckling analysis under general loads is developed for box beams, the present study is expected to contribute towards new possibilities for the efficient buckling analysis of more general box beam structures involving several joints.

References listed at the end of the paper:
Guorui Wang,1,4 Zhaohel Dai,2 Junkai Xiao,1 ShiZhe Feng,3 Chuanxin Weng,1 Luqi Liu,1 Zhiping Xu,3 Rui Huang,2 and Zhong Zhang1,4
1CAS Key Laboratory of Nanosystem and Hierarchical Fabrication, CAS Center for Excellence in Nanoscience, National Center for Nanoscience and Technology, Beijing 100190, China
2Department of Aerospace Engineering and Engineering Mechanics, The University of Texas at Austin, Austin, Texas 78712, USA
3Applied Mechanics Laboratory, Department of Engineering Mechanics and Center for Nano and Micro Mechanics, Tsinghua University, Beijing 100084, China
4CAS Key Laboratory of Mechanical Behavior and Design of Materials, Department of Modern Mechanics, University of Science and Technology of China, Hefei 230026, China

ABSTRACT: Out-of-plane deformation patterns, such as buckling, wrinkling, scrolling, and folding, formed by multilayer van der Waals materials have recently seen a surge of interest. One crucial parameter governing these deformations is bending rigidity, on which significant controversy still exists despite extensive research for more than a decade. Here, we report direct measurements of bending rigidity of multilayer graphene, molybdenum disulfide (MoS2), and hexagonal boron nitride (hBN) based on pressurized bubbles. By controlling the sample thickness and bubbling deflection, we observe platelike responses of the multilayers and extract both their Young’s modulus and bending rigidity following a nonlinear plate theory. The measured Young’s moduli show good agreement with those reported in the literature (E_{graphene} > E_{hBN} > E_{MoS2}), but the bending rigidity follows an opposite trend, D_{graphene} < D_{hBN} < D_{MoS2} for multilayers with comparable thickness, in contrast to the classical plate theory, which is attributed to the interlayer shear effect in the van der Waals materials.

References listed at the end of the paper:
(Cannot easily cut and paste them)

X.F. Xhang and H.S. Tzou, “Theoretical and experimental studies of a piezoelectric ring energy harvester”,

...
Journal of Intelligent Material Systems and Structures, 2019, DOI: 10.1177/1045389X19828479

ABSTRACT: Based on the electromechanical coupling of piezoelectricity, a piezoelectric ring energy harvester is designed and tested in this study, such that the harvester can be used to power electric devices in the closed-circuit condition. Output energies across the external resistive load are evaluated when the ring energy harvester is subjected to harmonic excitations, and various design parameters are discussed to maximize the power output. In order to validate the theoretical energy harvesting results, laboratory experiments are conducted. Comparing laboratory experiments with theoretical ones, the errors between them are under 10% for the output voltage. Laboratory experiments demonstrate that the ring energy harvester is workable in practical applications.

References listed at the end of the paper:


ABSTRACT: Energy harvesting based on distributed piezoelectric laminated structures has been proposed and extensively investigated for over a decade. The objective of this study is to develop a generic distributed piezoelectric shell energy harvester theory based on a generic linear/nonlinear double-curvature shell, which can be simplified to account for many linear/nonlinear shell and non-shell type distributed energy harvesters. Distributed electromechanical coupling mechanism of the energy harvester was discussed; voltage and power
output across the external resistive load of the shell energy harvester were evaluated. Those equations were explicitly expressed in terms of design parameters and modes. Once the intrinsic Lamé parameters and the curvature radii of the selected host structure are specified, one can simplify the piezoelectric energy harvesting equations to account for common shell and non-shell harvester structures. To demonstrate the simplifications, the generic piezoelectric shell energy harvesting mechanism was applied to a cantilever beam, a circular ring and a conical shell in cases studies. Again, the generic piezoelectric energy harvesting formulations derived from a double-curvature shell can be applied to many shell, e.g., ring shells, cylindrical shell, conical shells, paraboloidal shells, etc., and non-shell, e.g., plates, beams, etc., structures using two Lamé parameters and two curvature radii of the specified structures. Besides, these shell and non-shell structures can be either linear or nonlinear with the von Karman geometric nonlinearity. With given boundary conditions and external loading forces, generated voltage and power across the resistive load in the closed-circuit condition can be estimated for the distributed piezoelectric laminated structure.

References listed at the end of the paper:

ABSTRACT: This chapter involved energy harvesting of a simply supported tubular (circular) cylindrical shell laminated with piezoelectric patches. The distributed modal energy generations using different energy harvester patch sizes (i.e., (1 mm,3.6°) in Case 1, (10 mm,30°) in Case 2, and (20 mm,60°) in Case 3) at various mode numbers were evaluated in case studies. Analytical and simulation results suggest that the maximum magnitude of the spatially distributed modal energies changes at various modes in two cases, due to the patch size enlarged or the number of energy harvester patches in the circumferential direction decreased. It should be noted that the signal averaging effects on energy harvester patches become more significant when the patch size continuously increasing. Additionally, the bending energy components are much smaller than the circumferential membrane energy component, and they increase when mode number increases. Furthermore, the maximum magnitude of the (m, n)th modal energy, in general, increases when energy harvester’s thickness h, or shell’s thickness h increases, but decreases when the shell radius R increases. A tubular shell energy harvesting system was designed and tested in the StrucTronics and Control Laboratory at Zhejiang University. Experimental results suggest that there is an optimal external loading resistance leading to the maximal power output. Both analytical predictions and experimental data were compared favorably. These data evaluated in this study can be used as guidelines to design the optimum piezoelectric energy harvester in practical engineering applications.

References listed at the end of the paper:

Haidong Yu (1), Xun Xu (1), Bin Zheng (2) and Xinmin Lai (1)
(1) Shanghai Key Q1 Laboratory of Digital Manufacture for Thin-Walled Structures, Shanghai, China
(2) Shanghai Mitsubishi Elevator CO. LTD., Shanghai, China


ABSTRACT: The non-uniform welding stress distribution in large thin-walled cylindrical structures easily causes the buckling distortion due to weak structural stiffness and nonlinear geometric deformation. The non-uniform temperature field model induced by friction stir welding is analytically developed and is used to theoretically deduce the non-uniform stress model in the weld region. Both the two models are verified by the experimental data. A prediction model of critical buckling load is established for large thin-walled cylindrical structures considering the non-uniform welding stress distribution. The deflection function for buckling analysis is developed by using polynomials and the Chebyshev polynomials of the first kind that satisfy the boundary conditions along the four edges of the structure. The critical buckling loads are calculated for various cylindrical welded shell structures, which obviously decrease with the increase of the diameter-thickness ratio and the length-diameter ratio. The mitigation of buckling distortion is achieved by the correlation of the buckling load and the welding stress with various welding process parameters. The results are beneficial for the determination of geometric configuration and welding process parameters for large thin-walled cylindrical structures in fabrication of propellant tanks of launch vehicles.

References listed at the end of the paper:
2. Pattee F (1975) Buckling distortion of thin aluminum plates during welding. Massachusetts Institute of Technology
The spherical shell is the optimal shape for underwater pressure resistant structures. The results show that Cassini oval pressure hulls with the shape index of 0.10 can resist about 0.30 and one spherical pressure hull with the diameter of 2 m is devoted. Such hulls are numerically studied in the case of constant volume, material properties, and wall thickness. The results show that Cassini oval pressure hulls with the shape index of 0.10-0.11 can resist about 4% more external pressure than the spherical one. This deviates from the classical mechanics conclusion that spherical shell is the optimal shape for underwater pressure resistant structures.
Shell buckling is known for its extreme sensitivity to initial imperfections. It is generally understood that this sensitivity is caused by subcritical (unstable) buckling, whereby initial geometric imperfections rapidly erode the idealized buckling load of the perfect shell. However, it is less appreciated that subcriticality also creates a strong proclivity for spatially localized buckling modes. The spatial multiplicity of localizations implies a large set of possible trajectories to instability—also known as spatial chaos—with each trajectory affine to a particular imperfection. Using a toy model, namely a link system on a softening elastic foundation, we show that spatial chaos leads to a large spread in buckling loads even for seemingly indistinguishable random imperfections of equal amplitude. By imposing a dominant imperfection, the strong sensitivity to random imperfections is ameliorated. The ability to control the equilibrium trajectory to buckling via dominant imperfections or elastic tailoring creates interesting possibilities for designing imperfection-insensitive shells.

References listed at the end of the paper:
11. G. Domokos and P. Holmes, Euler's problem, Euler's method, and the standard map; or, the discrete charm of buckling, Nonlinear Sci. 3, 109 (1993).
23. R. M. J. Groh, Data for “Spatial chaos as a governing factor for imperfection sensitivity in shell buckling” (), 2019 https://dx.doi.org/10.5523/bris.35taudpdkustnj2c1j1d8flgos.

Bharat Bhaga and Craig A. Steeves, “Modeling hybrid polymer–nanometal lightweight structures”, Aerospace
ABSTRACT: Increasing the environmental sustainability of aviation is a key design goal for commercial aircraft for the foreseeable future. From the perspective of structural engineering, this is accomplished through reducing the mass of aircraft components and structures. Advanced manufacturing techniques offer new avenues for design, enabling more complex structures which can have highly tailored properties. One advanced manufacturing concept is the use of 3D printed polymer preforms that are coated with nanocrystalline metal through electrodeposition. This enables the use of high-performance materials in virtually any geometry. To exploit this manufacturing approach, it is incumbent to have well-established mechanical models of the behavior of such hybrid structures. In particular, hybrid polymer–nanometal structures tend to fail due to compressive instabilities. This paper describes a model of local shell buckling, a typical compressive instability, as it applies to hybrid polymer–nanometal structures. The analysis depends upon the Southwell stress function model for radially loaded solids of rotation, and couples this with the Timoshenko analysis of local shell buckling. This combination is applicable to a range of practical configurations for truss-like hybrid structures.

References listed at the end of the paper:

SIGNIFICANCE: Kirigami—the Japanese art of cutting paper—has become an emergent tool to realize highly stretchable devices and morphable structures. While kirigami structures are fabricated by simply perforating an array of cuts into a thin sheet, the applied deformation and associated instabilities can be exploited to transform them into complex 3D morphologies. However, to date, such reconfiguration always happen simultaneously through the system. By borrowing ideas from phase-transforming materials, we combine cuts and curvature to realize kirigami structures in which deformation-induced shape reconfiguration initially nucleates near an imperfection and then, under specific conditions, spreads through the system. We envision that such control of the shape transformation could be used to design the next generation of responsive surfaces and smart skins.

ABSTRACT: Kirigami-inspired metamaterials are attracting increasing interest because of their ability to achieve extremely large strains and shape changes via out-of-plane buckling. While in flat kirigami sheets, the ligaments buckle simultaneously as Euler columns, leading to a continuous phase transition; here, we demonstrate that kirigami shells can also support discontinuous phase transitions. Specifically, we show via a combination of experiments, numerical simulations, and theoretical analysis that, in cylindrical kirigami shells, the snapping-induced curvature inversion of the initially bent ligaments results in a pop-up process that first localizes near an imperfection and then, as the deformation is increased, progressively spreads through the structure. Notably, we find that the width of the transition zone as well as the stress at which propagation of the instability is triggered can be controlled by carefully selecting the geometry of the cuts and the curvature of the shell. Our study significantly expands the ability of existing kirigami metamaterials and opens avenues for the design of the next generation of responsive surfaces as demonstrated by the design of a smart skin that significantly enhances the crawling efficiency of a simple linear actuator.


ABSTRACT: Based on the Hermite curve, the buckling behavior of a variable stiffness composite cylindrical shell is investigated. Firstly, the cylindrical shell is unfolded into a plane, and the Hermite curve is taken as the basic reference path on the plane and the variation of the fiber orientation is obtained. Then, the finite element analysis pre-processing program of the variable stiffness composite cylindrical shell is written by Python to develop ABAQUS interactive interface. Finally, the GUI plug-in is developed successfully, the buckling analysis of the constant stiffness and variable stiffness cylindrical shells is carried out and the effect of buckling load on the initial tangential direction q, the initial point tangential magnitude L, the end point tangential direction q, and the end point tangential magnitude L is preliminarily explored. It is found that the buckling load of the variable stiffness cylindrical shell is improved greatly. The secondary development of ABAQUS by Python is used to realize the automatic modeling and calculation analysis of the variable stiffness cylindrical shell parts, which provides research ideas and processes for practical engineering research, and has certain practical significance.


ABSTRACT: Compressive residual stresses generated during thin film deposition may lead to undesirable film damage, such as delamination, buckling, and flaking, ultimately leading to the failure of the device employing the film. Understanding the residual stress generation and role in these damage mechanisms is necessary to preserve thin film integrity and optimize its functional properties. Thin shell theory has been used for decades to predict buckling but the results have not yet been correlated with experimental data since the techniques used to measure stress in metallic films were not able to do so at the required micron scale until recently. Micro scanning X-ray diffraction now enables the direct mapping of the local stress of metallic films. In this paper, finite element method based on thin shell theory and synchrotron X-ray micro diffraction have been used to determine stress maps of thin film buckling patterns. Calculations of the stress distribution in the metallic films have been performed taking into account the buckling geometry determined from optical measurements. Stress distributions over gold blisters and tungsten wrinkles obtained with the two techniques are in fair agreement and
allow for the accurate determination of the stress relaxation profile from the bottom to the top of the buckling, validating the thin shell theory model.

References listed at the end of the paper:
an ideal spherical landscape in both regimes. Upon approaching the buckling bifurcation at response state for nonlinear shallow shell equations about the Pogorelov mirror extended oscillations, which are well described by linear response. We find systematic expansions of the

\[ p/p_c \ll 1 \]

Two regimes: For \( p/p_c \ll 1 \), buckling patterns in SiAlNx films: From straight-sided to telephone-cord and bubble structures. Acta Mater. 2014, 64, 41–53.


ABSTRACT: This paper is devoted to the buckling problem of the composite cylindrical shell subjected to hydrostatic pressure. Both analytical and numerical methods are applied to investigate the buckling behavior. Based on the study of analytical formulas, it is found that the composite cylindrical shells with the same length-to-diameter ratio, diameter-to-thickness ratio, and type of layup have the same buckling pressure. Thus, a scale model experiment method is then proposed, which uses the scale model to replace the full-scale model in pressure test experiment to reduce the manufacturing cost of the test specimen. The feasibility of this method is verified by numerical calculation. The influences of ply orientation angle and length of shell on buckling shape and critical buckling pressure have been investigated numerically and demonstrated by several examples. Based on the study of the influence of shell length on critical buckling pressure, a modified finite element model, which can overcome the conservatism of optimization result due to the stress concentration caused by boundary conditions, is combined with the genetic algorithm to optimize the laminations for mass reduction.


ABSTRACT: We study the axisymmetric response of a complete spherical shell under homogeneous compressive pressure \( p \) to an additional point force. For a pressure \( p \) below the classical critical buckling pressure \( p_c \), indentation by a point force does not lead to spontaneous buckling but an energy barrier has to be overcome. The states at the maximum of the energy barrier represent a subcritical branch of unstable stationary points, which are the transition states to a snap-through buckled state. Starting from nonlinear shallow shell theory, we obtain a closed analytical expression for the energy barrier height, which facilitates its effective numerical evaluation as a function of pressure by continuation techniques. We find a clear crossover between two regimes: For \( p/p_c \ll 1 \) the postbuckling barrier state is a mirror-inverted Pogorelov dimple, and for

\[ (1-p/p_c) \ll 1 \]

the barrier state is a shallow dimple with indentations smaller than shell thickness and exhibits extended oscillations, which are well described by linear response. We find systematic expansions of the nonlinear shallow shell equations about the Pogorelov mirror-inverted dimple for \( p/p_c \ll 1 \) and the linear response state for \( (1-p/p_c) \ll 1 \), which enable us to derive asymptotic analytical results for the energy barrier landscape in both regimes. Upon approaching the buckling bifurcation at \( p_c \) from below, we find a softening of an ideal spherical shell. The stiffness for the linear response to point forces vanishes \( \propto (1-p/p_c)^{1/2} \); the buckling
energy barrier vanishes $\propto (1 - p/p_c)^{3/2}$ and the shell indentation in the barrier state vanishes $\propto (1 - p/p_c)^{1/2}$. This makes shells sensitive to imperfections which can strongly reduce $p_c$ in an avoided buckling bifurcation. We find the same softening scaling in the vicinity of the reduced critical buckling pressure also in the presence of imperfections. We can also show that the effect of axisymmetric imperfections on the buckling instability is identical to the effect of a point force that is preindenting the shell. In the Pogorelov limit, the energy barrier maximum diverges $\propto (p/p_c)^{-3}$ and the corresponding indentation diverges $\propto (p/p_c)^{-2}$. Numerical prefactors for proportionalities both in the softening and the Pogorelov regime are calculated analytically. This also enables us to obtain results for the critical unbuckling pressure and the Maxwell pressure.

References listed at the end of the paper:

ABSTRACT: The use of the Google Scholar produces about 78,000 hits on the term “Timoshenko beam.” The question of priority is of great importance for this celebrated theory. For the first time in the world literature, this study is devoted to the question of priority. It is that Stephen Prokofievich Timoshenko had a co-author, Paul Ehrenfest. It so happened that the scientific work of Timoshenko dealing with the effect of rotary inertia and shear deformation does not carry the name of Ehrenfest as the co-author. In his 2002 book, Grigolyuk concluded that the theory belonged to both Timoshenko and Ehrenfest. This work confirms Grigolyuk’s discovery, in his little known biographic book about Timoshenko, and provides details, including the newly discovered letter of Timoshenko to Ehrenfest, which is published here for the first time over a century after it was sent. This paper establishes that the beam theory that incorporates both the rotary inertia and shear deformation as is known presently, with shear correction factor included, should be referred to as the Timoshenko-Ehrenfest beam theory.

( Isaac Elishakoff wrote the following for an announcement of a lecture on this topic given at the Mechanics and Computation Seminar (ME395) in 2019 at Stanford University: “At the first glance there might be a confusion about the question in the title. One could retort: “Naturally, it was Timoshenko (1878–1972) who developed this theory!” In his 1977 paper, W.T. Koiter claimed that the Timoshenko beam theory is the illustration of the fact that the theory bearing someone’s name is usually by someone else. Koiter did not know how right he was. Hold your breath: Timoshenko WAS one of the developers of this theory! What is not known widely is that he had a collaborator, namely famous Austrian-Dutch physicist Paul Ehrenfest (1880–1933) whose dissertation was in classical mechanics. How did we find this fact? In defiance of the famous cynical definition by Mark Twain, “Classical work is the work that everyone cites but nobody reads,” this author read original papers and autobiographical book by Timoshenko, many times, as well as widely consulted with Archive of S.P. Timoshenko and Archive of P. Ehrenfest that are housed at Stanford and Leiden universities, respectively. In his forthcoming book titled “Timoshenko-Ehrenfest Beam and Uflyand-Mindlin Plate Theories” (World Scientific, Singapore, 2019) author shows that this theory ought to be called Timoshenko-Ehrenfest beam theory. Author conducted an ‘archeological’ dig as it were, to illuminate the fact that, as the ancient saying states “truth sprouts from the earth.” It is also shown that the Timoshenko-Ehrenfest beam theory is unnecessarily overcomplicated. Simplest possible version of the beam theory that takes into account both shear deformation and rotary inertia is suggested. Dr. Elishakoff is preparing another book tentatively titled “S.P. Timoshenko at 140: Going Strong,” and will appreciate any comment on Timoshenko’s life and/or work.”

Isaac Elishakoff (Department of Ocean and Mechanical Engineering, Florida Atlantic University, Boca Raton, FL 33431-0991), “Stepan Prokofievich Timoshenko and America”, ZAMM, January or February 2019 DOI: 10.1002/zamm.201800338
ABSTRACT: In this essay, we describe relationship of S. P. Timoshenko (1878–1972), who is often identified as “the father of American engineering mechanics” with America, where he arrived in 1922 and stayed until 1964. His autobiography appeared in 1963 in Paris in the Russian language; Timoshenko former students and colleagues at Stanford University arranged its translation into English that appeared in 1968 when Timoshenko became 90 years old. The book provides a testimony of the complex relationship that he developed towards America and Americans. Drawing from various documents in addition to his autobiography, this essay discusses in some detail various facets of his relationship. The main goal of this paper is to show that along harsh criticisms towards United States in his autobiographical book, in various documents he expressed positive views about the US.

ACKNOWLEDGEMENTS: Author wants to express sincere gratitude to Professors Norman Abramson of Southwest Research Institute; Holm Altenbach of Otto-von-Guericke-University, Magdeburg; Igor Andrianov of RWTH Aachen; Zdenek P. Bažant of Northwestern University; Nachum P. Fleishman of Lvov University; Raphael T. Haftka of University of Florida; Harry Hilton of University of Illinois, Urbana-Champaign; Julius Kaplunov of Keele University; Vladimir D. Raizer of San Diego State University for discussing various topics associated with this essay. Author also records sincere appreciation to late Professors Warner T. Koiter of the Delft University of Technology, Wilhelm Flügge of Stanford University, and Yehoshua Borishansky of the Technion-Israel Institute of Technology, Israel for various discussions on the topic of this essay. Naturally, none of the above individuals bear any responsibility on the contents of this essay. I also am extremely indebted to Dr. Daniel Hartwig of Stanford University Library for providing permission of incorporating some images associated with S.P. Timoshenko.

Yufei Zhang (1) and Fei Zhang (2)
(1) College of Aerospace Engineering, Shenyang Aerospace University, Shenyang 110136, China
(2) College of Sciences, Northeastern University, Shenyang 110819, China

“Vibration and buckling of shear deformable functionally graded nanoporous metal foam nanoshells”, Nanomaterials, Vol. 9, 271, 2019

ABSTRACT: This article aims to investigate free vibration and buckling of functionally graded (FG) nanoporous metal foam (NPMF) nanoshells. The first-order shear deformation (FSD) shell theory is adopted and the theoretical model is formulated by using Mindlin’s most general strain gradient theory, which can derive several well-known simplified models. The symmetric and unsymmetric nanoporosity distributions are considered for the structural composition. Hamilton’s principle is employed to deduce the governing equations as well as the boundary conditions. Then, via the Navier solution technique, an analytical solution for the free vibration and buckling of FG NPMF nanoshells is presented. Afterwards, a detailed parametric analysis is conducted to highlight the effects of the nanoporosity coefficient, nanoporosity distribution, length scale parameter, and geometrical parameters on the mechanical behaviors of FG NPMF nanoshells.

References listed at the end of the paper:
11. Wang, Y.Q.; Zu, J.W. Nonlinear dynamics of functionally graded material plates under dynamic liquid load and with longitudinal
38. Miller, R.E.; Shenoy, V.B. Size-dependent elastic properties of nanosized structural elements, Nanotechnology 2000, 11, 139.
42. Ansari, R.; Gholami, R.; Faghih Shojaei, M.; Mohammadi, V.; Sahmani, S. Size-dependent bending, buckling and free vibration of functionally graded Timoshenko microbeams based on the most general strain gradient theory. Compos. Struct. 2013, 100, 385–397.
46. Movassagh, A.A.; Mahmodi, M. A micro-scale modeling of Kirchhoff plate based on modified strain-gradient elasticity theory.
Yunfei Liu and Yanqing Wang (Department of Mechanics, Northeastern University, Shenyang 110819, China), “Size-dependent free vibration and buckling of three-dimensional graphene foam microshells based on modified couple stress theory”, Materials, Vol. 12, 279, 2019

ABSTRACT: In this research, the vibration and buckling of three-dimensional graphene foam (3D-GrF) microshells are investigated for the first time. In the microshells, three-dimensional graphene foams can distribute uniformly or non-uniformly through the thickness direction. Based on Love’s thin shell theory and the modified couple stress theory (MCST), size-dependent governing equations and corresponding boundary conditions are established through Hamilton’s principle. Then, vibration and axial buckling of 3D-GrF microshells are analyzed by employing the Navier method and Galerkin method. Results show that the graphene foam distribution type, size effect, the foam coefficient, the radius-to-thickness ratio, and the length-to-radius ratio play important roles in the mechanical characteristics of 3D-GrF microshells.

References listed at the end of the paper:


spongy graphene material with super compressive elasticity and near-zero Poisson’s ratio. Nat. Commun. 2015, 6, 6141.
17 Yong, Y.-C.; Dong, X.-C.; Chan, P.M.B.; Song, H.; Chen, P. Macroporous and monolithic anode based on polyaniline hybridized three-dimensional graphene for high-performance microbial fuel cells. ACS Nano 2012, 6, 2394–2400.
doi:10.1007/s00707-018-2331-z
HYDRAULIC RESEARCH

End of some 2019 and post-2019 papers not included elsewhere in this file

Some Papers On Fluid-Structure Interaction (prior to 2019)


the ASME Pressure Vessels and Piping Conference, Pressure Vessel Technologies for the Global Community, Vancouver, Canada, pp. 787–
Conveying Fluid, Anaheim, CA, Vol. 152, pp. 11–
Arch. Appl. Mech., Vol. 152, pp. 1–
of the ASME Winter Annual Meeting, Applied Mechanics Division, Stab
Fluids Struct., Fluids Struct., pp. 100–


ABSTRACT: The problem of the motion of an incompressible cylindrical shell with an explosive charge is \( \text{nonstationary problem of the motion of a shell under the action of detonation products} \), Journal of Applied Mechanics and Technical Physics, Vol. 13, No. 4.


ABSTRACT: The aeroelastic stability of a long, thin cylindrical shell with the outer surface exposed to an inviscid, helical flow of air is investigated. The cylinder behavior is described by classical shell equations, whereas the aerodynamic forces are described by the linearized potential theory. The approach that is used herein examines the nature of stability of the system when the system is "slightly" perturbed from its initial equilibrium state. In this paper, numerical results are presented only for the special case of swirl flow around a nonrotating shell, i.e., the axial flow velocity is set to zero. These results indicate that traveling wave type of flutter can be caused by coalescence of backward and forward traveling waves. Two approximate theories are presented and the results are compared.


ABSTRACT: The problem of the motion of an incompressible cylindrical shell with an explosive charge is solved numerically for the propagation of a plane detonation wave from the end of the charge. The strength of
the shell is not taken into account. A three-term equation of state [1] is assumed for the detonation products. A comparison is made with the one-dimensional case.

References listed at the end of the paper:

Dowell, E.H. (1), Srinivasan, A.V. (2), Mclean, J.D. (1), Ambrose, J. (1)
(1) Princeton University, Princeton, New Jersey, USA
(2) Pratt & Whitney Aircraft, East Hartford, Connecticut, USA

ABSTRACT: It is experimentally demonstrated that a cylindrical shell subjected to a rotating flow may become dynamically unstable. The flutter motion takes the form of a circumferentially traveling wave. The data confirm qualitatively earlier theoretical predictions, although further refinement of the theoretical modeling of the fluid motion is desirable in order to improve the quantitative agreement between theory and experiment.


ABSTRACT: This paper addresses direct time integration techniques for the transient response analysis of coupled fluid-structure problems treated by a class of surface interaction approximations. Efficient solution of the resulting equations of motion can be achieved by a modular computer implementation in which separate fluid and structure analyzers are interfaced through extrapolation of the coupling terms. Such an implementation is herein called a staggered solution strategy. The conventional realization of this strategy is handicapped, however, by severe temporal stepsize limitations. Several stabilized formulations are introduced, which circumvent such limitations and achieve unconditional stability for certain extrapolators.


ABSTRACT: Doubly asymptotic approximations (DAA) are differential equations for simplified analysis of the transient interaction between a flexible structure and a surrounding infinite medium. These surface interaction approximations approach exactness in the limit of low- and high-frequency motions and effect a smooth transition in the intermediate frequency range. A finite-element DAA formulation for an acoustic medium is presented herein, with attention focused on the first and second members of the DAA hierarchy. The free-vibration and forced-response characteristics of the first and second approximations are examined through specialization to a spherical geometry.

ABSTRACT: This report is a reference manual for the third version of the USA-STAGS Code that calculates the nonlinear transient response of a totally or partially submerged structure to a spherical shock wave of arbitrary pressure profile and source location. USA-STAGS is the…


ABSTRACT: Coupled-field dynamic problems in mechanics have been traditionally solved by treating the entire system as one computational entity. More recently, increasing attention has been directed to an alternative approach; partition the governing equations into subsystems, which are treated by subsystem analyzers. The selection of the subsystems may be based on weak-coupling considerations, widely different time response characteristics, isolation of nonlinear effects, or more pragmatic reasons such as the availability of analyzer software. In a staggered solution procedure the solution state of the coupled system is advanced by sequentially executing the subsystem analyzers. Subsystem coupling terms are accounted for by temporal extrapolation techniques. This paper focuses on the formulation and computer implementation of staggered solution procedures for two-field problems governed by semidiscrete second-order coupled differential equations. Such equations find application in the modeling of structure-fluid, structure-soil and structure-structure interaction. Following an introductory description of candidate problems and general solution strategies, direct time integration methods are formulated and applied to the coupled system. Staggered solution procedures are constructed through two alternative approaches which are based upon partitioning at the difference and differential equation level, respectively. Characteristic equations that govern the stability of the resulting implementations are derived, and the selection of stable extrapolators discussed. Finally, possible extensions of staggered solution procedures to coupled-field static and eigenvalue problems are suggested.


G.E. Cummings (1) and H. Brandt (2)
(1) Nuclear Systems Group, Department of Mechanical Engineering, Lawrence Livermore Laboratory, University of California, Livermore, Calif.
(2) Department of Mechanical Engineering, University of California, Davis, Calif.
ABSTRACT: A numerical solution technique is presented for determining the dynamic response of a thin, elastic, circular, cylindrical shell of constant wall thickness and density, in a potential fluid. The shell may be excited by any radial forcing function with a specified time history and spatial distribution. In addition, a pressure history may be specified over a segment of the fluid outer boundary. Any of the natural shell end conditions may be prescribed. The numerical results are compared to experimental results for a 1/12-scale model of a nuclear-reactor core-support barrel. Natural frequencies and modes are determined for this model in air, water, and oil. The computed frequencies are within 15 percent of experimental results. A sample application compares the numerical technique to an analytical solution for shell beam modes. The comparison resolves an uncertainty concerning the proper effective mass to use in the analytical technique.

T. Belytschko, H.-J. Yen and R. Mullen (Department of Civil Engineering, Northwestern University, Evanston,
ABSTRACT: The time integration of fluid-structure and soil-structure problem is often quite uneconomical when performed with a single integration method and a single time step. Three techniques for enhancing computational efficiency are presented: explicit-implicit partitions, explicit-explicit partitions with different time steps, and implicit-implicit partitions. The latter two require interpolation and extrapolation on the interface. A model problem is presented for examining the stability of these procedures and stabilization techniques are examined.

ABSTRACT: Computational methods for fluid-structure analysis are surveyed. Emphasis is placed on semi-discretization methods, such as finite element and finite difference methods. Appropriate mesh descriptions and time integration procedures for various classes of problems are discussed. The need for mesh partitions, where the fluid and structure are integrated by different methods, is indicated, and three types of mesh partitions are discussed: explicit-implicit (E-I), implicit-implicit (I-I), and explicit with different time steps (Em-E). Some examples are presented to illustrate the applicability of various methods.

ABSTRACT: Most of the failures of large tanks after severe earthquakes are suspected to have resulted from the dynamic buckling caused by overturning moments of seismically induced liquid inertia and surface slosh waves. In this paper, a nonlinear finite element method is presented which can treat the structural behavior of the tanks in conjunction with fluid, including the dynamics and buckling. Both the formulation and computer implementation aspects are presented. The areas upon which attention is focused are: the mixed Lagrangian-Eulerian kinematical description for modeling fluid subdomains in fluid-structure interaction problems, the finite rotation effects in numerical integration of rate constitutive equations arising in large-deformation analysis and the implicit-explicit finite element techniques for transient analysis. All these nonlinear methodologies have been integrated into a finite element computer code [47]. A number of physically important buckling and dynamic analyses of tanks are being investigated. Various other fluid structure phenomena such as the stability of off-shore structures can be analyzed with this computer program. The proposed nonlinear finite-element procedures can serve as a basis for future developments of various other fluid-structure phenomena such as the transient motion of submerged or partially submerged structures.

ABSTRACT: The May 1983 Coalinga Earthquake provided an opportunity to correlate earthquake performance of cylindrical liquid storage tanks with behavior observed in laboratory shaking table experiments. A 38.5 ft diameter steel water tank which developed typical 'elephant's foot' buckling has been found to be a good prototype for a 12 ft diameter aluminum tank. The properties of the prototype and model are correlated. From these relationships, the measured dynamic stress response of the model is extrapolated to obtain the stresses induced in the prototype.

ABSTRACT: The paper describes the theoretical formulation and computational implementation of a method for treating hull cavitation in underwater-shock problems. In addition, the method can be applied to the analysis of submerged structures that contain internal fluid volumes. In the present implementation, the Doubly Asymptotic Approximation (DAA) serves to simulate a radiation boundary that is located away from the fluid-structure surface at a distance sufficient to contain any cavitating region. The enclosed fluid is discretized with volume finite elements that are based upon a displacement-potential formulation. An explicit time-integration algorithm is used to advance the solution in the fluid-volume region, implicit algorithms are used for the structure and DAA boundary, and a staggered solution procedure has been developed to treat the interface conditions. Results for two example problems obtained with the present implementation show close agreement with those obtained by other methods.

D. F. Fischer and F. G. Rammerstorfer, “Stability of liquid storage tanks under earthquake excitation”, (publisher and date not given in the pdf file; the most recent reference is 1983)
SUMMARY: Based on potential flow theory for incompressible, inviscid fluid flow in conjunction with the response spectrum approach, the maximum pressure distribution in the deformable liquid-filled cylindrical tank is calculated. The coupled fluid-structure interaction problem is solved in a semi-analytical manner. By applying this maximum pressure distribution to the shell incrementally the loss of stability (mainly caused by axial compressive membrane forces near the base) is considered by a non-linear finite element analysis. Particularly the influence of shape imperfections on the stability is investigated in the non-linear numerical calculation.

ABSTRACT: The present paper deals with the numerical calculation of the behaviour of vertical wind-loaded cylindrical shells (large liquid storage tanks) with a very flexible bottom plate resting on an elastic foundation. The base of the tank, i.e. the lower boundary of the shell and the bottom plate, may partially uplift due to the shell deformations under the dead load, a hydrostatic pressure and due to wind forces. This behaviour represents non-linear boundary conditions of the tank wall. Hence, the stability of the wind-loaded tank is extremely influenced by the uplift conditions. This non-linear problem (large deformations and variable contact) is solved by the FE method

F.G. Rammerstorfer (1), F.D. Fischer (2) and K. Scharf (1)
(1) Institute of Light Weight Structures, Technical University of Vienna, Vienna, Austria
(2) Institute of Mechanics, University for Mining and Metallurgy, Leoben, Austria
“A proposal for the earthquake resistant design of tanks – Results from the Austrian Research Project”, Proceedings of Ninth World Conference on Earthquake Engineering, August, 1988, Tokyo-Kyoto, Japan (Vol. VI)
SUMMARY: An engineering approach is presented for calculating the maximum dynamic pressure distributions caused by horizontal and vertical earthquake excitation of tanks. Three different possibilities for superposing the dynamic pressure components due to the horizontal and the vertical earthquake components on the static pressure and the different modes of wall instabilities are discussed. The results show that the dynamic pressure component caused by vertical excitation must not be neglected especially for tall tanks. An essential aim of this project has been the development of simple formulas and diagrams for engineers dealing with the construction of liquid storage tanks made of steel.


ABSTRACT: In this paper, the governing equations which consider dynamic fluid-structure interaction, modal coupling in both axial and circumferential directions, and dynamic buckling are derived. The various pressure components acting on the shell wall due to a seismic event are also analyzed. The matrix equation of motion for liquid-filled shells is obtained through a Galerkin/Finite Element discretization procedure. The modal coupling among the various combinations of axial and circumferential modes are identified with a particular reference to the fluid-structure system under seismic excitation. Finally, the equations for the dynamic stability analysis of liquid-filled shells are presented.


ABSTRACT: In this paper, applications of the theory developed in the companion paper by Liu and Uras [1] are presented. The effects of various types of ground motion on the dynamic stability of the fluid-structure system are analyzed. The stability criteria of liquid-filled shells subjected to horizontal and rocking excitation, shear loading, bending/shear combined loading, and vertically applied load are established. The resulting instability regions and stability charts are given in tables and in _…-epsilon (Porson) plots. Under horizontal and rocking motion, modal coupling in the circumferential direction as well as in the axial direction is observed. The possible buckling modes for a tall tank can be identified as cos2theta, cos3theta and cos4theta under horizontal and rocking motion, and cos5theta and cos6theta, under vertically applied load. For a broad tank two sets of instability modes are found: cos6theta through cos9theta, and cos12theta through cos14theta under horizontal and rocking motion. When subjected to vertically applied load, the failure modes of a broad tank shift to cos10theta through cos12theta, and cos14theta through cos15theta. The effect of shear load on a broad tank appears to be important only if damping is relatively small. Under bending/shear combined loading, the bending forces dominate the stability of the fluid-filled shells.


ABSTRACT: An experimental investigation was conducted to determine the static and dynamic responses of a specific stiffened flat plate design. The air-backed rectangular flat plates of 6061-T6 aluminum with an externally machined longitudinal narrow-flanged T-stiffener and clamped boundary conditions were subjected to static loading by water hydropump pressure and shock loading from an eight-pound TNT charge detonated underwater. The dynamic test plate was instrumented to measure transient strains and free-field pressure. The static test plate was instrumented to measure transient strains, plate deflection, and pressure. Emphasis was placed upon forcing static and dynamic stiffener tripping, obtaining relevant strain and pressure data and studying the associated plate-stiffener behavior.

References listed at the end of the paper:
boundary conditions. Shell elements were employed in the complete model; this was made possible largely through the use of no
improvements may alter this result. Shell elements were employed for the steel to properly model bending of
the plate and frames, and to decrease problem size. A total of less than ten thousand elements (continuum and
improvements may alter this result. Shell elements were employed for the steel to properly model bending of
the plate and frames, and to decrease problem size. A total of less than ten thousand elements (continuum and
improvements may alter this result. Shell elements were employed for the steel to properly model bending of
the plate and frames, and to decrease problem size. A total of less than ten thousand elements (continuum and
A.N. Kounadis (1), O. Mahrenholtz (2) and R. Bogaz (3)

(1) National Technical University of Athens Structural Analysis and Steel Bridges, 42, Patission Str., 147, Athens, Greece
(2) Arbeitsbereich Meerestechnik II — Strukturmechanik, Technische Universität Hamburg-Harburg, Postfach 901403, D-2100, Hamburg 90, Germany
(3) Institute of Fundamental Technological Research, ul. Swietokrzyska 21, PL-00-049, Warszawa, Poland


SUMMARY: This paper deals with a simple fluid-structure interaction problem of floating bridges under step loading with main emphasis on the non-linear dynamic stability of the structure itself after been simulated by a simple discrete mechanical model. The analysis concerns systems which under the same loading applied statically experience a limit point instability. On the basis of a theoretical discussion of the non-linear response of a single degree-of-freedom model simple conditions for an unbounded motion associated with dynamic buckling have been properly established. According to these conditions one can determine the exact dynamic buckling load without solving the strongly non-linear differential equation of motion. Such a load corresponds to that equilibrium point of the unstable (static) post-buckling path for which the total potential energy of the model becomes zero, while at the same time its second variation is negative definite. This load is also a lower bound in case that damping is included in the analysis. The foregoing conditions of static evaluation of the dynamic buckling load do not hold, in general, for limit point systems of two degrees of freedom. The above theoretical predictions have been confirmed by means of numerical integration of the corresponding non-linear equation of motion.

References listed at the end of the paper:
R. A. Uras (1) and W. K. Liu (2)
(1) Reactor Analysis and Safety Division, Argonne National Laboratory, Argonne, Illinois 60439, U.S.A.
(2) Department of Mechanical Engineering, Northwestern University, Evanston, Illinois 60208, U.S.A.


ABSTRACT: A method for the investigation of the dynamic buckling of liquid-filled shells under horizontal excitation has been developed. Strikingly good agreement has been obtained in comparison to available experimental results. This provides guidelines for a better understanding of stability phenomenon of liquid-filled shells. The importance of modal interaction in the axial as well as circumferential directions is also demonstrated. In particular, the coupling between the nth and (n + 1)th circumferential modes is found to be the major cause for the instability of fluid-structure systems under horizontally applied ground motion. For failure conditions in which the buckling modes are not exactly known from the shaking table experiment, the significant bifurcation solutions can be identified from the present analysis.


ABSTRACT: Explosively generated underwater shock waves may interact with a compliant submerged structure or with the free surface to induce cavitation. A finite element analysis of the former case is described. Discretised equations are derived using a displacement potential as the dependent variable. Formulations for a variety of boundary conditions are described. Computational strategy is discussed. A one-dimensional example is presented and results are shown to be in good agreement with those obtained by the method of characteristics. References listed at the end of the paper:


ABSTRACT: This paper describes a modal method of analysis for the rapid evaluation of the linear elastic response of a ring stiffened circular cylindrical shell subjected to underwater explosion loading. The cylindrical wave approximation is used to define the interactive behavior of structure and fluid at the wet boundary. Two mathematical representations of the incident loading are assessed together with other factors which may influence the cylinder response such as stiffener design. The comparative behavior of frames and plating is studied and and assessment is made of the merits of the method through a comparison with the response predictions obtained from more complex discrete element analyses in which the interaction process is treated using a doubly asymptotic approximation.


ABSTRACT: This paper presents an analytical approach to the modelling of the nonlinear inelastic response of a cylindrical shell to underwater shock wave loading. Material nonlinearity is accommodated by the adoption of a linear elastic/plastic stress/strain relationship and geometric nonlinearity by the retention of second order terms in the deflection components which describe the deformation of the cylinder. A cylindrical wave approximation is used to couple the structural and fluid domains.


SUMMARY: The observed equipartition of kinetic energy between the poloidal (convergence/divergence) and toroidal (strike-slip) parts of the Earth's surface velocity field is evidence that large lateral viscosity variations exist in the mantle. The largest such variations probably occur within the lithosphere, in the form of relatively weak boundaries between nearly rigid plates. To understand better the dynamical effects of such viscosity variations, we study an Earth model consisting of a lithospheric shell of outer radius a with laterally variable thickness h(θ, φ) and viscosity ( , ) overlying a mantle whose viscosity η(r) is a function of depth only. Flow in the model is driven by lateral density variations beneath the shell. An asymptotic (long wave) analysis reduces the dynamics of the shell to a pair of boundary conditions, and shows that the effect of the shell is governed by a single dimensionless parameter, the ‘stiffness’ f= ε(γ − 1), where ε=h/a and (a). A
perturbation analysis for the case of small lateral stiffness variations shows that the poloidal flow generated by an internal load interacts with the stiffness variations to generate additional poloidal and toroidal fields of various wavelengths according to definite selection rules. A simple model in which the shell consists of stiff \((f \gg 1)\) ‘plates’ separated by narrow weak \((f \ll 0.5)\) zones shows that (1) large lateral stiffness variations give rise to surface motion with a substantial toroidal component; (2) the observed surface velocity field is extremely sensitive to lateral stiffness variations, and thus provides poor constraints on the mantle viscosity; (3) lateral stiffness variations have a large (~50 per cent) effect on geoid anomalies if the mantle viscosity increases with depth; and (4) geoid anomalies predicted by models that ignore the order-unity relative change of long-wavelength normal stress across the shell are likely to be in error by 30–50 per cent. These results suggest that previous models may have overestimated the viscosity increase in the lower mantle that is required to fit the geoid data.

ABSTRACT: The nonlinear dynamic response of a cylinder subjected to a side-on, far-field underwater explosion was studied using both numerical and experimental techniques. Both ends of the cylinder were closed with thick flat plates. An explosive charge was located 25 feet (7.62 m) from the cylinder on a line perpendicular to the cylinder axis and equidistant from the cylinder ends. Comparison of axial and hoop strains was made between the strain gage measurements and the numerical results at several different locations on the cylinder. Overall, the comparison was in a good agreement. However, it was found that there were asymmetric strain gage data from the experiment. With the postulation of cylinder rotation so that the charge was not located at center of the cylinder length, an additional numerical study was undertaken to investigate the effect of the rotation on the strain distributions. This study showed improvements of the numerical results compared to the experimental data. The numerical study indicated that the dynamic motion of the cylinder has an accordion mode, a breathing mode and a whipping mode.

ABSTRACT: A mathematical formulation and method of solution for the title problem are developed, and numerical results are presented for excitation by a plane step wave. The formulation is based on the familiar equations of motion for a thin spherical shell and the wave equation for the internal and external fluid domains. The Laplace transform is invoked, and the usual separation of variables method produces modal equations for each component of the Fourier-Legendre series solution. The modal equations are then restructured to facilitate transform inversion, yielding delayed differential equations in time for each response mode of the shell-fluid system, which are integrated numerically in time. Complete response solutions then follow by modal superposition, with special techniques being employed to improve modal convergence. Transient response histories are shown for a step-wave-excited steel shell containing water and submerged in water. Also, these results are compared with their counterparts for an empty submerged steel shell.


ABSTRACT: Doubly asymptotic approximations (DAAs) are approximate temporal impedance relations for a medium in contact with a flexible body. In this paper, the method of operator matching previously used for external acoustic domains is used to develop first- and second-order boundary integral DAAs for internal acoustic domains. Corresponding boundary element forms permit the numerical solution of transient structural acoustics problems with complex geometry. The accuracy of the DAAs is assessed in the following companion paper by comparing DAA and exact solutions for a canonical problem with spherical geometry.

Yuan Weifeng and Wu Lianyuan (Department of Engineering Mechanics, Shanghai Jiaotong University), “”On damage effect distance of shells structure subjected to underwater explosion shock”, Journal of Fuzhou University, April 1994

ABSTRACT: The buckling distance of the cylindrical shell subjected to the shock wave against the weight of explosive and the initial static pressure is considered. The estimating method of stiffened cylindrical shell subjected to underwater explosion shock is developed in terms of buckling of shells. Many exprimental results are explained by the present theory


ABSTRACT: Results are provided for an experimental study of the reaction to internal explosive loading of titanium alloy PT-3V welded cylindrical shells filled with air or water. It is established that shell failure develops a strong scale effect in the form of a sharp reduction in explosion resistance with an increase in dimensions. Recommendations are made for weakening the effect of the scale factor and increasing shell explosion resistance. Semi-empirical equations are obtained which are recommended for evaluating explosion deformation parameters for the shell of a cylindrical explosion protection chamber made of titanium alloy.

References listed at the end of the paper:


R. Ohayon (1) and H. Moranda (2)
(1) Office National d'Etudes et de Recherches Aérospatiales (ONERA), 92320 Chatillon, France
(2) Centre National d'Etudes Spatiales, 97387 Kourou, French Guiana, France


ABSTRACT: We present various variational formulations adapted to the problem of dynamic stability analysis of liquid propelled launch vehicles. Sloshing vibrations including surface tension effects, hydroelastic
vibrational and structural acoustic vibrations are analyzed, using appropriate symmetric finite element procedures, in order to obtain accurate modal characteristics of the launcher for stability analysis.

ABSTRACT: The nonlinear interaction problem is analyzed by simultaneously solving the mass, momentum, and energy conservation equations together with appropriate material constitutive equations governing the fluid dynamics of the explosion gaseous product and the water and the structural dynamics of the compliant shell. A finite difference technique in a coupled Eulerian–Lagrangian scheme is used. The computer program PISCES 2DELK is employed to carry out the numerical computations. The results demonstrate that to rigorously analyze the response of a submerged structure to a nearby explosion, the interactions among the explosion shock wave, the structure, its surrounding media, and the explosion bubble need to be considered.

ABSTRACT: A new simplified method of analysis is developed to predict the nonlinear dynamic response of submerged stiffened plates subjected to underwater explosions. The dynamic response of the structure is modelled by using rigid-plastic beam and beam-grillage approaches developed previously for air-blast loaded stiffened plates and the fluid-structure interaction is simulated by applying the simple Hains acoustic approximations directly on the wet surface of the structure. Large-deflection and strain-rate effects are considered and the phenomenon of water cavitation is included by using an appropriate pressure criterion. The mathematical formulation of the coupled field system is briefly outlined and some illustrative examples are presented.

ABSTRACT: SPH (Smoothed Particle Hydrodynamics) is a gridless Lagrangian technique which is appealing as a possible alternative to numerical techniques currently used to analyze high deformation impulsive loading events. In the present study, the SPH algorithm has been subjected to detailed testing and analysis to determine the feasibility of using PRONTO/SPH for the analysis of various types of underwater explosion problems involving fluid-structure and shock-structure interactions. Of particular interest are effects of bubble formation and collapse and the permanent deformation of thin walled structures due to these loadings. These are exceptionally difficult problems to model. Past attempts with various types of codes have not been satisfactory. Coupling SPH into the finite element code PRONTO represents a new approach to the problem. Results show that the method is well-suited for transmission of loads from underwater explosions to nearby structures, but the calculation of late time effects due to acceleration of gravity and bubble buoyancy will require additional development, and possibly coupling with implicit or incompressible methods.
References listed at the end of the paper:


ABSTRACT: The effect of the initial geometric imperfections to the damage response of submerged structures is investigated. The type of the submerged structure investigated is the ring-stiffened long circular cylinders submerged in the fluid. The strain hardening mild steel is used in the analysis. The type of the loading is the underwater shock induced by underwater explosions. The modal imperfection concept has been used to simulate the initial geometric imperfections. The numerical analyses were performed to look into the details of damage response of ring-stiffened cylindrical shells. The following models were considered: (i) three-dimensional infinite ring-stiffened cylinder model, and (ii) three-dimensional finite ring-stiffened cylinder model. A finite element hydrocode was used to numerically predict model responses.

References listed at the end of the paper:

ABSTRACT: A theory is presented to predict the influence of non-linearities associated with the wall of the shell and with the fluid flow on the dynamics of elastic, thin, orthotropic and non-uniform open cylindrical shells submerged and subjected simultaneously to an internal and external fluid. The open shells are assumed to be freely simply supported along their curved edges and to have arbitrary straight edge boundary conditions. The method developed is a hybrid of thin shell theory, fluid theory and the finite element method. The solution is divided into four parts. In part one, the displacement functions are obtained from Sander's linear shell theory and the mass and linear stiffness matrices for the empty shell are obtained by the finite element procedure. In part two, the modal coefficients derived from the Sanders–Koiter non-linear theory of thin shells are obtained for these displacement functions. Expressions for the second and third order non-linear stiffness matrices of the empty shell are then determined through the finite element method. In part three, a fluid finite element is developed; the model requires the use of a linear operator for the velocity potential and a linear boundary condition of impermeability. With the non-linear dynamic pressure, we develop in the fourth part three non-linear matrices for the fluid. The non-linear equation of motion is then solved by the fourth-order Runge–Kutta numerical method. The linear and non-linear natural frequency variations are determined as a function of shell amplitudes for different cases.

ABSTRACT: When the structural response of a submerged structure subjected to UNDERwater EXPlosion (UNDEX) loads is calculated, the shock loading from UNDEX must be estimated accurately. In this paper, firstly, characteristics of free field pressure and those of surface pressure on a cylindrical shell structure are discussed through experimental results. Secondly, through the comparison of numerical simulation results with the experimental results, the capability of simulating UNDEX phenomena is shown. And also, it is shown that fluid-structure interaction plays an important role in UNDEX phenomena. Main conclusions can be summarized as follows. (1) Doubly exponential function proposed here can be fitted to measured free field pressure with accuracy better than 5% for impulse and energy flux density of free field pressure. (2) The reflection factor seems to depend on the distance between explosive and a structure. In these experiments, the shadow effects of the test model to shock wave is so remarkable that the reflection factor of the back surface of the test model becomes about 0.3. (3) There are some occasions that sharp peak pressure is generated on the back surface of a cylindrical shell structure, where elastic stress waves through different paths meet. (4) Fluid-structure interaction greatly influences peak value, impulse and energy flux density of shock loading to the test model. Therefore, it is necessary to take it into account when estimating the shock loading by numerical simulation. (5) Using axi-symmetric numerical simulation model, efficient and reasonably accurate estimation of shock loading to a cylindrical shell structure can be performed.

K.Y. Lam (1), Z.J. Zhang (1), S.W. Gong (1) and E.S. Chan (2)
(1) Department of Mechanical and Production Engineering, National University of Singapore, Singapore 119260 Singapore
Department of Civil Engineering, National University of Singapore, Singapore 119260 Singapore


ABSTRACT: Paper presents an analysis of submerged orthotropic cylindrical shells subjected to underwater shock wave. The equations of motion of orthotropic circular cylindrical shells are used in conjunction with the Reflected-Afterflow-Virtual-Source (RAVS) model to model the fluid-structure interaction. The finite difference method is then employed to solve the governing equation for the problem of the infinitive length orthotropic cylindrical shell subjected to planar shock waves. A comparison of the results respectively obtained by present analysis and USA/LSDYNA3D code is made to verify the present solution. By using the present approach, the effects of orientation a, thickness-radius ratio and curvature on the transient responses of the shell are examined.

Mayumi Fukuyama, Masaki Nakagawa, Kiyoshi Ishihama, Yutaka Hagiwara, Yukihiro Toyoda, Hiroshi Akiyama

Mechanical Engineering Research Laboratory, Hitachi Ltd., 502 Kandatsu-machi, Tsuchiura, Ibaraki 300-0013, Japan
Hitachi Works, Hitachi Ltd., Ibaraki, Japan
Central Research Institute of Electric Power Industry, Chiba, Japan
Department of Architecture, University of Tokyo, Tokyo, Japan


ABSTRACT: The purpose of this paper is to clarify dynamic buckling behaviours such as buckling mode and buckling pressure for thin cylindrical shells immersed in fluid subjected to seismic excitations. For this purpose, dynamic buckling experiments of thin cylindrical shells placed inside a rigid liquid container are carried out using a shaking table. These shells and the container are intended to represent thermal baffles and a main vessel of a fast breeder reactor, respectively. The fluid pressure caused by horizontal excitation induces buckling deformation which involves flower-shaped deformation, which is a type of external pressure buckling. The buckling pressure is measured with various types of the test cylinders under seismic excitations and this pressure is confirmed to agree with static buckling pressure predicted by static buckling analysis. It is also found that sub-harmonic vibration occurs under a certain sinusoidal excitation inducing a sudden increase in response displacement at a lower pressure level than the buckling pressure under seismic excitations. Based on these experiments, it is pointed out that, in seismic design, to prevent the buckling of thermal baffles, static buckling analyses can be used as long as sub-harmonic vibration does not occur.


ABSTRACT: Benchmarks for submerged structure response to underwater explosions are compiled. Both analytical and empirical benchmarks are presented; each type has advantages and disadvantages for the purposes of model validation, though no methodology for employing these benchmarks in a model validation effort is proposed. Benchmark computations are also referenced as part of this compilation. Extension of this compilation to floating structure response to underwater explosions, and to hydrodynamic/hydraulic ram problems, is proposed.

References listed at the end of the paper:


[45] T. Young, "Documentation of SAMS Test Concluded at WES," Naval Surface Warfare Center, Indian Head Division, 1996.


[50] G.S. Harris, unpubl. data on Pipe Whip experiment, Naval Surface Warfare Center, Indian Head Division.


[137] G.L. Chahine, "Dynamics of the interaction of non-spherical cavities," in T. Miloh, ed., Mathematical Approaches in

ABSTRACT: This paper deals with the transient response of a glass-epoxy composite submersible hull subjected to underwater explosive shock. The doubly asymptotic approximation (DAA) method is employed in this study to describe the fluid-structure interactions. The fluid-structure coupled equations, relating structure response to fluid impulsive loadings, are solved using coupled finite-element and boundary-element codes. Transient stress of the composite submersible hull induced by the underwater explosive shock are studied. Effects of the explosive charge weight and the distance from the target on the transient stress are examined. In addition, a comparison between the transient responses to underwater explosive shock for the composite submersible hull and a steel submersible hull is made.


ABSTRACT: A numerical study was conducted for simplified finite element modeling of stiffened structures under a dynamic loading. The study considered submerged structures subject to an underwater explosion. The objective of this study was to develop a finite element modeling technique which is computationally efficient and still accurate in terms of the structural dynamic response. This paper investigated techniques for smearing of stiffeners, representation of a cylindrical shell by a beam with surface of revolution (SOR), and interface of a cylindrical shell with a SOR beam. The advantage and disadvantage: of those techniques in conjunction with an explicit time-integration scheme were also discussed.

M. Amabili (1), F. Pellicano (2) and A.F. Vakakis (3)
(1) Dipartimento di Ingegneria Industriale, Università di Parma, Parco Area delle Scienze 181/A, 43100, Parma, Italy
(2) Dipartimento di Scienze dell'Ingegneria, Università di Modena, Via Campi 213b, Modena, 41100, Italy
(3) Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois


DOI: 10.1115/1.1288593

ABSTRACT: (none given)
M. Amabili (1), F. Pellicano (2) and A.F. Vakakis (3)
(1) Dipartimento di Ingegneria Industriale, Università di Parma, Parco Area delle Scienze 181/A, 43100, Parma, Italy
(2) Dipartimento di Scienze dell'Ingegneria, Università di Modena, Via Campi 213b, Modena, I - 41100, Italy
(3) Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois

“Nonlinear vibrations and multiple resonances of fluid-filled, circular shells, Part 2: Perturbation analysis”,

ABSTRACT: The nonlinear ordinary differential equations describing the dynamics of a fluid filled circular cylindrical shell, obtained in Part 1 of the present study, is studied by using a second order perturbation approach and direct simulations. Strong modal interactions are found when the structure is excited with small resonant loads. Modal interactions arise in the whole range of vibration amplitude, showing that the internal resonance condition makes the system non-linearizable even for extremely small amplitudes of oscillation. Stationary and nonstationary oscillations are observed and the complex nature of modal interactions is accurately analyzed. No chaotic motion is observed in the case of 1:1:1:2 internal resonance studied.

References listed at the end of the paper:

M. Amabili (1), F. Pellicano (2) and M.P. Païdoussis (3)
(1) Dipartimento di Ingegneria Industriale, Università di Parma, Parco Area delle Scienze 181/A, 43100, Parma, Italy
(2) Dipartimento di Scienze dell'Ingegneria, Università di Modena, Via Campi 213b, Modena, I - 41100, Italy
(3) Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street W. Montreal, Québec, Canada, H3A 2K6


ABSTRACT: The response of a shell conveying fluid to harmonic excitation, in the spectral neighbourhood of one of the lowest natural frequencies, is investigated for different flow velocities. The theoretical model has
already been presented in Part I of the present study. Non-linearities due to moderately large-amplitude shell motion are considered by using Donnell's non-linear shallow-shell theory. Linear potential flow theory is applied to describe the fluid-structure interaction by using the model proposed by Paidoussis and Denise. For different amplitudes and frequencies of the excitation and for different flow velocities, the following are investigated numerically: (1) periodic response of the system; (2) unsteady and stochastic motion; (3) loss of stability by jumps to bifurcated branches. The effect of the flow velocity on the non-linear periodic response of the system has also been investigated. Poincaré maps and bifurcation diagrams are used to study the unsteady and stochastic dynamics of the system. Amplitude modulated motions, multi-periodic solutions, chaotic responses, cascades of bifurcations as the route to chaos and the so-called “blue sky catastrophe” phenomenon have all been observed for different values of the system parameters; the latter two have been predicted here probably for the first time for the dynamics of circular cylindrical shells.

Branislav B. Pujevic, Miodrag M. Sekulovic and Marija M. Nefovska (Civil Engineering, University of Belgrade, Yugoslavia), “Nonlinear analysis of thin-wall cylindrical liquid storage reservoirs under seismic action”, 12WCEE 2000 (12th European Conference on Earthquake Engineering)

SUMMARY: This paper summarizes some of the results of a comprehensive theoretical investigation concerning the seismic response of ground supported liquid storage reservoirs. Dynamic properties of the fluid-shell interaction system with arbitrary boundary conditions were examined first. Evaluation of the results have shown that the variation of natural frequencies to the geometrical properties and filling ratio are highly dependent to the lateral and circumferential mode number. Finally, the accuracy of Code specified procedures for seismic design are examined and compared with the results obtained from the dynamic nonlinear finite element analysis.

References listed at the end of the paper:


ABSTRACT: This paper presents a computational approach to safety assessment of submerged pipelines, exposed to underwater shock. The fluid–structure interaction between the seawater and pipeline are handled using the coupled finite-element and boundary-element codes, based on the Doubly Asymptotic Approximation (DAA). The shock pressure transmitted from the seawater and sea bottom is calculated based on published empirical equations, which are incorporated into the coupled fluid–structure codes. Four cases of pipeline configurations were modeled and simulated, in this study. The first case is a submerged empty pipeline without any cover, the second case is a submerged empty pipeline with concrete cover, the third case is an empty pipeline buried in sand and the fourth case deals with a fluid-filled pipeline buried in sand. A comparison
between the four pipeline configurations is made, and the effects of the concrete cover and sand for the protection of the pipeline are examined.


ABSTRACT: The general features of an isolated underwater explosion have been extensively studied and are considered to be reasonably well understood. However, our understanding of the interaction which ensues when an explosion occurs in the immediate vicinity of a floating or submerged structure is considerably less well developed. We describe the application of small-scale experiments incorporating cylindrical steel targets instrumented with accelerometers and underwater pressure transducers to investigate this question. Acceleration records clearly show the response of the targets to loading from the separate shock wave and bubble collapse events. Interpretation of this data demonstrates the dominance of bubble collapse loading for underwater explosions in close proximity to a submerged structure.

K. Ramajeyathilagam (1), C.P. Vendhan (1) and V. Bhujanga Rao (2)
(1) Ocean Engineering Centre, Indian Institute of Technology, Madras, Chennai 600036, India
(2) Naval Science and Technological laboratory, Visakhapatnam, 530027, India


ABSTRACT: Experimental and numerical investigations were carried out on clamped rectangular plates subjected to underwater explosion loading. Experiments were conducted on rectangular plates of size 0.55Y0.45Y0.004 m using a box model set-up under air-backed conditions in a water tank detonating small charge weights of PEK-I explosive. Corresponding plastic deformation of the plates were measured for different charge weights and stand off distances. Numerical analysis was carried out using the MARC finite element code for various test conditions and the results are compared with experimental results.

References listed at the end of the paper:

References listed at the end of the paper:
K. Ramajeyathilagam (1), C.P. Vendhan (2) and V. Bhujanga Rao (1)
(1) Shock and Vibration Center, Naval Science and Technological Laboratory, Visakhapatnam 530027, India
(2) Ocean Engineering Department, Indian Institute of Technology Madras, Chennai, 600036, India

“Experimental and numerical investigation on deformation of cylindrical shell panels to underwater explosion”, Shock and Vibration, Vol. 8, pp 253-270, 2001

ABSTRACT: Experimental and numerical investigations on cylindrical shell panels subjected to underwater explosion loading are presented. Experiments were conducted on panels of size 0.8 × 0.6 × 0.00314 m and shell
Simulation response of a submerged spherical shell subjected to strong, plane, incident shock waves, in which elastoplastic material behavior is considered.

ABSTRACT: Based on a procedure which couples the finite element method with the doubly asymptotic approximation, this work addresses the problem of the transient responses of a submerged spherical shell subjected to strong, plane, incident shock waves, in which elastoplastic material behavior is considered. Simulation results indicate that the procedure adopted shows good agreement with related literature, which rise-to-span ratios $h/l = 0.0, 0.05, 0.1$, using a box model set-up under air backed conditions in a shock tank. Small charges of PEK I explosive were employed. The plastic deformation of the panels was measured for three loading conditions. Finite element analysis was carried out using the CSA/GENSA [DYNA3D] software to predict the plastic deformation for various loading conditions. The analysis included material and geometric non-linearities, with strain rate effects incorporated based on the Cowper-Symonds relation. The numerical results for plastic deformation are compared with those from experiments.


SUMMARY: Viscoplastic response of a fully-clamped circular plate to an underwater explosion shock is studied in this paper. Strain-rate effect is included in the response. A fluid-structure interaction model is introduced, which is characterized by two stages: In the early stage, only the shock wave in water is considered, and the motion of structure is neglected. In the second stage, the wave propagation in structure and fluid is disregarded, and only long-term fluid force (added mass) and long-term structural force (membrane stress) are considered. Based on this model, the equation of motion of a fully-clamped circular plate is established, the solutions of which are compared with two experiments. The calculated maximum plastic deformations from present model are close to the observed values. The dependence of maximum plastic deformation on charge weight, plate radius and material property is also discussed.

References listed at the end of the paper:

considered linear elastic behavior of the shell. Also presented herein are the time histories of surface pressure, radial velocity and von Mises stress of the shell. Moreover, deformation diagrams and spreading of the plastic zone of the shell are described as well.


ABSTRACT: Results of studies into dynamic processes (both stationary and nonstationary) in differently excited shell systems interacting with a liquid are generalized and systematized. Problems related to this division of mechanics are formulated and methods developed for solving them are stated. Typical numerical results are presented.

References listed at the end of the paper:


129. E. N. Mnev and A. K. Pertsev, Hydroelastici
127. A. G. Leiko, Yu. E. Shamarim, and V. P. Godenko, “Interaction of a transient pressure wave with a rigid sphere near a free


ABSTRACT: Finite element analysis can be used to predict the transient response of submerged structures that
are externally loaded by an acoustic pressure shock wave resulting from an Underwater Explosion (UNDEX). This class of problem is characterized by a strong coupling between the structural motions and acoustic pressures at the fluid-structure wetted interface. The structural behavior is a combination of long time (low frequency) response dominated by an added mass effect, short time (high frequency) response dominated by radiation damping, and intermediate time-frequency response where both added mass and radiation damping behavior are present. For the finite element method to be useful, the analyst must develop modeling techniques and procedures that yield accurate and computationally tractable solutions. Modeling procedures and guidelines were developed for use with an explicit dynamics code that offers advanced features such as: pressure formulated acoustic elements, surface based fluid-structure coupling, surface based absorbing (radiation) boundaries, and automated incident wave loading for the fluid-structure wetted interface. The modeling guidelines address issues such as: location of the fluid acoustic domain outer boundary, meshing of the acoustic domain, representation of the shock wave, and solution efficiency. These modeling procedures and guidelines are demonstrated with an ABAQUS/Explicit analysis of an UNDEX experiment in which a submerged test cylinder was exposed to a 60-pound HBX-1 explosive charge (Kwon & Fox, 1993).

References listed at the end of the paper:

James L. O’Daniel (1), Theodor Krauthammer (2), Kevin L. Koudela (2) and Harry H. Strait (2)
(1) US Army Engineer Research and Development Center, Structural Mechanics Branch, 3909 Halls Ferry Road, Vicksburg, MS 39180, USA
(2) The Pennsylvania State University, 212 Sackett Building, University Park, PA 16802, USA


ABSTRACT: The assessment of the response of naval vessels to underwater shock creates a need for tools that can analyze and design such systems to withstand underwater explosions (UNDEX). This paper describes a preliminary attempt to develop a methodology for the assessment of structural systems to UNDEX effects. A methodology is proposed by which the response of a simplified structural component to UNDEX can be validated through the use of precision impact testing and numerical simulations. An iterative process was used where an UNDEX response, determined through previous results, preliminary UNDEX simulations, and impact simulations, provided the parameters necessary for a precision impact test that generates an equivalent response. Precision impact tests were performed, and the results correlated with the impact simulated data. The results from an UNDEX test were compared with the predictions from the validated numerical code. The structural component in both the tests and simulations was simplified to a flat rectangular panel. The numerical simulations were solved explicitly, and included either the impact loading environment—a hybrid impactor with an initial velocity—or the UNDEX loading environment—a plane shock wave applied to the surface of the target structure. Since close-in and early time UNDEX-related phenomena, such as gas bubble effects, are localized and very complicated, they were ignored in this preliminary phase of the study. Although the proposed methodology could require multiple iterations, the limited scope of this study only included one set of precision-impact tests on each type of material, one UNDEX test against an aluminum panel, and two UNDEX tests against composite panels. Once the methodology using precision shock testing and numerical simulations to validate the UNDEX response had been developed, it was used to develop a “design-for-shock” procedure.

Dalin Tang (1), Chun Yang (2), Homer Walker (1), Shunichi Kobayashi (3) and David N. Ku (4)
(1) Mathematical Sciences Department, Worcester Polytechnic Institute, Worcester, MA 01609-2280, USA
(2) Mathematics Department, Beijing Normal University, Beijing, China
(3) Department of Functional Machinery and Mechanics, Shinshu University, 3-15-1 Tokida Ueda, 386-8567 Nagano, Japan
(4) Georgia Institute of Technology, School of Mechanical Engineering, Atlanta, GA 30322, USA

“Simulating cyclic artery compression using a 3D unsteady model with fluid-structure interactions”, Computers
& Structures, Vol. 80, pp 1651-1665, 2002

ABSTRACT: High pulsating blood pressure and severe stenosis make fluid–structure interaction (FSI) an important role in simulating blood flow in stenotic arteries. A three-dimensional nonlinear model with FSI and a numerical method using GFD are introduced to study unsteady viscous flow in stenotic tubes with cyclic wall collapse simulating blood flow in stenotic carotid arteries. The Navier–Stokes equations are used as the governing equations for the fluid. A thin-shell model is used for the tube wall. Interaction between fluid and tube wall is treated by an incremental boundary iteration method. Elastic properties of the tube wall are determined experimentally using a polyvinyl alcohol hydrogel artery stenosis model. Cyclic tube compression and collapse, negative pressure and high shear stress at the throat of the stenosis, flow recirculation and low shear stress just distal to the stenoses were observed under physiological conditions. These critical flow and mechanical conditions may be related to platelet aggregation, thrombus formation, excessive artery fatigue and possible plaque cap rupture. Computational and experimental results are compared and reasonable agreement is found.

References listed at the end of the paper:


Almost all vessels carrying fluids within the body are flexible, and interactions between an excited oscillation of a single-phase fluid flow at low Reynolds number. We review recent advances in understanding the mechanics of composite material vessels and components, PVP 146, PD 18. ASME; 1988. p. 55–62.


ABSTRACT: The practicability of an improved procedure for simulating the response of a surface ship to an underwater explosion is demonstrated by examining transient responses for a 31,000-degree-of-freedom finite-element model of ship-like structure. The fluid model employs spectral elements of various order, and models the cavitating fluid as a nonlinear acoustic medium with a bilinear bulk modulus. The number of fluid degrees of freedom ranges from 10^7 to 10^10. Also studied is the viability of dramatic mesh truncation, which is essential to the feasibility of the procedure. The results indicate that useful simulations may be performed on a modern PC when all of the resource-conserving improvements are fully exploited.

Grothberg, J. B. (1), and O. E. Jensen (2)
(1) Biomedical Engineering Department, University of Michigan, Ann Arbor, Michigan, USA
(2) Mathematical Sciences, University of Nottingham, University Park, Nottingham, UK

ABSTRACT: Almost all vessels carrying fluids within the body are flexible, and interactions between an internal fluid and wall deformation often underlie a vessel’s biological function or dysfunction. Such interactions can involve a rich range of fluid-mechanical phenomena, including nonlinear pressure-drop/flow-rate relations, self-excited oscillations of single-phase flow at high Reynolds number and capillary-elastic instabilities of two-phase flow at low Reynolds number. We review recent advances in understanding the fundamental mechanics of flexible-tube flows, and discuss physiological applications spanning the cardiovascular system (involving wave propagation and flow-induced instabilities of blood vessels), the respiratory system (involving phonation, the closure and reopening of liquid-lined airways, and Marangoni
flows on flexible surfaces), and elsewhere in the body (involving active peristaltic transport driven by fluid-
structure/muscle interactions).

Marco Amabili (1) and Michael P. Païdoussis (2)
(1) Dipartimento di Ingegneria Industriale, Università di Parma, Parco Area delle Scienze 181/A, 43100 Parma, Italy
(2) Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street W., Montreal, Québec, H3A 2K6 Canada
ABSTRACT: (none given)

F. Cote (1), V.S. Deshpande (1), N.A. Fleck (1), A.G. Evans (2)
(1) Cambridge University Engineering Department, Trumpington Street, Cambridge, CB2 1PZ, UK
(2) Materials Department, University of California, Santa Barbara, CA 93106-5050, USA
ABSTRACT: Stainless steel square-honeycombs have been manufactured by slotting together steel sheets and then brazing the assembly. Their out-of-plane compressive response has been measured as a function of the relative density, the ratio of specimen height to cell size, and the degree of constraint associated with bonding of the honeycomb to face-sheets. It has been found that, for the practical range of relative densities (less than 20%), the peak strength is relatively insensitive to both the ratio of the specimen height to cell size and to the presence or absence of bonding to face-sheets. An analytical model, derived from existing models for the buckling of shells, for elastic and plastic buckling of the square-honeycombs is shown to be in good agreement with the experimental measurements.

References listed at the end of the paper:

N.A. Artsykova, A.K. Persev and S.V. Yakovlev (State Marine Technology University, St. Petersburg, Russia),
ABSTRACT: The paper studies the interaction of a spherical shock wave with an elastic circular cylindrical shell immersed in an infinite acoustic medium. The shell is assumed infinitely long. The wave source is quite close to the shell, causing deformation of just a small portion of the shell, which makes it possible to represent the solution by a double Fourier series. The method allows the exact determination of the hydrodynamic forces acting on the shell and analysis of its stress state. Some characteristic features of the stress state are described for different distances to the wave source. Formulas are proposed for establishing the safety conditions of the shell.
References listed at the end of the paper:


ABSTRACT: Surface ship shock trials have been conducted in many countries for shock qualification of ship integrity, systems and subsystems. The ship shock trial identifies design and construction deficiencies that have a negative impact on ship and crew survivability. It also validates shock hardening criteria and performance. However, ship shock trials are costly. As a possible alternative, numerical modeling and simulation may provide viable information to look into the details of dynamic characteristics of ship including component and sub-component level. Ship shock analyses were conducted using finite element based coupled ship and fluid model. Three-dimensional ship shock modeling and simulation has been performed and the predicted results were compared with ship shock test data. Surface ship shock analysis approach is presented and the important parameters are discussed.


ABSTRACT: During World War II many surface combatants were damaged or severely crippled by close-proximity underwater explosions from ordnance that had actually missed their target. Since this time all new classes of combatants have been required to conduct shock trial tests on the lead ship of the class in order to test the survivability of mission essential equipment in a severe shock environment. While these tests are extremely important in determining the vulnerabilities of a surface ship, they require an extensive amount of preparation, man-hours, and money. Furthermore, these tests present an obvious danger to the crew on board, the ship itself, and any marine life in the vicinity. Creating a virtual shock environment by use of a computer to model the ship structure and the surrounding fluid presents a valuable design tool and an attractive alternative to these tests. The research work shown in this paper investigated the accuracy of shock simulation using the shock trials conducted on USS WINSTON S. CHURCHILL (DDG 81) in 2001. All three explosions DDG 81 was subjected...
to are simulated and the resulting predictions compared with actual shock trial data. The ship shock modeling and simulation strategy is discussed and the effects of fluid volume size, mesh density, mesh quality are also investigated.

References listed at the end of the paper:

Timon Rabczuk, Esteban Samaniego and Ted Belytschko (Department of Mechanical Engineering, Northwestern University, 2145 Sheridan Road, Room A212, Evanston, IL 60208-3111, USA), “Simplified model for predicting impulsive loads on submerged structures to account for fluid-structure interaction”, Submitted to Elsevier Press, August 2005

ABSTRACT: A simplified method for accounting for the effects of fluid structure interaction (FSI) in sandwich structures subjected to dynamic underwater loads is developed. The method provides quite accurate predictions of the impulse on submerged structures for a large range of loads and core yield strengths. It is a simple model with two lumped masses, one of which is subjected to an incident wave and a rheological model to represent the
correlate well with each other. Both experimental tests and numerical analysis were compared. The experimental and numerical results using the package USA/DYNA. The acceleration, velocity and strain histories of the target plate panel under the same experimental conditions was numerically analyzed. Subsequent experiments on a plate panel were affected by an explosion of the aforementioned combined charge at various standoff distances. The plate panel under the same experimental conditions was numerically analyzed using the package USA/DYNA. The acceleration, velocity and strain histories of the target plate obtained from both experimental tests and numerical analysis were compared. The experimental and numerical results correlate well with each other.

References listed at the end of the paper:

Hung CF (1), Hsu PY (1), Hwang-Fu Io J (2)
(1) Department of Engineering Science and Ocean Engineering, National Taiwan University, Taipei, Taiwan, ROC
(2) Chung Shan Institute of Science and Technology, Taoyuan, Taiwan, ROC

ABSTRACT: This work compares experimental and numerical results concerning the elastic dynamic response of an air-backed rectangular aluminum plate subjected to an underwater explosion. Experiments were executed in a 4 x 4 x 4 m water tank. A small quantity of charge was applied to ensure the dynamic response of the target plate remained within the elastic range. A highly sensitive combined charge, which consists of a DP60 detonator and a Detasheet, was selected to enable a small quantity of charge to react fully when it explodes in the small water tank. The shock parameters of the combined charge were determined experimentally. Subsequent experiments on a plate panel were affected by an explosion of the aforementioned combined charge at various standoff distances. The plate panel under the same experimental conditions was numerically analyzed using the package USA/DYNA. The acceleration, velocity and strain histories of the target plate obtained from both experimental tests and numerical analysis were compared. The experimental and numerical results correlate well with each other.

A. Marzo (1), X.Y. Luo (2) and C.D. Bertram (3)
(1) Department of Mechanical Engineering, University of Sheffield, Sheffield, UK
ABSTRACT: Three-dimensional collapse of and steady flow through finite-length elastic tubes are studied numerically. The Navier-Stokes equations coupled with large, nonlinear deformation of the elastic wall are solved by using the finite-element software, FIDAP. Three-dimensional solid elements are used for the elastic wall, allowing us to specify any wall thickness required. Plane-strain results for the cross-sectional shape of thinner-walled tubes are validated by comparison with published numerical data. Three-dimensional results for flow through finite-thickness tubes are in excellent agreement with published numerical results based on thin-shell elements, and are used to show the effects of varying wall thickness. Finally, the computational predictions are compared with experimental pressure–area relationships for thick walled tubes. The simulations confirm a previously neglected experimental finding, that the Young wavespeed can be lower between buckling and osculation for thick tubes than for thinner ones.

References listed at the end of the paper:


ABSTRACT: This paper presents experimental results on the nonlinear dynamics and stability characteristics of thin-walled clamped–clamped circular cylindrical shells in contact with flowing fluid. The experiments were conducted with three experimental set-ups: one for experiments with elastomer shells in annular air-flow, the second for elastomer shells with internal air-flow, and the last one for aluminium or plastic cylindrical shells with internal water-flow. In all cases the interaction between the shell and the fully developed flow gives rise to instabilities in the form of static or dynamic divergence at sufficiently high flow velocities. The aim of the experimental study was (i) to gather data on the critical flow velocity for instability and on the post-critical flow/displacement–amplitude relationship, and (ii) to undertake an analysis of the experimental results and to compare them qualitatively with theoretical predictions. The experimental results show a softening type nonlinear behaviour, with a large hysteresis in the velocity for the onset and cessation of divergence.

K.N. Karagiozis (1), M. Amabili (2), M.P. Païdoussisa (1) and A.K. Misra (1)
(1) Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street West, Montreal, Québec, Canada H3A 2K6
(2) Dipartimento di Ingegneria Industriale, Università di Parma, Parco Area delle Scienze 181/A, Parma I-43100, Italy


ABSTRACT: In this study, the nonlinear vibrations are investigated of circular cylindrical shells, empty or fluid-filled, clamped at both ends and subjected to a radial harmonic force excitation. Two different theoretical models are developed. In the first model, the standard form of the Donnell’s nonlinear shallow-shell equations is used; in the second, the equations of motion are derived by a variational approach which permits the inclusion of constraining springs at the shell extremities and taking in-plane inertial terms into account. In both cases, the solution includes both driven and companion modes, thus allowing for a travelling wave in the circumferential direction; they also include axisymmetric modes to capture the nonlinear inward shell contraction and the correct type (softening) nonlinear behaviour observed in experiments. In the first model, the clamped beam eigenfunctions are used to describe the axial variations of the shell deformation, automatically satisfying the boundary conditions, leading to a 7 degree-of-freedom (dof) expansion for the solution. In the second model, rotational springs are used at the ends of the shell, which when large enough reproduce a clamped end; the solution involves a sine series for axial variations of the shell deformation, leading to a 54 dof expansion for the solution. In both cases the modal expansions satisfy the boundary conditions and the circumferential continuity condition exactly. The Galerkin method is used to discretize the equations of motion, and AUTO to integrate the discretized equations numerically. When the shells are fluid-filled, the fluid is assumed to be incompressible and inviscid, and the fluid–structure interaction is described by linear potential flow theory. The results from the
two theoretical models are compared with existing experimental data, and in all cases good qualitative and quantitative agreement is observed.


(1) Materials Department, University of California, Santa Barbara, CA 93106, USA
(2) Department of Engineering, University of Cambridge, Trumpington St., Cambridge CB2 1PZ, UK
(3) Division of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA


ABSTRACT: Stainless steel square honeycomb core sandwich and solid monolithic beams have been subjected to high-pressure, short-duration impulses using a shock simulation technique involving high-speed impact of Al foam projectiles. The experiments have been designed to achieve two objectives: (i) to demonstrate the benefits of sandwich construction, and (ii) to assess the fidelity of dynamic finite element calculations in simulating the structural response. The results affirm that, when subjected to impulse levels representative of those associated with nearby explosions, the sandwich beams exhibit smaller displacements than the solid beams at equivalent weight. The benefit is especially large at lower impulses where the effective dynamic strength of the honeycomb core prevents crushing. The measurements and finite element simulations having greatest relevance to the shock resistance are found to correspond closely, particularly the displacements and the core crushing strains. One implication is that the dynamic finite element model has the requisite fidelity at impulse levels of interest.

References listed at the end of the paper:


ABSTRACT: The application of the finite element corotational theory to model geometric nonlinear structures within a fluid–structure interaction procedure is proposed. A dynamic corotational approximately-energy-conserving algorithm is used to solve the nonlinear structural response and it is shown that this algorithm's application with a four-node flat finite element is more stable than the nonlinear implicit Newmark method. This structural dynamic algorithm is coupled with the unsteady vortex-ring method using a staggered technique. These procedures were used to obtain aeroelastic results of a nonlinear plate-type wing subjected to low speed airflow. It is shown that stable and accurate numerical solutions are obtained using the proposed fluid–structure interaction algorithm. Furthermore, it is illustrated that geometric nonlinearities lead to limit cycle oscillations.

Librescu, L. (1), Oh, S.Y. (1), Hohe, J. (2)  
(1) Department of Engineering Science and Mechanics, Virginia Polytechnic Institute and State University Mail Code (0219), Blacksburg, VA 24061-0219, USA  
(2) Fraunhofer Institut für Werkstoffmechanik, Wöhlerstr. 11, 79104 Freiburg, Germany  
ABSTRACT: The problem of the dynamic response of flat rectangular sandwich panels subjected to underwater and in-air explosions is analyzed. The study is carried out in the framework of a geometrically non-linear model of sandwich structures featuring anisotropic laminated face sheets and an orthotropic core, in conjunction with the unsteady pressure generated by an explosion. Effects of the core and of the orthotropy of its material, as well as those related to the ply-thickness, directional material property and stacking sequence of face sheets, geometrical non-linearities and of the structural damping ratio are investigated, and their implications upon the dynamic response are highlighted. To the best of the authors’ knowledge, the specialized literature addressing the dynamic response of sandwich structures to underwater and in-air explosions is rather scanty. This work is likely to fill a gap in the specialized literature on this topic.  
References listed at the end of the paper:
and test structures within the laboratory. The tube is struck at one end by a steel projectile, with the test structure placed at the opposite end of the tube. Realistic exponentially decaying pressure pulses are generated in the water with peak pressures in the range 15–70 MPa and decay times ranging from 0.1 to 1.5 ms. The peak pressure and the pulse duration are independently adjusted by varying the projectile velocity and mass, respectively. The underwater shock simulator is used to investigate the one-dimensional fluid–structure interaction of sandwich plates with steel face sheets and an aluminium foam core. The degree of core compression is measured as a function of both the underwater shock impulse and the Taylor fluid–structure interaction parameter. Fully coupled finite element simulations agree well with the measurements while decoupling the fluid–structure interaction phase from the core compression phase within the finite element analysis leads to an under-prediction of the degree of core compression.

J.Y. Zheng (1), Y.J. Chen (1), G.D. Deng (1), G.Y. Sun (1), Y.L. Hu (2) and Q.M. Li (3)  
(1) Institute of Chemical Machinery, Zhejiang University, Hangzhou 310027, China  
(2) Northwest Institute of Nuclear Technology, Xinjiang, 841700, China  
(3) School of Mechanical, Aerospace and Civil Engineering, Pariser Building, The University of Manchester, PO Box 88, Sackville Street, Manchester M60 1QD, UK  

ABSTRACT: A discrete multi-layered cylindrical shell (DMC) consists of a thin inner cylindrical shell and helically cross-winding flat steel ribbons. The dynamic elastic response of such cylindrical shell under uniformly distributed pressure pulse is studied in this paper. Under the axisymmetric plane strain assumption, the solution of the problem is divided into two parts: a quasi-static part satisfying inhomogeneous stress boundary conditions and a dynamic part complying with homogeneous stress boundary conditions. The quasi-static part is determined by homogeneous linearity method and boundary conditions, and the dynamic part was worked out by means of finite Hankel transform and Laplace transform. The dynamic response of a DMC is compared with the response of monobloc cylindrical shell. Parametric analyses with the consideration of major influential factors, such as thickness ratio of the inner shell to that of the complete shell, material parameters and winding-angle, are discussed.

Enrico Ferri, Emilio Antinucci, Ming Y. He, John W. Hutchinson, Frank W. Zok and Anthony G. Evans,  

ABSTRACT: When sandwich panels with prismatic cores are impulsively loaded, the stresses imposed by the core on the front face, as well as those transmitted through the core govern the response metrics, especially the center displacement, resistance to tearing, and loads transmitted to the supports. This article presents a basic study of the dynamic response with emphasis on the I-core. A prior assessment revealed buckle waves induced because of inertial phenomena accompanying the rapid compression of the members. The development of these waves is an integral aspect of the dynamic response. One objective of this investigation is to ascertain the characteristics governing such waves in I-core configurations through a combined experimental and numerical study. A particular emphasis is on the influence of manufacturing imperfections in the core members on the formation and propagation of the buckles. A second goal is to examine the stresses associated with the dynamic compression of the core, again through a combined experimental and numerical investigation. The investigation is conducted for stainless steel I-core panels supported at the back face and subjected to a constant velocity at the front. Imperfections to be included in the numerical study have been ascertained by comparing buckle patterns with those found experimentally over the relevant velocity range. The simulations reveal that the stresses induced differ on the front and back faces. On the front they are higher and velocity dependent. On the rear they are velocity invariant and scale with the relative density and material yield strength. The duration of the stress pulses, which is essentially the same on both faces, scales linearly with the core height. It correlates with the time needed for bucklewaves to propagate through the core to the back face. After the pulse terminates, the core continues to compress at a stress level about an order of magnitude smaller.
ABSTRACT: This paper presents an analysis on attenuation of floating structures response to underwater shock. An explicit finite element approach interfaced with the boundary element method is used for the shock interaction problems. The attenuation effects of the floating structure response to underwater shock are deduced.

References listed at the end of the paper:


ABSTRACT: In combat operations, a warship can be subjected to air blast and underwater shock loading, which if detonated close to the ship can damage the vessel form a dished for hull plating or more serious holing of the hull. This investigation develops a procedure which couples the nonlinear finite element method with doubly asymptotic approximation method, and which considers the effects of transient dynamic, geometrical nonlinear, elastoplastic material behavior and fluid–structure interaction. This work addresses the problem of transient responses of a 2000-ton patrol-boat subjected to an underwater explosion. The KSF=0.8 is adopted to describe the shock severity. Additionally, the shock loading history along keel, the acceleration, velocity and displacement time histories are presented. Furthermore, the study elucidates the plastic zone spread phenomena and deformed diagram of the ship. Information on transient responses of the ship to underwater shock is useful in designing ship hulls so as to enhance their resistance to underwater shock damage.

References listed at the end of the paper:

considered as the criterion for explosive shock
maximum energy, depending on its strength and ductility, it undergoes fracture. Terminal strain to fracture is
Deflect
deformation is predicted as a function of geometric and material properties of the plate and shock pulse impulse.
explosion progressively increases, the elastic to plastic transition occurs over a specific shock factor. Plastic
development in the plate is given as a function of the material and shock wave parameters.

deformation, yielding, plastic deformation or fracture. When the deformation is in the elastic range, the stress
a gas bubble pulsation. The interaction of the shock wave with a plate imparts energy to it, which is dissipated
associated with the evolution of large amount of heat generates a shock front in the water medium, followed by a
gas bubble pulsation. The interaction of the shock wave with a plate imparts energy to it, which is dissipated
in the form of deformation. The intensity of explosion determines whether a plate undergoes elastic
deformation, yielding, plastic deformation or fracture. When the deformation is in the elastic range, the stress
developed in the plate is given as a function of the material and shock wave parameters. As the intensity of
explosion progressively increases, the elastic to plastic transition occurs over a specific shock factor. Plastic
deformation is predicted as a function of geometric and material properties of the plate and shock pulse impulse.
Deflection-time history reveals the reloading effects of the shock wave. As the deforming plate absorbs
maximum energy, depending on its strength and ductility, it undergoes fracture. Terminal strain to fracture is
considered as the criterion for explosive shock performance of ship materials.

ABSTRACT: Behaviour of plate specimens subjected to underwater explosion – a review”,

ABSTRACT: This paper reviews the previous work on structural optimization with frequency constraints. The sensitivity analysis, constraint approximations, and optimization algorithms are discussed in the context of frequency optimization. Frequency related issues and structural applications are presented by discussing the difficulties in designing structures with frequency constraints.


ABSTRACT: Undersea weapons, including torpedoes need to be designed to survive extreme loading conditions such as underwater explosions (UNDEX). In this work, a multidisciplinary optimization problem is solved for a lightweight torpedo model subjected to UNDEX. A torpedo configuration with least possible weight for a given level of safety from an explosion at a critical distance is obtained. The torpedo is modeled using both metallic and composite material models. The similitude relations are used to model the pressure wave resulting from an explosive, which is assumed as a spherical wave. The response of the composite flat plate is obtained prior to the torpedo for validating the analysis routine and determining the stress levels in each of the layers. The response of a composite lightweight torpedo model is also obtained and structural optimization is performed to achieve the minimum weight subject to the required safety levels. Similar analysis and optimization was performed for a stiffened metallic torpedo. The optimal designs for both models are compared and it is observed that the composite torpedo model is stronger and lighter than the metallic design when subjected to an UNDEX at a given standoff distance.

References listed at the end of the paper:

17) Dyka, C.T., and Badaliance, R., “Damage in marine composites caused by shock loading,” Composites Science and Technology,
ABSTRACT: Nowadays, fluid-structure interaction problems are a great challenge of different fields in engineering and applied sciences. In civil engineering applications, wind flow and structural motion may lead to aeroelastic instabilities on constructions such as long-span bridges, high-rise buildings and light-weight roof structures. On the other hand, biomechanical applications are interested in the study of hemodynamics, i.e. blood flow through large arteries, where large structural membrane deformations interact with incompressible fluids. In the structural part of this work, a new methodology for the analysis of geometrically nonlinear orthotropic membrane and rotation-free shell elements is developed based on the principal fiber orientation of the material. A

References listed at the end of the thesis:


ABSTRACT: Wind turbines are a real alternative for clean power generation aimed at reducing global warming and improving sustainable energy. To withstand wind forces, aerogenerators should be properly analyzed to ensure a good operation in the system lifetime. Several approaches can be established to perform analysis and design of this kind of structure. However, wind turbines have collapsed all around the world, and a reason for its failure is still being searched. In this paper, an engineering solution considering fluid structure interaction for wind turbines is presented, aiming to find why wind turbines collapse. Wind action is modelled through a stabilized fluid flow formulation, while the structure is solved with geometrically nonlinear shell elements with only translation degrees of freedom. In both cases (i.e., the modelling of the fluid as well as the structure), the finite element method is used to find a solution. The main result found in this study is the location of principal stresses in the structure due to dynamic wind action. It is concluded that most of the times failure of wind turbines will not occur in its base as it is usually believed.

References listed at the end of the paper:

http://www.tdx.cat/handle/10803/6866?jsessionid=250C91164FBD9703B45D7135E0642330.tdx2

C.Y. Jen (1) and W.H. Lai (2)
ABSTRACT: From a structural perspective, the pressure hull is a significant structural component of underwater vehicles, to enable them to withstand environmental loadings such as hydrostatical pressure and underwater explosive loading. Hence, improving configuration design tends to be important for underwater vehicles. Applying a nonlinear FEM/DAA coupling procedure, which addresses the effects of transient dynamic, geometrical nonlinear, elastoplastic material behavior and the fluid structure interaction, this investigation examines the transient dynamic responses of a multiple intersecting spheres (MIS) deep-submerged pressure hull subjected to underwater explosion. The time histories of the wet-surface pressure, displacement, velocity, acceleration, von Mises stress and plastic strain are presented. Additionally, the deformed diagram and velocity distribution of MIS pressure hull are elucidated. The analytical results are valuable for designing novel pressure hulls to resist underwater explosion.


ABSTRACT: Significant reductions in the fluid structure interaction regulated transfer of impulse occur when sandwich panels with thin (light) front faces are impulsively loaded in water. A combined experimental and computational simulation approach has been used to investigate this phenomenon during the compression, of honeycomb core sandwich panels. Square cell honeycomb panels with a core relative density of 5% have been fabricated from 304 stainless steel. Back supported panels have been dynamically loaded in through thickness compression using an explosive sheet to create a plane wave impulse in water. As the impulse was increased, the ratio of transmitted to incident momentum decreased from the Taylor limit of 2, for impulses that only elastically deformed the core, to a value of 1.5, when the peak incident pressure caused inelastic core crushing. This reduction in transmitted impulse was slightly less than that previously observed in similar experiments with a lower strength pyramidal lattice core and, in both cases, was well above the ratio of 0.35 predicted for an unsupported front face. Core collapse was found to occur by plastic buckling under both quasistatic and dynamic conditions. The buckling occurred first at the stationary side of the core, and, in the dynamic case, was initiated by reflection of a plastic wave at the (rigid) back face sheet-web interface. The transmitted stress through the back face sheet during impulse loading depended upon the velocity of the front face, which was determined by the face sheet thickness, the magnitude of the impulse, and the core strength. When the impulse was sufficient to cause web buckling, the dynamic core strength increased with front face velocity. It rose from about 2 times the quasistatic value at a front face initial velocity of 35 m/s to almost 3 times the quasistatic value for an initial front face velocity of 104 m/s. The simulations indicate that this core hardening arises from inertial stabilization of the webs, which delays the onset of their buckling. The simulations also indicate that the peak pressure transmitted to a support structure from the water can be controlled by varying the core relative density. Pressure mitigation factors of more than an order of magnitude appear feasible using low relative density cores. The study reveals that for light front face sandwich panels the core strength has a large effect upon impulse transfer and the loading history applied to support structures.

References listed at the end of the paper:

ABSTRACT: Sandwich panel structures with thin front faces and low relative density cores offer significant impulse mitigation possibilities provided panel fracture is avoided. Here steel square honeycomb and pyramidal truss core sandwich panels with core relative densities of 4% were made from a ductile stainless steel and tested under impulsive loads simulating underwater blasts. Fluid-structure interaction experiments were performed to (i) demonstrate the benefits of sandwich structures with respect to solid plates of equal weight per unit area, (ii) identify failure modes of such structures, and (iii) assess the accuracy of finite element models for simulating the dynamic structural response. Both sandwich structures showed a 30% reduction in the maximum panel deflection compared with a monolithic plate of identical mass per unit area. The failure modes consisted of core crushing, core node imprinting/punch through/tearing and stretching of the front face sheet for the pyramidal truss core panels. Finite element analyses, based on an orthotropic homogenized constitutive model, predict the overall structural response and in particular the maximum panel displacement.

References listed at the end of the paper:
ABSTRACT: The dynamic response of deformable structures subjected to shock load and cavitation reload has been simulated using a multiphase model, which consists of an interface capturing method and a one-fluid cavitation model. Fluid–structure interaction (FSI) is captured via a modified ghost fluid method (Liu et al. in J Comput Phys 190: 651–681, 2003), where the structure is assumed to be a hydro-elasto-plastic material if subjected to a strong shock load. Bulk cavitation near the structural surface is captured using an isentropic model (Liu et al. in J Comput Phys 201:80–108, 2004). The integrated multiphase model is validated by comparing numerical predictions with 1D analytical solutions, and with numerical solutions calculated using the cavitation acoustic finite element (CAFÉ) method (Sprague and Geers in Shocks vib 7:105–122, 2001). To assess the ability of the multiphase model for multi-dimensions, underwater explosions (UNDEX) near structures are computed. The importance of cavitation reloading and FSI is investigated. Comparisons of the predicted pressure time histories with different explosion center are shown, and the effect on the structure is discussed.

References listed at the end of the paper:
ABSTRACT: In this paper, the acoustic scale effects and boundary effects for the similitude model of underwater complex shell-structure are investigated. The similitude conditions and relations between the similitude model and its prototype were studied in the references. This paper investigates the acoustic scale effects for the similitude model, which are influenced by loss factor, shear and rotatory inertia. At the same time, the boundary effects which are influenced by surface sound reflection are investigated in the experiment of similitude model. The results show that the acoustic scale effects may be controlled with model designing, the boundary effects can be controlled with experimental designing between the similitude model and its prototype.

References listed at the end of the paper:


ABSTRACT: Clamped circular copper plates have been subjected to exponentially decaying underwater blast waves with peak pressures in the range 10 MPa to 300 MPa and decay constants varying between 0.05 ms to 1.1 ms. The deformation and failure modes were observed by high-speed photography. For the thin plates considered in this study, the failure modes were primarily governed by the peak pressures and were reasonably independent of the blast wave decay constant. Three modes of deformation and failure were identified. At low pressures, the plates undergo bending and stretching without rupture (mode I). At intermediate pressures a range of tensile tearing modes were observed, from petalling failures to tearing at the supports with increasing blast pressures. These tearing modes are referred to as mode II failures. At the highest pressures investigated here, the plate tears at the supports in a manner that is reminiscent of a shear-off failure. This failure is labeled as mode III. Scanning electron micrographs of the failure surfaces showed that in all cases, the local failure mechanism was tensile necking. Finite element (FE) simulations employing a local shear failure criterion are used to model the rupture of the material. Appropriately calibrated FE models capture all failure modes with sufficient fidelity.

References listed at the end of the paper:


Nurick and Shave 2000 G. N. Nurick and G. C. Shave, “The deformation and tearing of thin square plates subjected to impulsive...

Frédéric Gosselin (1) & Michael P. Païdoussis (2)
(1) Ecole Polytechnique, Palaiseau cedex, France
(2) Department of Mechanical Engineering, McGill University, Montreal, Québec, Canada


ABSTRACT: A viscous flow model was developed to investigate the stability of a rotating cylindrical shell containing axial flow because the inviscid model was shown to be inadequate due to singularities in the solution. It was found that the stability of the system is very sensitive to the treatment of the shell-fluid interface and that a small rate of rotation tends to stabilise the system.

References listed at the end of the paper:

K.N. Karagiozis (1), M.P. Païdoussis (1), M. Amabili (2) and A.K. Misra (1)
(1) Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street West, Montreal, Québec, Canada H3A 2K6
(2) Dipartimento di Ingegneria Industriale, Università di Parma, Parco Area delle Scienze 181/A, Parma I-43100, Italy


ABSTRACT: This paper is concerned with the nonlinear dynamics and stability of thin circular cylindrical shells clamped at both ends and subjected to axial fluid flow. In particular, it describes the development of a nonlinear theoretical model and presents theoretical results displaying the nonlinear behaviour of the clamped shell subjected to flowing fluid. The theoretical model employs the Donnell nonlinear shallow shell equations to describe the geometrically nonlinear structure. The clamped beam eigenfunctions are used to describe the axial variations of the shell deformation, automatically satisfying the boundary conditions and the circumferential continuity condition exactly. The fluid is assumed to be incompressible and inviscid, and the fluid–structure interaction is described by linear potential flow theory. The partial differential equation of motion is discretized using the Galerkin method and the final set of ordinary differential equations are integrated numerically using a pseudo-arclength continuation and collocation techniques and the Gear backward differentiation formula. A theoretical model for shells with simply supported ends is presented as well. Experiments are also described for (i) elastomer shells subjected to annular (external) air-flow and (ii) aluminium and plastic shells with internal water flow. The experimental results along with the theoretical ones indicate loss of stability by divergence with a subcritical nonlinear behaviour. Finally, theory and experiments are compared, showing good qualitative and
reasonable quantitative agreement.

References listed at the end of the paper:


Marco Amabili (1), Kostas Karagiozis (2) and Michael P. Païdoussis (3)
(1) Dipartimento di Ingegneria Industriale, Universita di Parmi, Italy
(2) Mechanical Science and Engineering Dept., University of Illinois, Urbana, IL, USA
(3) Mechanical Engineering Dept., McGill University, Montreal, QC Canada
“Effect of geometric imperfections on nonlinear stability of cylindrical shells conveying fluid”, ENOC 2008, Saint Petersburg, Russia, June, 30-July, 4 2008

ABSTRACT: Circular cylindrical shells conveying subsonic flow are addressed in this study; they lose stability by divergence when the flow speed reaches a critical value. The divergence is strongly subcritical, becoming supercritical for larger amplitudes. Therefore the shell, if perturbed from the initial configuration, undergoes severe deformations causing failure much before the critical velocity predicted by the linear threshold. Both Donnell’s nonlinear theory retaining in-plane displacements and the nonlinear Sanders-Koiter theory are used for the shell. The fluid is modelled by potential flow theory. Geometric imperfections are introduced and fully studied. Non-classical boundary conditions are used to exactly simulate the conditions of the experiments performed. Comparison of numerical and experimental results is performed.

References listed at the end of the paper:


ABSTRACT: This paper investigates the nonlinear dynamic response of a shallow sandwich shell subject to blast loading with consideration of core compressibility. The shallow shell consists of two laminated composite or metallic face sheets and an orthotropic compressible core. Experimental results and finite element simulations in literature have shown that the core exhibits considerable compressibility when a sandwich panel is subjected to impulse loading. To address this issue properly in the analysis, a new nonlinear compressible core model is proposed in the current work. The system of governing equations is derived by means of Hamilton’s principle in combination with the Reissner–Hellinger’s variational principle. The analytical solution for the simply supported shallow shell is formulated using an extended Galerkin procedure combined with the Laplace transform. Numerical results are presented. These results demonstrate that this advanced sandwich model can capture the transient responses such as the stress shock wave effect and the differences in the transient behaviors of the face sheets and the core when a sandwich shadow shell is subjected to a blast loading. However, in the steady state dynamic stage, all the displacements of the face sheets and the core tend to be identical. This model can be further used to study the energy absorption ability of the core and the effects of different material and geometrical parameters on the behaviors of sandwich structures subject to blast loading.
REFERENCES LISTED AT THE END OF THE PAPER:


ABSTRACT: This paper deals with the human head response to a sudden motion without direct contact with another solid object, i.e. to non-contact impact. A computational simulation approach is presented for this study, which is accomplished by the integration of a coated articulated total body (ATB) model with a finite element (FE) head model. The present approach includes two major aspects: one is to simulate the sudden motion of the human head with the whole body by means of the ATB model; and the other is to predict the head deformation and stress induced by the sudden motion through using the FE head model. The agreement between the simulation results and the published experimental data [Wismans J, Hermans J. MADYMO 3D simulations of hybrid III dummy sled tests. In: Backailis SH, Mertz HJ, editors. Hybrid III: the first human-like crash test dummy, SAE PT-44, 1994. p. 735-49; Nahum AM, Smith R, War CC. Intracranial pressure dynamic during head injury. In: 21st Stapp car crash conference proceedings, SAE 770922; 1977] is obtained. The intracranial pressure response and the head stress response are then predicted using the present approach. The correlation between the head motion and the brain stresses are also explored. In addition, the head injury induced by the non-contact impact is evaluated.

Michael R. Ross (1), Carlos A. Felippa (2), K.C. Park (2), Michael A. Sprague (3)
(1) Analytical Structural Dynamics Department, Sandia National Laboratories, P. O. Box 5800, MS 0346, Albuquerque, NM 87185-0346, USA
(2) Department of Aerospace Engineering Sciences and Center for Aerospace Structures, University of Colorado, Campus Box 429, Boulder, CO 80309, USA
(3) School of Natural Sciences, University of California, P.O. Box 2039, Merced, CA 95344, USA


ABSTRACT: A new concept is presented for modeling the dynamic interaction between an acoustic fluid and an elastic structure. The coupling of this multiphysics system is done by inserting a kinematic interface frame between the fluid and the structure, and using node-collocated Lagrange multipliers to connect the frame to each subsystem. The time-domain response analysis is performed by a partitioned analysis procedure. The main advantages of this localized Lagrange multiplier (LLM) primal-dual coupling method are: complete localization...
of the structure and fluid subsystems, elimination of the conventional predictor in the partitioned time integration method, and the ability to accommodate non-matching meshes. The standard Newmark time integrator is used on both the fluid and structure models. It is shown that if the integrator is A-stable and second-order accurate for a monolithic treatment, it retains those properties for both Mortar and LLM partitioned solution procedures. Infinite and finite piston problems are used to explain and verify the methodology. A sequel paper under preparation presents and discusses a set of benchmark and application examples that involve the response of existing dams to seismic excitation.

D.H. Schubert (1), H. Liu (2), and R. Lang (2)
(1) GV Jones & Associates, Inc., Anchorage, Alaska, USA
(2) School of Engineering, University of Alaska Anchorage, Alaska, USA
“Nonlinear-inelastic seismic performance of water storage tanks”, The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China

ABSTRACT: This paper evaluates the seismic response of ground-level cylindrical steel water storage tanks, which were designed under the American Water Works Association standards for steel tanks. Three tank sizes were selected to represent different height to radius ratios. All tanks are anchored on concrete ring-wall foundations. Nine earthquake time history records were used to develop response spectrums as input for design level ground motion. A combined fluid-structure finite element model was developed for each of the tank geometries. The computer models were run using linear elastic and nonlinear inelastic model property assumptions. Results of this study show the substantial variation of values in base shear and overturning moment depending on the seismic inputs and modeling assumptions used. The ratios of base shear between linear elastic and nonlinear properties ranged from 1.0 to 3.1, and overturning moment values ranged from 1.0 to 3.0, which are mostly smaller or equal to the design standard reduction R-factored value of 3.0 for anchored tanks.

References listed at the end of the paper:
International Code Council (2006), 2006 International Building Code, Falls Church, VA.


ABSTRACT: Measurements of acceleration and pressure together with high-speed imaging have been used to study the interaction of an underwater explosion with a nearby steel cylinder. Variation of the initial separation between the cylinder and explosive charge generated different cases of interaction in which the response of the cylinder to the shock wave, the bubble pulse wave, water jetting and bubble collapse could be studied. Shock wave loading generated a significant response in all cases. The pressure wave from the pulsating bubble was a less significant load, generating a peak velocity about half that caused by the shock wave. However the collapse of the bubble onto the cylinder was found to be the most severe structural load, generating a peak velocity almost twice that caused by the shock wave and causing significant plastic deformation.

ABSTRACT: Based on the potential flow theory, the boundary element method (BEM) is applied to calculate the dynamics of an underwater explosion bubble near boundaries, and in conjunction with the finite element method (FEM) it is employed to compute the interaction between a bubble and an elastic–plastic structure. A complete 3D underwater explosion bubble dynamics code is developed; the simulated results compare well with an underwater explosion experiment. With this code, the interactions between an underwater explosion bubble and elastic–plastic structures such as a flat plate, a cylinder and other simple structures are calculated and analyzed. Besides, the damages caused by the after flow, pulsating pressure, and jetting load on the structures are also calculated, with or without a free surface. From the time history of the pressure and stress of the structure, it can be observed that the stress reaches its maximum value when the bubble collapses, which proves that the pressure and jet impact induced by the collapse of the bubble can result in severe damage to the structure. In particular, the 3D analysis code is applied to some engineering problems, for example it is used on a surface ship to study the interaction between a bubble and a complex elastic–plastic structure. Under the bubble load, the low-order eigenfrequency of the ship is aroused usually, leading to the so-called ‘whipping’ effect, because the pulsating frequency of the bubble ‘matches’ the low-order eigenfrequency of the ship. The ship moves up and down with the expansion and collapse of the bubble respectively. Meanwhile, the power of the bubble generated by a near-field underwater explosion in short range is discussed, and some important conclusions which can be applied to project application field are drawn.


ABSTRACT: The design of submarines has continually evolved to improve survivability. Explosions may induce local damage as well as global collapse to a submarine. Therefore, it is important to realistically estimate the possible damage conditions due to underwater explosions in the design stage. The present study applied the Arbitrary Lagrangian–Eulerian (ALE) technique, a fluid–structure interaction approach, to simulate an underwater explosion and investigate the survival capability of a damaged submarine liquefied oxygen tank. The Lagrangian–Eulerian coupling algorithm, the equations of state for explosives and seawater, and the simple calculation method for explosive loading were also reviewed. It is shown that underwater explosion analysis using the ALE technique can accurately evaluate structural damage after attack. This procedure could be applied quantitatively to real structural design.


ABSTRACT: The fluid-structure interaction simulation of shock-loaded thin-walled structures requires numerical methods that can cope with large deformations as well as local topology changes. We present a robust level-set-based approach that integrates a Lagrangian thin-shell finite element solver with fracture and fragmentation capabilities into an Eulerian Cartesian fluid solver with embedded boundary and mesh adaptation capability. As main computational applications, we consider the plastic deformation and rupture of thin plates subjected to explosion and piston-induced pressure waves in water.

References listed at the end of the paper:
5. Ashani, J. Z.; Ghamsari, A. K.: Theoretical and experimental analysis of plastic response of isotropic circular plates subjected to
Yu Xiao Fe (Huazhong University of Science and Technology) “Dynamic response and buckling of stiffened cylindrical shells subjected to underwater explosion loadings”, 2007

ABSTRACT: Model based on discrete reinforced rectangular section stiffeners for example, idealized fluid as incompressible ideal potential flow, a reasonable simplification underwater explosion shock wave generated by the load, to consider the impact of the hydrodynamic pressure stiffened cylindrical The theoretical analysis of the shell structure of the model, and the search for effective analysis calculation method, to explore the structure by the underwater explosion shock loads power response and dynamic buckling improve the impact resistance of underwater submersible structure provides some meaningful conclusions. Work of this paper are mainly the following aspects: First, a comprehensive review summarizes the free vibration of stiffened plate and shell structures under impact loading dynamic response and dynamic buckling focus stiffened cylindrical shell by the underwater explosion shock loads The dynamic characteristics of commence comments. The use of commercial finite element software MSC.DYTRAN, simulated spherical TNT charge in the underwater explosion, focus on using two coupling methods (General coupling and ALE) stiffened cylindrical shell underwater spherical explosive load of TNT kits under vibration and dynamic response characteristics, and the results with the experimental results in the relevant references compared two basic agreement. Ring stiffened cylindrical shell discretized into cylindrical shell and reinforced ribs and both rigidly connected to the contact the casing - ribs systems, taking into account the casing shear deformation and rotational inertia as well as reinforced ribs tensile, bending and shear deformation, Hamilton variational principle derived system equations of motion. Expand the displacement as a Fourier series form by the Galerkin method to displacement Fourier coefficients in the form dynamic buckling control equations using a fourth-order Runge-Kutta method calculated stiffened cylindrical shell in the underwater explosion shock loads under the action of the dynamic response. Focused on the hydrodynamic pressure, hydrostatic pressure, reinforced rib geometry parameters, the thickness of the shell, and the Fourier series, the number of items on the calculation results verify some common conclusions. And also discussed the free vibration problem of stiffened cylindrical shells under water. On the basis of the above analysis, taking into account large deformation and the impact of the initial defect stiffened cylindrical shell underwater explosion loads, nonlinear response, summed up some useful conclusions. Followed by analysis of ring stiffened cylindrical shell underwater explosion loads elastoplastic dynamic response. Elastoplastic constitutive relation given by Mises yield condition and isotropic hardening incremental theory. With the increment value (in the time domain using a fourth-order Runge-Kutta method) method to analyze the elastoplastic behavior of stiffened cylindrical shell. Analyzed the impact of the ring to the reinforced ribs, uniform radial external pressure and strain rate sensitivity and other factors on structural elastoplastic dynamic response. Then stiffened cylindrical shell in the underwater explosion shock - Solid Impact nonlinear dynamic buckling under a combined load used the BR criterion to determine the structure of the critical buckling load, compare the structure, respectively, in the axial flow and axial flow - solid impact loading, underwater explosive shock alone and two loads under the combined effects of buckling mode, the critical load, focuses on the relationship between the two directions of the critical load, hoop reinforced rib stiffened cylindrical shell structure Dynamic buckling behavior and anti-axial impact buckling capacity to draw meaningful conclusions. And also with the BR Standards and Southwell are two ways to calculate the radial shock loads Dynamic buckling load stiffened cylindrical shell in the underwater explosion. The power of the geometrical parameters, material hardening parameters of stiffened cylindrical shell structure critical buckling load.


ABSTRACT: Underwater explosion and its effect on structures including flat plate, cylindrical shell and torpedo shell were studied in this dissertation by using commercial software AUTODYN, ABAQUS and LS-DYNA. The main work includes: (1) Numerical simulation of underwater explosion process, (2) The re-exploitation of ABAQUS based on Taylor’s plate theory and the first-order doubly asymptotic approximation and its application, (3) Numerical study of dynamic response of cylindrical shell subjected to deep water blast wave, (4) The modification of the simulation method of LS-DYNA to calculate far-field underwater shock wave, (5) The elementary analysis of the terminal effect of torpedo-damaging by underwater shock waves, (6) Numerical simulation of the dynamic response of torpedo shell structure subjected to near-field and far-field
underwater shock waves. Chapter 1: The research content in this dissertation, as well as the research method and background, were concisely presented, and the evolution of relative research, as well as the software of numerical simulation and the method to validate the calculation results, were given. Chapter 2: Underwater explosion shock wave and bubble pulse were simulated by using the hydrocode AUTODYN. By comparing calculation results with empirical formulas, theoretical formulas and experimental results, one can conclude that AUTODYN can simulate much of the important physics of underwater explosion, and the suggestion for the engineering application of AUTODYN was given. Chapter 3: Based on Taylor’s plate theory and the first-order doubly asymptotic approximation (DAA) without considering low-frequency response, a simple and practical method has been presented to simulate the high-frequency dynamic plastic response of basic structure including flat plate and cylindrical shell subjected to underwater explosion shock waves without modeling the fluid field. Commercial finite element code, ABAQUS, was used to conduct this simulation. In order to validate this method, two examples including a fixed flat plate and a free cylindrical shell, all subjected to underwater explosion shock waves, were simulated by the method, and the simulation results are in good agreement with experiment results. Chapter 4: Numerical investigation was carried out on a cylindrical shell subjected to underwater explosion shock waves in deep water by using both static state analysis and dynamic analysis via ABAQUS software package. The influence of the depth of the cylindrical shell lies, orientation of the explosion and prestress were identified, and the breakage of the cylindrical shell in deep water was also studied. Chapter 5: The elementary analysis of the terminal effect of torpedo-damaging by underwater shock waves was presented, and a simple model to analyze this problem was given. Then the main factors to influence the terminal effect were identified, and an idea was given to direct the following numerical study. Aim at the problem that the peak pressure of shock waves induced by far-field underwater explosion are smaller than actual magnitude when using LS-DYNA to simulate underwater explosion, a equivalent mass method which had been validated was presented to solve it. After this, the dynamic response of a lightweight torpedo shell structure subjected to shock waves induced by far-field underwater explosion was simulated by LS-DYNA, and influence of the torpedo insides and shock environment of the torpedo shell structure were studied. The damage mechanism of torpedo shell subjected to underwater explosion shock waves was simulated by using LS-DYNA. The damage mechanism of the torpedo shell, as well as shock environment and vulnerability of the different torpedo cabin shell, were investigated. Chapter 6: The main conclusions and suggestions for the following investigation are given.


ABSTRACT: The underwater explosion needs considering five parts: shock wave, cavitations and bubble, jet, fluid-solid coupling phenomenon, the dynamic response of structure. In this paper, the flow field of the bubble pulsation was solved by using the theory analysis and numerical simulation method under near the underwater explosion. The response of the plate under the bubble pulsation pressure effect was analyzed. Connection the underwater acoustic energy and explosion shock wave, by using the fluid-solid coupling method the failure of cylindrical shell and the vibration response of cylinder under the far fielded directional shock wave was researched. For the underwater acoustic energy technology attacking the near ship target provides basis. The bubble produced by near underwater explosion was analyzed. According to the one dimensional incompressible fluid unsteady motion theory, considering addition the work by the virtual force, the existing law equation of bubble pulsation underwater explosion was improved. Comparison analysis the calculation results with the experimental values, considering the addition of the virtual force, the radius, period and velocity of the calculation bubble pulsations by the theory formula were more anatomists with the practical condition. Further improving the law equation of bubble pulsation pressure distribution, the addition effect of the bubble energy, the results were more according with the practical condition than previous analysis. Under the near bubble pulsation, the bubble pulsation load was treatment for spherical wave. Then the clamped circular plate was affected by it. By the Ritz equation the deflection formula of the circular plate was calculated. The income data were fitted a unified formula. Based on the deflection change graph, the center of circular plate was most easily failure. The boundary of circular plate also possibly was damaged under the condition of the thin plate. According to the features between the underwater acoustic energy technology and explosion, the acoustical parameters were converted into the form of explosion shock wave pressure. The strength analysis of cylindrical shell was calculated under the effect of the shock wave. According to the feature of the far field shock wave, it
was assumed plane wave to directly apply on a little layer water surface nearby the shell. Using the fluid-solid coupling analysis method of LS-DYNA, the strength of the cylindrical shell was simulated calculated under effect of the underwater directional acoustic energy at 30m. Over 280db sound source grade of the underwater directional shock wave could be certain failure to the cylindrical shell at 30m. The dynamic response of cylinder was simulated under the effect of underwater directional acoustic energy at 100m. When the cylinder was affected by the large energy shock wave pressure, the response of acceleration was rapidly reached the peak which was large and the waveform was steep. However, due to the cylinder coupling with water the vibration energy was quickly dissipated. When the acceleration reached 30g, the internal components may be failure. If according to this standard test the failure situation was caused by the vibration of cylinder. When the sound source grade ≥ 280dB, the internal components maybe could be damaged because of the vibration. The theory and numerical basis were provided by the contents in this paper for the underwater directional acoustic energy technology attacking the near ship target.


Tim Dunbar and Dave Whitehouse (1888 Brunswick Street, Suite 400, Halifax, NS, Canada B3J 3J8) “Simulation of structural failure from contact underwater explosions”
ABSTRACT: A numerical method for performing large-deformation two-way coupled fluid-structure interaction simulations has been developed to model a wide class of problems in which structural response significantly influences subsequent fluid flow, through motion-induced cavitation, structural failure or both. We demonstrate the suitability of the approach to such events by applying our method to the early-time response of plates to contact and near-contact underwater explosions in three dimensions. The plates exhibit a variety of behaviors including petalling failure with venting of explosive products through the resulting holed plates. The deformation and failure patterns of the plates are compared with experimental data from trials performed by Defense Research Development Canada at Suffield.

Serguei Iakovlev (Dalhousie University, Halifax, Nova Scotia, Canada) “Modeling shell-shock interaction in a multi-fluid environment”
ABSTRACT: A fluid-filled submerged cylindrical shell is considered for the most general case of contact with fluid, i.e., when the internal and external fluids are different. It is shown that the interaction in this case is very different from the case of two identical fluids. Specifically, it is demonstrated that the response of the system is much more complex in terms of the fluid-structure interaction effects, and that a wider variety of shock wave reflection phenomena is observed. The ratio of the acoustic speeds in the internal and external fluids is shown to be the single most important parameter determining the main features of the interaction. Depending on the value of the ratio, four qualitatively different regimes of interaction are shown to exist. Each regime has its unique dynamic features of which the most notable is the possibility of observing different reflection-focusing sequences for the pressure wave inside the shell. The practical relevance of the fluid-structure interaction effects observed is discussed. This is a joint work with Garrett Dooley, Bryan MacDonald and Jonathan Gaudet.

Cedric Leblond and Jean-Francois Sigrist (Service Technique et Scientifique, DCNS Propulsion / LEPTIAB, Universite de La Rochelle) “Semi-analytical methods for the study of transient fluid-structure interaction problems”
ABSTRACT: We study semi-analytical methods related to the effects of highly transient loads on
underwater vehicles. Firstly, simple fluid-structure interaction models are derived so as to highlight the physical phenomena occurring in this problem. More precisely, interactions between circular thin shells or elastic structures and the radiated field by an underwater explosion are considered. The approach is based on the classical methods of Laplace transform in time, Fourier series expansions and separation of variables in space. Secondly, an extension of this approach is proposed for more complex geometries. It is based on Laplace transform in time, in vacuo eigenvector expansion with time-dependent coefficients for the structural dynamics and boundary-integral formulation for the fluid. The projection of the fluid pressure on the in vacuo eigenvectors leads to a fully coupled system involving the modal time-dependent displacement coefficients, which are the problem unknowns. They are simply determined by matrix inversion in the Laplace domain. This fluid-structure numerical method is exact in the sense that classical early-time or doubly asymptotic approximations are not made. This appears to be a versatile approach which can be efficiently and extensively used for design purposes, once part of the numerical resolution has been performed one time for a given geometry.

Julie Young (Princeton University) “Numerical Investigation of Shock and Blast Loads on Composite Marine Structures”

ABSTRACT: A strongly coupled 2D/axisymmetric Eulerian–Lagrangian numerical solver is presented for the modeling of shock and blast loads on composite marine structures. An overview of the numerical formulation is given for the compressible multiphase fluid, the generalized continuum solid, and the fluid-fluid and fluid-solid interface coupling methodology using modified versions of the ghost fluid method. The resulting strongly coupled Eulerian–Lagrangian solver is able to efficiently capture nonlinear fluid-structure and shock-bubble interactions involving strong shocks, gas bubble dynamics, cavitation inception and collapse, and complex stress and deformation fields of anisotropic, composite marine structures. Analytical, numerical, and experimental validation studies are shown. The objective of this work is to use the newly developed coupled Eulerian–Lagrangian method to study the transient response of composite marine structures subject to shock and blast loads. Special attention is given to quantify the influence of surface and core material elasticity/plasticity, boundary conditions, surface curvature, and strain-rate dependency on the fluid-structure interaction response caused by planar shocks and underwater explosions. The goal is to develop parametric curves that can assist the design of general composite structures subject to shock and blast loads, and to explore potential shock mitigation strategies.

M. Amabili (1), K. Karagiozis (2) and M.P. Païdoussis (1)
(1) Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street W., Montreal, Québec, Canada H3A 2K6
(2) Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, USA


ABSTRACT: Circular cylindrical shells conveying incompressible flow are addressed in this study; they lose stability by divergence when the flow velocity reaches a critical value. The divergence is strongly subcritical, becoming supercritical for larger amplitudes. Therefore the shell, if perturbed from the initial configuration, has severe deformations causing failure much before the critical velocity predicted by the linear threshold. Both Donnell's non-linear theory retaining in-plane displacements and the Sanders–Koiter non-linear theory are used for the shell. The fluid is modelled by potential flow theory but the effect of steady viscous forces is taken into account. Geometric imperfections are introduced and fully studied. Non-classical boundary conditions are used to simulate the conditions of experimental tests in a water tunnel. Comparison of numerical and experimental results is performed.
References listed at the end of the paper:

ABSTRACT: In this paper, a numerical model based on the potential flow theory is established to simulate the interaction of a gas bubble with a nearby wall. The time-integration boundary integral method is used to solve the dynamics of a gas bubble. With this method the numerical calculations show an excellent agreement with
the experimental data. Employing the numerical code based on the presented algorithm, the dynamics of a gas bubble close to a rigid wall is investigated systematically, especially the relationship between various characteristic parameters and the Bjerknes effect due to the presence of a nearby wall. It is found that Blake's criterion, which is usually used to predict the direction of the bubble jet, has a great degree of accuracy for the bubble relatively far away from the wall and bubble near a wall, there is a significant error, attributed to its simplifications and assumptions. Further studies show that an oblique jet will be formed when a bubble close to an inclined wall collapses, direction and width of which have a close relationship with the characteristic parameters used to characterize the bubble. For the bubble near a horizontal wall, a liquid jet pointing directly to the wall is developed generally when the Bjerknes attraction and buoyancy are in the same direction; and at the same time, if the Bjerknes attraction is in the opposite direction of buoyancy, the direction of the jet will depend on a criterion. Then the interaction of gas bubble between complicated walls of some a submarine is also studied, which shows the most dangerous induced loading condition of structure in water, and the evidently effects of bubble jet on loading. The special phenomena mentioned above have a great significance for the further study on the interaction of the bubble with its boundaries.

(1) State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, 800 Dong Chuan Road, 200240 Shanghai, PR China  
(2) Naval Research Center, Box 1303-14, 120 CuiWei Road, 100073 Beijing, PR China  
(3) Shanghai Marine Diesel Engine Research Institute, 18 JiangNan Road, 200011 Shanghai, PR China  

ABSTRACT: How to moderate ship the damages caused by the underwater explosions is of great interest to the modern ship designers. This investigation explores the protective effects of a layer of rubber sandwich with the square honeycomb core coated onto ship hull. Two slender steel scaled ship models were manufactured and tested. One model was coated with a layer of rubber coating while the other kept intact. A series of comparative tests were carried out to comprehend the dynamic performance of the protective layer when both shock wave and bubble pulse loading were considered. Modal characteristics of both models were measured firstly and then live UNDEX tests were made on the free floating ship models. The acceleration and strain peaks were selected as the major comparative criterions. The free field and wall pressure were also monitored. Detailed discussions on test results show that the protective rubber layer is capable of moderating damage of the ship body caused by shock wave while not very effective in reducing the whipping damage excited by bubble pulse.

Bertrand Langrand (1), Nicolas Leconte (1), Aude Menegazzi (2) and Thierry Millot (3)  
(1) French Aerospace Lab (ONERA), Aeroelasticity and Structural Dynamic Department, 5 boulevard Paul Painlevé, 59045 Lille Cedex, France  
(2) French Ministry of Defence (DGA), DET/CEP/TC/PMA, 5–7 rue des Mathurins, 92221 Bagneux Cedex, France  
(3) French Military Shipyard (DCNS), CESMAN/RDMPC, Indret BP30, 44620 La Montagne, France  

ABSTRACT: The paper deals with numerical methodologies to model and study the structural resistance of submarine hull against explosions, where fluid and solid phenomena interact. Explosion Crack Starter Tests (ECST), which are a standard procedure to study submarine materials and weldments with respect to blast loading, are modelled using an explicit FE code that solves Fluid/Structure (F/S) interactions within the same computation. The proposed numerical methods aim at computing the structural response of a target subjected to sequential explosions. Numerical results are compared to the corresponding explosion tests (ECST) performed by DGA (French Ministry of Defence).

Z. del Prado (1), P.B. Gonçalves (2) and M.P. Païdoussis (3)  
(1) Department of Civil Engineering, Federal University of Goiás, 74605-200 Goiânia, GO, Brazil
ABSTRACT: The high imperfection sensitivity of cylindrical shells under static compressive axial loads is a well-known phenomenon in structural stability. On the other hand, less is known of the influence of imperfections on the nonlinear vibrations of these shells under harmonic axial loads. The aim of this work is to study the simultaneous influence of geometric imperfections and an axial fluid flow on the nonlinear vibrations and instabilities of simply supported circular cylindrical shells under axial load. The fluid is assumed to be non-viscous and incompressible and the flow to be isentropic and irrotational. The behavior of the thin-walled shell is modeled by Donnell's nonlinear shallow-shell equations. It is subjected to a static uniform compressive axial preload plus a harmonic axial load. A low-dimensional modal expansion, which satisfies the relevant boundary and continuity conditions, and takes into account all relevant nonlinear modal interactions observed in the past in the nonlinear vibrations of cylindrical shells with and without flow is used together with the Galerkin method to derive a set of eight coupled nonlinear ordinary differential equations of motion which are, in turn, solved by the Runge–Kutta method. The shell is considered to be initially at rest, in a position corresponding to a pre-buckling configuration. Then, a harmonic excitation is applied and conditions for parametric instability and dynamic snap-through are sought. The results clarify the marked influence of geometric imperfections and fluid flow on the dynamic stability boundaries, bifurcations and basins of attraction.


ABSTRACT: One of the major problems confronted by the designer of submersibles is to minimize the weight of the pressure hull for increasing the payload of a crew and necessary equipment and to simultaneously enhance the strength of the pressure hull for withstanding hydrostatic pressure, underwater explosive loading and other environmental loading. Hence, this paper presents the optimal design of a small-scale midget submersible vehicle (MSV) pressure hull with a ring-stiffened cylinder and two hemispherical ends subjected to hydrostatic pressure, using a powerful optimization procedure combined the extended interior penalty function method (EIPF) with the Davidon-Fletcher-Powell (DFP) method. According to the above optimum design results, we built up midget submersible vehicle finite element model. Then, the coupled acoustic-structural arithmetic from the widely used calculation program of the finite element – ABAQUS, was used to simulate and analyze the transient dynamic response of a midget submersible vehicle pressure hull that experiences loading by an acoustic pressure shock wave resulting from an underwater explosion (UNDEX). The analytical results are presented which will be used in designing stiffened optimum submersible vehicle so as to enhance resistance to underwater shock damage.


ABSTRACT: A submerged fluid-filled circular cylindrical shell subjected to a shock wave propagating in the external fluid is considered. The study focuses on a number of acoustic and structural effects taking place during the interaction. Specifically, the influence of the acoustic phenomena in the fluid on the stress–strain state of the shell is analysed using two different visualization techniques. The effect that the parameters of the shell have on the internal acoustic field is addressed as well, and the ‘shock transparency’ of various shells is discussed. Special attention is paid to the analysis of the contribution of the terms in the shell equations representing bending stiffness, and the limits of applicability of the membrane theory of thin shells are discussed in the fluid–structure interaction context. The possibility of cavitation in the internal fluid is investigated, and the effect that cavitation could have on the structural dynamics of the shell is discussed. The
The present paper is a follow-up of the author's earlier study of the interaction between fluid-filled cylindrical shells and external shock waves.


**ABSTRACT:** A submerged fluid-filled cylindrical shell subjected to an external shock wave is addressed for the most general case when the internal and external fluids have different properties. Three distinctly different scenarios of interaction are identified depending on the parameter $\zeta$ defined as the ratio of the acoustic speed in the internal fluid to that in the external one. The first scenario corresponds to the values of $\zeta$ below unity, and it can follow two sub-scenarios that exhibit qualitatively different focusing and reflection sequences, with the transition between the sub-scenarios occurring at $\zeta \approx 0.52$. The second scenario, $\zeta = 1$, corresponds to the relatively well-studied case of two identical fluids, yet some interesting, previously unreported effects are observed for such $\zeta$ as well. The third scenario corresponds to the values of $\zeta$ above unity, and it also exhibits a number of unique features of the wave propagation and reflection. The dynamics of the complete internal-external field is visualized and analyzed for the three scenarios, with the emphasis on both the theoretical significance of the effects observed and their practical implications.


**ABSTRACT:** Ambient temperature underwater explosion bulge test is simulated using ANSYS/LS-DYNA. Elastic and inelastic numerical experiments are carried out. Inelastic prediction is validated with a physical experimental data. Terminal strain to fracture is established. A methodology is thus arrived at for carrying out the material qualification for explosive loading using numerical simulation.


**ABSTRACT:** The response of a lightweight torpedo when subjected to an underwater explosion (UNDEX) is an important criterion for multidisciplinary design. This paper investigates the effect of structural stiffeners on the performance of a lightweight torpedo. The finite element package ABAQUS was used to model the UNDEX and the fluid–structure interaction (FSI) phenomena, which are critical for accurate evaluation of torpedo stress levels. The pressure wave resulting from an underwater explosion was modeled using similitude relations and it was assumed to be a spherical wave. Various explosive weights and explosion distances were explored to determine the critical distance both for an unstiffened and a stiffened torpedo. Once it was established that the stiffened torpedo performed better under explosive pressure loads, various configurations were studied to determine the optimal number of ring and longitudinal stiffeners. A final configuration was obtained for the torpedo that had minimum weight and was least sensitive to small manufacturing variations in
the dimensions of the stiffeners. This paper presents details of the torpedo and fluid models and the finite element analysis method for FSI.

ABSTRACT: In order to evaluate the strength and comparability of impulsive environment of model and practical structure in the water when subjected to underwater explosion, a new shock factor based on energy acting on the structure is presented to describe the loading of underwater explosion. To test the validity of this new factor, numerical experiments of double stiffened cylindrical shells are carried out a series of cases designed by the new factor and two other standard shock factors respectively. The results of the cases designed by the new factor indicate that the kinetic energy, potential energy and shock response spectrums of the structures agree well with each other in different cases designed by the equal new shock factor. However, the results of the cases designed by the two other standard shock factors are rather diverse. The analysis considers that the old shock factors do not take the spherical characteristics of shock wave front and relative position between detonation and structure into account, which can hardly reflect the similarity of underwater explosion loadings. The new shock factor can make up for such limitations.

C.F. Hung (1), B.J. Lin (1), J.J. Hwang-Fuu (2) and P.Y. Hsu (3)
(1) Dept. of Engineering Science and Ocean Engineering, National Taiwan University, Taipei, Taiwan, ROC
(2) Chung Shang Institute of Science and Technology, Taoyuan, Taiwan, ROC
(3) Northeast Technology Corporations, Taipei, Taiwan, ROC
ABSTRACT: This study investigated the linear and nonlinear dynamic responses of three cylindrical shell structures subjected to underwater small charge explosions in a 4m x 4m water tank. The dimensions of the cylindrical shell structures were 90 cm x 30 cm x 1mm (length x diameter x thickness). Both ends of the cylindrical shell were mounted with thick plates to provide support and create an enclosed space. The three cylindrical shell structures were unstiffened, internally stiffened and externally stiffened. The experiments involving the dynamic response of cylinders subjected to underwater explosion (UNDEX) were performed under different standoff distances, varying from 210 cm to 35 cm. A small quantity of explosives was used to generate the shock loading. The plastic deformation of the cylindrical shell was observed at a standoff distance of less than 50 cm. Other conditions were tested to examine cylinder linear response. Dynamic analyses were performed for the experimental model using FEM and compared with the test results. The acceleration and dynamic strains of cylindrical shells obtained from the experiment were compared with those obtained by FE analysis. Finally, problems related to small-scale UNDEX experiments performed in small water tanks were analyzed.

ABSTRACT: The problem of the transient vibration of an elastic laminated composite cylindrical shell with infinite length exposed to an underwater shock wave is solved approximately. The linear acoustic plane wave assumption and Sanders thin shell theory are adopted. The reflected-afterflow virtual-source (RAVS) procedure is used to model the fluid–structure interaction involved during the underwater shock event. For the validity of the present analysis, the response of a laminated cylindrical shell under step plane wave is first analyzed and compared with the numerical solution available in the literature. Detailed numerical results for the transient responses of the shells under an exponentially decaying underwater shock wave are presented, and the influences of fiber angle, shell radius and thickness upon the dimensionless radial velocity, mid-surface strain, 0th mode radial displacement and 1st mode radial velocity of the shells, are investigated.
ABSTRACT: Plates form one of the basic elements of structures. Land-based structures may be subjected to air blast loads during combat environment or terrorist attack, while marine structures may be subjected to either air blast by the attack of a missile above the water surface or an underwater explosion by the attack of a torpedo or a mine or a depth charge and an aircraft structure may be subjected to an in-flight attack by on-board explosive devices. Furthermore, gas explosion occurs in offshore installations and industries. This review focuses on the phenomenological evolution of blast damage of plates.

References listed at the end of the paper:


ABSTRACT: In this work, Donnell’s non-linear shallow shell equations are used to study the dynamic instability of imperfect simply supported orthotropic cylindrical shells with internal flowing fluid subjected to a compressive axial static pre-load plus a harmonic axial load. The fluid is assumed to be non-viscous and incompressible and the flow isentropic and irrotational. An expansion with eight degrees of freedom,
containing the fundamental, companion, gyroscopic and five axi-symmetric modes is used to describe the lateral displacement of the shell. The geometric imperfections are described by the same expansion as the lateral displacement and the Galerkin method is used to obtain the non-linear equations of motion which are, in turn, solved by the Runge-Kutta method. Numerical methods are used to identify the most important bifurcations as the fluid flow is varied, special attention is given to the influence of the material properties and the influence of initial geometric imperfection on the global stability of the system.

References listed at the end of the paper


Frederico M. A. Silva (1), Paulo B. Gonçalves (2) and Zenon J.G.N. del Prado (1)
(1) Federal University of Goiás, Goiânia, Brazil
(2) Pontifical Catholic University, Rio de Janeiro, Brazil

“Nonlinear vibrations of axially loaded cylindrical shells partially filled with fluid”
9th Brazilian Conference on Dynamics, Control and their Applications, June 7-11, 2010

ABSTRACT: This work investigates the nonlinear dynamic behavior and instabilities of partially fluid-filled cylindrical shell subjected to axial load. A discrete low-dimensional model for the nonlinear vibration analysis is derived to study the shell vibrations. The influence played by the height of the internal fluid on the nonlinear shell response is examined.

References listed at the end of the paper:

ABSTRACT: In the present study, the geometrically nonlinear vibrations of circular cylindrical shells, subjected to internal fluid flow and to a radial harmonic excitation in the spectral neighbourhood of one of the lowest frequency modes, are investigated for different flow velocities. The shell is modelled by Donnell's nonlinear shell theory, retaining in-plane inertia and geometric imperfections; the fluid is modelled as a potential flow with the addition of unsteady viscous terms obtained by using the time-averaged Navier–Stokes equations. A harmonic concentrated force is applied at mid-length of the shell, acting in the radial direction. The shell is considered to be immersed in an external confined quiescent liquid and to contain a fluid flow, in order to reproduce conditions in previous water-tunnel experiments. For the same reason, complex boundary conditions are applied at the shell ends simulating conditions intermediate between clamped and simply supported ends. Numerical results obtained by using pseudo-arclength continuation methods and bifurcation analysis show the nonlinear response at different flow velocities for (i) a fixed excitation amplitude and variable excitation frequency, and (ii) fixed excitation frequency by varying the excitation amplitude. Bifurcation diagrams of Poincaré maps obtained from direct time integration are presented, as well as the maximum Lyapunov exponent, in order to classify the system dynamics. In particular, periodic, quasi-periodic, subharmonic and chaotic responses have been detected. The full spectrum of the Lyapunov exponents and the Lyapunov dimension have been calculated for the chaotic response; they reveal the occurrence of large-dimension hyperchaos.
References listed at the end of the paper:

C. Y. Jen (1) and Y. S. Tai (2)
(1) Department of Marine Mechanical Engineering, ROC Naval Academy, 81300 Kaohsiung City, Taiwan, ROC
(2) Department of Civil Engineering, ROC Military Academy, 83059 Kaohsiung County, Taiwan, ROC
ABSTRACT:
Given the superior strength-to-weight ratio, stiffened panels have been used extensively in the main structure of ships and underwater vehicles. The loads acting on a stiffened panel in a ship is in-plane compression or tension, resulting from the overall hull-girder bending moment or torsion, shear force resulting from the hull-girder shear force, and lateral pressure resulting from the external wave or shock loading. This work addresses the transient responses of a panel structure reinforced by ribs of different sizes to underwater shock loads using non-linear finite element code-ABAQUS. Verification of the reliability was made between the Ramajeyathilagam’s experiments results [Ramajeyathilagam K, Vendhan CP, Rao VB. Non-linear transient dynamic response of rectangular plates under shock loading. Int J Impact Eng 2000;24:999–1015, Ramajeyathilagam K, Vendhan CP. Deformation and rupture of thin rectangular plates subjected to underwater shock. Int J Impact Eng 2004;30:699–719] at several different locations on the plates. The shock factor is adopted to describe the shock severity. Additionally, the displacement–time histories under different shock loadings are presented which will be used in designing stiffened panels so as to enhance resistance to underwater shock damage.

Leblond C (1), Sigrist JF (2)
(1) LEPTIAB, Université de la Rochelle, Pôle Science et Technologie, Avenue Michel Crépeau, 17042 La Rochelle Cedex 1, France
(2) DCNS Propulsion, Service Technique et Scientifique, 44620 La Montagne, France
ABSTRACT: The transient response of submerged two-dimensional thin shell subjected to weak acoustical or mechanical excitations is addressed in this paper. The proposed approach is first exposed in a detailed manner: it is based on Laplace transform in time, in vacuo eigenvector expansion with time-dependent coefficients for the structural dynamics and boundary-integral formulation for the fluid. The projection of the fluid pressure on the in vacuo eigenvectors leads to a fully coupled system involving the modal time-dependent displacement coefficients, which are the problem unknowns. They are simply determined by matrix inversion in the Laplace domain. Application of the method to the response of a two-dimensional immersed shell to a weak acoustical excitation is then exposed: the proposed test-case corresponds to the design of immersed structures subjected to underwater explosions, which is of paramount importance in naval shipbuilding. Comparison of a numerical calculation based on the proposed approach with an analytical solution is exposed; versatility of the method is also highlighted by referring to “classical” FEM/FEM or FEM/BEM simulations. As a conspicuous feature of the method, calculation of the fluid response functions corresponding to a given geometry has to be performed once, allowing various simulations for different material properties of the structure, as well as for various excitations on the structure. This versatile approach can therefore be efficiently and extensively used for design purposes.

Y.J. Chen (1,2,3), X.D. Wu (1,4), J.Y. Zheng (1), G.D. Deng (1) and Q.M. Li (5)
(1) Institute of Process Equipment, Zhejiang University, Hangzhou 310027, PR China

ABSTRACT: Explosion containment vessels (ECVs) are widely used to completely contain the effects of explosions. A theoretical model for calculating the dynamic plastic responses of discrete multi-layered explosion containment vessels (DMECVs) has been established, which considered the effects of the strain-hardening and strain-rate on the material. The maximum displacement and equivalent plastic strain formulae have been derived for “moving separately” and “moving together” response modes. With the considerations of the effects of strain-hardening and strain-rate, three-dimensional finite element models have been developed in LS-DYNA to calculate the dynamic plastic responses of DMECVs under partial loadings. It shows that analytical and numerical results support each other, which indicates their validity. The two response modes of DMECV are confirmed in different material combinations, and a non-membrane response phase of the outer ribbon layers has been identified. Furthermore, the equivalent plastic strain of the outer ribbon layer does not change during the non-membrane response phase, which is an important characteristic for the dynamics of DMECVs.


ABSTRACT: The objective of this combined numerical and experimental study is to analyze the dynamic response of sandwich structures which play an important role in applications requiring shock resistance, high capacity for energy-absorption and out-of-plane shear strength. This investigation focuses on the overall structural response, deformation, damage, and energy-absorption through delamination and core crushing. Air-backed and water-backed/submerged composite structures are subject to a range of blast loading. The damage and failure characteristics of individual components of the sandwich structures are studied using laser-based in-situ diagnostics and postmortem analysis. In the finite-element simulations, the underwater blast loading intensity is considered using the Mie-Gruneisen equation-of-state of a linear Hugoniot form. Configurations analyzed include polymer foam core structures with planar and cylindrical geometries. Core crushing is accounted for through the crushable foam plasticity model. Calculations reveal a significant difference between the response of air-backed and water-backed/submerged structures in terms of deflection, core crushing and energy-absorption. The experiments and computations offer approaches for improving the blast mitigation capabilities of submerged composite sandwich structures in the critical parts of a ship structure like keel, turbine-blades and rudders.

References listed at the end of the paper:
Luciana Loureiro Silva and Theodore A. Netto (Ocean Engineering Department, Federal University of Rio de Janeiro, Brazil), “On the dynamic collapse of cylindrical shells under hydrostatic and impulsive pressure loadings”, Mecánica Computacional Vol XXIX, págs. 7787-7797, Eduardo Dvorkin, Marcela Goldschmit, Mario Storti (Eds.) Buenos Aires, Argentina, 15-18 Noviembre 2010

ABSTRACT: The dynamic collapse of submerged cylindrical shells subjected to lateral impulsive pressure loads caused by underwater explosions is studied via coupled experimental and numerical work. The parent problem of the dynamic collapse of such structures under hydrostatic pressure is also investigated. Two sets of experiments were performed. Initially, 50.6mm outside diameter aluminum tubes with diameter-to-thickness ratio of 32.3 were tested inside a pressure vessel. Hydrostatic pressure was applied quasi-statically up to the onset of collapse in order to obtain the collapse pressure of the tubes tested. Subsequently, similar tubes were tested in a 5m x 5m x 1.6m deep water tank under various explosive charges placed at different distances. Explosive charges and standoff distances were combined so as to eventually cause collapse of the specimens. In both sets of experiments, dynamic pressure and strain measurements were recorded using a fit-for-purpose data acquisition system with sampling rates of up to 1 Mega Samples/sec per channel. In parallel, finite element models were developed using commercially available software to simulate underwater explosion, pressure wave propagation, its interaction with a cylindrical shell and the subsequent onset of dynamic collapse. The surrounding fluid was modeled as an acoustic medium, the shells as J2 flow theory based materials with isotropic hardening, and proper fluid-structure interaction elements accounting for relatively small displacements of the boundary between fluid and structure were used. Finally, the physical explosion experiments were numerically reproduced with good correlation between results.

References listed at the end of the paper:


ABSTRACT: This study investigates the dynamic linear, nonlinear responses, and shock damage of two kinds of submerged cylindrical shell models exposed to underwater spherical trinitrotoluene (TNT) charge explosions in a circular lake. Two endplates and a middle plate are mounted on the cylindrical shells to provide support and create two enclosed spaces. The two kinds of cylindrical shell models are unfilled and main hull sand-filled, respectively. Fifteen different tests are carried out according to changing the TNT explosive weights of 1 kg and 2 kg, standoff distances ranging from 3 m to 0.3 m, and two explosion positions, and the measured experimental results are compared with each other. Detailed discussions on the experimental results show that the dynamic responses and damage modes are much different, and the main hull sand-filled cylindrical shell is more difficult to be damaged by the shock wave loading than the unfilled model. The edge cracks are mainly observed at the instrument hull of the main hull sand-filled model, but surface tearing and cracks take place both on the main and instrumental hulls of the unfilled model, respectively.


ABSTRACT: An approximation solution is introduced for the dynamic response of a two-layered cylindrical shell of circular cross-section subjected to an underwater explosive shock wave. The solution is obtained within the framework of the Flügge thin shell theory and the reflected-afterflow-virtual-source (RAVS) method is used to account for the fluid–structure interaction. Detailed numerical computations are carried out, in dimensionless form, for the cases of infinitely long two-layered cylindrical shells. Time histories of nondimensional radial velocity, mid-surface strain, 0th mode radial displacement and 1st mode radial velocity are presented in graphical form and the effects of elastic modulus, shell radius and thickness on the transient response characteristics of the shells are investigated.

V. Rameshbabu and A.V.S. Chari (Shock & Vibration Centre, Naval Science and Technology Laboratory, Vishakhapatnam, India), “Damage estimation of floating structure in water due to underwater explosion”, NSTL, HTC09

ABSTRACT: (cannot cut and paste)


ABSTRACT: The security evaluation of some structures shocked by an underwater explosion (UNDEX) frequently plays a key role in some cases, and it is necessary to accurately predict the damage condition of the structure in an UNDEX environment. This study investigates the dynamic linear and non-linear responses and shock damages of two kinds of submerged cylindrical shell models exposed to underwater spherical trinitrotoluene (TNT) charge explosions in a circular lake. Two endplates and a middle plate are mounted on the cylindrical shells to provide support and to create two enclosed spaces. The two kinds of cylindrical shell models with the same geometry characteristics are unfilled and main hull sand-filled. Fifteen different tests are carried out by changing the TNT explosive weights of 1 and 2 kg, standoff distances ranging from 3 to 0.3 m, and two explosion positions. Measured experimental results are compared with each other, and some transformed data are obtained. A detailed discussion on experimental results shows that the dynamic responses and damage modes are much different, and the main hull sand-filled cylindrical shell is more difficult to be damaged by the shock wave loading than the unfilled model. Edge cracks are mainly observed at the instrument
hull of the main hull sand-filled model, but surface tearing and cracks are observed on both the main hull and the instrumental hull of the unfilled model, respectively.

H. Shah Mohammadi and S. Mohammadi (School of Civil Engineering, University of Tehran, Iran), “Analysis of blast shock waves on immersed pipes”, Civil Engineering Infrastructures Journal (CEIJ), Vol. 44, No. 1, pp 61-72, March 2010

ABSTRACT: As a result of wide spread application of marine structures, especially in oil and gas industries, their safe design is of paramount importance. In this regard, explosion loading, which may result from accidents or military/terrorist actions, should be considered, although they may not always be included in the final structural design. The impulsive nature of explosive loading, which comprises a high peak pressure followed by a relative fast decay, and complex phenomena of reflection of incident waves on flexible curved surfaces of a structure, leads to highly complicated analysis of underwater explosion. Detonation of a high explosive material under water produces two pressure pulses: a shock wave which has a very short duration (about several ten to several hundred micro seconds) and a bubble pulse associated with the expansion of the products of detonation. Roles of the underwater shock wave, flow and bubble in the damage process of structures are not as yet, clear. Only effects of the primary shock wave generated from an explosion on circular and rectangular plate specimens and empty submerged cylinders are studied in this research. Effects of bed and water surfaces are not taken into account. The structure and its surrounding water are modeled by solid finite elements. They are attached to each other to enforce for coupling analysis. The water is bounded by nonreflecting boundaries to avoid unwanted reflections from the finite boundaries of the domain. Results of the numerical simulations are compared to the experimental data and the results obtained from available empirical relations.

References listed at the end of the paper:


ABSTRACT: The underwater blast response of free standing sandwich plates with a square honeycomb core
and a corrugated core has been measured. The total momentum imparted to the sandwich plate and the degree of core compaction are measured as a function of (i) core strength, (ii) mass of the front face sheet (that is, the wet face) and (iii) time constant of the blast pulse. Finite element calculations are performed in order to analyse the phases of fluid-structure interaction. The choice of core topology has a strong influence upon the dynamic compressive strength and upon the degree of core compression, but has only a minor effect upon the total momentum imparted to the sandwich. For both topologies, a reduction in the mass of the front (wet) face reduces the imparted momentum, but at the expense of increased core compression. Conversely, an increase in the time constant of the blast pulse results in lower core compression, but the performance advantage over a monolithic plate in terms of imparted momentum is reduced. The sandwich panel results are compared with analytical results for monolithic plates of mass equal to that of (i) the sandwich panel and (ii) the front face alone. (Case (i) represents a rigid core while (ii) represents a core of negligible strength.) For most conditions considered, the sandwich results lie between these limits reflecting the coupled nature of core deformation and fluid-structure interaction.

References listed at the end of the paper:
25. St-Pierre L, Deshpande VS, Fleck NA. The three-point bending response of sandwich beams with corrugated and Y-frame cores:

ABSTRACT: This paper gives an overview of experimental data on the behavior of steel cylindrical shells filled with water or air and repeatedly loaded by an explosion from inside, up to failure. Semi-empirical formulas are obtained which provide fairly easy and reliable estimates of the main parameters of impulsive deformation of the shells within experimental scatter.

References listed at the end of the paper:


ABSTRACT: This paper presents numerical simulations of dynamic responses of a ship section to non-contact underwater explosion using ABAQUS. The finite element model of the ship section including the size of fluid mesh, initial and boundary conditions etc. has been built up. Comparisons of the acceleration and velocity response between the experimental and numerical results have been investigated. The numerical results agree well with the measured results. Furthermore, the effect of the mass proportional damping factor on the velocity response have been investigated numerically. The dynamic response modes of the ship section subjected to a side-on non-contact underwater explosion are discussed.
Panahi B (1), Ghavanloo E (1), Daneshmand F (1,2)
(1) Faculty of Mechanical Engineering, Shiraz University, Shiraz 71348-51154, Iran
(2) Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street W., Montreal, Québec, Canada H3A 2K6


ABSTRACT: Predicting the dynamic response of submerged vehicles subjected to hydrostatic pressure and underwater shock loading is of great interest to many structural designers and engineers for improving material and configuration design in recent years. In this paper, the finite element method is used to evaluate the dynamic response of a submerged cylindrical foam core sandwich panel subjected to shock loading. The sandwich panel consists of a foam core surrounded by fiber-reinforced laminates. The effect of fluid–structure coupling is included in the finite element analysis whereas the fluid is assumed to be compressible and inviscid. Time histories of circumferential stress for different composite plies are presented in graphical form and the effects of core type on circumferential stress and velocity of stand-off point are also investigated. Additionally, the distribution of pressure in fluid domain and the deformation of cylindrical foam core sandwich panel are estimated. To the best of the authors’ knowledge, the specialized literature addressing the dynamic response of submerged cylindrical foam core sandwich panel to underwater shock loading is rather scanty. This work is likely to fill a gap in the specialized literature on this topic.

E. Wang (1) and A. Shukla (2)
(1) Department of Aerospace Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, USA
(2) Dept. of Mechanical, Industrial and Systems Engineering, University of Rhode Island, Kingston, RI USA


ABSTRACT: An experimental investigation was conducted to evaluate the dynamic performance of E-glass Vinyl Ester composite face sheet / foam core sandwich panels when subjected to pre-compression and subsequent blast loading. The sandwich panels were subjected to 0 kN, 15 kN and 25 kN of in plane compression respectively, prior to transverse blast wave loading with peak incident pressure of 1 MPa and velocity of 3 Mach. The blast loading was generated using a shock tube facility. During the experiments, a high-speed photographic system utilizing three digital cameras was used to acquire the real-time 3-D deformation of the sandwich panels. The 3D Digital Image Correlation (DIC) technique was used to quantify the back face out-of-plane deflection and in-plane strain. The results showed that in-plane compressive loading facilitated buckling and failure in the front face sheet. This mechanism greatly reduced the blast resistance of sandwich composites.

References listed at the end of the paper:

LeBlanc, J., Shukla, A., 2011. Dynamic response of curved composite panels to underwater explosive loading: experimental and computational comparisons. Compos. Struct. Vol 93, No. 11, pp 3072–3081, October 2011 ABSTRACT: The response of E-Glass/Vinyl ester curved composite panels subjected to underwater explosive loading has been studied. The work consists of experimental testing utilizing a water filled conical shock tube facility and computational simulations with the commercially available LS-Dyna finite element code. The composite specimens are 0/90 biaxial laminates with a thickness of approximately 1.3 mm. The samples are round panels with curved midsections. The transient response of the plates is measured using a three-dimensional (3D) Digital Image Correlation (DIC) system, along with high speed photography. This ultra high speed system records full field shape and displacement profiles in real time. The DIC data and the computational results show a high level of correlation using the Russell error measure.

Zhang, A. M. (1,2), Zhou, W. X. (1), Wang, S. P. (1) and Feng, L. H. (1)
(1) College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China
(2)  Department of Mechanical Engineering, University College London, Torrington Place, London WC1E 7JE, UK
“Dynamic response of the non-contact underwater explosion on naval equipment”, Marine Struct., 24(4): 396–411, 2011 ABSTRACT: Shock resistance capacity of the shipboard equipment especially for large ones, has been a strong concern of navies all over the world for a long time. The shipboard equipment have previously generally been studied separate from hull structure before. In this paper the coupling elastic effect between equipment and hull structure is taken into account. With the ABAQUS software, the integrated model of the equipment coupled with the hull structure is established to study the dynamic response of the shipboard equipment to the shock wave load as well as the bubble pulsation load. In order to verify the numerical method, the simulated results are compared to the experimental data, which are from a specific underwater explosion on an actual ship. On this basis, by changing the charge location, attack angle, equipment installation location and other parameters, the characteristics of dynamic response under different conditions can be obtained. In addition, the results of the integrated calculation and the non-integrated one are compared and the characteristic parameters which affect the equipment shock response are analyzed. Some curves and conclusions are obtained for engineering applications, which provides some insights into the shock resistance of shipboard equipment.

A-man Zhang (1,2), L. Zeng (3), X. Cheng (1), S. Wang (1), and Y. Chen (1)
ABSTRACT: Whipping response will happen when a ship is subjected to underwater explosion bubble load. In that condition, the hull would be broken, and even the survivability will be completely lost. A calculation method on the dynamic bending moment of bubble has been put forward in this paper to evaluate the impact of underwater explosion bubble load on the longitudinal strength of surface ships. Meanwhile the prediction equation of bubble dynamic bending moment has been concluded with the results of numerical simulation. With wave effect taken into consideration, the evaluation method of the total damage of a ship has been established. The precision of this evaluation method has been proved through the comparison with calculation results. In order to verify the validity of the calculation results, experimental data of real ship explosion is applied. Prediction equation and evaluation method proposed in this paper are to be used in ship structure design, especially in the preliminary prediction of the ultimate withstanding capability of underwater explosion damage for the integrated ship in preliminary design phase.

F.M.A. Silva (1), P.B. Goncalves (2) and Z.J.G.N. Del Prado (1)
(1) Civil Engineering Department, Federal University of Goiás, UFG, Goiânia, Brazil
(2) Department of Civil Engineering, Pontifical Catholic University, Rio de Janeiro, Brazil
ABSTRACT: The aim of the present paper is to study the parametric instability and snap-through buckling of an axially pre-loaded, partially fluid-filled cylindrical shell. The Donnell non-linear shallow shell theory is used to study the nonlinear vibrations of the shell. For this, the Galerkin method is used, together with a suitable expansion that takes into account the main nonlinear interactions, to discretize the shell. The resulting nonlinear equations of motion are solved by numerical integration. The fluid is assumed to be non-viscous and incompressible and its inertial effects on the shell surface are obtained by the potential flow theory. A detailed parametric analysis is carried out to demonstrate the influence of the fluid height within the shell on the parametric instability load and on the snap-through buckling load in the main parametric resonance region. Using bifurcations diagrams, the main bifurcation events associated with these stability boundaries are identified. The influence of the different types of bifurcation and fluid height on the safety is also discussed. References listed at the end of the paper:
H.H. Ibrahim and H.H. Yoo, “Nonlinear flutter oscillations of composite shallow shells subject to aerodynamic and thermal loads”, 13th International Conference on Aerospace Sciences & Aviation Technology (ASAT), May 26-28, 2009, Military Technical College, Kobry Elkobbah, Cairo, Egypt

ABSTRACT: The nonlinear flutter oscillations of a traditional composite shallow shell subject to combined aerodynamic and thermal loads are investigated. A nonlinear finite element model is developed using Marguerre curved plate theory with von Karman geometric nonlinearity and the principle of virtual work. The aerodynamic pressure is modeled using the quasi-steady first-order piston theory. Thermal load is assumed to be steady state constant temperature distribution. Nonlinear temperature-dependence of material properties is considered in the formulation. The dynamic nonlinear equations of motion are transformed to modal coordinates to reduce the computational efforts. Newton-Raphson iteration method is employed to obtain the dynamic response at each time step of the Newmark numerical integration scheme. Finally, numerical results for the nonlinear flutter limit-cycle oscillations of composite shallow shells are presented, illustrating the effect of aerodynamic pressure and temperature rise on the panel response.

References listed at the end of the paper:

ABSTRACT: This paper review focuses mainly on development and application of a hybrid finite element approach used for linear and geometrically nonlinear vibration analysis of isotropic and anisotropic plates and shells, with and without fluid-structure interaction. Development of a hybrid element for different geometries of plates and shells is briefly discussed. In addition, studies dealing with particular dynamic problems such as dynamic stability and flutter of plates and shells coupled to flowing fluids are also discussed. This paper is structured as follows: after a short introduction on some of the fundamentals of the developed model applied to vibrations analysis of shells and plates in vacuo and in fluid, the dynamic analysis of anisotropic structural elements is discussed. Studies on dynamic response of plates in contact with dense fluid (submerged and/or subjected to liquid) follow. These studies present very interesting results that are suitable for various applications. Dynamic response of shell type structures subjected to random vibration due to a turbulent boundary layer of flowing fluid is reviewed. Aeroelasticity analysis of shells and plates (including the problem of stability; divergence and flutter) in contact with light fluids (gases) are also discussed. References listed at the end of the paper:


Toorani, M. H.; Lakis A.A. (2000): General Equations of Anisotropic Plates and Shells Including Transverse Shear Deformation and
ABSTRACT: This paper focuses mainly on development and application of a hybrid finite element approach used for linear and geometrically nonlinear vibration analysis of isotropic and anisotropic plates and shells, with and without fluid-structure interaction. Development of a hybrid element for different geometries of plates and shells is briefly discussed. In addition, studies dealing with particular dynamic problems such as dynamic stability and flutter of plates and shells coupled to flowing fluids are also discussed. This paper is structured as follows: after a short introduction on some of the fundamentals of the developed model applied to vibrations analysis of shells and plates in vacuo and in fluid, the dynamic analysis of anisotropic structural elements is discussed. Studies on dynamic response of plates in contact with dense fluid (submerged and/or subjected to liquid) follow. These studies present very interesting results that are suitable for various applications. Dynamic response of shell type structures subjected to random vibration due to a turbulent boundary layer of flowing fluid is reviewed. Aeroelasticity analysis of shells and plates (including the problem of stability; divergence and flutter) in contact with light fluids (gases) are also discussed.

References listed at the end of the paper:

A.A. Lakis (1), M.H. Toorani (2), Y. Kerboua (3), M. Esmailzadeh (3), F. Sabri (3)
(1,3) Mechanical Engineering Department, École Polytechnique of Montréal, Canada
(2) Nuclear Engineering Department, Babcock & Wilcox Canada, Cambridge, Canada


ABSTRACT: Underwater contact explosion involves lots of complex issues such as high speed, strong compression, large deformation and density ratio, multi-phase flow, etc., which makes the numerical simulation extremely difficult. In this paper, a modified SPH approach based on volume approximation is applied and the entire process of shock wave propagation and structure destruction is successfully simulated. Results show that the modified method remains effective at interfaces with high density ratio, with no distortion of physical quantities. Therefore, the method has advantages of solving problems involving high speed, strong compression and high density ratio. In addition, shock wave propagation characteristics and a steel failure mod are found with simulation, which can be valuable reference for structural design of naval architecture and engineering of underwater explosion.

A-man Zhang (1,2), Wen-shan Yang (3) and Yao Zong-liang (1)
(1) College of Shipbuilding and Ocean Engineering, Harbin Engineering University, Harbin 150001, China
(2) Department of Mechanical Engineering, University College London, Torrington Place, London WC1E 7JE, UK
(3) Wuhan Second Ship Design and Research Institute, Wuhan 430064, China

Tang Ting (1,2), Zhu Xi (2), Wei Zhuobin (1) and Hou Hailiang (2)
(1) Tianjin Campus, Naval University of Engineering, Tianjin 300450, China
(2) College of Naval Architecture and Power, Naval University of Engineering, Wuhan 430033, China
ABSTRACT: By reviewing the response of warship structures subjected to a close underwater explosion, the theoretic, experimental and numerical study developments on loading of close underwater explosion were illustrated, and the fluid-structure interaction and response of plates, cylindrical shells, beams and warship structures subjected to a close underwater explosion were summarized. Four aspects that should be studied urgently were presented as follows: characteristics of underwater explosion loading in complex boundary conditions, simulation of impact destroy of structures, comparability of models test, and response of new materials and structures to close underwater explosion.

J. Li (1,2) and J.-L. Rong (2)
(1) Department of Automobile Engineering, Guang Xi University of Technology, Liuzhou 545006, Guang Xi, China
(2) School of Aerospace Engineering, Beijing Institute of Technology, Beijing 100081, China


ABSTRACT: The propagation of the shock wave and the bubble pulse of an underwater explosion and the dynamic response of a cylindrical shell were examined in a water pool. Numerical simulations of the experimental model were performed using the MSC.DYTRAN software, which included a developed subroutine that defined the initial conditions of the fluid field. A fluid-structure interaction method was introduced to define the interaction between the water and the cylindrical shell. The finite element models were built according to the experimental models, and the calculated results were compared with the experimental data. It was found that the artificial bulk viscosity had a significant effect on the peak pressure of the shock wave. The peak pressure of the shock wave, the period of the bubble pulse and the deformation displacement of the cylinder were consistent between the experiment and the finite element analysis. The effects of the length-to-diameter ratio and the angle to the peak pressure of the shock wave for a cylindrical explosive were discussed. Different plastic deformations were measured at different standoff distances, obtaining generalising curves.


ABSTRACT: Laboratory-scale fluid-structure interaction (FSI) experiments are performed in order to examine the response of submerged, clamped composite plates to dynamic loading by underwater shock waves. Experiments are conducted in a recently developed transparent shock tube [1] and allow measurements of deflection history and cavitation processes. Analytical models are implemented for the underwater blast response of orthotropic composite plates and analytical predictions are compared to those of explicit finite element (FE) simulations and to experimental evidence.

Gong, Shi Wei and Lam, Khin Yong (SingaporeNanyang Technological University, Singapore), “Functionally graded shells subjected to underwater shock”, American Institute of Physics Conference, 2012, DOI: 10.1063/1.3686251

ABSTRACT: This paper deals with the problem of functionally graded (FG) cylindrical shells subjected to underwater shock. A computational approach to predict the dynamic response of the FG cylindrical shells to underwater shock is presented. The effective material properties of functionally graded materials (FGMs) for the cylindrical shells are assumed to vary continuously through the shell thickness and are graded in the shell thickness direction according to a volume fraction power law distribution. Based on Doubly Asymptotic Approximation (DAA) method, the fluid-structure interaction equation for a submerged structure is derived, in which the constitutive relation for functional graded material is implemented. The coupled fluid-structure equations, relating structure response to fluid impulsive loading, are solved using coupled finite-element and
boundary-element codes. The computational procedure for the prediction of transient response of the FG graded cylindrical shells subjected to underwater shock is described, with a discussion of the results.

Zhi Zong (1), Yanjie Zhao (1), Fan Ye (2), Haitao Li (1) and Gang Chen(1)
(1) School of Naval Architecture Engineering, Dalian University of Technology, Dalian, China
(2) Marine Design & Resesarch Institute of China, Shanghai, China

"Parallel computing of the underwater explosion cavitation effects on full-scale ship structures”, Journal of Marine Science and Application, Vol. 11, No. 4, pp 469–477, December 2012

ABSTRACT: As well as shock wave and bubble pulse loading, cavitation also has very significant influences on the dynamic response of surface ships and other near-surface marine structures to underwater explosive loadings. In this paper, the acoustic-structure coupling method embedded in ABAQUS is adopted to do numerical analysis of underwater explosion considering cavitation. Both the shape of bulk cavitation region and local cavitation region are obtained, and they are in good agreement with analytical results. The duration of reloading is several times longer than that of a shock wave. In the end, both the single computation and parallel computation of the cavitation effect on the dynamic responses of a full-scale ship are presented, which proved that reloading caused by cavitation is non-ignorable. All these results are helpful in understanding underwater explosion cavitation effects.

References listed at the end of the paper:
4. Hollyer RS (1959). Direct shock wave damage to merchant ships from non-contact underwater explosions. ANAME, 773–784.
ABSTRACT: The focus of the paper is on the numerical analysis of cylinder shells with arbitrary cross-section, containing flowing fluid. A three-dimensional problem is considered and solved by the finite element method. The motion of the shell is described by applying the variational principle of virtual displacements, which incorporates the linearized Bernoulli equation for evaluating the hydrodynamic pressure. A compressible inviscid fluid is considered.

Strengthening the framework of the potential theory. The governing equations are converted using the Bubnov–Galerkin method. To demonstrate the possibilities of three-dimensional numerical simulation two problems on the natural vibrations and stability of elliptical cylindrical shells are investigated.

References listed at the end of the paper:

ABSTRACT: In the present work, a set of finite element analyses (FEA) was carried out, using Abaqus to reproduce the mechanical behaviour of integrally stiffened panels when subject to longitudinal compression. Since most fabrication processes, such as welding, introduce distortions and affect the material properties, the sensitivity to these defects was assessed. Different shapes and magnitudes of the initial geometrical imperfections were tested and a high sensitivity was observed to both factors on the ultimate load. The existence of a heat affected material showed no influence on the ultimate strength of the tested panels.

Diogo Cardoso, Robert Valente, R.M.F Paulo (GRIDS Research group, Center for Mechanical Technology and Automation, Department of Mechanical Engineering, University of Aveiro, Campus de Santiago 3810-193, Aveiro, Portugal), “Numerical simulation and design of extruded integrally stiffened panels (ISP) for aeronautical applications subjected to blast loading: Sensitivity analyses to different stiffener configurations”, 2nd ECCOMAS Young Investigators Conference (YIC 2013), Sep 2013, Bordeaux, France. <hal-00855834>

ABSTRACT: Protection of structures against explosions due to terrorism actions or accidents is a growing concern in the current times. The need for engineers to understand the structural mechanics during blast load events motivated the research leading to this work. This paper investigates the structural response of integrally stiffened panels, with different stiffener configurations, subjected to blast loading conditions through a set of finite element analyses (FEA) carried out using LS-Dyna commercial code. The numerical models developed in this work are validated by comparing the results to two small-scale blast loading experiments presented in the literature. The influence of different parameters, such as, numerical (i.e. element type, element size) and geometrical parameters, with respect to the accuracy of the finite element results are investigated. It is concluded which numerical parameters present the more accurate results with reduced computational effort and which stiffener configuration results in a more stable behaviour for the structure.

References listed at the end of the paper:
Chul-Hong Kim and Young S. Shin (Division of Ocean Systems Engineering, Korea Advanced Institute of Science and Technology (KAIST), 335 Science Road, Yuseong-gu, Daejeon 305-701, Republic of Korea), “Numerical simulation of surface shield effects to waterblast wave”, Ocean Engineering, Vol. 60, pp 99-114, March 2013

ABSTRACT: When a naval ship is attacked by an underwater explosion (UNDEX), the ship can be severely damaged by shock waves and gas bubble pulse: such an attack can put the crew in danger and possibly destroy the ship. Preventing damage to ships is of great interest in ship design. Elastomers, or rubber-like materials, and core sandwich structure are well known to reduce impact loading. This study researched these materials, structures and verified their ability to mitigate shock loading in an UNDEX environment. Furthermore, formulas to optimize sandwich structure design are presented and its effectiveness has been confirmed.

S. Iakovlev (1), C.T. Seaton (1) and J.-F. Sigrist (2)
(1) Department of Engineering Mathematics and Internetworking, Dalhousie University, Halifax, Nova Scotia, Canada B3J 2X4
(2) Département Dynamique des Structures, CESMAN, DCNS research, Indret, 44620 La Montagne, France


ABSTRACT: A submerged evacuated circular cylindrical shell subjected to a sequence of two external shock waves generated at the same source is considered. A semi-analytical model combining the classical methods of mathematical physics with the finite-difference methodology is developed and employed to simulate the interaction. Both the hydrodynamic and structural aspects of the problem are considered, and it is demonstrated that varying the delay between the first and second wavefronts has a very significant effect on the stress–strain state of the structure. In particular, it is shown that for certain values of the delay, the constructive superposition of the elastic waves travelling around the shell results in a ‘resonance-like’ increase of the structural stress in certain regions. The respective stress can be so high that it sometimes exceeds the overall maximum stress observed in the same structure but subjected to a single-front shock wave with the same parameters, in some cases by as much as 50%. A detailed parametric analysis of the observed phenomenon is carried out, and an easy-to-use diagram summarizing the finding is proposed to aim the pre-design analysis of engineering structures.


ABSTRACT: The development of efficient algorithms to understand implosion dynamics presents a number of challenges. The foremost challenge is to efficiently represent the coupled compressible fluid dynamics of internal air and surrounding water. Secondly, the method must allow one to accurately detect or follow the interface between the phases. Finally, it must be capable of resolving any shock waves which may be created in air or water during the final stage of the collapse. We present a fully Lagrangian compressible numerical framework for the simulation of underwater implosion. Both air and water are considered compressible and the equations for the Lagrangian shock hydrodynamics are stabilized via a variationally consistent multiscale method. A nodally perfect matched definition of the interface is used and then the kinetic variables, pressure and density, are duplicated at the interface level. An adaptive mesh generation procedure, which respects the interface connectivities, is applied to provide enough refinement at the interface level. This framework is then used to simulate the underwater implosion of a large cylindrical bubble, with a size in the order of cm. Rapid collapse and growth of the bubble occurred on very small spatial (0.3mm), and time (0.1ms) scales followed by Rayleigh-Taylor instabilities at the interface, in addition to the shock waves traveling in the fluid domains are
ABSTRACT: In this paper, a scaled 3D ship under shock loading is modeled and analyzed by finite element method. By using a shock factor, there is no need to have different tests or even numerical simulation. Shock factor is an important parameter which clarifies shock severity. It was found that although the new shock factor introduced by Yao et al. (2009), when constant, predict the response better than older shock factor, but for varying values of shock factors, the older would predict better. It is also found that costly and time-consuming experiments can be avoided by proper finite element modeling, yet the errors can remain within an acceptable range. The results of the present work can be used as benchmarks for future works.

References listed at the end of the paper:

A. Ghorbanpour Arani (1,2), M.R. Bagheri (1), R. Kolahchi (1) and Z. Khoddami Maraghi (1)

(1) Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
(2) Institute of Nanoscience & Nanotechnology, University of Kashan, Kashan, Iran


ABSTRACT: Nonlinear free vibration and instability of fluid-conveying double-walled boron nitride nanotubes (DWBNNTs) embedded in viscoelastic medium are studied in this paper. The effects of the transverse shear deformation and rotary inertia are considered by utilizing the Timoshenko beam theory. The size effect is applied by the modified couple stress theory and considering a material length scale parameter for beam model. The nonlinear effect is considered by the Von Kármán type geometric nonlinearity. The electromechanical coupling and charge equation are employed to consider the piezoelectric effect. The surrounding viscoelastic medium is described as the linear visco-Pasternak foundation model characterized by the spring and damper. Hamilton’s principle is used to derive the governing equations and boundary conditions. The differential quadrature method (DQM) is employed to discretize the nonlinear higher-order governing equations, which are then solved by a direct iterative method to obtain the nonlinear vibration frequency and critical fluid velocity of fluid-conveying DWBNNTs with clamped-clamped (C-C) boundary conditions. A detailed parametric study is conducted to elucidate the influences of the small scale coefficient, spring and damping constants of surrounding viscoelastic medium and fluid velocity on the nonlinear free vibration, instability and electric potential distribution of DWBNNTs. This study might be useful for the design and smart control of nano devices.

References listed at the end of the paper:

We experimentally and numerically investigate the response of fluid-filled composite tubes under shock wave loading. Our study focuses on the fluid–structure interaction when the shock wave in the fluid propagates parallel to the axis of the tube, creating pressure waves in the fluid coupled to flexural waves in the shell. The in-house-developed computational scheme couples an Eulerian fluid solver with a Lagrangian shell solver, which includes a new and simple material model to capture the response of fiber composites in finite kinematics. In the experiments and simulations we examine tubes with fiber winding angles equal to 45° and 60°, and we measure the precursor and primary wave speeds, hoop and longitudinal strains, and pressure. The experimental and computational results are in agreement, showing the validity of the computational scheme in complex fluid–structure interaction problems involving fiber composite materials subjected to shock waves. The analyses of the measured quantities show the strong coupling of axial and hoop deformations and the significant effect of fiber winding angle on the composite tube response, which differs substantially from that of a metal tube in the same configuration.

References listed at the end of the paper:


ABSTRACT: In the present study, a hybrid finite element method is applied to investigate the dynamic behavior of a spherical shell partially filled with fluid and subjected to external supersonic airflow. The structural formulation is a combination of linear spherical shell theory and the classic finite element method. In this hybrid method, the nodal displacements are derived from exact solution of spherical shell theory rather than approximated by polynomial functions. Therefore, the number of elements is a function of the complexity of the structure and it is not necessary to take a large number of elements to get rapid convergence. Linearized first-order potential (piston) theory with the curvature correction term is coupled with the structural model to account for aerodynamic loading. It is assumed that the fluid is incompressible and has no free surface effect. Fluid–structure and fluid–structure–bubble interaction effects during underwater explosions near composite structures. Journal of Applied Mechanics – Transactions of the ASME 76, 051303-1–051303-10.

References listed at the end of the paper:
Jianping Zhang (1), Kaige Zhang (1), Aixi Zhou (2), Tingjun Zhou (1), Danmei Hu (1) and Jianxing Ren (1)
(1) Énergy and Mechanical Engineering, Shanghai University of Electric Power, China
(2) Engineering Technology and Construction Management, University of North Carolina, Charlotte, NC, USA
ABSTRACT: In this paper, the entity model of a 1.5 MW offshore wind turbine blade was built by Pro/Engineer software. Fluid flow control equations described by arbitrary Lagrange-Euler (ALE) were established, and the theoretical model of geometrically nonlinear vibration characteristics under fluid-structure interaction (FSI) was given. The simulation of offshore turbulent wind speed was achieved by programming in Matlab. The brandish displacement, the Mises stress distribution and nonlinear dynamic response curves were obtained. Furthermore, the influence of turbulence and FSI on blade dynamic characteristics was studied. The results show that the response curves of maximum brandish displacement and maximum Mises stress present the attenuation trends. The region of the maximum displacement and maximum stress and their variations at different blade positions are revealed. It was shown that the contribution of turbulence effect (TE) on displacement and stress is smaller than that of the FSI effect, and its extent of contribution is related to the relative span length. In addition, it was concluded that the simulation considering bidirectional FSI (BFSI) can reflect the vibration characteristics of wind turbine blades more accurately.

ABSTRACT: The response of single-curvature composite panels under external blast was studied. For the single-curvature composite shells under external pressure pulse loading, Lagrange’s equations of motion were established to determine the shell response and the Budiansky-Roth criterion was used to examine the instability. The predicted transient shell response compared very well with FEA results from ABAQUS Implicit, and the predicted buckling loads also agreed with experiments on steel arches. Under various load durations, buckling was impulsive, dynamic and quasi-dynamic. Thicker composite shells were more likely to fail by first-ply failure rather than buckling. It was shown that the composite lay-up could be adjusted to increase the buckling resistance of the shell. For the single-curvature composite sandwich panels under external pressure pulse loading, a multi-layered approach was used to distinguish facesheets and core deformations. Core compressibility and transverse shear through the thickness were accounted for using linear displacement fields through the thickness. Equations of motion for the facesheet transient deformations were again derived from Lagrange’s equations of motion, and predicted solutions using this approach compared very well with FEA results from ABAQUS Implicit. In the case of core undergoing elastic deformations only, both facesheet fracture during stable deformation response and local dynamic pulse buckling of facesheets were considered as possible modes of failure in the curved sandwich panel. It was found that local facesheets buckling is more likely to occur than facesheet fracture in thin and deeply curved sandwich panels. The facesheet laminate lay-up could also be adjusted to improve the local buckling resistance of the curved sandwich panel. In the case of the core undergoing elastic-plastic deformations, a parametric study showed that blast resistance of the curved sandwich panel can be increased by allowing cores to undergo plastic crushing. Very thick (i.e., radius-to-thickness aspect ratio less than 10) and shallow shells derived much of their resistance to blast from core crushing. Strong, dense foam cores did not increase the blast resistance of the curved sandwich panel but allowed facesheets to fracture while the core remained elastic.

References listed at the end of the dissertation:

P.S. Kovalchuk (1), L.A. Kruk (2) and V.A. Pelykh (1)
(1) S. P. Timoshenko Institute of Mechanics, National Academy of Sciences of Ukraine, 3 Nesterova St., Kyiv, Ukraine
(2) National University of Transport, 1 Suvorova St., Kyiv, Ukraine
ABSTRACT: The effect of added masses on the quasistatic (divergence) and dynamic (flutter) loss of stability of cylindrical shells interacting with the internal fluid flow is studied. The dependence of the critical velocity of the fluid on the type of attachment of the added masses is analyzed.
References listed at the end of the paper:
References listed at the end of the paper:


P.S. Kovalchuk (1), L.A. Kruk (2) and V.A. Pelykh (1)
(1) S. P. Timoshenko Institute of Mechanics, National Academy of Sciences of Ukraine, 3 Nesterova St., Kyiv, Ukraine
(2) National University of Transport, 1 Suvorova St., Kyiv, Ukraine

ABSTRACT: The problem of the stability of a fluid-conveying pipeline modeled by a composite orthotropic cylindrical shell of finite length with different boundary conditions at the ends is solved. The shell is subject to hydrodynamic pressure and uniform external static load. The effect of boundary conditions of the shell under external loading on the qualitatively different types of instability, quasistatic (divergence) and dynamic (flutter), that occur at certain “critical” velocities of the fluid is studied.

P.S. Kovalchuk (1), L.A. Kruk (2) and V.A. Pelykh (1)
(1) S. P. Timoshenko Institute of Mechanics, National Academy of Sciences of Ukraine, 3 Nesterova St., Kyiv, Ukraine
(2) National University of Transport, 1 Suvorova St., Kyiv, Ukraine


ABSTRACT: In this study, the vibration and stability analysis of a single-walled carbon nanotube (SWCNT) conveying nanoflow embedded in biological soft tissue are performed. The effects of nano-size of both fluid flow and nanotube are considered, simultaneously. Nonlocal beam model is used to investigate flow-induced vibration of the SWCNT while the small-size effects on the flow field are formulated through a Knudsen number (Kn), as a discriminant parameter. Pursuant to the viscoelastic behavior of biological soft tissues, the SWCNT is assumed to be embedded in a Kelvin–Voigt foundation. Hamilton's principle is applied to the energy expressions to obtain the higher-order governing differential equations of motion and the corresponding higher-order boundary conditions. The differential transformation method (DTM) is employed to solve the differential equations of motion. The effects of main parameters including Kn, nonlocal parameter and mechanical behaviors of the surrounding biological medium on the vibrational properties of the SWCNT are examined.


ABSTRACT: Dynamic buckling of submerged structures is a challenging problem for which experimental data is scarce and generalized theoretical models are difficult to employ. In addition to the complexities of dynamic buckling, this problem features additional difficulties due to the strong fluid–solid interaction that is characteristic of structures submerged in a dense fluid. This chapter reviews some recent experiments in which time-resolved measurements of pressure and strain were made during the buckling of submerged tubes. This data clarifies the buckling behavior over a useful range of conditions and provides a means to validate theoretical models with a rigor not possible using post-collapse measurements alone. Observations from the experiments are then used to develop simple models of buckling and fluid–structure interaction; comparisons with the experimental data demonstrate good agreement in spite of the many simplifications used in the modeling.

References listed at the end of the paper:
ABSTRACT: Truncated Conical vessels are commonly used as liquid containers in elevated tanks. Despite the widespread of this type of structures worldwide, no direct code provisions are currently available covering their seismic analysis and design. During a seismic excitation, two components of hydrodynamic pressure develop inside a liquid-filled tank. Those are the impulsive component, which synchronizes with the vibration of the walls of the tank and the convective component associated with the free surface sloshing motion. The current study describes the seismic behaviour of an elevated conical tank having a composite steel/concrete construction. The study is conducted numerically using a coupled finite/boundary element model developed in-house. The walls of the tank are modeled using a degenerated consistent shell element. The impulsive component of the hydrodynamic pressure is formulated taking into account the fluid-structure interaction that occurs between the fluid pressure and the shell vibration. The numerical model also predicts the sloshing motion associated with a seismic excitation. Due to the inclination of the walls, the vertical component of seismic ground motion produces meridional axial stresses in a conical tank. As such, both the horizontal and vertical components of the seismic motion are considered in the study. Time history seismic analyses are conducted under a number of pre-recorded seismic excitations. The bending and membrane stresses obtained from the analyses are evaluated in various location of the structure and are compared to the values associated with hydrostatic pressure in order to assess the importance of seismic stresses in this type of structures. The maximum values for the free surface sloshing motion are also obtained from the seismic analyses. Finally, comparisons are made between the seismic forces calculated using the equivalent cylinder approach adopted in some of the design codes.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: This paper presents investigation of combined mechanisms of collapse of discrete single-layer domes. Main factors influencing sustainable behavior are: morphology of the grid configuration, geometry and material characteristics of the structural elements, type of joints and the supporting conditions. On this basis, representative configuration of discrete spherical dome for structural analysis is selected. The numerical solution is performed by software based on the Finite Element Method. Several load cases are considered. These are consistent with the surfaces of influence that have been determined. In order to define the critical value of the load parameter, the loading is increased incrementally and iterative procedure is used in a given load step in order to exclude the structural elements which have reached their limit capacity. Thus the boundary equilibrium of the system is defined. The study reveals geometric nonlinearities by accounting for P-A effects, i.e. the influence of normal forces on the stiffness of the system. It is assumed that the displacements increase after exclusion of the elements which have reached their limit capacity. The equilibrium conditions are defined for the deformed shape of the structure. Results are presented in graphical and tabular form.

References listed at the end of the paper:
Here we consider the effect of underwater blasts on marine structures. Near the explosive charge, the explosion bubble can induce whipping of nearby structures and induce severe damage. Shock waves can propagate over long distances and cause damage to structural panels but usually do not transfer enough momentum to induce overall deformation of the ship. Explosion bubbles oscillate with very low frequencies and can induce whipping of nearby structures and induce severe damage. In this work a geometric theory of diffraction is used to study the interaction of an underwater shock wave with fluid filled shells. The fluid inside may be different than the fluid outside the shell.

ABSTRACT: The influence of the outer hull on the response of a double hull structure induced by underwater explosion is studied. The simple plane wave theory was introduced to analyze the transmitting shock wave and the response of the structure. The calculation of transmission wave of the double cylindrical shell was carried on. The results show that the calculation of transmission wave is in quite agreement with the test data. The transmitting wave rate and transmitting wave energy decay in exponential curve with the thickness of the outer hull. The impulse contrast was increased a little. The peak value of transmitting wave was descended by 66.7%. Thickness of the outer hull is an extremely important factor to anti-shock capability of double cylindrical shell.


SUMMARY: In this work a geometrical theory of diffraction is used to study the interaction of an underwater shock wave with fluid filled shells. The fluid inside may be different than the fluid outside the shell. The shock waves can propagate over long distances and cause damage to structural panels but generally do not transfer enough momentum to induce overall deformation of the ship. Explosion bubbles oscillate with very low frequencies and can induce whipping of nearby structures and induce severe damage. Here we consider the effect of underwater blasts on nearby structures. Near the explosive charge, the
ABSTRACT: This paper presents a general approach for analysing the response of beam, plates and shells to short duration pressure pulses typically encountered as a result of underwater explosions. The problem is formulated in terms of curvilinear coordinates and the resulting equations can then be specialized for each particular geometry. Results are presented for several examples.

References listed at the end of the paper:


ABSTRACT: This chapter examines the interaction of shock waves generated by underwater explosions and submerged structures. Cylindrical shells filled with air, water, or a liquid with a different speed of sound are considered and the specific issue considered is the prediction of the position of the various wave fronts as a function of time. This is a challenging problem for both analytical and numerical approaches due to the sharp discontinuities, the complex shapes of these wave fronts and their numbers. A simple ray tracing procedure is developed to predict the exact position of all the wave fronts. It provides great insight into the physics of the problem and explains the evolution of the shape of the various fronts and the formation of singularities. Applications to the medical field are also presented.

References listed at the end of the paper:

In summary, the Rayleigh wave velocity can be expressed in terms of the elastic properties of the medium. Further research is needed to refine these expressions and to develop more accurate models for practical applications. The integrals over the mass density function can be challenging to compute, and numerical methods are often employed. Additionally, the simplified models are useful for preliminary assessments and for understanding the underlying physics of the problem.

References:

- Graff KF (1975) Wave motion in elastic solids. Ohio State University, Columbus
- Willis HF (1941) Underwater explosions: the time interval between successive explosions. British Report, WA-42-21
- Willis HF (1941) Underwater explosions: the time interval between successive explosions. British Report, WA-42-21


The effects of high-rate impact and shock loading of structures have become an increasingly important design concern for various applications, particularly those of civil and military backgrounds. The mechanical properties, in particular high specific strength, of continuous Fibre Reinforced Polymer Composites (FRPCs) have been subject to widespread investigation. This is due to the increasing need for engineers to understand their performance and constraints with regard to the design of critical components. Moreover, FRPCs have been employed for naval ship superstructures owing to their low radar return. It would therefore be favourable to protect the integrity of the structure to prevent losses in stealth properties. This study outlines the recent high-rate impact studies conducted: high-speed photography, in conjunction with Digital Image
Correlation (DIC), has been used to monitor the deformation of sandwich FRPCs under shock loading of an air-blast to observe the failure mechanisms occurring during the event. Underwater-blast loading experiments were also conducted using strain gauges to monitor the response of the sandwich panel to the underwater shocks. Origins and mechanisms of failure such as core crushing, skin/core cracking and fibre breakage have been identified; moreover, the data reported provided further understanding of each loading case.

References listed at the end of the paper:


ABSTRACT: The resistance of glass-fibre reinforced polymer (GFRP) sandwich panels and laminate tubes to blast in air and underwater environments has been studied. Procedures for monitoring the structural response of such materials during blast events have been devised. High-speed photography was employed during the air-blast loading of GFRP sandwich panels, in conjunction with digital image correlation (DIC), to monitor the deformation of these structures under shock loading. Failure mechanisms have been revealed by using DIC and confirmed in post-test sectioning. Strain gauges were used to monitor the structural response of similar sandwich materials and GFRP tubular laminates during underwater shocks. The effect of the backing medium (air or water) of the target facing the shock has been identified during these studies. Mechanisms of failure have been established such as core crushing, skin/core cracking, delamination and fibre breakage. Strain gauge data supported the mechanisms for such damage. These studies were part of a research programme sponsored by the Office of Naval Research (ONR) investigating blast loading of composite naval structures. The full-scale experimental results presented here will aid and assist in the development of analytical and computational models. Furthermore, it highlights the importance of support and boundary conditions with regards to blast resistant design.

References listed at the end of the paper:
8. Jackson, M. and Shukla, A., Performance of sandwich composites subjected to sequential impact and air blast loading. Composites
17. Deegan, M., Email - Strain gauge application to underwater explosive events, 2010.


ABSTRACT: The study of underwater explosions (UNDEX) on ship/submarines became of interest during World War II when torpedo explosions near a ship created more damage than a direct hit. Following the war, many full scale ship shock trials were conducted by various countries providing the empirical data that is widely employed. The biggest threat to any marine platform is due to underwater weapons and hence understanding the phenomenon is essential. The sequence of events involved in an UNDEX starting from the detonation, shock wave, bubble pulses and cavitation have been introduced and the dynamics of the process including governing laws have been enumerated in the paper. The associated aspects of loading and method of analyzing the fluid structure interaction have also been highlighted. The development of such numerical methods to analyze the explosion and its effect on the fluid-structure can lead to design of safer ships and submarines. Moreover, the numerical simulation will eliminate the need for conducting expensive shock tests and trials.

References listed at the end of the paper:
(cannot easily cut and paste)

Ikeda, C.M. and Duncan, J.H., “Explosion-induced implosions of cylindrical shell structures”, American Physical Society, 63rd Annual Meeting of the APS Division of Fluid Dynamics, November 2010

ABSTRACT: An experimental study of the explosion-induced implosion of cylindrical shell structures in a high-pressure water environment was performed. The shell structures are filled with air at atmospheric pressure and are placed in a large water-filled pressure vessel. The vessel is then pressurized to various levels $P = \alpha P_c$, where $P_c$ is the natural implosion pressure of the model and $\alpha$ is a factor that ranges from 0.1 to 0.9. An explosive is then set off at various standoff distances, $d$, from the model center line, where $d$ varies from $R$ to $10R$ and $R$ is the maximum radius of the explosion bubble. High-speed photography (27,000 fps) was used to observe the explosion and resulting shell structure implosion. High-frequency underwater blast sensors recorded dynamic pressure waves at 6 positions. The cylindrical models were made from aluminum (diameter $D = 39.1$ mm, wall thickness $t = 0.89$ mm, length $L = 240$ mm) and brass ($D = 16.7$ mm, $t = 0.36$ mm, $L = 152$ mm) tubes. The pressure records are interpreted in light of the high-speed movies. It is found that the implosion is induced by two mechanisms: the shockwave generated by the explosion and the jet formed during the explosion-bubble collapse. Whether an implosion is caused by the shockwave or the jet depends on the maximum bubble diameter and the standoff distance.
Christine M. Ikeda (Department of Mechanical Engineering, University of Maryland, College Park, Maryland, USA), “Fluid structure interactions: implosions of shell structures and wave impact on a flat plate”, Ph.D. dissertation, 2012, 3543523

ABSTRACT: The work in this dissertation examines the fluid-structure interaction phenomena in a series of three experimental studies. The first two sets of experiments were conducted in a large, water-filled pressure vessel with a nominal internal diameter of 1.77 m. Cylindrical shells were made from thin-walled aluminum and brass tubes with circular cross-sections (internal diameters D) and internal clearance-fit aluminum end caps. Implosion and explosion events were photographed with a high-speed camera (27,000 frames per second), and the waterborne pressure waves resulting from the implosion were measured simultaneously with underwater blast sensors. The natural implosions were generated by raising the ambient water pressure slowly to a value, P, just above the elastic instability limit of the models. For the models with larger L/D, where L is the internal length of the model, the model cross sections flattened during the implosion (mode 2). It was found that the amplitude of these mode 2 pressure waves scale with the pressure difference \( \Delta P = P - P_i \) (where \( P \) is the internal pressure of the air inside the cylindrical models) and the time scales with \( (D/2) \) [special characters omitted] (where \( \varphi \) is the density of water). The geometry and material properties of the structure seem to play only a secondary role. During the explosion experiments, the pressure vessel is pressurized to various pressure levels below the natural implosion pressure of the models and an explosive was set off nearby. It was found that the implosion is induced by one of two mechanisms: the shockwave generated by the explosion and the hydrodynamic pressure field of the explosion bubble during its collapse and re-expansion. In the final experimental study, the impact of a plunging breaking wave (wavelength \( \approx 1.2 \) m) on a partially submerged cube (with dimensions \( L = 0.3048 \) m) is studied in a wave tank (14.8 m long). The water free surface shape upstream of the cube before and after the wave impact was measured with a high-speed digital movie camera, and the pressure waves resulting from the implosion were measured simultaneously with underwater blast sensors. It was observed that for some cube positions, the free surface between the front face of the cube and the wave crest forms a circular arc that converges to a point and forms a high-velocity vertical jet (\( \approx 3 \) m/s). Although these problems are intrinsically different, they are flows dominated by inertial forces (viscous effects are not important) where a rapidly collapsing interface shape produces high-pressure waves.


ABSTRACT: The implosion of cylindrical shell structures in a high-pressure water environment is studied experimentally. The shell structures are made from thin-walled aluminium and brass tubes with circular cross sections and internal clearance-fit aluminium end caps. The structures are filled with air at atmospheric pressure. The implosions are created in a high-pressure tank with a nominal internal diameter of 1.77 m by raising the ambient water pressure slowly to a value, \( P \), just above the elastic stability limit of each shell structure. The implosion events are photographed with a high-speed digital movie camera, and the pressure waves are measured simultaneously with an array of underwater blast sensors. For the models with larger values of length-to-diameter ratio, \( L/D \), the tubes flatten during implosion with a two-lobe (mode 2) cross-sectional shape. In these cases, it is found that the pressure wave records scale primarily with \( P \) and the time scale \( R_i \sqrt{\rho_i/P_c} \) (where \( R_i \) is the internal radius of the tube and \( \varphi \) is the density of water), whereas the details of the structural design produce only secondary effects. In cases with smaller values of \( L/D \), the models implode with higher-mode cross-sectional shapes. Pressure signals are compared for various mode-number implosions of models with the same available energy, \( PV \), where \( V \) is the internal air-filled volume of the model. It is found that the pressure records scale well temporally with the time scale \( R_i \sqrt{\rho_i/P_c} \), but that the shape and amplitudes of the pressure records are strongly affected by the mode number.

References listed at the end of the paper:
2. von Mises R. 1929. Der kritische aussendruck fur allseits belastete zylindrischer rohre (the critical external pressure of cylindrical tubes under uniform radial and axial load), Transl. by DF Windenburg in 1933. Festschrift, Prof. Dr. A. Stodola, Orell Fussli Verlag 53, 418–430

ABSTRACT: An annular geometry is used to experimentally study fluid-structure interaction and dynamic buckling of tubes submerged in water and subjected to axially-propagating pressure waves. Wave propagation, vibration, and buckling of the specimen tubes are characterized using pressure and strain measurements. Emphasis is placed on pressures near or slightly exceeding the buckling threshold, where buckling deformation is excited but remains elastic or only slightly plastic due to the short duration of the pressure pulse. Measured wave speeds and non-axisymmetric vibration frequencies are in good agreement with predictions from simple fluid-structure interaction models. Near the buckling threshold, the amplitude of non-axisymmetric deformation is observed to grow rapidly with small increases in pressure until plastic deformation occurs, which results in a substantial loss of strength of the tube. Systematic mode 2 variations in wall thickness are found to control the buckle orientation, since the major axis of mode 2 buckles is always aligned with the location where the tube wall is thinnest.

References listed at the end of the paper:
A-man Zhang, Shao-fei Ren, Qing Li and Jia Li, “3D numerical simulation on fluid-structure interaction of structure subjected to underwater explosion with cavitation”, Applied Mathematics and Mechanics, Vol. 33, No. 9, pp 1191-1206, September 2012

ABSTRACT: In the underwater-shock environment, cavitation occurs near the structural surface. The dynamic response of fluid-structure interactions is influenced seriously by the cavitation effects. It is also the difficulty in the field of underwater explosion. With the traditional boundary element method and the finite element method (FEM), it is difficult to solve the nonlinear problem with cavitation effects subjected to the underwater explosion. To solve this problem, under the consideration of the cavitation effects and fluid compressibility, with fluid viscosity being neglected, a 3D numerical model of transient nonlinear fluid-structure interaction subjected to the underwater explosion is built. The fluid spectral element method (SEM) and the FEM are adopted to solve this model. After comparison with the FEM, it is shown that the SEM is more precise than the FEM, and the SEM results are in good coincidence with benchmark results and experiment results. Based on this, combined with ABAQUS, the transient fluid-structure interaction mechanism of the 3D submerged spherical shell and ship stiffened plates subjected to the underwater explosion is discussed, and the cavitation region and its influence on the structural dynamic responses are presented. The paper aims at providing references for relevant research on transient fluid-structure interaction of ship structures subjected to the underwater explosion.

References listed at the end of the paper:


ABSTRACT: Laboratory-scale fluid–structure interaction (FSI) experiments and finite element (FE) simulations are performed to examine the one-dimensional blast response of double-walled hulls, consisting of two skins sandwiching a layer of water. Both monolithic and sandwich designs are considered for the outer skin. Experiments are conducted in a transparent shock tube which allows measurements of water cavitation and hull response by high-speed photography. Experiments and FE predictions are found in good agreement and allow concluding that the impulse imparted to double hulls by underwater explosions can be dramatically reduced by employing the sandwich construction of the outer skin; such reductions are scarcely sensitive to the thickness of the water layer.

N. Zhang (1,2), Z. Zong (2), and W. Zhang (2)
(1) China Ship Development and Design Center, Wuhan 430064, China
(2) School of Naval Architecture Engineering, State Key Laboratory of Structural Analysis for Industrial Equipment, Dalian University of Technology, Dalian 116024, China


ABSTRACT: Bubble load in a noncontact underwater explosion can cause the ship hull global response and local response. In current literature, the ship hull is usually simplified as a hull girder to analyze its global response. However, literature dealt with the local response of a 3-D surface ship hull subjected to an underwater bubble were limited. This investigation develops a procedure which couples the finite element method with doubly asymptotic approximation (DAA) method to study the problem of transient responses of a ship hull structure subjected to an underwater explosion bubble. Using a 3-D ship model as examples, the global and local responses of the ship model in vertical, transverse and longitudinal directions are performed in detail. The acceleration, velocity and displacement time histories are presented. The characteristics of both the global and local responses of the ship model are discussed. The numerical results show that besides global whipping response, the ship hull also sustains severe local responses in different directions subjected to underwater explosion bubble jetting, which should be taken into consideration.

D. Cardoso, R.M.F. Paulo and R.A.F. Valente (GRIDS Research Group, Center for Mechanical Technology and Automation, Department of Mechanical Engineering, University of Aveiro, Campus De Santiago, Aveiro, Portugal), “Numerical study and design of extruded integrally stiffened panels (ISP) for aeronautic applications subjected to blast loading”, 11th World Congress on Computational Mechanics (WCCM XI), 5th European Conference on Computational Mechanics (ECCM V), 6th European Conference on Computational Fluid Dynamics (ECFD VI) E. Oñate, J. Oliver and A. Huerta (Eds), Barcelona, Spain, 2014

ABSTRACT/PARTIAL INTRODUCTION: Fuselage panels in aircraft applications are reinforced structural parts subjected to strong buckling effects under normal flight loads. These loads are typically in-plane compression and in-plane shear solicitations, leading to complex buckling behaviors [1]. The ability of a structure to survive non-typical loads, i.e. blast loading from a terrorist attack or an incidental explosion, has also became a major concern. The detonation of an explosive material in the air generates an expanding shock front of finite amplitude moving supersonically [2]. The space and conditions between the point of detonation and the encountered obstacles affect the propagation and magnitude of the pressure wave, resulting in a complex transient structural load [3, 4, 5]. Advanced numerical techniques, such as the Finite Element Method (FEM), can be used in understanding the influence of the blast load and the resulting dynamic structural
response in detail. However, the reliability and stability of finite element results must be validated with experimental data. Analysis of the dynamic response of plates subjected to different kinds of impulsive loads has been an area of active research over the last decade [6, 7]. More recently, Spranghers et al. [2] presented an experimental and numerical study of aluminum plates under blast loading with some numerical considerations that are adopted in the present work. Also, Kumar et al. [8] presented a study on the response of aluminum plates under blast loading and the effect of the plates curvature on the structural response. Nurick et al. [9] presented an experimental study on the deformation and tearing of blast-loaded stiffened square steel plates. In addition, Nurick and Shave [10] and Teeling-Smith [11] performed experiments on plates attached to a ballistic pendulum under impulsive loads and presented an experimental study on the deformation and tearing of thin circular plates subjected to blast loading, respectively. Neuberger et al. [12, 13] measure the deflection of the central point of a circular plate subjected to free air blast loading and detonations of buried charges, obtaining a good agreement between numerical simulations predictions and test results. Finally, Ramajeyathilagam et al. [14] and Chan-Yung Jen et al. [15] both presented studies of the dynamic behaviour of rectangular plates and stiffened panels, respectively, subjected to underwater shock loading. In this study, the Finite Element Method was used to analyze the structural response of integrally stiffened panels (ISP) subject to a blast loading from a Composition C4 explosive material. For this purpose, two approaches were made in the development of the numerical models, the first approach corresponding to the validation of the numerical model. In this approach, 4 types of models were developed, being divided in 2 groups: (i) type of elements used in the model (shell or solid); and (ii) the complexity of the models. The simplified model considered only the thin aluminum plate (target), while the complete model considered the set used in the experimental setup (steel frame, aluminum clamp and plate) . . .

References listed at the end of the paper:


ABSTRACT: Energy flow analysis (EFA) can be used effectively to predict structural vibration in the medium-to-high frequency ranges. In this study, the energy flow finite element method (EFFEM), based on EFA, was used to predict the vibrations of a reinforced cylindrical structure in water. The predicted results of the
vibrational energy density for the structure were compared with corresponding experimental results. The structure was divided into several subsystems in the experiment, with several accelerometers attached to each subsystem. The input power excited into the experimental structure was measured using an impedance-head adhered to an exciter. Measured input power was used to predict vibration of the reinforced cylindrical structure by EFFEM in water for comparing experimental and numerical results. A comparison between the experimental and predicted results for the vibrational energy density showed that EFFEM was an effective tool for predicting structural vibration.

References listed at the end of the paper:


ABSTRACT: Owing to the existence of the flow field boundary, the shock wave load near the boundary is different from the free field shock wave load. In the present paper, the hull plate load subjected to underwater shock wave is investigated based on wave motion theories; in addition, the experimental study of the hull plate load is carried out. According to the theoretical analysis of the hull plate pressure, we find that the hull plate pressure oscillates repeatedly and decays rapidly with time passing, the maximum hull plate pressure is $2/(1+n)$ times the maximum free field pressure, where $n$ is the ratio of impedance, and the impulse is much smaller than the free field impulse. Compared with the experimental study, the theoretical results agree well with the experimental data.

References listed at the end of the paper:
ABSTRACT: In this paper, a numerical model on fluid-structure interaction is established and the validation of the model is carried out. The doubly asymptotic approximation for external domain is used to model the external fluid, the doubly asymptotic approximation for internal domain is used to model the internal fluid and the nonlinear finite element software ABAQUUS is employed to model the structure. Based on the numerical model, the influence of internal fluid to the dynamic response of double ring-stiffened cylindrical shell is investigated. The main results are as follows. Compared with the analytic solution, the oscillation period and amplitude of late time response obtained by the first order doubly asymptotic approximation decrease. But, the solution of the second order doubly asymptotic approximation agrees well with the analytic solution. The existence of internal fluid makes the plastic deformation and velocity response of double ring-stiffened cylindrical shell decrease.
ABSTRACT: In this paper, a numerical method is established to analyze the response of fluid-filled structure to underwater explosion with cavitation. The method is illustrated. In the present implementation, the second-order doubly asymptotic approximation (DAA2) other than curved wave approximation (CWA) is used to simulate non-reflecting boundary. Based on the method, the difference between DAA2 non-reflecting boundary and CWA non-reflecting boundary is investigated; then, the influence of internal fluid volume and the influence of cavitation on dynamic response of spherical shell are analyzed. Compared with CWA non-reflecting boundary, DAA2 non-reflecting boundary treats added mass effects better. When the internal fluid is full, the displacement and velocity of spherical shell decrease, but, when the internal fluid is half, the displacement and velocity of spherical shell increase. The effect of cavitation is more obvious at the trailing point than at the leading point of spherical shell.
References listed at the end of the paper:

ABSTRACT: High-pressure shock performance of sandwich composites consisting of nano-scale core-shell rubber (CSR) toughened E-glass Vinyl-Ester face-sheets and Corecell® A500 (Gurit (USA) Inc., Bristol, Rhode Island, USA) foam was studied using a shock tube apparatus. The core material and thickness, as well as overall specimen dimensions, were held constant, with the only difference arising in the resin system used during the infusion. The non-core-shell rubber toughened resin system (Non-CS drift) consisted of a vinyl-ester resin only, while the CSR toughened resin consisted of the same vinyl-ester resin, but with Kane Ace MX 153 CSR particles added to the vinyl-ester resin system. Prior to the shock tube experiments, the quasi-static and dynamic constitutive behaviour of the face-sheets (tensile/compressive) and foam (compressive) was evaluated. During the shock tube testing, a high-speed photography system coupled with the optical technique of digital image correlation was utilized to capture the real-time deformation process, as well as mechanisms of failure in the sandwich composites. Post-mortem analysis was also carried out to evaluate the overall shock performance of these configurations. Results indicated that adding CSR particles to sandwich composites aids in dispersing the initial shock wave loading, thus reducing the overall deflection, strain, and velocity and improving the overall blast resistance of the structure.

Elsayed Fathallah (1,2), Hui Qi (1), Lili Tong (1) and Mahmoud Helal (1,3)
(1) College of Aerospace and Civil Engineering, Harbin Engineering University, No. 145 Nantong Street, Nangang District, Harbin, Heilongjiang 150001, China

ABSTRACT: A numerical simulation has been carried out to examine the response of steel plates with different arrangement of stiffeners and subjected to noncontact underwater explosion (UNDEX) with different shock loads. Numerical analysis of the underwater explosion phenomena is implemented in the nonlinear finite element code ABAQUS/Explicit. The aim of this work is to enhance the dynamic response to resist UNDEX. Special emphasis is focused on the evolution of mid-point displacements. Further investigations have been performed to study the effects of including material damping and the rate-dependant material properties at different shock loads. The results indicate that stiffeners configurations and shock loads affect greatly the overall performance of steel plates and sensitive to the materials data. Also, the numerical results can be used to obtain design guidelines of floating structures to enhance resistance of underwater shock damage, since explosive tests are costly and dangerous.

References listed at the end of the paper:


Chen Song (1), Yang Xionghui (2), Tang Wenyou (3), Guo Ya (3) and Su Yiran (3)
(1) Naval Military Representativ Office in China Ship Development and Design Center, Wuhan 430064, China
(2) China Ship Development and Design Center, Wuhan, China
(3) State Key Laboratory of Marine Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

Abstract: This paper provides direct technical support to the explosion-resistance design by considering both the shock wave and jet load simultaneously and taking into account of the effect of double shell structure types and sizes during the underwater near-field explosion. Based on the bubble pulsation analysis using Eulerian method in the vicinity of a rigid wall and the principle of energy equivalence, the dynamic response of a double shell structure subjected to underwater near-field explosion is numerically simulated. The jet load is then simplified and applied after the shock wave by using the MSC.Dytran software subroutine. Models with different structural types and sizes are also calculated and an optimal solution set which targets both the weight of the structure and the explosion-resistance capability is obtained via the multi-objective optimization approach. The results show that the optimum thickness of the support structure can be determined when the thickness of outer and inner shells and the distance between them are constant. Meanwhile, Y-frame double shell structures tend to provide higher explosion-resistance capability when the weight of structure is constant.


Abstract: The great use of circular cylindrical shells for conveying fluid in modern industrial applications has made of them an important research area in applied mechanics. Many researchers have studied this problem, however just a reduced number of these works have as object the analysis of orthotropic shells. Although most investigations deal with the analysis of elastic isotropic shells in contact with internal and external quiescent or flowing fluid, several modern and natural materials display orthotropic properties and also stiffened cylindrical shells can be treated as equivalent uniform orthotropic shells. In this work, the influence of internal flowing fluid on the dynamic instability and non-linear vibrations of a simply supported orthotropic circular cylindrical shell subjected to axial and lateral time-dependent loads is studied. To model the shell, the Donnell’s non-linear shallow shell theory without considering the effect of shear deformations is used. A model with eight degrees of freedom is used to describe the lateral displacements of the shell. The fluid is assumed to be incompressible and non-viscous and the flow to be isentropic and irrotational. The Galerkin method is applied to derive the set of coupled non-linear ordinary differential equations of motion which are, in turn, solved by the Runge-Kutta method. The obtained results show that the presence of the internal fluid and material properties have a great influence on the vibration characteristics of the shell.

DOI: 10.4028/www.scientific.net/AMM.799-800.660

Abstract: In the paper nonlinear vibrations of a drill string’s section in a supersonic gas flow are studied. The drill string is modelled in the form of a circular cylindrical shell under the effect of a longitudinal compressing load and torque. In contrast to the previous research, pressure of an unperturbed gas is defined.
nonlinearly in the third approximation. The eighth order partial differential equation describing the motion of the shell reduces to a nonlinear system of ordinary differential equations with application of the Bubnov-Galerkin technique. An implicit Runge-Kutta method is applied to construct modes of vibrations.


ABSTRACT: An experimental investigation on deformation shape of a cylindrical shell with internal medium subjected to lateral contact explosion was carried out briefly. Deformation shapes at different covered width of lateral explosive were recovered experimentally. Based on the experimental results, a corresponding analytical approach has been undertaken with rigid plastic hinge theory. In the analytical model, the cylindrical shell is divided into end-to-end rigid square bars. Deformation process of the cylindrical shell is described by using the translations and rotations of all rigid square bars. Expressions of the spring force, buckling moment, and deflection angle between adjacent rigid square bars are conducted theoretically. Given the structure parameters of the cylinder and the type of the lateral explosive charge, deformation processes and shapes are reported and discussed using the analytical approach. A good agreement has been obtained between calculated and experimental results, and thus the analytical approach can be considered as a valuable tool in understanding the deformation mechanism and predicting the deformation shapes of the cylindrical shell with internal medium subjected to lateral contact explosion. Finally, parametric studies are carried out to analyze the effects of deformation shape, including the covered width of the lateral explosive, explosive charge material, and distribution of initial velocity.

References listed at the end of the paper:
ABSTRACT: Contemporary nuclear submarines are built with double hulls which enhance the protection against explosive attacks. As the two hulls are separated by a distance (stand off), blast loading on the inner hull diminishes significantly. Thus, warheads fitted to underwater weapons with limited quantity of explosive become ineffective. In the present study, an attempt is made to quantify the enhanced protection to the underwater vessels due to double hull construction, through Explosion Bulge Test (EBT) experiments. Four different cases of air back up, water back up, partial water back up and free flood water back up are studied in the EBTs. The extent of reduction in damage to the double hulled vessel under various modes of back up are studied and discussed in this paper. Through these experiments, it is established that there is a significant reduction in damage from 22.5 to 63% to the hull when compared to air back up depending on different test conditions of water back up. The response of double hull to proximity explosion with air and water back up is simulated using a Finite Element (FE) model and compared.

References listed at the end of the paper:

M. Pinto and A. Shukla (Dynamics Photomechanics Laboratory, Department of Mechanical, Industrial and Systems Engineering, University of Rhode Island, Kingston, RI, 02881, USA), “Shock-initiated buckling of carbon/epoxy composite tubes at sub-critical pressures”, Experimental Mechanics, April 2015, 10.1007/s11340-015-0033-1

ABSTRACT: A comprehensive investigation on the implosion of composite cylinders subjected to a nearby explosion is performed. Experiments are conducted in a large pressure vessel, designed to provide constant hydrostatic pressure throughout the event. Carbon fiber/epoxy filament-wound tubes are studied with constant hydrostatic pressure and varying charge standoff distances to determine the effect of the explosive loading on the mechanisms of collapse. 3-D Digital Image Correlation (DIC) is used to capture the full-field displacements and velocities during the implosion event, and to characterize the initial dynamic response of the tube. Dynamic pressure transducers measure the shock waves generated by the explosive and also the pressure pulse generated by the collapse. Results show that different magnitudes of explosive loading produce drastic differences in the way implosions are initiated, and in the extent of damage to the structure. Experiments with strong explosive loading show immediate collapse of the tube upon the arrival of shock wave. Relatively smaller explosive loading result in collapses due to the additional bubble pulse loading, or after accumulating damage for extended periods of time.

References listed at the end of the paper:

Maria Laura De Bellis (1), Giuseppe C. Ruta (1) and Isaac Elishakoff (2)
(1) Dipartimento d’Ingegneria Strutturale e Geotecnica, “Sapienza” University, Rome, Italy
(2) Department of Mechanical Engineering, Florida Atlantic University, Boca Raton, FL, USA


ABSTRACT: We investigate the dynamic stability of a pipe that conveys fluid, clamped or pinned at one end and with an intermediate support, thus exhibiting an overhang. The model of the pipe incorporates both Euler–Bernoulli and Bresse–Timoshenko schemes as well as transverse inertia. Material and external damping mechanisms are taken into account, while the conveyed fluid is supposed to be in fully turbulent flow. The pipe can rest on a linear elastic Winkler soil. The influence of all the physical quantities and of the overhang length on the critical velocity of the fluid front is investigated. Some numerical results are presented and discussed.

References listed at the end of the paper:

35. Wieghardt, K.: Über den balken auf nachgiebiger Unterlage. ZAMM 2(3), 165–184 (1922); (in German)
45. Winkler, E.: Die Lehre von der Elastizität und Festigkeit. Prague, Dominicus (1867); (in German)

Guillaume Renaud (1), Johan G. Bosch (2), Antonius F. W. van der Steen (2) and Nico de Jong (2)

(1) Sorbonne, UPMC Paris
(2) Dept. of Biomedical Engineering, Erasmus Medical Center, Rotterdam, The Netherlands

Dynamic acousto-elastic testing is applied to a mixture of lipid-coated microbubbles in water. A dynamic
change of ambient pressure is produced by a 16 kHz pressure wave having a peak pressure amplitude of 28 kPa. The induced changes of phase velocity and attenuation are captured by a sequence of short ultrasound pulses with a center frequency of 4 MHz. As a consequence of the dispersion brought about by the resonance of microbubbles at a frequency close to 2 MHz, time-domain approaches like the cross-correlation method are shown to be unsuited to determine the variation in ultrasound wavespeed. A frequency-domain analysis shows that the acousto-elastic effect (first order pressure derivative of ultrasound phase velocity) depends on the ultrasound frequency. The acousto-elastic effect tends to that measured in water for an ultrasound frequency above the resonance frequency of microbubbles, while it is two orders of magnitude larger for an ultrasound frequency close to or below the resonance frequency of microbubbles. Besides the large magnitude of the acousto-elastic effect observed for an ultrasound frequency below the resonance frequency of microbubbles, the first order pressure derivative of ultrasound phase velocity is negative. This supports the occurrence of shell buckling of lipid-coated microbubbles induced by the 16 kHz pressure wave.

K.V. Avramov (1), M.V. Chernobryvko (1), O. Kazachenko (1) and T.J. Batutina (2)
(1) Department of Vibrations, Podgorny Institute for Mechanical Engineering, National Academy of Science of Ukraine, 2/10 Dm. Pozharskogo St., Kharkiv, 61046, Ukraine
(2) Design office “Yuzhnoe”, Dnepropetrovsk, Ukraine


ABSTRACT: The dynamic instability of the parabolic shells in a supersonic gas flow is analyzed numerically. Such structures describe a rocket fairing. Finite degrees of freedom dynamical system is obtained by the assumed-modes method to describe the shell motions. The numerical approach for calculations the modes of the shell self-sustained vibrations is suggested. The Mach numbers range of the shell dynamic instability is analyzed numerically. The influence of the paraboloid height on the regions of the dynamic instability is analyzed. The frequencies of the self-sustained vibrations are investigated. The effect of the shell boundary conditions on the regions of the dynamic instability is analyzed.

References listed at the end of the paper:
The fluid forces are described by the three-dimensional inviscid potential flow. The influences of angular flow on the critical axial velocity and the thermal loads are determined by the thermo-elastic theory. The numerical analyses are conducted by a zero-level contour method. The study shows the effects of annular gaps and boundary conditions on stability of shells. The influences of angular flow on the critical axial velocity and axial flow on the critical annular velocity are discussed. Moreover, the thermal loads decrease the critical flow velocity and the critical temperature rise is found.

References listed at the end of the paper:

conditions are derived by Hamilton's principle. An analytical solution method is also employed to solve the velocity of nano and wall of nanoshell, and the average velocity correction parameter is used to obtain the modified flow volume shear deformation shell theory. In order to capture the size effects, Mindlin's strain gradient theory (SGT) materials (FGMs) with internal fluid flow in thermal environment are studied in this pa

10.1016/j.tws.2016.04.009

ABSTRACT: The free vibration and instability characteristics of nanoshells made of functionally graded materials (FGMs) with internal fluid flow in thermal environment are studied in this paper based upon the first-order shear deformation shell theory. In order to capture the size effects, Mindlin's strain gradient theory (SGT) is utilized. The mechanical and thermal properties of FG nanoshell are determined by the power-law relation of volume fractions. The Knudsen number is considered to analyze the slip boundary conditions between the flow and wall of nanoshell, and the average velocity correction parameter is used to obtain the modified flow velocity of nano-flow. The governing partial differential equations of motion and associated boundary conditions are derived by Hamilton's principle. An analytical solution method is also employed to solve the
governing equations under the simply-supported end conditions. Then, some numerical examples are presented to investigate the effects of fluid velocity, longitudinal and circumferential mode numbers, length scale parameters, material properties, temperature difference and compressive axial loads on the natural frequencies, critical flow velocities and instability of system.

Wei Wang (1), Xiao Zhu (2), Zhou Zhou (1), Jingbo Duan (3)
(1) College of Aeronautics, Northwestern Polytechnical University, Xi’an 710072, China
(2) Science and Technology of UAV Laboratory, Northwestern Polytechnical University, Xi’an 710065, China
(3) Ordnance Engineering College, Shijiazhuang 050003, China

ABSTRACT: Very flexible aircraft with high aspect ratio wings subjected to aerodynamic loads undergoes large deformation, which will lead to distinct changes on the mass distributions, stiffness characteristics and aerodynamic characteristics of the complete aircraft. The aeroelasticity and flight dynamics of such aircrafts are nonlinear and the linear elastic theory model cannot be used. A new method is developed for the analysis of nonlinear aeroelasticity and flight dynamics of very flexible aircraft through combining the co-rotational beam theory with the modified ONERA dynamic stall model. Based on a form of co-rotational technique which is external to the element, a spatial two-node beam element, which depicts the geometrically nonlinear dynamic characteristics of the flexible wing, is developed. Both tangential stiffness matrix and mass matrix of the beam element are formulated to establish the nonlinear dynamic equations. In addition, the modified ONERA dynamic stall model is adapted to evaluate the unsteady nonlinear aerodynamic loading of the very flexible wing. Using the present method, the nonlinear aeroelastic response, trim and stability characteristics of a very flexible aircraft are predicted in this paper. The obtained results show a good agreement to the literature, which indicates that the present method is accurate and efficient.

ABSTRACT: The primary function of a heart valve is to allow blood to flow in only one direction through the heart. Triangular thin-shell finite element formulation is implemented, which considers only translational degrees of freedom, in three-dimensional domain to simulate heart valves undergoing large deformations. The formulation is based on the nonlinear Kirchhoff thin-shell theory. The developed method is intensively validated against numerical and analytical benchmarks. This method is added to previously developed membrane method to obtain more realistic results since ignoring bending forces can result in unrealistic wrinkling of heart valves. A nonlinear Fung-type constitutive relation, based on experimentally measured biaxial loading tests, is used to model the material properties for response of the in-plane motion in heart valves. Furthermore, the experimentally measured linear constitutive relation is used to model the material properties to capture the flexural motion of heart valves. The fluid structure interaction solver adopts a strongly coupled partitioned approach that is stabilized with under-relaxation and the Aitken acceleration technique.

T.E. Tezduyar (1), K. Takizawa (2) and Y. Bazilevs (3)
(1) Mechanical Engineering, Rice University, Houston, Texas, USA
(2) Department of Modern Mechanical Engineering and Waseda Institute for Advanced Study, Waseda University, Shinjuku-ku, Tokyo, Japan
(3) Department of Structural Engineering University of California, San Diego, La Jolla, CA, USA
ABSTRACT: Flows with moving boundaries and interfaces (MBI) include fluid–structure interaction and a number of other classes of problems, such as fluid–object interaction, fluid–particle interaction, free-surface and multi-fluid flows, and flows with solid surfaces in fast, linear or rotational relative motion. These problems are
frequently encountered in engineering analysis and design, pose some of the most formidable computational challenges, and have a common core computational technology need. Bringing solution and analysis to them motivated the development of a good number of core computational methods and special methods targeting specific classes of MBI problems. This chapter is an overview of some of those core and special methods, with a focus on computational examples from the ST-VMS and ALE-VMS methods and special methods developed in conjunction with the two.

References listed at the end of the paper:


10.1002/cm.1433.

Kenji Takizawa (1), Tayfun E. Tezduyar (2), Ryan Kolesar (2), Cody Boswell (2), Taro Kanai (1) and Kenneth Montel (2)
(1) Department of Modern Mechanical Engineering and Waseda Institute for Advanced Study, Waseda University, Shinjuku-ku, Tokyo, Japan
(2) Mechanical Engineering, Rice University, Houston, Texas, USA
“Multiscale methods for gore curvature calculations from FSI modeling of spacecraft parachutes”,
ABSTRACT: There are now some sophisticated and powerful methods for computer modeling of parachutes. These methods are capable of addressing some of the most formidable computational challenges encountered in parachute modeling, including fluid–structure interaction (FSI) between the parachute and air flow, design complexities such as those seen in spacecraft parachutes, and operational complexities such as use in clusters and disreefing. One should be able to extract from a reliable full-scale parachute modeling any data or analysis needed. In some cases, however, the parachute engineers may want to perform quickly an extended or repetitive analysis with methods based on simplified models. Some of the data needed by a simplified model can very effectively be extracted from a full-scale computer modeling that serves as a pilot. A good example of such data is the circumferential curvature of a parachute gore, where a gore is the slice of the parachute canopy between two radial reinforcement cables running from the parachute vent to the skirt. We present the multiscale methods we devised for gore curvature calculation from FSI modeling of spacecraft parachutes. The methods include those based on the multiscale sequentially-coupled FSI technique and using NURBS meshes. We show how the methods work for the fully-open and two reeved stages of the Orion spacecraft main and drogue parachutes. References listed at the end of the paper:


====== End of some papers on fluid-structure interaction prior to 2019 ======

=== Some papers not in Part 1 on chaos in the nonlinear dynamic response of thin-walled structures ===


ABSTRACT: Forced oscillations of flexible plates with a longitudinal, time dependent load acting on one plate side are investigated. Regular (harmonic, subharmonic and quasi-periodic) and irregular (chaotic) oscillations appear depending on the system parameters as well as initial and boundary conditions. In order to achieve highly reliable results, an effective algorithm has been applied to convert a problem of finding solutions to the hybrid type partial differential equations (the so-called von Karman form) to that of the ordinary differential equations (ODEs) and algebraic equations (AEs). The obtained equations are solved using finite difference method with the approximations $0(h^4)$ and $0(h^2)$ (in respect to the spatial coordinates). The ODEs are solved using the Runge–Kutta fourth order method, whereas the AEs are solved using either the Gauss or relaxation methods. The analysis and identification of spatio-temporal oscillations are carried out by investigation of the series $w(t), w(t), \text{phase portraits } w(t), w(t) \text{ and the mode portraits in the planes } w(t), w(t) \text{ and in the space } w(t), w(t) \text{ and in the space } w(t), w(t) \text{ as well as the Poincare sections and pseudo-sections.}

References listed at the end of the paper:


ABSTRACT: The nonlinear dynamics of a two-degree-of-freedom mechanical system is considered. This system consists of a linear oscillator under the action of a time-periodic force and a snap-through truss, which acts as an absorber of the forced oscillations of the linear main system. The forced oscillations of the snap-

ABSTRACT: In this work complex vibration of flexible elastic shells subjected to transversal and sign changeable local load in the frame of non-linear classical theory are studied. A transition from partial to ordinary differential equations is carried out using the higher order Bubnov-Galerkin approach. Numerical analysis is performed applying theoretical background of nonlinear dynamics and qualitative theory of differential equations. Mainly the so called Sharkovskiy’s periodicity is studied.

References listed at the end of the paper:


ABSTRACT: Determination of the chaos onset in some mechanical systems with several equilibrium positions are analyzed. Namely, the snap-through truss and the oscillator with a nonlinear dissipation force, under the external periodical excitation, are considered. Two approaches are used for the chaos onset determination. First,
Pade and quasi-Pade approximants are used to construct closed homoclinic trajectories for a case of small dissipation. Convergence condition used earlier in the theory of nonlinear normal vibration modes as well conditions at infinity make possible to evaluate initial amplitude values for the trajectories with admissible precision. Mutual instability of phase trajectories is used as criterion of chaotic behavior in nonlinear systems for a case of not small dissipation. The numerical realization of the Lyapunov stability definition gives us a possibility to observe a process of appearance and fast enlargement of the chaotic behavior regions if some selected parameters of the dynamical systems under consideration are changing.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: A closed cylindrical shell with circular cross-section having constant stiffness and density and subjected to sign changeable loading and embedded into a temperature field is analyzed. Both Bubnov-Galerkin (with a higher approximation) and Fourier methods are applied to solve the derived nonlinear nondimensional partial differential equations. Among others, the novel scenario of transition from shell harmonic to chaotic vibrations via the collapse of quasi-periodic vibrations with one independent frequency and Hopf bifurcation is detected, illustrated and discussed. In addition, it is shown how for various intensities of the temperature field (including its absence) the increase of the loading yields qualitative changes in the investigated shell dynamics, and how chaotic zones are transmitted into periodic ones and vice versa.

A.V. Krysko, M.V. Zhigalov and V.V. Soldatov (Saratov State Technical University, Saratov, Russia),
“Analysis of chaotic vibrations for the distributed systems in the form of the Bernoulli-Euler beams using the wavelet transform”, in: Structural Mechanics and Strength of Flight Vehicles, ISSN 1068-7998, Russian Aeronautics (Izv. VUZ) Vol. 52, No. 4, pp 399-407, 2009
DOI: 10.3103/S1068799809040059

ABSTRACT: A problem on chaotic vibrations of the Bernoulli–Euler beams is formulated. The wavelet transform was first applied to investigate the complex beam vibrations. The validity of results is provided by using two methods of solution, namely, the finite element method and finite difference method.

INTRODUCTION: The Fourier analysis, that is, the analysis based on the fast Fourier transform, is one of the most spread for investigating the chaotic dynamics of different physical nature. Its application for the distributed mechanical systems such as beams, plates, and shells is discussed in [1–8]. In addition, at present, the signal analysis based on the wavelet transform is rapidly progressing. In this paper, we demonstrate the advantage of this line that permits studying the processes of time variation in the vibration character on the basis of a frequency-time spectrum.

References listed at the end of the paper:


ABSTRACT: In this work regular and chaotic dynamics of cylindrical elastic and isotropic panels is studied. Geometrical nonlinearities are introduced following the Kármán hypothesis. A solution to PDEs is reduced to that of the corresponding ODEs via the second order Bubnov-Galerkin approach. A problem of approximation of the studied continuous system by a lumped one is discussed. It is shown that first order rough approximation reduces the problem to that of the Duffing equation analysis. Influence of the higher modes on the panel dynamics is studied. Scenarios of transition from regular to chaotic dynamics are detected and illustrated. The so-called vibration type charts of the cylindrical panels supported on the flexible and non-stretched in a tangent plane ribs versus geometrical and external excitation parameters are constructed and analyzed.

References listed at the end of the paper:

V.A. Krysko (1), M. Zhigalov (1), V. Soldatov (1), S. Mitskevitch (1), E.S. Kuznetsova (1) and K.F. Shagivaleev (1), J. Awrejcewicz (2) and J. Mrozowski (2)

INTRODUCTION: One of the challenging directions of the continual system chaotic dynamics investigations is that of plates and shells dissipative dynamics, and in particular detection of the scenarios leading to chaos in those systems plays a crucial role both in theory and applications. Almost in all studied so far cases, the infinite dimensional objects (plates and shells) are modeled as one- and/or two-degree-of-freedom systems. In contrary, here we deal with the infinitely dimensional problem, which is solved by qualitatively different numerical approaches including the Bubnov-Galerkin method (BGM) and the Rita method (RM) in higher approximations as well as the Finite Difference Method (FDM) with various space coordinates partition. This approach will validate both suitability of the numerical algorithms as well allows to trace scenarios leading to chaos in continual mechanical systems.


SUMMARY: Non-linear dynamics of flexible rectangular plates subjected to external shear-harmonic load action is investigated. It is shown that the application of the classical and widely used Fourier analysis does not allow us to obtain a real picture of the frequency vibration characteristics in every time instant. On the other hand, the application of the wavelets approach enables us to follow frequency time evolutions. Our numerical results indicate that vibrations in different plate points occur with the same frequencies set although their power is different. Hence, the vibration characteristics can be represented by one arbitrarily taken plate point. Scenarios of transitions from regular to chaotic dynamics are illustrated and discussed including two novel scenarios not reported so far in the existing literature.

References listed at the end of the paper:

ABSTRACT: In the first part of the paper we propose a novel method devoted to the estimation of Lyapunov exponents using neural networks. In the referenced earlier attempts many approaches and algorithms have been proposed to compute the Lyapunov exponents, but in general almost all of them apply the algorithm proposed already by Benettin [1]. However, while studying non-linear dynamics of structural members (beams, plates and shells) it is of great importance to estimate the spectrum of Lyapunov exponents in an efficient way. This paper part addresses this problem. In the second paper part we illustrate and discuss the application of various types of wavelets to study non-linear dynamics of shells. The obtained PDEs are reduced to ODEs using the Finite Difference Method, which then are solved using the fourth-order Runge-Kutta method. In addition, the classical Fourier analysis versus the wavelet analysis is discussed.

References listed at the end of the paper:


ABSTRACT: In the first paper part we study the mathematical model of a two-layer cylindrical shell (with clearance between both shells) having constant stiffness and density and subjected to a periodic transversal load action. The derived mathematical model allows us to study non-linear dynamics of both structural members with regard to external load and internal interaction between the two layers, as well as the force action coming from the inside of the second cylinder. The developed mathematical model includes geometric non-linearity of both cylinders and their contact interactions. Differential equations governing the dynamics of both shells are solved by the Bubnov-Galerkin higher order approximation method, whereas the obtained Cauchy problem is solved using the fourth order Runge-Kutta method. Convergence of the Bubnov-Galerkin method versus the number of approximating series terms is considered. Namely, we solve the problem of two embedded cylindrical shells including their interaction as systems with an infinite number of degrees of freedom. In the second paper part chaotic dynamics of continuous multi-layer structural members in the form of flexible shallow spherical panels is analyzed. The PDEs governing panels dynamics are reduced to the Cauchy problem through the FDM (Finite Difference Method) of the second accuracy order, and then the ODEs obtained are analyzed via the fourth-order Runge-Kutta method. A novel scenario of transition from regular to chaotic panel dynamics is reported and illustrated. We develop approaches to detect and monitor spatial chaos, and then we illustrate how both timing and spatial chaos appears simultaneously. We show also how the two-layer structural member exhibits non-symmetric chaotic vibrations, which after transition into windows with periodic dynamics exhibit again symmetric vibrations.

References listed at the end of the paper:
thickness as well as magnitude of the gap between layers is investigated and reported. Studied multi
transition from regular to chaotic vibrations. We quantify regular and chaotic vibrations via signs estimation of the Lyapunov exponents. Different scenarios of
the efficiency of different wavelets is illustrated and discussed. Furthermore, we propose a novel approach to
modal portraits, Poincarè maps, autocorrelation functions, Fourier spectra as well as wavelets. In the latter case
the efficiency of different wavelets is illustrated and discussed. Furthermore, we propose a novel approach to
quantify regular and chaotic vibrations via signs estimation of the Lyapunov exponents. Different scenarios of
transition from regular to chaotic dynamics exhibited by the studied objects for the mentioned types of non-
linearity are illustrated and discussed. We show how the non-linearity type leads to a dramatic change of the
transition from regular to chaotic vibrations. In addition, the influence on the non-linear vibrations of the
studied multi-layer continuous systems of the non-linearity type, layer number, boundary conditions, layer
thickness as well as magnitude of the gap between layers is investigated and reported.

References listed at the end of the paper:


ABSTRACT: We study the interaction of multi-layer packets consisting of beams, plates and shells, where there are gaps between the mentioned structural members. The proposed mathematical model takes into account various types of non-linearity: (i) geometrical (in the Kármán form); (ii) physical (layer material properties depend on the space co-ordinates, deformation intensity and time); (iii) design (it either switches on or off a contact between layers). Physical properties of the material can be different. The governing partial differential equations, boundary and initial conditions are obtained using Hamilton’s variation principle. The so far obtained boundary value problem is then reduced to the Cauchy problem by the following methods: FDM (Finite Difference Method) and the hybrid method matching FEM (Finite Element Method) and the Bubnov-Galerkin method with high order approximations. The obtained initial value problem is solved using the 4th, 6th and 8th Runge-Kutta techniques. It will be shown that those approaches are necessary to get the reliable results of our problem exhibiting strong non-linearity effects and chaotic vibrations. It should be emphasized that the obtained results are studied for all engineering required intervals of changes of the input load parameters, i.e. its amplitude and frequency (charts of vibration-type are constructed). Each output signal is analyzed via phase and modal portraits, Poincarè maps, auto-correlation functions, Fourier spectra as well as wavelets. In the latter case the efficiency of different wavelets is illustrated and discussed. Furthermore, we propose a novel approach to quantify regular and chaotic vibrations via signs estimation of the Lyapunov exponents. Different scenarios of transition from regular to chaotic dynamics exhibited by the studied objects for the mentioned types of non-linearity are illustrated and discussed. We show how the non-linearity type leads to a dramatic change of the transition from regular to chaotic vibrations. In addition, the influence on the non-linear vibrations of the studied multi-layer continuous systems of the non-linearity type, layer number, boundary conditions, layer thickness as well as magnitude of the gap between layers is investigated and reported.
References listed at the end of the paper:


ABSTRACT: In this paper chaotic vibrations of flexible plates of in finite length are studied. The Kirchhoff Love hypotheses are used to derive the nondimensional partial differential equations governing the plate dynamics. The finite difference method (FDM) and finite element method (FEM) are applied to validate the numerical results. The numerical analysis includes both standard (time histories, fast Fourier Transform, phase portraits, Poincaré sections, Lyapunov exponents) as well as wavelet-based approaches. The latter one includes the so called Gauss 1, Gauss 8, Mexican Hat and Morlet wavelets. In particular, various plate dynamical regimes including the periodic, quasi-periodic, sub-harmonic, chaotic vibrations as well as bifurcations of the plate are illustrated and studied. In addition, the convergence of numerical results obtained via different wavelets is analyzed.

References listed at the end of the paper:
4 W. Zhang, S. Song and M. Ye, Further studies on nonlinear oscillations and chaos of a symmetric cross-ply laminated thin plate

https://www.researchgate.net/publication/269108970
ABSTRACT: Chaotic vibrations of rectangular spherical shells subjected to the action of periodic load have been rarely analyzed. This work extends investigations initiated in the works by Awrejcewicz et al. [1-3].

References listed at the end of the paper:
Usually the data provided by numerical experiments are presented in time domain. In other words, we take time as an independent co-ordinate, and amplitude as a dependent co-ordinate, and the studied signal as analyzed through its amplitude-time representation. However, in order to understand deeply non-linear continuous systems subjected to various types of load actions and in order to fully understand the occurring dynamics, we have to apply the information hidden in the spectral signal characteristics. The Fourier transformation has been applied for a long time. However, it has been demonstrated recently that the Fourier analysis (FFT) is reliable only for the study of frequency components of stationary processes, i.e. the processes which through the whole period of investigation keep constant frequency components in time. It happens that in particular the dynamics of continuous mechanical systems may exhibit quite complicated output, and their frequency characteristics may change strongly in time. This is why in spite of the standard Fourier approach the wavelet analysis is applied allowing us to detect and understand many interesting non-linear phenomena of the mentioned mechanical systems.

Chaotic dynamics of structural members has been investigated by many researchers [1-10]. In this work we propose a novel approach to study non-linear vibrations of a plate based on the neural network approach and we analyze dynamics of flexible shells with constant stiffness and density subjected to harmonic load action. In the latter case mathematical model is built on the Kirchhoff-Love hypothesis and taking into account non-linear relation between deformation and displacement in the von Kármán form. This approach yields a system of non-linear PDEs regarding the deflection function and stresses (Airy’s function) as well as the system of equations regarding displacements [11]. We use further FDM with approximation $O(h^2)$ and BGM in higher approximations, which allows to study the system with infinite numbers of degrees of freedom without any truncation of the obtained system of ODEs, which is solved via the fourth-order Runge-Kutta method.

References listed at the end of the paper:


ABSTRACT: The aim of this chapter is to present a study of periodic and chaotic dynamics of plates and shells and weak turbulent behavior exhibited by these solid structural members modeled as 2D infinite objects. Besides the new results obtained with respect to the transition from a regular to weak turbulent and weak hyper turbulent behavior, we also present novel methods and approaches to get reliable and validated results of
numerical analysis of nonlinear partial differential equations. In particular, besides the standard numerical techniques for chaos monitoring, new effective approaches are presented and applied including the wavelet-based analysis, charts of vibration regimes, computation of the spectra of Lyapunov exponents via generalization of the classical Benettin’s approach, and application of the neural network technique. This common strategy aimed at numerical computations through various types of robust discretization allowed us to obtain novel scenarios of transition from regular/laminar (periodic, quasiperiodic) to spatiotemporal chaotic (weak turbulent) dynamics of flexible shells either parametrically excited (Sect. 2) or through the periodic shear load action in the shell volume unit (Sect. 3), flexible multilayer rectangular (Sect. 4) and cylindrical shells with gaps (Sect. 5), as well as a flexible plate of infinite length (Sect. 6).

References listed at the end of the paper:
16 Kornichin, M.S.: Non-Linear Problems of the Theory Plates and Shallow Shells and Methods of Their Solutions. Nauka, Moscow (1964) (in Russian)

ABSTRACT: Vibrations of flexible cylindrical and sector shells subjected to the action of uniformly distributed static loads are studied. The analyzed problems are solved using two methods: the Bubnov–Galerkin method (BGM) and the finite difference method (FDM). Validity and reliability of the results is verified through a comparison to the results obtained by Andreev et al. (Stability of Shells Under Non-Symmetric Deformation. Nauka, Moscow, 1988) in the case of a nonlinear static problem.

References listed at the end of the paper:


ABSTRACT: In this work a mathematical model of chaotic vibrations of flexible curvilinear Euler-Bernoulli beams embedded into temperature and electric fields is proposed. In particular, the influence of the curvature parameter k_\alpha on the vibration beam regimes under the action of transversal harmonic load is investigated. First, charts associated with the signs of the Lyapunov exponents versus two control parameters \{q_0, w_p\}, where \(q_0\) , \(w_p\) is the amplitude and the frequency of harmonic excitation, respectively, are constructed. Dynamic regimes and transitions of chaos-hyperchaos (two positive Lyapunov exponents), hyper-hyperchaos (three positive Lyapunov exponents), and deep chaos (four positive Lyapunov exponents) are reported. Second, different charts of the vibration character estimation are compared with each other showing remarkable coincidence. Finally, it has been shown that the electric field applied to both sides of the straight line beam negligibly influences chaotic vibrations of the studied beam.

References listed at the end of the paper:
ABSTRACT: We investigate chaotic vibrations of flexible spherical rectangular shells loaded harmonically and explain the phenomenon of transition from symmetric to asymmetric vibrations. Vibration-type charts are given regarding two control parameters: amplitude $q_0$ and frequency $\omega_p$ of the uniformly distributed periodic excitation. Furthermore, we detected and illustrated how the so called temporal–space chaos is developed following the transition from regular to chaotic system dynamics.


ABSTRACT: We investigate chaotic vibrations of flexible spherical rectangular shells loaded harmonically via the boundary conditions. In the first part of the paper we consider one-layer shell made from an isotropic and homogeneous material. The second part addresses non-linear dynamics of multi-layer shells, taking into account gaps between the layers (design non-linearity). Contact pressure between the layers was explicitly defined. Phase portraits, Fourier power spectra and wavelet spectra were constructed and investigated. In addition, an appropriate choice of the wavelets suitable to study the state transitions listed at the end of the paper: [1] Sethna P.R. Yang, X.L. Local and global bifurcations in parametrically excited vibrations of nearly square plates. International Journal of Nonlinear Mechanics, 26:199-220, 1991.
[30] Pikoovsky A.S. Rosenblum M.G. Kurths J. Osipov, G.V. Phase synchronization effects in a lattice of nonidentical r

J. Awrejcewicz, E.Yu. Krylova, I.V. Papkova and V.A. Krysko, “Regular and chaotic dynamics of flexible plates”, Shock and Vibration, Vol. 2014, Article ID 937967, 8 pages, http://dx.doi.org/10.1155/2014/937967 ABSTRACT: Nonlinear dynamics of flexible rectangular plates subjected to the action of longitudinal and time periodic load distributed on the plate perimeter is investigated. Applying both the classical Fourier and wavelet analysis we illustrate three different Feigenbaum type scenarios of transition from a regular to chaotic dynamics. We show that the system vibrations change with respect not only to the change of control parameters, but also to all fixed parameters (system dynamics changes when the independent variable, time, increases). In addition, we show that chaotic dynamics may appear also after the second Hopf bifurcation. Curves of equal deflections (isoclines) lose their previous symmetry while transiting into chaotic vibrations.

References listed at the end of the paper:

ABSTRACT: We present chaotic dynamics of flexible curvilinear shallow Euler–Bernoulli beams. The continuous problem is reduced to the Cauchy problem by the finite-difference method of the second-order accuracy and finite element method (FEM). The Cauchy problem is solved through the fourth- and sixth-order Runge–Kutta methods with respect to time. This preserves reliability of the obtained results. Non-linear dynamics is investigated with the help of a qualitative theory of differential equations. Frequency power spectra using fast Fourier transform, phase and modal portraits, autocorrelation functions, spatiotemporal dynamics of the beam, 2D and 3D Morlet wavelets, and Poincaré sections are constructed. Four first Lyapunov exponents are estimated using the Wolf algorithm. Transitions from regular to chaotic dynamics are detected, illustrated and discussed. Depending on signs of four Lyapunov exponents the chaotic, hyper chaotic, hyper-hyper chaotic, and deep chaotic dynamics is reported. Curvilinear beams are treated as systems with an infinite number of degrees of freedom. Charts of vibration character, elastic–plastic deformations, and stability loss zone versus control parameters of the studied beams are reported.

References listed at the end of the paper:


References listed at the end of the paper:

References listed at the end of the paper:

The aim of the paper was to analyze the given nonlinear problem by different methods of computation of the Lyapunov exponents (Wolf method, Rosenstein method, Kantz method, the method based on the modification of a neural network, and the synchronization method) for the classical problems governed by differential equations (Hénon map, hyperchaotic Hénon map, logistic map, Rössler attractor, Lorenz attractor) and with the use of both Fourier spectra and Gauss wavelets. It has been shown that a modification of the neural network method makes it possible to compute a spectrum of Lyapunov exponents, and then to detect a transition of the system regular dynamics into chaos, hyperchaos, and others. The aim of the comparison was to evaluate the considered algorithms, study their convergence, and also identify the most suitable algorithms for specific system types and objectives. Moreover, an algorithm of calculation of the spectrum of Lyapunov exponents based on a trained neural network has been proposed. It has been proven that the developed method yields good results for different types of systems and does not require a priori knowledge of the system equations.
References listed at the end of the paper:


ABSTRACT: Parametric non-linear vibrations of flexible cylindrical panels subjected to additive white noise are studied. The governing Marguerre equations are investigated using the finite difference method (FDM) of the second-order accuracy and the Runge-Kutta method. The considered mechanical structural member is treated as a system of many/infinite number of degrees of freedom (DoF). The dependence of chaotic vibrations on the number of DoFs is investigated. Reliability of results is guaranteed by comparing the results obtained.
using two qualitatively different methods to reduce the problem of PDEs (partial differential equations) to ODEs (ordinary differential equations), i.e. the Faedo-Galerkin method in higher approximations and the 4th and 6th order FDM. The Cauchy problem obtained by the FDM is eventually solved using the 4th-order Runge-Kutta methods. The numerical experiment yielded, for a certain set of parameters, the non-symmetric vibration modes/ forms with and without white noise. In particular, it has been illustrated and discussed that action of white noise on chaotic vibrations implies quasi-periodicity, whereas the previously non-symmetric vibration modes are closer to symmetric ones.

References listed at the end of the paper:

The difference between vibrations of a circular and an elliptic plate is the following. For a circular plate a
Dynam. 87 (2017) 1721e1730.
[37] N. van de Wouw, A. de Kraker, D.H. van Campen, H. Nijmeijer, Non-linear dynamics of a stochastically excited beam system
(2014) e18.
periodic and white noise excitations, in: I. Dimov, I. Farago, L. Vulkov (Eds.), Numer. Anal. Its Appl. 6th Int. Conf. NAA 2016,
[41] A.V. Krysko, J. Awrejcewicz, I.V. Papkova, O. Szymanowska, V.A. Krysko, Principal component analysis in the nonlinear
(2017) e19.
[42] V.Z. Vlasov, General Theory for Shells and its Application in Engineering, National Aeronautics and Space Administration,
1964.
Bernoulli beams, Chaos 23 (2013) 043130.

===== Some papers not included in Part 1 from sources other than those listed in Part 1 =====

A.L. Smirnov and E.A. Dolgova (Saint Petersurg State University, Russia), “Vibrational spectra of thin elliptic plates”, ICMAMS 2018, First International Conference on Mechanics of Advanced Materials and Structures, Turin, June 17-20, 2018
ABSTRACT: Thin plates of different shapes are used as structural components in almost all engineering
applications, where high strength, stiffness and light weight materials are highly needed. The aim of this
research is to study free transverse vibrations of an elliptic thin plate with a varying eccentricity and a plate with
an elliptic cutout with the same eccentricity. Plates of such shape are widely used not only in engineering but
also in biomechanical modeling. For example, for all human eyes the Lamina Cribrosa (anatomical structure)
appears as an elliptical plate with multiple holes.
Both analytical and numerical methods are used to examine the problem. The analytical solution is represented
as a combination of Mathieu functions. For plates with small eccentricity and/or small central elliptic cutout
asymptotic methods are used to describe the effect of the eccentricity and cutout on the vibrational spectra.
The difference between vibrations of a circular and an elliptic plate is the following. For a circular plate a
vibrational mode can be expressed by one particular solution of the differential equation governing vibrations,
for an elliptic plate all appropriate particular solutions should be summed up to express even one vibrational
mode. One should remember it when consider the perturbation of the vibrational spectrum of a circular shell
with non-zero eccentricity.
For elliptic plates of constant thickness and mass the effect of the eccentricity is the following: i) all frequencies
increase with the eccentricity, but with different rate, ii) double frequencies of non-axisymmetric vibrations of a
circular plate split into two, the lower frequency corresponds to the mode stretched along the long semi-axis, the
effect on the frequencies for small values of the axis ratio (up to 1:2) is linear with the high accuracy, iii) lower
frequencies go up with the eccentricity faster, as a result for some values of the eccentricity the mode order
Changes.
Frequencies and modes were also found by finite element method using the package ANSYS 18.1. The results were compared with those obtained by other authors who used Rayleigh-Ritz and other numerical methods.

--- End of some papers not included in Part 1 from sources other than those listed in Part 1

More papers published in the journal, Thin-Walled Structures (2019 and on):
Google “thin-walled structures”; click on “thin-walled structures | ScienceDirect.com”; click on “All issues”


ABSTRACT: A series of tests was conducted to investigate the web crippling behaviour of cold-formed lean duplex stainless steel (LDSS) tubular sections. The LDSS had two grades, including EN 1.4062 and EN 1.4162. The tests were performed under three different conditions of concentrated end bearing loads, namely, the loading conditions of End-One-Flange (EOF), the End-Two-Flange (ETF) and end loading (EL). The loading conditions of EOF and ETF are specified in the American and Australian/New Zealand cold-formed stainless steel design specifications, while the loading condition of EL simulated the floor joist members positioned on a solid foundation under concentrated end bearing load. The test specimens were mainly failed by web crippling. The test strengths were compared with the predicted strengths that calculated by the stainless steel design specifications, including the American Society of Civil Engineers (ASCE) Specification, Australian/New Zealand Standard (AS/NZS) and European Code (EC). In addition, the web crippling strengths predicted by the North American Specification (NAS) for cold-formed carbon steel structures and using the design equations proposed in the literature for cold-formed duplex stainless steel tubular sections were also compared with the test strengths. It was found that the predicted strengths calculated by the ASCE, AS/NZS and EC specifications are conservative and reliable for LDSS sections under the three different concentrated end bearing loads. The predictions by NAS and proposed equations in the literature are generally less conservative compared with those by ASCE, AS/NZS and EC. However, the predictions by NAS are found to be unconservative and not reliable for the loading condition of ETF.


ABSTRACT: Multi-cell concrete-filled steel tubular (CFST) column is a type of composite members developing from conventional CFST columns. Featuring greater cross-sectional dimensions and the use of internal webs to separate inner concrete into smaller isolated cells, multi-cell CFST columns have been used in super high-rise buildings recently as the main vertical load bearing members. However, existing research on CFST members is mainly focused on conventional single-cell CFST members. To fill this research gap, this paper numerically investigates the mechanical performance of hexagonal multi-cell CFST stub columns under axial compression. A finite element analysis (FEA) model was initially established to simulate the mechanical performance of hexagonal multi-cell CFST columns. The FEA model was validated against existing experimental data. The mechanical performance of the multi-cell CFST columns were analysed, including the full-range load versus deformation relationships, the stress distributions of the main components and the distribution of contact stress on each concrete cell. A parametric study was then conducted to investigate the sensitivity of various geometric and material parameters on the compressive behaviour of multi-cell CFST columns. Finally, analytical formulae were derived to predict the axial compressive ultimate strength of hexagonal multi-cell CFST columns. The methods were found to be acceptable with reasonably good accuracy.

References listed at the end of the paper:
ABSTRACT: The following paper presents a Finite Element formulation based on the Generalized Beam Theory (GBT), to analyse the buckling behaviour of isotropic conical shells under various loading and boundary conditions. The formulation offers the solution of the 1st order analysis from which the pre-buckling stresses are computed, including stress concentrations, and the linear (bifurcation) buckling solution. Due to the variable cross-section of conical shells, the mechanical and geometrical properties are no longer constant along the bar’s axis as they are in the case of cylindrical structures and thin-walled prismatic bars. Special focus is given to the effect of the pre-buckling stress concentrations and non-conventional cross-section deformation modes. The proposed formulation is validated by comparing results obtained from GBT and Shell Finite Element Analyses.

References listed at the end of the paper:
1 R. Lorenz, Achsensymmetrische verzerrungen in dünnwandigen hohlzyllindern, Z. Ver. Dtsch. Ing., 52 (43) (1908), pp. 1706-1713
5 V.V. Novozhilov, Foundations of the Nonlinear Theory of Elasticity, Graylock Press, Rochester, NY, USA (1953) (now available from Dover, NY, USA)
17 T.G. Ghazijahani, T. Zirakian, Determination of buckling loads of conical shells using extrapolation techniques, Thin-Walled Struct., 74 (2014), pp. 292-299
23 N. Silvestre, Generalised beam theory to analyse the buckling behaviour of circular cylindrical shells and tubes, Thin-Walled Struct., 45 (2) (2007), pp. 185-198
25 M. Nedelcu, GBT formulation to analyse the buckling behaviour of isotropic conical shells, Thin-Walled Struct., 49 (7) (2011), pp. 812-818
26 M. Nedelcu, GBT formulation to analyse the behaviour of thin-walled members with variable cross-section, Thin-Walled Struct., 48 (8) (2010), pp. 629-638
28 MATLAB, version 7.10.0 (R2010a), The MathWorks Inc., Massachusetts, 2010.
30 R. Bebiano, N. Silvestre, D. Camotim, GBT formulation to analyse the buckling behaviour of Thin-walled members subjected to non-uniform bending, Struct. Stab. Dyn., 7 (1) (2007), pp. 23-54

ABSTRACT: In recent years, hierarchical structures were popularly investigated due to its significant promotion on structural strength and stiffness. In this study, the concept of vertex-based hierarchy is incorporated into multi-cell square tubes by replacing every vertex with miniature cell itself. Mechanical performance of vertex-based hierarchical vs. square thin-walled multi-cell structure were conducted theoretically and numerically, mainly in terms of total energy absorption (TEA), crush force efficient (CFE) and fluctuation degree. A static theoretical model was constructed for vertex-based structures based on classic angle-fold element. The equation of half-wave length as well as the mean force in each fold was constructed based on the Minimal Energy Principle. Then, detailed numerical simulations were carried out by means of explicit dynamic finite element method. Based on these, further parametric studies with different scale ratios were performed and the influence of geometric configuration was determined. In addition, the explanations for promotion have been given. As the results confirmed that comparing with the conventional multi-cell structure, the vertex-based hierarchical one can evidently improve the folding response with stable compression history. The scale ratio significantly influences the specific mean force. The wall thickness shows more sensitivity on mechanical performances. All these achievements pave a way of designing novel thin-walled and light-weight energy absorption device.

References listed at the end of the paper:
1 J. Li, G. Gao, H. Dong, et al., Study on the energy absorption of the expanding--splitting circular tube by experimental investigations and numerical simulations, Thin-Walled Struct., 103 (2016), pp. 105-114
3 X. Zhang, Z. Wen, H. Zhang, Axial crushing and optimal design of square tubes with graded thickness, Thin-Walled Struct., 84 (2014), pp. 263-274
8 Y. Yu, G. Gao, H. Dong, W. Guan, J. Li, A numerical study on the energy absorption of a bending-straightening energy absorber with large stroke, Thin-Walled Struct., 122 (2018), pp. 30-41

ABSTRACT: Material properties, residual stress distributions and cross-sectional behavior of cold-formed steel elliptical hollow sections are investigated in this study. Four cross-section series with the nominal section aspect ratio ranging from 1.65 to 3 were included in the experimental investigation. The material properties for each cross-section series and material properties distribution on half of the cross-section profile of a representative section were measured through tensile coupon tests. The distributions of bending and membrane residual stresses in both longitudinal and transverse directions were measured on the half-section profile of the same representative section. Initial local geometric imperfections were measured on five stub column specimens. Besides, stub column tests were conducted between fixed ends to ascertain the material properties of the complete cross-section in the cold-worked state as well as to study the structural behavior of cold-formed steel elliptical hollow section stub columns. In addition to experimental investigation, a finite element model was developed and verified against the test results, with which an extensive parametric study covering a broad range of cross-section geometries was carried out. Currently, there is no codified design rule for elliptical hollow section compression members. The stub column strengths obtained from experimental program and numerical analysis were only compared with the predicted strengths by the equivalent diameter method and equivalent rectangular hollow section approach proposed by previous researchers for design of hot-finished steel elliptical hollow sections, the existing traditional design rules originally developed for circular hollow section with equivalent diameter incorporated as well as the Direct Strength Method and the Continuous Strength Method that the equations were not calibrated for cold-formed steel elliptical hollow sections. The comparisons show that the Direct Strength Method offers the most accurate and reliable design strength predictions among the existing design methods, but further improvement remains possible. In this study, modifications on the Direct Strength Method and the Continuous Strength Method are proposed, which are shown to improve the accuracy of the design strength predictions.

References listed at the end of the paper:

6 L. Gardner, T.M. Chan, Cross-section classification of elliptical hollow sections, Steel Compos. Struct., 7 (3) (2007), pp. 185-200

ABSTRACT: This paper presents a method to calculate modal displacement, stress, and strain energy participation in shell finite-element eigen-buckling solutions of thin-walled structural members using Generalized Beam Theory (GBT). The method provides quantitative information that can be used to interpret coupled buckling in structural designs. A finite-element (FE) eigen buckling solution is transformed to a GBT solution, and equivalent GBT modal amplitudes representing the FE solution are retrieved. The modal displacement field, stress tensor and strain energy are retrieved using GBT modal amplitude field and applying GBT constitutive relationships between strain and stress. Theory and examples are provided.

References listed at the end of the paper:


(http://www.worldscientific.com/doi/10.1142/S0219455403001002)

(http://www.sciencedirect.com/science/article/pii/S0965997806001992)

(ISSN 02638231, URL (http://linkinghub.elsevier.com/retrieve/pii/S026382311100231X))

(ISSN 02638231, URL (http://linkinghub.elsevier.com/retrieve/pii/S026382311000856))

(ISSN02638231, URL (http://linkinghub.elsevier.com/retrieve/pii/S0263823113000207))

9 M. Nedelcu, GBT-based buckling mode decomposition from finite element analysis of thin-walled members, Thin-Walled Struct., 54 (2012), pp. 156-163, 10.1016/j.tws.2012.02.009
(ISSN0263-8231, URL (http://www.sciencedirect.com/science/article/pii/S0263823112000390))
References listed at the end of the paper:

24 G. Hanswille, M. Bergmann, R. Bergmann, Design of composite columns with cross-sections not covered by Eurocode 4, Steel Constr., 10 (1) (2017), pp. 10-16
38 American Concrete Institute. Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary. MI, USA: Farmington Hills, 2014.
cracked homogeneous plates are performed and a comparison is presented between the present results, previously published ones, and those obtained from commercial finite element software. The proposed approach is further applied to analyze the buckling of Al/Al2O3 FGM rectangular plates with side cracks and skewed rhombic plates with central internal cracks while considering the effects of material distributions, plate thickness, skew angles, crack lengths, inclination angles and positions, boundary conditions, and loading conditions on the buckling loads of these plates.

References listed at the end of the paper:
1 M. Niino, S. Maeda, Recent development status of functionally gradient materials, ISIJ Int., 30 (1990), pp. 699-703
7 X.L. Chen, K.M. Liew, Buckling of rectangular functionally graded material plates subjected to nonlinearly distributed in-plane edge loads, Smart Mater. Struct., 13 (6) (2004), pp. 1430-1437
11 T. Yu, S. Yin, T.Q. Bui, C. Liu, N. Wattanasakulpong, Buckling isogeometric analysis of functionally graded ceramic-metal plates under combined thermal and mechanical loads, Compos. Struct., 162 (2017), pp. 54-69
14 B. Uymaz, M. Aydogdu, Three dimensional mechanical buckling of FG plates with general boundary conditions, Compos. Struct., 96 (2013), pp. 174-193
24 Y.V. Satish Kumar, J.K. Puik, Buckling analysis of cracked plates using hierarchical trigonometric functions, Thin-Walled Struct., 42 (2004), pp. 687-700
28 A.A. Rad, D. Panahandeh-Shahraki, Buckling of cracked functionally graded plates under tension, Thin-Walled Struct., 84 (2014), pp. 26-33

ABSTRACT: Structural design formulae for beam-columns require accurate end points (i.e. accurate resistance predictions for pure compression and pure bending), should be of suitable form to capture the interaction between the different components of loading and should take due account of the influence of a moment gradient along the member length. However, existing design rules for stainless steel beam-columns do not fully capture the interaction responses observed in experiments and numerical simulations, and are often tied to inaccurate end points; the adopted equivalent uniform moment factors can also be unconservative in the case of high moment gradients. As a consequence, previous comparisons of stainless steel beam-column experimental and finite element results with codified strength predictions have often revealed a rather high degree of scatter. This prompted the present research, to develop improved design proposals for stainless steel square hollow section (SHS) and rectangular hollow section (RHS) beam-columns under moment gradients. To this end, revised design approaches are proposed firstly through the derivation of more accurate design interaction curves for stainless steel SHS and RHS beam-columns under uniform bending moment and then through the employment of more suitable equivalent uniform moment factors, underpinned by and validated against over 1500 test and numerical data points. The new design approaches are shown to lead to improved (safe-sided, accurate and consistent) resistance predictions for stainless steel SHS and RHS beam-columns under moment gradients over the current codified design rules. Finally, statistical analyses are performed to demonstrate the reliability of the proposed approaches, according to the requirements specified in EN 1990.

References listed at the end of the paper:
9 A. Talja, P. Salmi, Design of stainless steel RHS beams, columns and beam-columns, Technical Research Centre of Finland, Finland (1995)
11 Y. Huang, B. Young, Experimental investigation of cold-formed lean duplex stainless steel beam-columns, Thin-Walled Struct., 76 (2014), pp. 105-117
Structures, 8 (2016), pp. 63-74

13 I. Arrayago, E. Real, E. Mirambell, Experimental study on ferritic stainless steel RHS and SHS beam-columns, Thin-Walled Struct., 100 (2016), pp. 93-104


27 SEI/ASCE 8-02. Specification for the design of cold-formed stainless steel structural members. Reston: American Society of Civil Engineers (ASCE); 2002.


33 O. Zhao, B. Rossi, L. Gardner, B. Young, Experimental and numerical studies of ferritic stainless steel tubular cross-sections under combined compression and bending, J. Struct. Eng. (ASCE), 142 (2) (2016), p. 04015110


42 H.N. Hill, Determination of stress–strain relations from offset yield strength values, (Technical note No 927) National advisory committee for aeronautics, Washington DC (1944)


47 B. Zheng, G. Shu, L. Xin, R. Yang, Q. Jiang, Study on the bending capacity of cold-formed stainless steel hollow sections, Structures, 8 (2016), pp. 63-74

ABSTRACT: A finite element formulation is developed to predict the lateral torsional buckling resistance of plane frames with moment connections. The solution focuses on the simple characterization the elastic warping behavior of moment connections in a manner that allows them to interface seamlessly with existing beam buckling finite elements, thus providing means for realistically modelling the lateral torsional buckling of plane frames. Special attention is devoted to the joint rotation effects. The technique successfully captures the interaction between beams and columns of frames, an effect that is neglected in present design methodologies based on individual member checks. The solution is shown to provide lateral torsional buckling resistance predictions in very good agreement with shell based finite element solutions at a fraction of the modelling and computational effort. For typical frames that are laterally supported at the joints, the study suggests that present design methodologies that isolate the member from the rest of the structure provide conservative buckling resistance predictions. Conversely, for frames with no lateral restraints at some of the joints, the present solution predicts lateral torsional buckling resistances that are significantly different from those based on design standard equations, suggesting the need to account for interaction effects in such situations

References listed at the end of the paper:

3 M.G. Salvadori, Stability of I-Beams under thrust and unequal end moments, Proceeding ASCE, 79(291) 1-25, 1953.
The effects of warping on the postbuckling behaviour of thin-walled structures have been studied extensively. It is shown that circular openings may be represented for analysis purposes as an equivalent rectangular web, which adds to the deflection of the solid web beam. The additional deflection is a function of the ratio of opening diameter, h, to section depth, d, and also of the spacing of the openings. This paper presents derived formulae for the additional deflection of beams with circular web openings that are expressed as a function of the pure bending deflection of the unperforated beam. The formulae are calibrated against finite element models and against short span beam tests with opening diameters, h, of 0.6 h and 0.72 h, in which the additional deflection is mainly due to the effects of shear. Further simplified design formulae for additional deflection are also presented which are shown to be accurate for C-section beams with a span: depth ratio exceeding 15. It is also shown that circular openings may be represented for analysis purposes as an equivalent rectangle of width x depth equal to 0.75 h × h.
References listed at the end of the paper:
2 R.J. Redwood, Design of Beams with Web Holes, Canadian Steel Industries Construction Council (1973)
19 Outokumpu Data sheet, LDX 2101, 2304, 2205-Duplex steels for structural hollow sections
21 A. Basta, Behaviour of Stainless Steel and Cold Formed Sections with Large Web Openings in Bending and Shear (Ph.D. Thesis), University of Surrey (2017)


ABSTRACT: Face-to-face built-up cold-formed steel channel sections are becoming increasingly popular for column members in cold-formed steel structures; its applications include cold-formed steel trusses, space frames and portal frames. In such an arrangement, the independent buckling of the members is resisted by intermediate fasteners. In the literature, no research is available for such face-to-face built-up cold-formed steel columns. The issue is addressed herein. This paper presents the results of 36 experimental tests, conducted on face-to-face built-up cold-formed steel channel-sections covering a wide range of slenderess from stub to slender columns. A nonlinear finite element model is then described that shows good agreement with the experimental results. The finite element model includes material non-linearity, initial imperfections and modelling of intermediate fasteners. Both finite element and experimental results are compared against the design strengths calculated in accordance with the American Iron and Steel Institute (AISI), Australian and New Zealand Standards (AS/NZS) and Eurocode (EN 1993-1-3). The verified finite element model is used for the purposes of a parametric study comprising 90 models. The effect of fastener spacing on the axial strength was investigated. From the results of experiments and finite element investigations, it is shown that the design in accordance with the AISI & AS/NZS and Eurocode (EN 1993-1-3) is generally conservative by around 15%, however, AISI & AS/NZS and Eurocode (EN 1993-1-3) can be un-conservative by 8% on average for face-to-face built-up columns failed through local buckling.

ABSTRACT: Metallic circular tube with external uniform grooves has excellent behaviors on axial crashworthiness during axial compression because it can generate stable responses. In the present research, three novel energy absorbers are proposed based on uniform grooved tube (UGT), namely, depth gradient grooved tube (D-GGT), thickness gradient grooved tube (T-GGT) and coupling gradient grooved tube (C-GGT). A theoretical model considering both the depth and thickness gradients and an efficient numerical model based on axisymmetric assumption are put forward. Meanwhile, some quasi-static compression experiments are performed to validate the theoretical and numerical models. The results conclude that the deformation of gradient grooved tubes (GGTs) under axial buckling can be classified into two modes, namely, random asymptotic buckling (RAB) and sequential asymptotic buckling (SAB). Compared with UGT, the D-GGT has a slight improvement on the axial energy performance even though the sum of depth of thin-walled sections is constant; for T-GGT, a force-displacement curve with upward trend and an obvious improvement of energy absorption are observed; specially, the energy absorption characteristics of D-GGT and T-GGT will occur simultaneously when C-GGT is subjected to axial loading.

References listed at the end of the paper:

7 S. Palanivelu, W.V. Paepengi, J. Degrieck, J. Vantomme, D. Kakogiannis, J.V. Ackeren, et al., Crushing and energy absorption performance of different geometrical shapes of small-scale glass/polyester composite tubes under quasi-static loading conditions, Compos Struct., 93 (2) (2011), pp. 992-1007
9 A. Athaprayangkul, B.G. Prusty, Experimental and numerical analysis on the geometrical parameters towards the maximum SEA of CFRP Components, Compos Struct., 164 (2017), pp. 229-236
14 A.A.A. Alghamdi, Collapsible impact energy absorbers: an overview, Thin-Walled Struct., 39 (2) (2001), pp. 189-213
ABSTRACT: The dynamic responses of large-span space structures are significantly associated with some higher structural frequency modes. A proper finite element model with accurate modal damping ratios is a key factor in obtaining precise structural seismic responses in numerical analyses. The complex damping model is often used in frequency domain structural analyses because of its characteristics of constant modal damping
ratio with frequency and frequency-independent energy dissipation. Based on the five-parameter integer-order derivative method, a user subroutine of ABAQUS is developed to estimate the complex damping model in time-domain dynamic analyses. A shaking table test of a scaled and simplified single-layer reticulated dome is first conducted to validate the user subroutine. Detailed test data, including the identified natural frequencies and modal damping ratios, free vibration curves, and representative maximum responses, are summarized and compared with the corresponding finite element results using the complex damping model and a Rayleigh damping model. The comparisons indicate that the results of the complex damping model can yield a better estimation of the test data. Finally, the effect of the complex damping on the seismic responses of a single-layer reticulated dome is systematically studied by comparing the structural frequency properties and dynamic characteristic responses with those of Rayleigh damping. The results show that the complex damping model provides smaller structural modal damping ratio variation, lower ultimate seismic loading, and severer structural plastic developments.

References listed at the end of the paper:
6 Y.G. Li, F. Fan, H.P. Hong, Effect of support flexibility on seismic responses of a reticulated dome under spatially correlated and coherent excitations, Thin-Walled Struct., 82 (2014), pp. 343-351
13 Y.G. Li, F. Fan, H.P. Hong, Influence of number of records and scaling on the statistics of seismic demand for lattice structure, Thin-Walled Struct., 87 (2015), pp. 115-126
ABSTRACT: The vibration and stability problems of functionally graded material (FGM) cylindrical shells subjected to external pressures with mixed boundary conditions (MBCs) using first order shear deformation theory (FOSDT) is studied. The governing equations of FGM cylindrical shells (FGMCs) are displayed according to the Donnell type shell theory and solved using the Galerkin's method. The novelty in this study is to obtain closed-form solutions of the eigen-value problem in mixed boundary conditions within the framework of the FOSDT. Finally, the effects of different volume fractions, FG profiles and shell characteristics on the critical parameters of FGMCSs with MBCs are studied in detail.

References listed at the end of the paper:

ABSTRACT: Understanding the characteristics of internal and external pressures on structures is important for structural design. This paper has experimentally observed internal and external pressures on long-span domes and investigated their non-Gaussian characteristics. Wind tunnel tests on internal and external pressure measurements for a single dome and two neighboring domes were performed. The distribution, non-Gaussian characteristics, and non-Gaussian peak factor of the internal and external wind pressure on the single dome were analyzed. After the results were validated, the distribution, non-Gaussian characteristics, and non-Gaussian peak factor of the internal and external wind pressure on the two neighboring domes under different wind attack angles (interference effect) were discussed. The results show that the characteristics of internal pressures on the single dome and the two neighboring domes are different from that of external pressures, and both the internal and external pressure show remarkable non-Gaussian characteristics. According to these characteristics, positive and negative areas of the internal and external pressure on the domes were defined, and the non-Gaussian peak factors were determined. This study has not only advanced our understanding on characteristics of internal and external pressure on long-span domes, but determined non-Gaussian peak factors that are used for structural design.

References listed at the end of the paper:
1 D. Yang, C. Yun, J. Wu, Y. Yao, Seismic response and failure mechanism of single-layer latticed domes with steel columns and braces as substructure, Thin-Walled Struct., 124 (2018), pp. 458-467
4 J. Blachut, Locally flattened or dented domes under external pressure, Thin-Walled Struct., 97 (2015), pp. 44-52
7 Y. Zhao, Y. Lin, Y.-b. Shen, Wind loads on large cylindrical open-topped tanks in group, Thin-Walled Struct., 78 (2014), pp. 108-120
ABSTRACT: This study presents a new fiber reinforced polymer tube/filling strengthening method (i.e., FRP tube/filling strengthening) that creates a new composite compression member with a novel mechanical behavior, “bilinear behavior.” Previous experimental and theoretical studies have been conducted based on the ultimate state of the section. To thoroughly study the stiffness and entire loading process of this novel member, finite element analysis (FEA) models are built in this paper. First, the model development process considers the initial deflections and interface properties, and these models are verified by the experimental results. Two models of typical load-axial displacement curves describe the experimental results: a Bilinear model and a Trilinear model. Second, finite element modeling (FEM) is used to conduct a parametrical analysis that considers 7 parameters, and the results identify the mechanism of the strengthened member. Specifically, the Bilinear model corresponds to an unreinforced or relatively weakly reinforced specimen, and the Trilinear model corresponds to a relatively strongly reinforced specimen. If the exterior restraint system is weak, then the core steel buckles and subsequently yields; this behavior is described by the Bilinear model. If the exterior restraint system is strong (e.g., the length or the bending stiffness of the exterior restraint system is great), then the specimen can continue to bear a higher force after steel yielding until elastic-plastic buckling occurs; this behavior is described by the Trilinear model. Third, the FEA results and previous experimental and theoretical studies are used to obtain the stiffness and load-axial displacement curves, which are helpful for the design process. In general, relatively accurate FEA models are built in this paper that are capable of describing the mechanical behaviors of the novel member.

References listed at the end of the paper:

2 P. Feng, Y.H. Zhang, Y. Bai, L.P. Ye, Strengthening of steel members in compression by mortar-filled FRP tubes, Thin-Walled Structures, 64 (2013), pp. 1-12
3 P. Feng, Y.H. Zhang, Y. Bai, L.P. Ye, Combination of bamboo filling and FRP wrapping to strengthen steel members in compression, J. Compos Constr., 17 (2013), pp. 347-356
9 A. Shaat, A.Z. Fam, Slender steel columns strengthened using high-modulus CFRP plates for buckling control, J. Compos Constr., 13 (2009), pp. 2-12
10 N. Silvestre, B. Young, D. Camotim, Non-linear behaviour and load-carrying capacity of CFRP-strengthened lipped channel steel columns, Eng. Struct., 30 (2008), pp. 2613-2630
25 Y. Zheng, Experimental and Theoretical Research on Fatigue Behavior of Steel Structures Strengthened with CFRP, Tsinghua University, Beijing (2007)


ABSTRACT: This paper presents experimental and numerical study on the behaviour of ultra-high strength steel (UHSS) hollow tubes under low velocity lateral impact loading. A total of six specimens were tested under lateral impact loading. The finite element (FÉ) model was established with the consideration of the strain rate effect and validated against test results. The parametric study showed that UHSS hollow tubes had the similar failure pattern when compared to that of normal strength steel members. The mid-span deflection and the residual deformation decreased significantly when the UHSS tube was applied.

References listed at the end of the paper:
3 AS 4100-1998 (R2016), Steel Structures, Standards Association of Australia, New South Wales (2016)
8 C.C. Roth, D. Mohr, Effect of strain rate on ductile fracture initiation in advanced high strength steel sheets: experiments and modeling, Int. J. Plast., 56 (2014), pp. 19-44
relations are obtained based on the

The FG cylindrical shell with internal and external spiral stiffeners is investigated. The strain material properties of the shell and

cylindrical shell

2019,

Habib Ahmadi and Kamran Foro

conditions

space domain by a method called Variational D

principle

nonlinearity
equations are written based on the

vibrations

ABSTRACT: In this article, a variational

Structures, Vol. 135, pp 12

magneto

R. Ansari, R. Gholami and H. Rouhi, “Geometrically nonlinear free vibration analysis of shear deformable


ABSTRACT: In this article, a variational numerical method is utilized to investigate the nonlinear free vibrations of magneto-electro-elastic (MEE) plates under thermal environment. To this end, first, the basic equations are written based on the first-order shear deformation theory and von Kármán's geometric nonlinearity. Next, the constitutive equations are represented in matrix form. In the context of Hamilton's principle, the quadratic and matricized form of energy functional is derived which is then directly discretized on space domain by a method called Variational Differential Quadrature (VDQ). Periodic time differential operators are also constructed for discretizing on time domain. The final solution is obtained by the pseudo arc-length continuation algorithm. The effects of applied electric voltage, applied magnetic potential, temperature change and geometrical parameters on the response curves of MEE plates with different types of boundary conditions are studied.


ABSTRACT: This paper studies a nonlinear primary resonance of spiral stiffened functionally graded (SSFG) cylindrical shell with viscous damping force. The cylindrical shell is subjected to the harmonic excitation. The material properties of the shell and stiffeners are assumed to be continuously graded in the thickness direction. The FG cylindrical shell with internal and external spiral stiffeners is investigated. The strain-displacement relations are obtained based on the von Kármán nonlinear equations and the classical plate theory of shells. The
smeared stiffener technique is used to model the under-studied SSFG cylindrical shell. The obtained partial differential equations of motion are discretized by means of the Galerkin method. In order to find the nonlinear primary resonance, the multiple scales method is adopted. The effects of various geometrical characteristics and material parameters on the nonlinear primary resonance response of spiral stiffened simply supported FG cylindrical shells are investigated.


ABSTRACT: The third-order shear deformation theory (TSDT) effects on the thick functionally graded material (FGM) plates with fully homogeneous equation under thermal vibration are investigated by using the generalized differential quadrature (GDQ) method. The nonlinear coefficient c1 term of displacement field of TSDT is used to derive the equations of motion for thermal vibration of thick FGM plates. The dynamic equilibrium differential equations with TSDT of FGM plates in terms of partial derivatives of displacements and shear rotations subjected to partial derivatives of thermal loads, mechanical loads and inertia terms are derived in matrix forms. Three parametric effects of varied-modified shear correction factor, environment temperature and FGM power law index on the thermal stress and center deflection of FGM thick plates with and without containing the nonlinear coefficient c1 term are investigated.


ABSTRACT: In this work, an appraisal of the influence of the residual stresses and geometric imperfections is carried out for thin-walled I-shaped sections covering both hot-rolled and welded profiles based on a numerical study using the Finite Element Method. The Eurocode 3 design provisions for local buckling are presented and evaluated in comparison to the numerical results. Several residual stress patterns and geometric imperfection’s amplitude and shape are considered to determine their effect on the ultimate strength of the cross-sections. Additionally, it is described a procedure to assess the flange and web interaction under different imperfection assumptions, and its influence investigated. The conclusions from this study are that the Eurocode 3 design provisions for hot-rolled sections are appropriate, but should be further improved for welded sections, mainly because the influence of the welded residual stresses is detrimental for the cross-section capacity and its effect is not to accounted for adequately. Finally, this study provides relevant information for the numerical modelling of thin-walled I-shaped sections concerning the consideration of geometrical imperfections and residual stresses.


ABSTRACT: This paper presents experimental and numerical studies on the effect of multi-stitching pattern on the energy absorption capability of composite tubular structures under impact loading. A new multi-stitching pattern was developed to study the increase of specific energy absorption capabilities in GFRP and CFRP crash absorbers. The stitching pattern on both specimens showed a significant increase in energy absorption capability under impact loading. According to our results, the specific energy absorption of GFRP and CFRP composite tubes are 17% and 18% higher than non-stitched specimens respectively. A multi-shell finite element model was constructed to predict the axial crushing behaviour and energy absorption capability of composite structures under impact loading. The method is based on an energy-based contact card modelling technique in the stitched and non-stitched area, and the initiation of main central crack growth occurs when the critical separation (PARAM function) is attained, and this represents the functionality of the stitched area during an impact event. The developed numerical approach is efficient in terms of accuracy and simplicity in comparison with the existing methods for multi-layered composites structures.

ABSTRACT: Increasing the development in industrial technology and need for energy absorption, lightweight and cost effective composite materials such as composite sandwich panels have been in the center of attention. In this paper energy absorption properties of proposed composite sandwich panels with different corrugated core geometries under quasi static out of plane loading conditions is experimentally investigated. Three different corrugated shapes, i.e. rectangular, trapezoidal and triangular fabricated with the same thickness are used. The specimens were subjected to three different quasi-static compression loading condition i.e. concentrated, linear and planar. The effect of the number of unit cells and corrugated core geometries in determining the overall deformation and local collapse behavior of the panels also investigated. Based on the comparative results, it is found that three unit cell rectangular corrugated geometry possessed the best performance than other types of corrugated core geometries. Moreover, through visual observation the damage mechanisms under loading conditions and subsequent failure modes are inspected. Plastic buckling of cell walls and foam densification identified as the initial failure modes and by continuing the loading, fiber breakage, localized delamination as well as debonding between the skins and the core were the main damage mechanisms in these corrugated systems.


ABSTRACT: In engineering, the bending deformations of thin-walled tubes mostly are under three-point loading. However, for the dual rectangle thin-walled tube (DRTWT), the theoretical prediction of the three-point bending collapse is still an unsolved problem. In this paper, the three-point bending collapse of the DRTWT is innovatively investigated using theoretical prediction and experimental verification. The global energy equilibrium theory is applied to derive the bending characteristic of the DRTWT. It is assumed that all the bending energy is absorbed and distributed along the hinge lines and in the toroidal surfaces during the bending collapse. The analytical results show good agreement with the experimental results. Finally, a simplified bumper structure of automobile is created by using beam elements and spring elements with the derived bending characteristics, which can effectively replace the detailed finite element model (FEM) to accelerate the crashworthiness design of automotive structure at the conceptual design stage.


ABSTRACT: Concrete-filled steel tubular (CFST) structures are extensively used in engineering applications in China owing to their high strength and section modulus, ease of construction, and good seismic performance. However, the steel tubes of CFST members are prone to outward buckling under compression loads. Welding longitudinal stiffeners on these steel tubes is one of the most efficient approaches used for delaying the local buckling and improving the mechanical performance of CFST members. This study attempted to investigate the eccentric compression behaviour of concrete-filled stiffened steel tubular members with square sections by experimental studies and finite element analysis (FEA). First, 12 CFST columns with different slenderness ratios and loading eccentricities were subjected to compression loads and tested. It was found that the use of stiffeners increased the ultimate strength and improved the stability of the columns. Subsequently, the behaviour of the stiffened CFST columns was investigated by performing a three-dimensional FEA. The accuracy of the FEA model was verified based on the test results. The working mechanisms of the stiffened CFST members were analysed in detail in terms of the failure modes, load versus deformation responses, deformation of the steel tubes, interaction between the steel tube and core concrete, as well as axial stress distribution of the core concrete. A parametric study was conducted to further evaluate the stiffening schemes that affected the ultimate strength and ductility of the CFST members. Finally, design recommendations on the type of eccentrically-loaded stiffened CFST columns were provided.
ABSTRACT: The low-velocity impact response of sandwich beams with aluminum alloy face-sheets and three core configurations (i.e., the positive layered-gradient core, negative layered-gradient core and non-gradient monolithic core) was first investigated by using a drop-weight machine. The impact bending tests were performed on specimens at five impact energy levels – 9.80 J, 22.05 J, 39.19 J, 61.24 J and 88.18 J – by varying the drop height of the weight. Based on experimental results, the corresponding numerical simulations and a multi-objective design optimization were performed. The experimental results show that all sandwich beams fail via the global bending deformation without local crack/fracture under lower initial impact energy, while they fail via larger bending deformation accompanied by obvious core tensile crack at mid-span and core shear at clamped ends with the increased initial impact energy. The resistance of both gradient core sandwich beams to impact flexure loading is weaker than that of non-gradient monolithic core sandwich beams. Simulation results indicate that the ratio of energy absorbed by core decreases with the increased impact energy, while the ratio of energy absorbed by face-sheets increases with the increased impact energy. The boundary condition is demonstrated to have great influence on the force-displacement response for all sandwich beams. Finally, the corresponding Pareto fronts representing a group of best trade-off designs were obtained.

ABSTRACT: Elevated cylindrical metal silos are often supported on a ring beam which rests on discrete column supports. The ring beam plays an important role in redistributing the majority of the discrete forces from the column supports into a more uniform stress state in the cylindrical wall, which is necessary to reduce the potential for buckling of the shell wall. Traditional design treatments assumed that the discrete support forces can be fully redistributed by the ring beam, producing circumferentially uniform axial membrane stresses in the silo shell. But it has previously been shown that only a very stiff ring beam can produce even relatively uniform axial membrane stresses in the shell. The ring beam stiffness must be evaluated relative to the stiffness of the silo shell in compatible deformation, since even a thin shell is extremely stiff in its own plane. A test for the ring beam to shell stiffness ratio was previously devised by the authors to determine the ring beam stiffness needed to achieve uniform membrane stresses. This new study assesses ring beams of practical dimensions and stiffness, to evaluate their effectiveness in smoothing the shell axial membrane stresses towards the uniform condition and then to find their effect on the buckling resistance of the shell. This study explores the stress resultants in a closed section ring beam of practical dimensions that is less stiff than the ideal stiffness using a finite element parametric study of the flexible ring beam and connected silo shell. The results show that the ring beam stress resultants, relative to those in an isolated ring beam under the same loading, can be directly related to the established shell to ring beam stiffness ratio (ψ). This treatment may be used to significantly enhance current design practice which, according to the Eurocode EN 1993-4-1 for silos, assumes that the shell applies the full uniform transverse loading onto an isolated ring beam.

ABSTRACT: Aluminium alloys have high strength-to-weight ratios and great durability; thus, they have been extensively used in structural applications. Channel sections have a smooth and aesthetically pleasing line shape, good integrity, and are easy to connect. An experimental program using 28 specimens and a numerical study that generated 100 results were conducted on aluminium alloy columns of plain and lipped channel sections. The nominal length of columns ranged from 300 mm to 3000 mm. The generated 128 results were evaluated with respect to the existing design specifications from America, Australia/New Zealand, Europe and China. Furthermore, the direct strength method (DSM) and the continuous strength method (CSM) were also used to predict results for comparison. The results showed that the design specifications produced conservative compression strengths of aluminium alloy columns of both plain and lipped channel sections. The CSM
provided more accurate and consistent design strengths. In addition, the reliability levels of the four international design codes, DSM and CSM for channel sections of aluminium alloy columns were also evaluated.


ABSTRACT: Free vibration of ultralight all-metallic (Ti-6Al-4V alloy) sandwich beams with corrugated channel cores was investigated by experiments and finite element (FE) simulations. The natural frequencies and mode shapes were measured and compared with simulations from both three-dimensional model (3D model) and two-dimensional equivalent model (2D model). Predictions of the 2D model agreed well with results obtained from the 3D model and experiments. It was found that for sandwich beams, the topological change from corrugated core to corrugated channel core eliminates the anisotropy of the structural stiffness and suppresses the local modes of vibration. The effect of geometrical parameters on the first natural frequency was also explored. In addition, preliminary assessment of the influence induced by varying the core topology was carried out. The first natural frequency of sandwich beams with corrugated channel cores having an inclination angle $\theta > 45^\circ$ is higher than those of sandwich beams constructed with competing core topologies, including tetrahedral, Kagome and pyramidal trusses and hexagonal honeycombs.


ABSTRACT: Based on the Simplified Super Folding Element (SSFE) theory, the theoretical prediction of average crushing force ($F_{\text{avg}}$) for multi-cell thin-walled structures is inferred and a combined five-cell thin-walled structure used in high speed train is proposed and investigated in this paper. The finite element model of the proposed structure and the theoretical prediction are validated by a full scaled impact experiment. Then, parametric studies are performed to evaluate the effects of design variables, including the thickness ($t$) and the side length ($a$) of the orthohexagonal cell, on collision responses based on the validated FE model and theoretical prediction. It is found that both specific energy absorption (SEA) and the maximum initial force ($F_{\text{max}}$) are obviously affected by the design parameters. Particularly, the effect of parameter $t$ on crushing performance is greater than that of parameter $a$. In further, to minimize the $F_{\text{max}}$ and maximum SEA under the constraint of $F_{\text{max}}$, a multi-objective robust optimization methodology is adopted. The Optimal Latin Hypercube Design (OLHD) and orthogonal design are combined to perform Design of Experiment (DoE) and dual response surface models (DRSM) are constructed for the optimization. The optimal results of deterministic optimization indicate that the $F_{\text{max}}$ decreases by 11.07% compared with the original design while the robust optimization optimal result of $F_{\text{max}}$ decreases by 10.01%. However, the robust optimization optimal design is more acceptable considering the robustness, which means the robust optimization is more attractive than deterministic optimization in practical engineering application.


ABSTRACT: This paper describes a numerical study on the section moment capacity of a doubly symmetric hollow flange steel plate girder (HFSPG) for use in long span applications. The HFSPG is manufactured by welding industrially available cold-formed rectangular hollow sections to a steel web plate. Suitable finite element models were developed first to simulate the section moment capacity tests conducted on the proposed HFSPGs using a four-point bending test arrangement. The experimental conditions in terms of boundary conditions, lateral restraints, mechanical properties, initial geometric imperfections and residual stresses were modelled carefully. The comparison of ultimate moment capacities, moment versus deflection plots and failure modes proved the validity of the developed finite element models to investigate the section moment capacities of HFSPGs. However, the slenderness of the tested HFSPGs was limited to the inelastic region. Hence the validated finite element models were used in a detailed parametric study to extend the results to a wider
slenderness range. The parametric study results of the section moment capacities were compared with the predictions of the relevant Australian, American and European hot-rolled and cold-formed steel design standards and suitable recommendations were made in relation to their accuracy in predicting the capacities of compact, non-compact and slender HFSPGs. Finally this paper proposes a new Direct Strength Method based design for HFSPGs.


ABSTRACT: This paper proposes a new circumferentially corrugated square tube (CCST) with a cosine profile. The cross section of the CCST is controlled by a cosine expression with parameters that include the number (N) of cosine wave crests, the amplitude (A) and the nominal side length (2L). Finite element (FE) models validated by experimental results were constructed in LS_dyna to analyse the crashworthiness performance of the CCSTs. The numerical results show that the collapse modes of CCSTs are classified into five types, i.e., non-ordered progressive mode (NPM), ordered progressive mode (OPM), inversion mode (IM), global buckling mode (GBM) and extensional mode (EM). After analysing the collapse characteristics, force-displacement characteristics and crashworthiness indexes, we found that the OPM has better crashworthiness performance than the other modes. Moreover, a more comprehensive parametric study was conducted to understand the effects of the geometric parameters N, A and wall thickness (t) on the crashworthiness performance of CCSTs. The results show that the collapse modes of CCSTs are fairly sensitive to the cross-sectional configuration and wall thickness. Increases in N, A and t all cause increases in the initial peak crushing force (IPCF), and the wall thickness t has the most significant effect on IPCF. However, the effects of the three geometric parameters on specific energy absorption (SEA) are much more complicated and are largely dependent on whether the collapse modes change or not with increases in the three parameters. The numerical results also show that the SEA of CCSTs is improved by 51.62% compared with that of a square tube (ST) when they have the same mass (55.3 g) and by 69.24% when they have the same wall thickness (t=1.25 mm). These results reveal that CCSTs with OPM have good energy absorption ability.


ABSTRACT: The paper deals with buckling of metal cylindrical silos composed of corrugated sheets and thin-walled open-sectional columns. A simplified silo wall segment model with a few columns was proposed for calculations of the global buckling strength of silos instead of comprehensive 3D computations of the entire silo structure. Calculations were carried out for three real silos with a different geometry (two slender silos and one intermediate slender silo). Comprehensive linear bifurcation/buckling analyses and geometrically non-linear stability analyses for both imperfect and perfect silos were applied. Silos and silo wall segments were mainly modelled both with an equivalent orthotropic shell for walls and 1D beam elements for thin-walled columns and with shell elements for walls and columns. The silo walls were loaded by tangential wall pressure, horizontal wall pressure and patch load according to Eurocode 1. The simplified silo wall segment models fully proved their efficiency in FE calculations of the buckling strength of silos.


ABSTRACT: Cold formed steel sections are normally produced by cold work manufacturing processes. The amount of cold work to form the sections may induce residual stresses in the section, especially in the area of bending. Studies by previous researchers of the effects of local buckling on the failure mechanics of thin-walled compression members have shown that ultimate failure will occur when the yielding has reached most of the middle surface in the corner region of the sections. Hence, these cold work processes may have significant effects on the section behaviour and load-bearing capacity. Most of the studies have investigated the effect of residual stresses raised from roll-forming operation and its influence on steel section behaviour. However,
press-braking has not received much attention. Therefore, a 3D finite element simulation has been employed to simulate this forming process. This study investigated the magnitude and distribution of residual stresses along the length of the corner region and through thickness residual stress variations induced by the press-braking forming process. The study concluded that residual stresses are not linear longitudinally (along the corner region). Maximum residual stresses exist near the middle surface of the plate. The neutral surface contains a combination of compressive and tensile residual stresses. The neutral axis is shifted from mid-surface by 7.5% of the plate thickness due to bending. The comparison of the 3D-FE results with the existence of 2D-FE results illustrates that the 3D-FE results show a variation in the transverse and longitudinal residual stresses along the plate length.


ABSTRACT: Circular holes can be commonly found in the web of cold-formed steel beams to accommodate services such as electric wires and pipelines. The presence of holes will reduce the critical buckling stress of the beams. Hancock proposed solution for determining the distortional critical stress of channel section beams, but limited to the sections without holes. This paper presents an analytical study on the distortional buckling of cold-formed steel channel-section beams with circular holes in the web. Hancock’s solution has been modified to derive a simple formulation for approximating the elastic critical stress and moment of distortional buckling of the channel-section beams with circular holes in the web, which are compared with those from the finite element buckling analysis using ANSYS. Finally, the influence of multiple holes on the distortional buckling behaviour and corresponding elastic buckling stress of beams in bending is discussed.


ABSTRACT: As a first endeavor, the nonlinear bending behavior of functionally graded carbon nanotube reinforced composite (FG-CNTRC) annular plates with variable thickness on an elastic foundation is scrutinized in this research. The nonlinear governing equations are established according to the third-order shear deformation theory (TSDT) in conjunction with the nonlinear von Karman strain field. A Pasternak elastic foundation is assumed to be in contact with the annular plate during deformation. To discretize the nonlinear governing equations and boundary conditions, the generalized differential quadrature method (GDQM) is adopted and the nonlinear system of equations is solved via the Newton-Raphson iterative method. Through the numerical results, effects of the elastic foundation, geometrical parameters, boundary conditions, CNT dispersion and volume fraction, thickness-to-radius ratio and thickness profile are investigated in detail. It is shown that CNT volume fraction and dispersion have a remarkable effect on improving bending behavior of the annular plate. It is found that thickness profile plays an essential role in the bending response of the annular plate.


ABSTRACT: A solution of the vibration problem for a composite orthotropic cylindrical shell with rigid weightless disks attached to its ends is presented in the paper. Using the Ritz method, the frequencies of the axisymmetric vibrations of the shell are determined. The clamped-clamped beam functions and their third derivatives are adopted as approximating functions for the shell deflection and axial displacement. Such an approximation satisfies the boundary conditions, according to which the shell deflections, angles of rotation, and axial reactive forces exerted on the end disks are zero. Based on this solution an analytical formula is derived for the calculations of the frequencies of axisymmetric vibrations. Using this formula, the vibration frequencies have been calculated for composite orthotropic shells with different lengths. The results were successfully verified by the finite element analyses. The effect of the fibre orientation on the vibration frequencies of the shell made of unidirectional carbon fibre reinforced plastic is investigated. Based on this analysis, the angles of the reinforcement orientation delivering the maximum and minimum values of the
frequencies are determined. It is found that irrespective of the shell length, the high mode frequencies reach their maximum values for the shells reinforced in the hoop direction.


ABSTRACT: In the present work, nonlinear dynamics of fluid-conveying functionally graded material (FGM) sandwich nanoshells is investigated. In order to describe the large-amplitude motion, the von Kármán nonlinear geometrical relations are taken into account. Compressibility and viscosity of the fluid are neglected, and the velocity potential and Bernoulli's equation are used to describe the fluid pressure acting on the nanoshells. Based on the classical shell theory and incorporating the surface stress effect, the governing equations are derived by using Hamilton's principle. After that, the Galerkin method is used to discretize the equation of motion, resulting in a set of ordinary differential equations with respect to time. The ordinary differential equations are solved analytically by utilizing the method of multiple scales. Results show that the surface stress plays important roles on the nonlinear vibration characteristics of fluid-conveying FGM sandwich thin-walled nanoshells. Furthermore, the fluid speed, the power-law index, the fluid mass density, the core thickness and the initial surface tension can also influence the vibration characteristics of fluid-conveying FGM sandwich nanoshells.


ABSTRACT: Temporary structures, which are designed to be quickly erected and in service for short periods of time, are widely used in performances and sports competitions. This temporary characteristic requires special construction to be implemented. This paper presents a new modular support structure that can be used as temporary grandstands, stages, ski runs and disaster relief rooms. This modular support structure is composed of the foldable plane frame with corresponding joints. The assembly property is achieved through joint connection among these frames. The local folding characteristic of these plane frames improves both erection and transportation efficiency. As a core component of this modular support structure, the aluminum alloy assembly column was particularly concerned and the axial stability of the column was investigated experimentally. The results indicated that the use of the connection ring could improve the stability of the assembly column along with the connections between the foldable plane frames. Numerical analysis of the tested specimens under axial compression was developed. The ultimate strength, failure modes and load-displacement curves obtained from the numerical results agreed well with the test results. Equivalent stability factors of the assembly columns were calculated to further illustrate axial stability of the column.


ABSTRACT: This paper presents the buckling and postbuckling behaviors of graphene-reinforced composite (GRC) laminated cylindrical shells subjected to torsion in thermal environments. The GRC layers of the shell are arranged in a piece-wise functionally graded (FG) distribution pattern in the thickness direction and each layer of the shell contains different volume fraction of graphene reinforcement. The extended Halpin-Tsai micromechanical model is employed to determine the temperature dependent material properties of GRC layers. The governing equations of the GRC laminated cylindrical shells under torsion are derived based on a higher-order shear deformation shell theory with the geometric nonlinearity being defined by the von Kármán strain-displacement relationship. A singular perturbation technique along with a two-step perturbation approach is employed to determine the buckling torques and the torsional postbuckling equilibrium paths of the FG-GRC laminated cylindrical shells in thermal environments. The numerical results obtained reveal that the piece-wise FG distribution of graphene volume fraction can enhance the buckling torque and the torsional postbuckling strength while the rise of temperature may lead to the reduction of the torsional buckling torques and torsional postbuckling strength of the GRC laminated cylindrical shell.

ABSTRACT: Tensegrity systems have the potential of offering a high level of structural efficiency and result in lightweight reconfigurable structures. However, there is few actual application of the tensegrity concept in engineering practice, which can be mainly attributed to the inadequate knowledge concerning the mechanical behavior of these systems. Although, most of the performed instability analyses on tensegrity systems to date concern with progressive collapse under static loads, so far no investigation has been conducted on the dynamic instability of these systems. In this paper, two geometrically rigid configurations assembled from half-cuboctahedron (HC) modules and crystal-cell pyramid (CP) modules under impulsive loads are analyzed, for demonstration purposes, with the intention of comparing critical dynamic loads to critical static loads. Also, other parameters, considered in this work, include the impulsive time duration, self-stress level, struts slenderness ratios, damping ratios, support conditions, and struts strengthening. It is found that in the investigated cases, as the time durations are reduced, being less than quarter of the first natural frequency, the critical load ratios increase and the systems are able to withstand dynamic loads that are substantially in excess of the critical static loads. Decreasing self-stress level by 40% in the studied HC configuration can significantly increase the amount of relative dynamic to static load ratio up to 193%, 177% and 170% under rectangular, triangular and half-wave sine loadings with time duration of 0.05 s, respectively. The increase in critical impulsive load capacity of the studied CP configuration is typically less than 10% for the same reduction of the self-stress level. There is a significant increase in dynamic loads attaining approximately 20% for an increase of 24% in cross-section of critical struts in the studied HC configuration.


ABSTRACT: In the proposed buckling-restrained brace (BRB), a concrete infilled glass-fibre reinforced polymer (GFRP) tube is used instead of a conventional concrete infilled steel tube to restrict steel inner core buckling. It has the following advantages: 1) The GFRP is a high-strength and flexible material available for structural components; 2) Its use as an outer constraint material is also a solution for poor corrosion resistance of the outer steel tube; In this study, 11 BRB specimens with concrete infilled GFRP tubes and 3 BRB specimens with concrete infilled steel tubes were designed to investigate the effects of the types of GFRP and constraint ratios on the hysteretic behaviour of the GFRP tube BRBs. The performance of the GFRP tube BRBs was also compared to the steel tube BRBs composed of three different lengths of steel tubes with the same wall thickness. All the GFRP tube BRB specimens had the same rectangular steel inner core and included two types of GFRP tubes with three different lengths and thicknesses. The medium- and long-length filaments winding GFRP tube BRB specimens buckled at the last stage of the test, while global buckling developed the cracks in the middle of the GFRP tube. All other BRB specimens didn’t buckle and underwent the complete loading process without degradation in stiffness and strength. The finite element models of BRBs were built using ABAQUS, considering the constitutive models of the GFRP, steel and concrete subjected to cyclic loading. The finite element model of the GFRP tube BRBs could simulate the performance of the BRBs well, and the results of analysis were calibrated with experimental results. All the BRB specimens exhibited good hysteretic behaviour, sufficient load-bearing capacity, large ductility and energy dissipation capacity. The GFRP tube BRBs may share the same design criteria as the traditional steel tube BRB by limiting their constraint ratios, and the GFRP tube may be used as an alternative to the traditional outer restraining tube especially for those BRBs with strict durability requirement.


ABSTRACT: In this paper, the ability of the active thermography as a non-destructive testing technique to detect internal damages in circular cylindrical shells is investigated. The transient heat transfer problem of the damaged structure is analyzed using the ABAQUS numerical modeling software. To reveal the defects more

ABSTRACT: This paper addresses an improved cross-section analysis approach for calculating the deformation modes of thin-walled cross-sections with circular rounded corners in the framework of generalized beam theory (GBT). The cross-section discretization, in contrast to the classic GBT one, the circular rounded corners are treated as independent circular walls, and deflection functions of the corresponding circular arches, which play the role of basis functions, are used to approximate the in-plane displacements of any points on the corner mid-line. Because the geometries of the circular corners are accurately modelled by curved elements, the proposed procedure is more efficient than those based on the polygonal approximation of the corner mid-lines. Illustrative cases concerning the employment of the procedure to four cold-formed cross-sections are presented to show its validity and potential. Through comparisons of the proposed procedure against that based on the polygonal approximation, it is shown that it yields accurate results with much coarser cross-section discretization.


ABSTRACT: The paper investigates the effects of the geometrical imperfections in buckling analyses of plated steel elements at elevated temperatures and provides an alternative branch-switching procedure to perform post-buckling analyses without introducing initial imperfections into the model. This procedure is appealing since the choice of appropriate imperfections in classical analyses is not straightforward, above all at elevated temperature. Several numerical analyses show that the choice of the imperfections is not trivial and that the buckling mode may vary with temperature. They also show that the proposed branch-switching procedure is an interesting preliminary tool to understand the instability behaviour of steel structural members.


ABSTRACT: This paper is focused on the stability of polymer disks subjected to uniform radial edge compression and proposes a methodology to determine the critical pressure at the onset of buckling. The methodology involves the design and fabrication of a tooling system to compress the outer disk surfaces and move material inward in order to apply a uniform radial pressure in the free (unconstrained) volume of the disks. The main objective is to circumvent the application of classical analytical solutions to polymers that exhibit a decrease of the stress-strain curve and negative values of the tangent modulus after initial yielding through determination of the critical pressure at the onset of buckling by matching the experimental and finite element predicted evolutions of the force vs. displacement. A lower bound stress solution is provided to perform a simple and fast conversion of the experimental data into the critical pressure of the polymer disk at the onset of buckling. The results of this investigation can be successfully applied to characterize the forming conditions that give rise to out-of-plane buckling deformation of the polymer centre during the production of a new generation of polymer-metal coins.


ABSTRACT: This study examined the buckling of spherical caps fabricated under different conditions of wall-thickness reduction. The spherical caps were fabricated using photosensitive resin and had a base diameter of 150 mm and height of 41.1 mm; they were subjected to uniform external pressure. In total, 42 spherical caps—6 with full thickness reduction and 36 with partial thickness reduction—were fabricated through rapid
prototyping; after their external surface and wall thickness were measured, all caps were tested to collapse to experimentally and numerically evaluate their buckling properties, namely buckling pressures and collapse modes. Moreover, the effects of site, magnitude, and range of the thickness reduction on the buckling properties were evaluated. Herein, the experimental and numerical results are comparatively presented in tables and figures.


ABSTRACT: A semi analytical method is employed to analyze free vibration behaviors of composite laminated cylindrical and spherical shells subject to complex boundary conditions. The analytical model is established on the basis of multi-segment partitioning strategy and first-order shear deformation theory. The displacement functions are made up of the Jacobi polynomials along axial direction and Fourier series along circumferential direction. In order to obtain continuity conditions and satisfy complex boundary conditions, the penalty method about spring technique is adopted. The solutions about free vibration behaviors of composite laminated cylindrical and spherical shells were obtained by approach of Rayleigh–Ritz. The convergence study and numerical verifications for composite laminated cylindrical and spherical shells with different boundary conditions, Jacobi parameters, spring parameters and truncation of permissible displacement functions are carried out. Through the comparison and analysis study, it is obvious that the proposed method has a good stable and rapid convergence property and the results of this paper closely agreed with those obtained by published literatures, FEM and experiment. In addition, some interesting results about free vibration characteristics of composite laminated cylindrical and spherical shells are investigated.


ABSTRACT: This paper focuses on the stability of steel columns with cruciform section under uniform compressive and shear stresses. The complex finite strip method (CFSM) is employed to solve the buckling of open thin-walled steel columns. CFSM results are validated against other numerical techniques. CFSM has high convergence, accuracy and superior computational efficiency. Due to the use of complex functions, it can also capture shear buckling. The influence of longitudinal stiffeners and section geometry on the buckling behavior of stiffened cruciform sections is investigated. The buckling behavior of cruciform sections is compared against U, I, and T section steel columns.


ABSTRACT: In this paper, the optimum positions of multiple (two) longitudinal stiffeners for steel plates subjected to pure bending, and combined bending and shear forces, are investigated by using the gradient-based interior point optimization algorithm. An eigenvalue analysis is performed by means of the finite element method, and an optimization algorithm is employed to maximize the buckling coefficients until attaining the optimum position of the stiffeners under various loading conditions. In order to ensure the accuracy of the method, the results obtained from this research are compared with analogous results found in the literature. Based on this study, the optimal location of a single and two longitudinal stiffeners are recommended for plates under pure bending. In addition, the interaction curves between the optimum stiffener location and bending-shear ratio for plates subjected to combined bending and shear forces are proposed for practical design.


ABSTRACT: In this study, for the first time, we present a shell finite element based on positions and generalized vectors for instability analysis of thin-walled members. The presence of generalized vectors and
transverse strain enhancement guarantee to the proposed formulation a good representation of strain and stress fields inside the element, allowing the use of complete three-dimensional constitutive law without any locking. The proposed formulation is total Lagrangian and naturally covers large displacement modeling. In past studies, the presence of generalized vectors limited the connection of shell portions or non-tangential panels, making it difficult to model thin-walled members. To solve this problem, a strategy to ensure the connection between non-coplanar elements, considering the stiffness of the connecting material, is originally developed and presented in this paper. In numerical examples we explore differences among buckling load achieved using small displacements and first limit points (or bifurcation points) using large displacements. The influence and the sensitivity of the connection stiffness are also tested when comparing these values. Results are validated against literature reference values and new examples are proposed to show the applicability of the positional formulation.

M. Javani (1), Y. Kiani (2) and M.R. Eslami (1)
(1) Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran
(2) Faculty of Engineering, Shahrekord University, Shahrekord, Iran


ABSTRACT: Natural frequencies of circular deep arches made of functionally graded materials (FGMs) with general boundary conditions are obtained in this research based on the unconstrained higher-order shear deformation theory taking into account the depth change, complete effects of shear deformation, and rotary inertia. The material properties are assumed to vary continuously through the thickness direction of the arch. Displacement field within the arch is obtained through expansion up to an arbitrary order. Governing differential equations of the in-plane vibration are derived using Hamilton's principle. These equations are solved numerically utilizing the differential quadrature method (DQM) formulation. In order to illustrate the validity and accuracy of the presented results, results are compared with the available data in the open literature. Afterwards, novel numerical results are given for free vibration behaviour of the FGM deep arches with various boundary conditions.


ABSTRACT: This paper describes a numerical investigation into distortional-global buckling interaction of cold-formed steel perforated rack uprights when subject to axial compression. The numerical modelling strategy is carefully validated against existing experimental data. The strengths and failure modes of perforated uprights obtained from finite element analysis are compared with design strengths predicted using the direct strength method (DSM). The comparisons indicate that the ultimate strengths predicted by the current DSM are unsafe for perforated rack uprights. Hence, modifications on the DSM formulae were proposed and are presented by considering the interaction of distortional and global buckling modes for perforated rack uprights.


ABSTRACT: Cold-formed steel (CFS) is an emerging construction material that has been gaining momentum over the past few years. While the behavior of structural members made of CFS has been extensively studied at ambient conditions, the performance of these members under extreme events such as that associated with fire, is yet to be understood. In order to bridge this knowledge gap, this paper presents outcome of numerical studies aimed at understanding fire response of CFS beams. More specifically, this study explores the effect of temperature-induced shear-based instability on response of C-shaped CFS beams with slotted webs. For studying this phenomenon, a three-dimensional nonlinear numerical model is developed using the finite element (FE) simulation environment; ANSYS. The developed FE model is designed to incorporate temperature-dependent material properties as well as to account for unique geometric features and restraint conditions, as to accurately trace thermal and structural response of CFS beams. Once validated, the developed model was utilized to examine the effect of a number of factors namely; channel depth, web perforation pattern, as well as boundary conditions, on temperature-induced buckling susceptibility of CFS beams. The obtained results
showed that these examined factors can significantly affect shear response of CFS channels with slotted webs at elevated temperatures. Findings observed from FE simulations were also shown to agree with that obtained from especially derived design expressions that give due consideration to geometric features and temperature-dependent material properties of slotted webs. This study concludes that in order to accurately capture the response of fire-exposed CFS beams, an accurate presentation of geometric and material features in such members is essential.


ABSTRACT: This paper presents an experimental study on concrete-filled steel tubular (CFST) beam-columns with square sections under combined sustained load and chloride corrosion. A total of 11 specimens (including 7 CFST members and 4 reference hollow steel tubes designed for comparison) were tested under 120-day sustained load in accelerated chloride corrosion environment and then loaded to failure. The main test parameters include load ratio (ratio between the long-term sustained load and the ultimate capacity of the specimen under short-term loading) and corrosion depth. The failure modes, full-range load-displacement relationship, load-strain relationship and ductility were measured and compared. Based on the experimental observation, mechanism of CFST beam-column members under the combined effects of sustained load and chloride corrosion was discussed and compared to the reference hollow steel tubes. Traditional design methods were modified for the consideration of combined sustained load and corrosion, which were calibrated and evaluated against the test results.


ABSTRACT: The present paper introduces two types of inner cellularization geometry in the thin-walled cylinders derived from previous studies on this area of subject. Novel geometries were proposed in this research. These configurations were the result of modifications to the previous works. Moreover, these absorbers were proposed to increase the specific energy absorption, reduce the peak energy, and improve crushing. The maximum Specific Energy Absorption (SEA), minimum Initial Peak Crushing Force (IPCF) under quasi-static axial compression test at the rate of 10 mm/min, and thickness and height parameters of the thin-walled cylinder and length of the inner square's sides were considered the design variables to achieve the optimal state. In the present work, two DOEs (design of experiment) were performed in Design-Expert in accordance with the given surfaces for both geometries of the thin-walled cylinder's inner cores. Subsequently, for further investigation, the experimental results were compared with those obtained from the finite element simulation in Abaqus, revealing the desirable accuracy of the results. Finally, by applying the equations derived from the proposed model to each of the responses and geometries, their optimal states were obtained using both the desirability approach in Design-Expert and the MOPSO method in MATLAB. Thickness had the highest impact on both configurations. Moreover, the optimal thickness for both configurations was 1.4 mm in the selected range. As regards the multi-objective function, the best inner square edge lengths for the C2R and S2R configurations were the central and upper limits, respectively. Finally, the cylinder heights for the C2R and S2R geometries were 174 and 153 mm, respectively.


ABSTRACT: Thin-walled circular cylindrical shells are used in many civil engineering applications. Any initial geometric imperfections and the type of applied load determine the buckling and the post buckling of cylindrical thin-walled shell structures. Fourteen thin-walled cylindrical shell models in two groups (labelled without CFRP and with CFRP) with different dent directions (H= horizontal, V= vertical and D= 45° diagonal direction) and dent depths (2t and 4t) subjected to external pressure were tested in the present research (t is the
thickness of the cylindrical shell). The results of testing under different theories and codes are compared. Moreover, the results are identified and investigated in the present experimental research.


ABSTRACT: Thin-walled energy absorbers are one of the common structures that are used in vehicle body for increasing the crashworthiness and consequently decreasing injuries. Investigated new type of thin-walled aluminum matrix and a thin-walled steel punch energy absorber structure has been investigated in this paper. Energy is absorbed as the matrix expansion followed by simultaneous matrix and punch folding. Present study proposes a sandwich panel based on expanding-folding absorber units to evaluate their crush mechanism. Parametric study has been done using finite element code LS-DYNA while experimental tests have been implemented to validate the FE model. The panels have been tested under three axial quasi-static loading conditions including a rigid half-cylinder and a rigid plate. Parametric study considers the punch angle, matrix thickness and punch thickness. The optimum structure based on energy absorption has then been used as a structural member in the sandwich panel until a panel with high specific energy absorption be introduced. Also it have been seen that all the curves for the expansion section can be estimated using polynomial second order functions, with a high accuracy.


ABSTRACT: This paper presents a comprehensive analysis of mathematical models for estimating the shear strength of trapezoidal-corrugated steel webs. The existing database of experimental data on trapezoidal corrugated steel web beams and girders is updated by adding more test results, yielding a total of 144 tests. The three-parameter model, previously developed by the authors based on Richards equation is reduced to a two-parameter improved version based on Hill equation. Both models were found to have, essentially, the same performance when compared against test results of the updated database. Based on the Akaike Information Criterion, the new model was retained. The performance of the improved and previously published models is reviewed and tested against the updated database of test results. It was found that the improved model performed better than the existing models in many aspects. An uncertainty analysis was performed on the proposed model considering both, geometric and material parameters as random variables. Bootstrapping and the Point Estimate Method (PEM) were employed to propagate uncertainty and construct confidence intervals for the normalized shear strength. It was found that, overall, the coefficient of variation of the normalized shear strength increases with the slenderness ratio.


ABSTRACT: Thin-walled stainless steel channels are becoming more widely used in the residential and commercial sectors because of their high corrosion resistance, especially in situations where low maintenance is required. However, there is a need also for web perforations for ease of installation of services; as a result such sections are susceptible to crippling in the web, particularly under concentrated loads applied near to the web perforations. This paper considers the use of perforated cold-formed ferritic stainless steel unlimped channels with restrained flanges subject to interior-one-flange and end-one-flange loadings, known as one-flange loadings. A total of 288 results are presented, comprising 18 laboratory and 270 numerical results. The numerical analysis in this paper uses nonlinear quasi-static finite element analysis with an implicit integration scheme. A comprehensive parametric study is described to determine web crippling strength reduction factors for different sizes of web perforations and cross-section dimensions. It is noted that no cold-formed stainless steel standard provides strength reduction factors for any one-flange loading. The strength reduction factors are
first compared to reduction factors previously recommended for lipped cold-formed stainless steel channels. It is found that these existing equations are unreliable and unconservative for unlipped channels by as much as 20%. From both laboratory and finite element results, web crippling design equations are proposed for perforated channels under one-flange loadings; the proposed equations are shown to be reliable when compared against laboratory and numerical results.


ABSTRACT: Steel-concrete-steel (SCS) sandwich shells, which are combined with steel plates, concrete core and shear connectors, are usually applied as protective structures in the civil engineering. In this paper, nine curved SCS sandwich shells subjected to concentrated load by a hemi-spherical head were tested to obtain the failure characteristic, ultimate strength and load–displacement response. The finite element (FE) models of curved SCS sandwich shells were also established by using LS-DYNA. The accuracies of the FE models were verified by comparing the load–displacement curves, local and global deformation between the experimental results and FE predictions. The factors influencing the ultimate strength and deformation behavior of curved SCS sandwich shells were analysed, including concrete core and steel plate thickness, top to bottom steel plate thickness ratio and spacing of shear connectors. Through experiments and numerical simulations, three failure modes could be summarized. It was also found that increasing concrete core and top steel plate thickness and reducing the spacing of shear connectors could increase yield strength and ultimate strength of curved SCS sandwich shell. The increase of concrete core and steel plate thickness also led to higher energy absorption capacity; whereas, the spacing of shear connectors showed little effect on energy absorption capacity.


ABSTRACT: In order to develop an efficient energy absorption structure for protecting equipment against impact and blast shock, this research proposes a fourfold-tube system (FT) consisting of four tubes. Its performance was analyzed experimentally (quasi-static test) and numerical simulation with FE (finite element) models. The deformation mode of the FT system was described in detail by simulation and experiment. With the collapse of the outer tube, the upper inner tubes were pushed towards both sides of the lower inner tube, then three inner tubes are side-by-side in the outer tube and all the tubes were collapsed simultaneously, therefore the stress transmits to the protected structure to be distributed more evenly. As a consequence, the protection capability of the nested tube system is improved by enhancing energy absorption capacity and the robustness of deformation mode. The performance of FT system was compared with that of the triple-tube system (TT) and single-tube system (ST), both the experimental result and simulation results show that the FT system can provide the most stable deformed mode and the highest energy absorption efficiency. For mild-steel nested tube systems, the energy absorbed by the FT system is larger than that of the TT system by 30%, so the defense ability of the FT system is better than the TT system. The deformation mode of the FT system under dynamic load tested experimentally, the results prove that the nested system can works as expected at high strain rates. Finally, the FT system was tested with two type of dynamic loading conditions, impact and blast shock. The results demonstrate that the FT system can provide the most efficient impact force reduction and blast mitigation in protecting the structures from damage under impact and shock wave from the explosion.

Kshitij Kumar Yadav and Simos Gerasimidis (First author is from: Department of Civil and Environmental Engineering, University of Massachusetts Amherst, 130 Natural Resources Road, Amherst, MA 01003, United States), “Instability of thin steel cylindrical shells under bending”, Thin-Walled Structures, Vol. 137, pp 151-166, April 2019, https://doi.org/10.1016/j.tws.2018.12.043

ABSTRACT: Bending of steel cylindrical shells is generally characterized by the interaction among ovalization, bifurcation, and material plasticity when the slenderness of the shell is relatively low. It is a nonlinear phenomenon, which is dictated by buckling-sensitivity of the shells to imperfections. The behavior of
ABSTRACT: This study aims to develop an analytical solution for the elastic buckling pressure and its corresponding equilibrium path of confined, thin-walled liners subjected to temperature variations. The admissible radial displacement function and the minimum potential energy of liners are employed to establish the equations of equilibrium. The steel liners are modelled with two-dimensional finite elements for both elastic and inelastic behaviors. The elastic buckling pressure and the equilibrium path from the computational model are in excellent agreement with the analytical predictions. The analytical solutions for elastic liners and the numerical results for inelastic liners with material and geometric nonlinearities compare well with their respective test results available in the literature. Parametric studies are performed in terms of temperature.
variation, out-of-roundness imperfection, non-uniform liner-pipe gap, pipe supporting medium flexibility, and steel liner yield strength.


ABSTRACT: This paper proposed an innovative composite folded thin shell structure consisting of concrete, expanded polystyrene foam (EPS), and glass-fiber reinforced polymer (GFRP) to improve the mechanical performance of the traditional concrete thin shell structure. This lightweight structure was investigated through a scaled model test to characterize the load bearing behavior. For comparison the corresponding concrete thin shell and the concrete folded shell were also undergone loading tests. The results demonstrate that the bearing capacity of the composite folded thin shell is 4.876 times that of the concrete thin shell and 1.219 time that of the concrete folded shell respectively. The typical failure mode of composite folded thin shells is the crush of the top concrete layer at the mid-span. The presence of the bottom GFRP face sheet and the EPS core can effectively slow down the appearance of initial cracks in the concrete layer. The destruction of the composite folded thin shell shows a good ductility characteristic when compared with other two shells.

Zhixin Huang and Xiong Zhang (Department of Mechanics, Huazhong University of Science and Technology, Wuhan 430074, Hubei, PR China), “Three-point bending of thin-walled rectangular section tubes with indentation mode”, Thin-Walled Structures, Vol. 137, pp 231-250, April 2019,
https://doi.org/10.1016/j.tws.2019.01.015

ABSTRACT: The local indentation and bending collapse are two typical energy dissipation mechanisms of thin-walled tubes under lateral impacts. These two mechanisms are always developed simultaneously for tubes under three-point bending, but there are still few studies concerned with this phenomenon. This paper addresses the indentation mode of thin-walled tubes under three-point bending. Quasi-static experimental tests are conducted first for square tubes with particular dimensions, and the nonlinear finite element code LS-DYNA is then used to simulate the tests. Parametrical studies are conducted to analyze the influence of geometrical parameters on deformed shapes and force response. Results show that the span, wall thickness and punch diameter have significant influence on the response of tubes, while the sectional width has a small influence. On the basis of the analysis of energy dissipation mechanisms, a theoretical model is proposed to predict the force response of thin-walled tubes. Ideal rigid perfectly-plastic material assumption and the dimensional analysis method are employed to help derive the force-displacement characteristics. Finally, the theoretical predictions are validated by experiments and simulation results of thin-walled rectangular tubes with a wide range of geometric parameters.


ABSTRACT: The present research is aimed at verifying design rules for cold-formed steel (CFS) members under axial compression when local-distortional buckling modes (LD) is achieved. Sets of experimental results previously available were applied to calibrate a shell finite element model addressed to survey the structural behavior of CFS lipped channels under LD bucking interaction. A large range of distortional-local slenderness ratio was considered in order to obtain numerical results of LD interaction including strong and weak interaction conditions. Based on both experimental and numerical results, the nature of LD interaction was assessed and the column strength variation was observed according with the representative slenderness variables, $\lambda_s$, $\lambda_w$ and $R_m$, respectively local and distortional slenderness factors and distortional-local slenderness ratio $\lambda_d/\lambda_s$. The column strength variation was established based on the Winter-type equation, conceived to cover the complete range of LD interaction. The proposed solution follows the direct strength method concept, is easy to apply and accurate enough for the structural design of lipped CFS columns. Additional research is under way to include other CFS types in the proposed design approach.

ABSTRACT: The paper investigates the possibility of bifurcation buckling from axisymmetrical equilibrium states of a heated circular plate with immovable edge. The plate is composed of a functionally graded material whose mechanical and physical properties are varied in the thickness direction according to the power law. Because of high compressive circumferential stresses that develop near the edge, the symmetrically deformed plate can buckle into asymmetric equilibrium configurations characterized by local circumferential waves (wrinkles). The problem of determining wrinkling thermal loads is formulated using the von Karman nonlinear plate theory based on the concept of physically neutral surface and solved by the power series method. The existence of wrinkling loads is examined for various pressure levels and boundary conditions. The calculation results are compared to the finite-element solution obtained by a general-purpose shell element.


ABSTRACT: Thin-walled structures are widely used in energy absorbing devices attributed to their light weight and excellent energy absorption efficiency. In this paper, an innovative sandwich sinusoidal lateral corrugated tubes (SSLCTs) was proposed. It consists of the outer circular tubes (OCTs), the inner circular tubes (ICTs) and a new type of lateral corrugated tubes (LCTs) with a sinusoidal cross-section in the middle. Systematic crashworthiness study for SSLCTs is carried out with multi-objective optimization design. The results show that the wall thickness of ICTs plays an important role in the specific energy absorption, while the wall thickness of OCTs plays a major role in initial peak force. The multi-objective optimizations of SSLCTs with \( N = 6 \) and \( N = 10 \) were performed. The optimization results show that the Pareto frontier coverage is wider for SSLCTs with \( N = 6 \) than \( N = 10 \). But these two different SSLCTs get almost identical optimal solutions. Finally, the interaction effects were also studied and it was found that the highest initial peak force was reduced by 22.39\%, and the specific energy absorption was increased by 16.75\% compared to the separate compression of individual tube.


ABSTRACT: Shear buckling resistance is one of the most important load cases to be considered when designing steel plate girders with slender cross-sections. However, there is a lack of guidance for the fire design of steel plate girders subjected to shear buckling. After the evaluation of the contribution from the flanges to shear buckling resistance in previous works, an extended numerical analysis has been carried out, dealing with the evaluation of the shear buckling resistance of steel plate girders at both normal and elevated temperatures. The numerical results have been compared with those obtained from the application of the Eurocode 3 (EC3) design expressions. A methodology for analysis of the results, which considers three failure zones based on shear-bending interaction diagram, has been used in order to compare the numerical results with the analytical expressions. Moreover, maintaining the EC3 principles, a new expression for the contribution from the web to shear buckling resistance is presented for both normal and elevated temperatures. Finally, a study on the influence of the girders geometrical relations on the increase of strength provided by the rigid end post has been performed.


ABSTRACT: Recent measurements made by our research group of a super-large cooling tower indicate that its fluctuations in wind-induced responses exhibit a degree of nonstationarity, echoing similar observations.
reported for other structures. This might cause errors in estimates of extreme responses and misunderstanding of wind-induced effects if nonstationarity is neglected. In this study, the wind-induced response signals of a super-large cooling tower (height 190 m) in a coastal region were measured for the first time under real Reynolds number and turbulent flow conditions. After noise reduction had been performed, nonstationarity of the signals was identified within various time intervals. The mean wind effect, pulsating wind effect, probability density distribution, dynamic amplification factor, and extreme responses of the super-large cooling tower were studied based on stationary and non-stationary models. Finally, the power spectral density (PSD) and evolutionary power spectral density (EPSD) of the wind-induced response signal were analyzed. The resonance spectral expression of wind-induced responses at resonance excitation points, which is applicable to super-large cooling towers, is summarized. The wind-induced responses presented strong nonstationarity. Non-stationary models that consider response nonstationarity are important in the authentic assessment of the extreme responses of super-large cooling towers. The extreme constant calculated by the stationary model cannot provide an adequate assurance rate and reduces the economic efficiency of extreme response estimates. The vibration energy distributions of resonance excitation points in different regions of the cooling tower were similar, but the PSD functions at quasi-static points were dramatically different from each other. The energy distribution of the resonant excitation points showed a phased trend, and the proposed resonance spectral expression considers three stages of variation in the PSD function of the responses to achieve high predictive accuracy.


ABSTRACT: Traditional buckling experiments of imperfection-sensitive structures like cylindrical shells can cause the permanent failure of the specimen. Nevertheless, an experimental campaign is crucial for validation of the design and numerical models. There is, therefore, interest in nondestructive methods to estimate the buckling load of such structures from the prebuckling stage. The vibration correlation technique allows determining the buckling load without reaching the instability point. Recently, a novel empirical vibration correlation technique based on the effects of initial imperfections on the first vibration mode demonstrated interesting results when applied to composite and metallic unstiffened cylindrical shells. In this context, this paper explores this novel approach for determining the axial buckling load of a metallic orthotropic skin-dominated cylindrical shell under internal pressure, which represents a simplified downscaled model of a launcher propellant tank. An experimental campaign consisting of buckling tests and noncontact vibration measurements for different axial load levels is conducted considering the specimen without and with three different internal pressure levels. The experimental results validate the above-mentioned vibration correlation technique for determining the axial buckling load of pressurized cylindrical shells. Moreover, finite element models are calibrated in order to evaluate the frequency variation within a broader and dense range of the axial loading leading to an assessment of the considered maximum load level and number of load steps as related to the deviation of the estimation. The results corroborate the applicability of the vibration correlation technique as a nondestructive experimental procedure to assess the axial buckling load of imperfection-sensitive orthotropic skin-dominated cylindrical shells under internal pressure.

Junyan Zhang, Bingquan Lu, Danfeng Zheng and Zhongyu Li (State Key Laboratory of Automobile Simulation and Control, Jilin University, Changchun 130000, China), “Axial crushing theory of metal-FRP hybrid square tubes wrapped with antisymmetric angle-ply”, Thin-Walled Structures, Vol. 137, pp 367-376, April 2019, https://doi.org/10.1016/j.tws.2019.01.005

ABSTRACT: Hybrid square tubes wrapping fiber reinforced polymer (FRP) around metallic tubes are excellent structures for both collision energy absorption and lightweight. This paper deals with axial crushing theory of hybrid square tubes wrapped with antisymmetric angle-ply. The energy dissipation mechanism of hybrid square tubes is analyzed based on deformation of metallic square tubes. Considering the effects of stacking sequences of FRP on the crashworthiness and energy absorption, theoretical expressions of the membrane force and fully plastic bending moments per unit length of hybrid squares tube are derived. Then, the expression of mean crushing force of hybrid square tubes wrapped with antisymmetric angle-ply is established. Theoretical
predictions compare well with the results of three groups of experiments and forty simulation models. The theoretical calculation presented in this paper can predict the behavior of hybrid square tubes during the conceptual design.


ABSTRACT: This paper systematically investigates the low-velocity impact response and resulting damage behavior of aluminum honeycomb sandwich structures with carbon fiber reinforced plastic (CFRP) face sheets by combining the experimental and numerical methods. Low-velocity impact tests are conducted to determine and quantify the effects of structural parameters, such as face sheet thickness, cell wall thickness, honeycomb core height and hexagon side length, on the impact load, energy absorption, and failure mode. To further elucidate the impact behavior, a user VUMAT subroutine is developed to predict the progressive failure behavior of composite face sheets. Numerical simulation is performed to characterize the impact response and explore the deformation/failure mechanisms. The predicted impact load, energy absorption, contact time and failure mode agree well with measured counterparts. These studies reveal the face sheet thickness has particularly significant influence on the impact resistance performance of honeycomb structures. Cell wall thickness and side length of honeycomb core have notable effect on the impact load and structural stiffness of such structures, while which do not play a great role in energy absorption. Increase in core height has comparatively little effect on initial stiffness and energy absorption but makes the second peak loads decreasing for the perforation cases.

Vuon Nguyen Van Do, Thanh Hi Ong and Chin-Hyung Lee (First author is from: Applied Computational Civil and Structural Engineering Research Group, Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam), “Isogeometric analysis for nonlinear buckling of FGM plates under various types of thermal gradients”, Thin-Walled Structures, Vol. 137, pp 448-462, April 2019, https://doi.org/10.1016/j.tws.2019.01.024

ABSTRACT: This study attempts at analyzing buckling responses of functionally graded material (FGM) plates under diverse types of thermal loadings. An accurate and effective numerical approach based on isogeometric analysis (IGA) to predict the nonlinear thermal buckling behavior is developed. A refined higher-order shear deformation theory (HSDT) which accounts for the geometric nonlinearity in the von Kármán sense is presented and used to derive the equilibrium and governing equations for FGM plate in thermal environments. Two different types of transverse shear functions are considered in the refined HSDT. IGA uses non-uniform rational B-spline (NURBS) basis functions which enable to accomplish easily the smoothness of arbitrary continuity order. Thus, the present method satisfies the C-continuity of the displacement field required by the proposed HSDT. Several numerical examples involving buckling behavior of various kinds of FGM plates subjected to uniform, linear and nonlinear temperature distributions across the thickness are simulated, and the results are compared to the analytical solutions for the verification purpose. Parametric studies are also carried out on FGM plates under the different through-thickness temperature variations to scrutinize the thermal buckling features. Temperature gradient through the thickness by the one-dimensional (1-D) heat conduction and thermal profile developed by the three-dimensional (3-D) heat conduction are also taken into account. Results demonstrate that the proposed IGA method can be used as an accurate and effective numerical tool for analyzing the thermal buckling responses of FGM plates, and the 3-D heat conduction needs to be considered in the buckling analysis of FGM plates subjected to thermal conduction.


ABSTRACT: It is necessary to master the propagation and distribution of the overpressure on a building under an explosive load before an anti-explosion design is achieved. However, there is very less available test data which can be applicable to multi-curved large-span space structure under a surface burst. In this work, a series of tests were performed to study the wave diffraction behaviour of a hemispherical structure by changing the
nearest distance between the charge and structure and TNT equivalent. The purpose of the experiment was to develop an experimental dataset which could evaluate the accuracy and efficiency of the numerical model. A simplified method to study the blast load distribution on the hemispherical structure was proposed by numerical and geometric analysis. The numerical results showed that the peak overpressure, impulse, blast wave front arrival time, and positive phase duration were highly dependent on the span–distance ratio and span–charge ratio, which affect the significance of the reflecting and shielding effects. For a convenient engineering application, a series of pseudo-analytical formulas were suggested to estimate the pressure–time histories for an ideal hemisphere structure.


ABSTRACT: This paper focuses on the buckling of thin-walled confined liner with grouting voids, subjected to uniform external pressure. Based on the analytical and numerical results for three different void lengths, the single lobe deformation of the liner is observed for small void length; the double lobes deformation occurs for the medium void length, and single lobe deformation is found for large void length. Small grouting voids show negligible effects on the confined liner, and the critical buckling pressure can be predicted analytically by Glock's model. The analytical expressions of buckling pressure for medium and large voids are developed analytically and numerically in the present work. Analytical solutions are based on the principle of minimum potential energy and admissible displacement functions. In the numerical analysis, a two-dimensional (2D) finite element model (FEM) is developed by tracing the pressure-displacement equilibrium paths to obtain the critical buckling pressure. Both the analytical and numerical results show the medium and large grouting voids significantly reduce the buckling pressure. The numerical equilibrium paths and critical buckling pressures excellently agree with their corresponding analytical solutions.


ABSTRACT: Experimental study is carried out to investigate the behavior and strength of square hollow structural section (SHS) columns, strengthened with an innovative polymer-mortar system. Thirteen specimens of cold-formed SHS columns with different variables are chosen. Three short-column and ten long-column SHS specimens were experimentally tested. The local and overall buckling of specimens are measured in the laboratory. The tested specimens are subjected to an axial compressive load. The effect of the thickness of polymer-mortar applied directly to the well-prepared steel surface was studied. The effect of slenderness ratio \((kL/r)\) and width-to-thickness ratio \((b/t)\) on the effectiveness of mortar strengthening was also discussed. Different failure modes are discussed as well as complete axial strength curves are drawn for different cross-sections and member lengths. A maximum axial strength gain of 31.6% was achieved for SHS short columns strengthened with 6 mm thickness polymer-mortar layer. For long columns, a maximum strength gain of 76.7% was achieved with 6 mm thickness polymer-mortar layer applied on four sides. In all mortar-strengthened SHS short and long columns, the axial and lateral deflection, and the axial strain were reduced. The axial strength of SHS long slender columns increased greatly as the overall slenderness ratio increases.


ABSTRACT: Both symmetric and anti-symmetric post-buckling of the notched tension sheets are modelled using the spline finite strip method to study the nonlinear effects of the post-buckling state on stress and displacement fields. Nonlinear elastic fracture mechanics is introduced to consider the effect of post-buckling state on the fracture behaviour and new stress intensity correction factors are defined for the buckled notched sheets. Finally, analytical approaches were provided to evaluate the fracture capacity and the fatigue life of the
notched sheets in the presence of buckling. The remarked outcomes were verified by the existing analytical, numerical and experimental results.


ABSTRACT: A novel and effective computational approach within the context of isogeometric analysis (IGA) is developed for analyzing size-dependent mechanical behaviors of functionally graded (FG) microbeams. To capture the size effects, an extension of quasi-3D theory is established to integrate with the modified couple stress theory. The nonuniform rational B-spline (NURBS) basis functions are employed and can directly meet the first-order derivative demand of the quasi-3D theory, where four variables are involved at each node. In this new setting, both normal and shear deformations are considered, while the shear correction factor is avoided. Numerical examples are studied, in which the effects of several factors, including material gradient factor, boundary conditions, parameter of material length scale, and aspect ratio, on deflections, stresses, and fundamental frequencies of FG microbeams are explored.


ABSTRACT: This paper reports a series of experimental and analytical assessments on the flexural behaviour of cold-formed thin-walled lipped-channel section truss (CTLST) beams with profiled steel sheeting-concrete (PSSC) slabs or autoclaved lightweight concrete (ALC) slabs. Three test parameters were studied, including the floor type, the U-shaped shear connector, and the connection type among CTLST members. Besides, testing phenomena, failure modes, load versus deflection curves, and strain response for these CTLST composite beams were also analyzed. The experimental data showed that flexural strength of CTLST composite beam was significantly increased by adopting reliable connection type; bond performance of the interface between the profiled steel sheeting (PSS) and concrete slab was improved by erecting U-shaped shear connectors. These CTLST composite beams were in accordance with specification recommendations of deflection limits. In addition, three-dimensional finite element (FE) modelling of CTLST composite beams were developed and verified by test data. Effect of material and geometrical parameters on the flexural feature of the CTLST beams with PSSC slabs was explored. Finally, a simplified method, which was verified by the tested and simulated results, was proposed to predict the mid-span deflection of the CTLST composite beam using reliable connection type under serviceability loads.


ABSTRACT: Thin-walled cylindrical tubes have been renowned as an ideal energy absorber in aerospace and automotive industries for their lightweight potential and extraordinary energy absorbing capability. In this research article, systematic investigations on the specific energy absorption characteristics and lateral crushing behaviour of deep drawn non-capped and plain end-capped cylindrical tubular structures were performed. Initially, finite element models were developed with ABAQUS/CAE® code to predict the deformation characteristics of the proposed tubes under quasi-static lateral compression. Subsequently, detailed experimental studies on the aluminium cylindrical tubes of various thickness (1.63 mm, 2.04 mm and 3.25 mm) under lateral quasi-static loading have been performed and the lateral crushing force-deformation histories obtained were analyzed. The lateral deformation response of the proposed tubes under impact lateral loading has been studied further and analyzed with the validated finite element model. Also, the impact crushing performance of the plain end-capped cylindrical tubes was related to the non-capped cylindrical tubes and within tested samples, the plain end-capped tubes absorbed 0.8–1.6 times more specific energy than the conventional non-capped cylindrical tubes. Finally, it was found that the plain end-capped tubular structures exhibit desirable force–
deformation characteristics such as uniform crushing force with a long crush stroke and maximum energy which is very important in the design of energy absorbers for transverse direction.


ABSTRACT: This paper presents and discusses numerical results concerning the (i) elastic local and distortional post-buckling behaviours and (ii) imperfection sensitivity of regular convex polygonal cross-section (RCPS) simply supported tubes under uniform compression (columns). Although it was shown recently that the local and distortional buckling behaviours may be often characterised by duplicate bifurcation modes, knowledge concerning the corresponding post-buckling behaviour is still lacking. The results presented are obtained through a geometrically non-linear Generalised Beam Theory (GBT) formulation previously reported by the authors. This GBT formulation is first employed to characterise the column bifurcation behaviour, namely by helping to pinpoint the occurrence of the above two distinct buckling behaviours. Then, post-buckling results are presented and discussed for (i) different combinations of the local-to-distortional buckling load ratio and the (ii) amplitude of the critical-mode initial geometrical imperfections, in order to characterise the RCPS column imperfection sensitivity. Such results provide the evolution, along given equilibrium paths, of the column deformed configurations (expressed in GBT modal form), relevant displacement profiles and participation diagrams based on either stress resultant strain energies or amplitude functions. For comparison and validation purposes, ABAQUS shell finite element values are reported.


ABSTRACT: This paper intends at numerically analyzing the simultaneous influences of base-isolator system and vertical baffle on the seismic performance of a three-dimensional (3D) rectangular liquid storage container, presuming irrotational, inviscid, and incompressible flows. A boundary element technique with meaningful computational efficiency is primarily formulated to treat the spectral problem of liquid motion using the zoning method including the velocity potentials alone of the half free-surface length, which is coupled with Finite elements for tank wall using equilibrium and compatibility conditions. In the soil/foundation component, the foundation is modeled by shell finite elements and the half-space soil medium is modeled employing the external boundary elements, which fulfill the radiation condition of homogeneous media. Eventually, above two parts are attached to equation for isolator motion in the time domain, to attain the total system’s nonlinear seismic response. The validity and efficiency of the present coupled numerical method is confirmed against available theoretical solutions and numerical predictions, revealing a good agreement with benchmark results. The sensitivity of base forces, the maximum hydrodynamic pressure and liquid oscillation in relation to some system parameters involving the baffle height, the base-isolator stiffness and the soil properties have been highlighted.


ABSTRACT: Cold-drawing is one of the typical cold-forming techniques in producing stainless steel circular hollow sections (CHS). Compared with cold-rolling, cold-drawing can produce large scale stainless steel tubes which have wide applications in highly corrosive environment. Nevertheless, few researches have been carried out on the duplex stainless steel CHS columns. In this paper, cold-drawn duplex S22053 stainless steel CHS of three types of cross-sections were tested, including 8 material tensile coupon tests, 6 axially compressed stub column tests and 7 axially compressed long column tests. The material stress-strain curves of the cold-drawn CHS tubes, ultimate loads and failure modes of the stub and long columns were obtained. It has been revealed that material properties of cold-drawn stainless steel CHS tubes are close to those of the virgin plate in the
annealed state. Moreover, all the stub columns show local buckling in “elephant foot” mode, while all the long columns undergo overall flexural buckling, among which a long column specimen with the nominal length of 700 mm (CHS-700) shows local buckling after the peak load due to the interaction of axial compression and second-order bending moment. Furthermore, comparing the test values with the predicted values based on the European, American, Australian/New Zealand and Chinese design codes, and the calculation methods available in literatures, it is concluded that the predicted values of the stub columns and the long columns with relatively large member slenderness are all lower than the test values, while the predicted values using the design methods except that in the Chinese design code are higher than the test values for the long columns with relatively small member slenderness. Chinese design code could provide safety predictions for cold-drawn duplex stainless steel CHS columns.

Mizan Ahmed, Qing Quan Liang, Vipulkumar Ishvarbhai Patel and Mohammad N.S. Hadi (First and Second authors are from: College of Engineering and Science, Victoria University, PO Box 14428, Melbourne, VIC 8001, Australia), “Numerical analysis of axially loaded circular high strength concrete-filled double steel tubular short columns”, Thin-Walled Structures, Vol. 138, pp 105-116, May 2019, https://doi.org/10.1016/j.tws.2019.02.001

ABSTRACT: Circular high-strength concrete-filled double steel tubular (CFDST) columns are high performance members where the internal and external steel tubes offer significant confinement to the concrete infill. The confinement remarkably improves the concrete compressive strength and ductility. However, no fiber element models have been formulated for computing the responses of CFDST columns with circular steel tubes filled with high-strength concrete incorporating accurate confinement to the core and sandwiched concrete. In this paper, a new fiber-based numerical model is developed that computes the axial load-strain responses of circular high-strength CFDST short columns under axial loading. Based on existing experimental results, a new confining pressure model is developed for the determination of the confining pressures on the core-concrete in CFDST columns with circular sections. A new strength degradation parameter is also proposed that allows the concrete post-peak characteristics to be quantified. The fiber-based numerical model validated by experimental data is used to assess the responses of high-strength CFDST columns considering important parameters, which include the inner steel tube, external tube diameter-to-thickness ratio and concrete and steel strengths. A simple expression is derived for the estimation of the axial load-carrying capacities of circular short CFDST columns and comparisons with several design codes are made. The proposed fiber-based analysis technique and design equation can accurately determine the responses of short circular high-strength CFDST columns.


ABSTRACT: The impact performance of lightweight structures represents an important design criterion in modern applications. Within this framework, the self-reinforced PET (poly-ethylene terephthalate) materials prove to exhibit large deformations till failure, which enables them to be proper candidates for impact energy absorption. Apart from the advantages offered by the lightweight characteristics, they are made of recyclable materials, an additional reason for their consideration in engineering applications. In this paper, the behavior of a hierarchical sandwich structure made out of self-reinforced PET (matrix & fibre) combined with PET foam is numerically investigated with respect to the specific energy absorption (SEA) capacity in out-of-plane quasi-static loading conditions. The numerical model of the structure is developed and its behavior is firstly validated through experimental tests. The specific energy absorption is further on determined for several geometric configurations of the hierarchical sandwich structure and compared with the behavior of other cellular structures found in the technical literature. A competitive behavior is observed with respect to impact energy absorption.

ABSTRACT: The paper presents the findings of a pioneering study investigating the newly developed polymer-aluminium alloy hybrid foam as fillers of thin-walled square tubes made of aluminium alloy, as an alternative to the conventional closed-cell aluminium foams. The hybrid foam filled structures were prepared by infiltrating an aluminium alloy open-cell foam with silicone or epoxy inside the thin-walled tubes. Quasi-static and dynamic crush compressive response, deformation and failure modes and energy absorption characteristics of the hybrid foam filled structures were evaluated and compared to the empty tubes and tubes filled with conventional aluminium alloy open-cell foam (with voids). Results show that the deformation of the square thin-walled is improved due to the open-cell foam filler. It stabilises the tube and prevents the unstable global bending mode or a mixed buckling mode that is considered as an inefficient mode from the crashworthiness point of view. The deformation of the hybrid foam filled tubes was accompanied with a progressive folding mode. It was also observed that the polymer fillers caused the rupture of the outer tube at the corners, which results in higher energy apportion but might limit their application. However, it was found that the most efficient hybrid foam filled structures studied, in terms of crashworthiness, were the tubes filled with the epoxy-aluminium alloy hybrid foam. An increase of 610% and 300% in energy absorption and 78% and 51% in specific energy absorption of hybrid foam filled structures with length of 25 mm and 50 mm in comparison to the empty tubes (at strain of 0.7) was noted, respectively.


ABSTRACT: Steel sections in steel-concrete composite columns have been proofed to be less susceptible to local buckling and have higher capacity than bare steel columns, attributed to the internal restraints provided by the infilled concrete. This article presents a theoretical study concerning the local and post-local buckling of fabricated normal and high strength steel sections filled with concrete, including concrete filled steel tubular (CFST) sections and partially encased composite (PEC) sections. A nonlinear finite element (FE) model was established and validated to simulate the behavior of steel plates in contact with concrete, with both geometric imperfections and residual stresses explicitly incorporated. This model was subsequently applied in a parametric study to investigate the effects of several critical factors on the local buckling behavior of box and I steel sections. Based on the available test and FE results, new design formulas were proposed to predict the local buckling and post-buckling ultimate strengths of concrete-restrained steel box and I sections, taking into consideration high material strengths, residual stresses and geometric imperfections. The enhancement of strength due to the presence of concrete infill was confirmed through a comparison with the post-buckling strength of bare steel sections. Recommendations were also made for design purpose based on the formulas proposed.


ABSTRACT: Stress analysis of thin-walled composite laminated box beams having variable stiffness is realized in this study based on an analytical model accounting for flexural-torsional coupling and warping effects. The variable stiffness of the beam is acquired by constructing laminates with curvilinear fibers having certain specific paths. The fiber paths of variable stiffness layers are classified in three groups as antisymmetric, symmetric and asymmetric. A displacement based finite element method is used to solve the analytical model and to calculate the distributions of axial and transverse shear stresses at different locations of the cantilever composite beam subjected to the transverse and the torsional loading at its free end. Numerical results obtained are compared with available results in the literature for specific cases. A detailed investigation is performed to understand the relation between the stress distributions along the cross section of the beam and the shape of curvilinear fibers for antisymmetric and symmetric cases.

Francesco S. Liguori, Giovanni Zucco, Antonio Madeo, Domenico Magisano, Leonardo Leonetti, Giovanni Garcea and Paul M. Weaver (Primarily from: Dipartimento di Ingegneria Informatica, Modellistica, Elettronica...
ABSTRACT: The stiffness-tailoring capability of Variable Angle Tow (VAT) laminates gives enhanced freedom to design thin-walled structures. One key advantage of tow steering is the ability to redistribute stresses improving buckling performance, leading to reduction in material weight and costs. The aim of this work is to optimise the initial postbuckling behaviour of a recently proposed VAT composite wingbox. The optimisation process is based on a fibre path parameterisation. It involves seeking the stacking sequence that minimises the displacements occurring in the postbuckling regime. This problem is solved by coupling the multi-modal Koiter asymptotic approach implemented with a solid-shell Finite Element environment through stochastic optimisation strategies. Results obtained regarding different optimisation scenarios show a much improved performance for the buckling and postbuckling response of the wingbox with respect to the initial VAT design. Additionally, manufacturing constraints are readily included in the optimisation program. The possibility of performing an efficient and robust optimisation process of a complex structure with a multi-modal Koiter asymptotic approach is demonstrated, showing its viability as a design tool for buckling dominated structures. A parametric study regarding the influence of steering radii shows that overcoming the current manufacturing constraint on minimum radius is worthy of investigation.


ABSTRACT: A number of classic problems in the stability of thin walled structures in the elastic-plastic range which have been examined to some extent by the present author over the years are collected and discussed in order to highlight the advantages and drawbacks of analytical and numerical approaches. Issues related to the modes interaction, to the material modelling and to the imperfection sensitivity are examined with respect to well-known conundrums in the theory of stability and it is shown that the combination of all these aspects is such that any numerical analysis, despite the availability of modern very powerful nonlinear FE packages, must be preceded by a careful examination of the particularities of the problem at hand. In fact, a capable insight into the mechanics of the problem is shown to remain paramount in order to attain a good agreement with experimental results and provide reliable predictions for a large number of engineering tasks.


ABSTRACT: This paper presents an experimental investigation of the mechanical behaviour of the concrete-filled double-skin tube (CFDST) with stiffeners. A total of 40 CFDST columns were prepared and subjected to axial and eccentric loading. The failure modes and ultimate load-bearing capacities, together with the deformation and strain responses of the specimens, were analysed. The effects of the stiffener type, slenderness ratio, and eccentricity ratio were researched in this study. The test results indicated that the ductility of the CFDST specimens was improved greatly by the presence of stiffeners, which gave a lower load-bearing capacity owing to the reduction in the effective area of the inner concrete. Moreover, an analytical-numerical model was developed to analyse the mechanical behaviour of the CFDST specimen, and an improving mechanism was considered. In addition, theoretical estimations to predict the ultimate load-bearing capacities of CFDST specimens subjected to axial and eccentric loading were established. These estimations showed good agreement with the theoretical results and the test results.


ABSTRACT: This study examines the previous experimental results of ratcheting behavior of elbow pipe made of Z2CN18.10 austenitic stainless steel subjected to constant internal pressure and reversed in-plane bending by Chen-Jiao-Kim (CJK) kinematic hardening model as a user subroutine of ANSYS. A set of more precise CJK
model parameters were determined. Based on the new model parameters, the evolutions of ratcheting behavior of pressurized elbow pipe were made under two sets of different loading paths. The paths consist of the alternation of internal pressure and bending moment, and bending-torsion combination under constant internal pressure. The preliminary results claim that different loading paths have a significant effect on ratcheting behavior of pressurized elbow pipe.

ABSTRACT: Variable angle tow (VAT) composites have demonstrated better performance in buckling and post-buckling over straight fiber composites based on the mechanics of load redistribution from critical regions to supported edges. In this work, the dynamic instability behavior of a curved VAT composite panel subjected to periodic axial compression load is investigated. The governing energy functional of a curved symmetric VAT panel under external loading is derived using Donnell's shallow shell theory. Later, the discretized equations of motion are derived using the Rayleigh–Ritz method combined with the generalized differential integral quadrature method (GDIQM). Initially, the pre-buckling problem is solved by applying a uniform compression load to compute the stress resultant distribution which is used to evaluate the buckling load of the curved VAT panel. Subsequently, the dynamic/parametric instability region of a curved VAT panel subjected to periodic axial compression load is determined using Bolotin's first-order approximation. Then, the dynamic instability performance is evaluated for a curved VAT panel with linear fiber angle distribution and compared with straight fiber laminates. Finally, the influence of fiber angle orientation, the radius of curvature, aspect ratio and plate boundary conditions on the dynamic instability of VAT panel is presented.

ABSTRACT: In this paper, comprehensive studies on the size-dependent thermal post-buckling and coupled bi-directional transverse-longitudinal free vibration behavior of post-buckled rotating pre-twisted functionally graded (FG) microbeams in thermal environment are presented. The material properties are assumed to be temperature-dependent and graded in the thickness direction with mid-plane symmetric distribution, i.e., symmetric functionally graded (S-FG). At first, the discretized nonlinear post-buckling governing equations are derived based on the modified strain gradient theory (MSGT) in conjunction with the first-order shear deformation theory (FSDT) of beams under the von Kárman geometric nonlinearity assumptions using Hamilton's principle and Chebyshev-Ritz method. The resulting nonlinear equations under different boundary conditions are solved iteratively by employing Newton-Raphson's method. Then, using the same theories and solution procedure, the free vibration equations around the post-buckled configuration are derived and solved. After validating the approach, the effects of angular velocity, twist angle, length scale parameters, thickness-to-length ratio, hub radius, material gradient index and boundary conditions on the post-buckling equilibrium path and linear free vibration behavior of rotating pre-twisted S-FG microbeams are investigated. The results are prepared for both linear and nonlinear variations of the twist angle along the microbeam axis.

ABSTRACT: This article presents some observations related to the phenomenon that occurs when transversally and longitudinally stiffened steel plate girders are subjected to patch loading. The failure mechanism differs considerably for the particular structural case of girders with largely spaced transverse stiffeners, which have been studied thoroughly in last decades. Steel plate girders with closely spaced stiffeners are occasionally found in bridge design and for such cases, the current EN1993-1-5 rules underestimate the strength of the webs to transverse forces. Research work on girders with closely spaced transverse stiffeners is available but for such cases, the web plates are longitudinally unstiffened. Some comparisons between the results obtained and those
provided by EN1993-1-5 are discussed. Preliminary results suggest that the resistance of densely stiffened steel girders (both transversally and longitudinally) must be studied and subsequently revised accordingly. In addition, it is pointed out that a certain degree of imperfection sensitivity is inferred from the results. Further studies on this topic are necessary.


ABSTRACT: This work presents and discusses numerical results of an ongoing investigation concerning the elastic post-buckling behaviour and imperfection sensitivity of regular convex polygonal cross-section (RCPS) tubular columns affected by local-distortional (L-D) interaction. This investigation is conducted by means of geometrically non-linear Generalized Beam Theory (GBT) analyses, extending the knowledge on the “pure” local and distortional post-buckling behaviours of RCPS tubes recently reported by Martins et al. [1]. Due to their inherent modal nature, the GBT analyses make it possible to acquire in-depth knowledge on the structural behaviour of RCPS tubes and also to include, in a straightforward fashion, arbitrary member initial geometrical imperfections. Columns with distortional-to-local critical buckling load ratios (i) close to 1 (“true L-D interaction” – the most trivial L-D interaction type) and (ii) significantly above 1 (“secondary-distortional bifurcation L-D interaction” – the most relevant L-D interaction type) are investigated. Local/distortional critical-mode initial geometrical imperfections and (linear) combinations of both are considered in the former columns, while only local initial imperfections are dealt with in the latter ones – several amplitudes are dealt with to assess the imperfection sensitivity. For comparison and validation purposes, ABAQUS shell finite element analysis results are also reported.


ABSTRACT: The influence of flexural anisotropy or bend-twist coupling on the buckling performance of CFRP composite plates in compression and shear and thin-walled CFRP composite tubes in torsion is examined in this paper using the finite strip method of analysis. The finite strip formulation employed in the analysis procedure is readily able to deal with the many complexities associated with typical laminated composite construction. Lay-up configurations resulting in membrane anisotropy, flexural anisotropy and membrane-flexural coupling are all easily dealt with. The strip perturbation or buckling displacement fields are postulated to vary sinusoidally along the strip length and algebraically across the strip width and any combination of linearly varying bi-axial tension or compression coupled with in-plane shear loading on the strip can be accommodated. The paper gives an in-depth understanding of the complex buckling mechanics associated with flexural anisotropy in polymer composite construction and highlights the importance of realising the significance of the applied in-plane shear or torque direction on buckling performance. Markedly different stability levels are shown to be in existence for the load cases of positive and negative shear in composite plates and for the clockwise and anticlockwise torsional loading of thin-walled composite tubes. This situation is, of course, not realised in isotropic metal construction or in orthotropic composite construction since such material systems are devoid of the effects of bend-twist coupling.


ABSTRACT: In this study, additively manufactured aluminum thin-walled tubes with different slit dimensions are proposed to improve energy absorption efficiency. A total of 18 samples, which varied in the number of slits, slit length, slit width, and slit ends, were tested under quasi-static axial compression at a rate of
20 mm/min. The deformation and failure modes, load-displacement curves, and a number of crashworthiness factors were investigated. The factors considered included, but were not limited to, the specific energy absorption, crushing force efficiency, and energy absorbed per stroke. The results indicated that all the considered physical parameters, except for the slit ends, had an influence on the crashworthiness of the structures. The initial peak load decreases significantly as the number, width, and length of the slits increase. The bulk of the tested tubes exhibited a crushing force efficiency greater than 0.8. Overall, the presence of slits with length 15 mm and width 5 mm resulted in lower and smoother crushing forces than the straight tubes and, therefore, greater crushing force efficiency, validating them as crashworthy structures.


ABSTRACT: The existing studies on thin-walled structures have focused on structural optimization mainly for enhancing crashworthiness and lightweighting, whilst relatively little attention has been paid to analysis of cost efficiency of an optimized structure. How to develop cost-effective products has always been a primary goal pursued by enterprises in different ways. To address this issue, this study aims to elucidate a systematic approach for exploring the effects of various material grades and structural dimension (e.g. wall thickness) on cost efficiency relative to the crashworthiness performance by taking the double-hat (DH) thin-walled structure as an example. First, a series of drop-weight tests for the DH structure are carried out under axial and lateral impacts. The experimental results show that different material grades and dimensions have different effects on the crashworthiness under different impact velocities. Second, the finite element (FE) models are established and validated with the experiments to analyze the effects of the three factors (wall thickness, material grade, and impact velocity) on the crashworthiness criteria. Third, the surrogate models for each crashworthiness performance indicator and cost efficiency (namely, specific energy absorption – SEA, bending moment – Mb, SEA/cost and Mb/cost) are constructed by using the regression technique. Finally, the combined effects of material grade and structural dimension on cost and performance are analyzed and compared respectively; and the results show that there is room to significantly reduce production cost without sacrificing the crashworthiness performance. For mass production implemented in modern automotive industry, the proposed design methodology allows to better balance performance and cost.


ABSTRACT: The existing studies on thin-walled structures have focused on structural optimization mainly for enhancing crashworthiness and lightweighting, whilst relatively little attention has been paid to analysis of cost efficiency of an optimized structure. How to develop cost-effective products has always been a primary goal pursued by enterprises in different ways. To address this issue, this study aims to elucidate a systematic approach for exploring the effects of various material grades and structural dimension (e.g. wall thickness) on cost efficiency relative to the crashworthiness performance by taking the double-hat (DH) thin-walled structure as an example. First, a series of drop-weight tests for the DH structure are carried out under axial and lateral impacts. The experimental results show that different material grades and dimensions have different effects on the crashworthiness under different impact velocities. Second, the finite element (FE) models are established and validated with the experiments to analyze the effects of the three factors (wall thickness, material grade, and impact velocity) on the crashworthiness criteria. Third, the surrogate models for each crashworthiness performance indicator and cost efficiency (namely, specific energy absorption – SEA, bending moment – Mb, SEA/cost and Mb/cost) are constructed by using the regression technique. Finally, the combined effects of material grade and structural dimension on cost and performance are analyzed and compared respectively; and the results show that there is room to significantly reduce production cost without sacrificing the crashworthiness performance. For mass production implemented in modern automotive industry, the proposed design methodology allows to better balance performance and cost.


ABSTRACT: This paper is mainly focused on the longitudinal residual stress of cold-formed thick-walled square hollow section (SHS) and rectangular hollow section (RHS) annealed and non-annealed steel tubes. The sectioning method was used to study the longitudinal residual stress. It was found that the longitudinal residual
stress consisted of bending and membrane components and the magnitude of residual stress was mainly influenced by factors such as thickness \((t)\), depth to thickness ratio \((D/t)\), depth to outer radius ratio \((D/R)\), yield strength of flat plate \((f_y)\) and tensile strength to yield strength ratio of flat plate \((f/f_y)\). On this basis, the distribution models were proposed separately for annealed and non-annealed specimens and it was proved to have a high accuracy. Finally, a comparison was made between the annealed and non-annealed specimens and it was found that the bending and membrane residual stress of annealed specimens could be reduced by about 80% and 50% respectively which means that the annealing process could significantly reduce the longitudinal residual stress.


ABSTRACT: This paper presents the generalisation of an energy-based method for the modal decomposition of buckled shapes of thin-walled members. This comprehensive method is derived and validated for fully decomposing the elastic buckling solution of a thin-walled member into the pure buckling mode classes of global, distortional, local, shear and transverse extension. The first three modes are de-facto prerequisites for buckling capacity predictions found in current design standards for thin-walled structures. In the literature, two main methods, namely the generalised beam theory (GBT) and the constrained finite strip method (cFSM), are widely employed for modal decomposition. Recently, an alternative energy-based approach has been presented for the decomposition of buckling modes into the classical local, distortional and global modes. This method is generalised in the present study to achieve a complete decomposition that also accounts for shear and transverse extensional modes in addition to global, distortional and local modes. In this method, each of the buckling classes is separated by imposing constraints that are defined by enforcing specific criteria on the total strain energy of the member. The adopted criteria are based on the fundamental mechanical assumptions of the GBT which were also implemented in the conventional cFSM and later were further detailed for modal classification in the generalised cFSM. This paper is accompanied by a paper in which derivation of a modified global torsion mode for sections with closed loops is presented and the applicability of the proposed method is demonstrated using a series of numerical examples.


ABSTRACT: This paper is a companion to (Khezri and Rasmussen, 2019) [1], where the generalised strain energy-based method for the modal decomposition of buckled shapes of thin-walled members is introduced. The paper presents the application of the proposed method for full modal decomposition to various thin-walled members. A series of numerical examples are presented in order to verify the robustness and capabilities of the proposed modal finite strip method (mFSM). In addition, the problem of global torsional modes in sections with closed cell(s) is revisited in this paper. In sections with closed loops, the classical global torsion modes does not exist due to presence of in-plane shear strains. In the context of the proposed energy-based method, a modified global torsion buckling mode is derived that allows for the occurrence of shear in closed cell. The pure global buckling curves obtained incorporating the modified global torsion base vectors are compared with the generalised constrained FSM (cFSM) and generalised beam theory (GBT) results. It is shown that the proposed modal decomposition method is capable to accurately capture the modal behaviour of thin-walled sections.


ABSTRACT: To obtain a strong and weight-efficient cylindrical column, we proposed a novel foam core sandwich-walled hollow column reinforced by stiffeners (FSCRS). The FSCRS was consisted of glass fibre-reinforced polymer (GFRP) faces, polyvinyl chloride (PVC) foam core, and GFRP stiffeners. Four full-diameter specimens, including two FSCRS and two traditional foam core sandwich-walled hollow columns (FSC), were

ABSTRACT: This paper presents the results of an experimental and numerical study of the behavior of circular hollow section (CHS) steel tubes strengthened by Aramid fiber-reinforced polymer (AFRP). The aramid fiber used for this experiment is available under the trade name of Kevlar 49. In this study, thin-walled circular steel tubes externally bonded with fiber in the hoop direction were tested under axial compression to examine the effects of the AFRP thickness, on their axial load carrying and shortening capacity. The three-dimensional finite element models (FEM) of AFRP strengthened circular hollow section (CHS) was developed using ANSYS Workbench Ver. 19.0 and ACP (ANSYS Composite Prep/Post) tool considering both geometric and material nonlinearities. The effects combined of AFRP damage and interlaminar failures for the bonded interface are modeled within FEM using “Hashin” failure criteria and Cohesive Zone Model (CZM), respectively, to provide an accurate simulation. The results involving the failure modes, load vs. axial shortening curve and ultimate load capacity, were obtained from the experimental and numerical simulation and compared for validation. Both the experimental and numerical results are consistent, demonstrating that AFRP external strengthening can considerably enhance the strength of steel tube columns by 96% for short tubes and 23% for long tubes using 3 mm thickness of AFRP.

Minhao Dong, Mohamed Elchalakani, Ali Karrech, Mostafa Fahmi Hassanein, Tianyu Cie and Bo Yang (First author is from: School of Civil, Environmental and Mining Engineering, The University of Western Australia, WA 6009, Australia), “Behaviour and design of rubberized concrete filled steel tubes under combined loading conditions”, Thin-Walled Structures, Vol. 139, pp 24-38, June 2019, https://doi.org/10.1016/j.tws.2019.02.031

ABSTRACT: Rubberised concrete has the benefit of utilising waste material, preventing resource extraction and improving concrete ductility, however at the cost of reduced strength and stiffness. This paper explored the option to effectively confine the rubberised concrete with steel tubes to obtain enhanced strength and ductility. The behaviour and performances of thirty rubberised concrete-filled single-skin steel tubes of various rubber content, steel section and load eccentricities was systematically investigated in this study. The results have shown that confined rubberised concrete and the restrained steel tube improved ductility of the composite section. The rubberised concrete was more effective in delaying the premature buckling failure of the steel tube compared to the more brittle normal cement concrete. The 15% rubber replacement ratio showed a good balance of strength and ductility and thus recommended for design of roadside barriers. The behaviour of the rubberised concrete filled steel tubes could be accurately predicted using existing design guidelines and safe designs can be produced. This study demonstrated the possibility of using rubberised concrete as a solution to problems that require high moment and deformation capacity, such as the roadside barriers and columns in buildings located in seismic active zones.


ABSTRACT: Taking the von Kármán geometrically nonlinearity into account, this paper presents a nonlinear finite element formulation of axially functionally graded (AFG) tapered microbeams, which is based on the modified couple stress and Euler–Bernoulli beam theory. The profiles of physical parameters such as elasticity modulus and mass density of the microbeam are assumed to be a simple power-law form along the length direction, while either width or height of the beam changes linearly in axial direction. The size-dependent
nonlinear free vibration of AFG non-uniform microbeams is analyzed by using finite element simulation. The correctness of the present analysis is validated by comparing computed results with those available for AFG tapered beams. The effects of vibration amplitude, variation of the taper ratio in cross section and gradient index of material along the length and material length scale parameter as well as boundary conditions on nonlinear fundamental frequency are discussed.


ABSTRACT: The paper investigates the stability and post-buckling states of compressed thin-walled composite struts with predamage as a result of low-velocity impact. The struts were made of a GFRP composite material with a symmetrical lay-up by the autoclave technique. The produced channel-section struts were subjected to 20J impact in different areas of the structure: on the web and on the flange. The struts with composite damage were subjected to axial compression to investigate the effect of composite material damage on the stability and operation of the structure in the post-buckling range. A numerical analysis was performed by the finite element method to compare two models of composite material damage: the proposed Simplified Damage Model (SDM) and the model developed by Fardin Esrail and Christos Kassapoglou. The limit load when the structure loses its stability was determined by the progressive failure criterion, according to which damage initiation in the composite material is based on the Hashin criterion while damage evolution is described with the energy criterion.


ABSTRACT: Stainless steel tube confined concrete (SSTCC) stub column is a new form of steel-concrete composite column in which the stainless steel tube is used to confine the core concrete without resistance to the axial load directly. It could take the advantages of both the stainless steel tube and the steel tube confined concrete columns. This paper presents the experimental investigation of circular SSTCC stub columns subjected to axial load. Meanwhile, comparative tests of the circular concrete-filled stainless steel tubes and circular hollow stainless steel tubes were also conducted. The experimental phenomena of specimens are introduced in detail and the experimental results are analyzed. Through the investigation of axial stress and hoop stress on the stainless steel tube, the interaction between stainless steel tube and core concrete is studied. The experimental results showed that the stainless steel tube provides confinement to the core concrete, increasing the compressive capacity of core concrete significantly. In addition, the confinement of stainless steel tube in SSTCC stub columns is larger than that in concrete-filled stainless steel tubes. Therefore, the load-carrying capacity of SSTCC columns is higher than that of concrete-filled stainless steel tubes. Besides, an equation was proposed to calculate the load-carrying capacities of SSTCC columns and concrete-filled stainless steel tube columns. The calculated results agree well with the experimental results.


ABSTRACT: A non-linear theory for straight thin-walled box beam (STBB) subjected to an eccentric force, considering the distortional deformation and unequal thickness of the webs, is developed to determine the buckling capacity in this paper. Due to the coupling of warping, torsion and distortion of the cross-section, the kinematic model becomes considerably complicated. The theory considers the geometric non-linear coupling caused by the non-linear terms in each deformation mode under the generalized displacement coordinate. The non-linear differential equations is discretized by Galerkin's method, which has been shown that the interaction effects can be successfully captured between the pre-buckling deflections and geometric non-linearity. The post-buckling response of the present beam model is compared with the results of the finite element simulation.
(Ansys 15.0) and F. Mohri’s method (2002), which appears to be very conservative. The formulation is solved exactly by checking the effect of the variable parameters: the width-to-height ratio of the cross-section, the load height and the thickness of the webs. The viability and effectiveness of this method has been established by comparing with other existing numerical solutions.

Haogui Fan (School of Chemical Machinery and Safety Engineering, Dalian University of Technology, No. 2 Linggong Road, Dalian, Liaoning 116023, PR China), “Critical buckling load prediction of axially compressed cylindrical shell based on non-destructive probing method”, Thin-Walled Structures, Vol. 139, pp 91-104, June 2019, https://doi.org/10.1016/j.tws.2019.02.034

ABSTRACT: Critical buckling load prediction of axially compressed cylindrical shell is investigated based on the non-destructive probing method in this paper. Finite element model of the cylindrical shell under combined axial load and radial probe is established using ABAQUS and the static modified Newton-Raphson method that uses artificial damping is chosen in the geometrically and materially nonlinear buckling analysis. By the means of repeatedly probing the shell under different prescribed axial loads, the three-dimensional representation of probe force, probe displacement and prescribed axial load is established. Based on that, the critical buckling load of the shell is predicted by the fitting curve that reflecting the relationship between the maximum probe force and the prescribed axial load. Applying this prediction method, the perfect cylindrical shell, the cylindrical shells with dimple-shape imperfections and the cylindrical shell with measured imperfections have been studied. All of the predicted results are compared with the real critical loads in buckling behavior of the shells under axial compression. Effects of poker size and probing location on the prediction results are analyzed. Results show that the critical loads for the first buckling pattern of the cylindrical shells with notable local imperfections can be predicted accurately when the shell is probed at the location with the largest imperfection amplitude. If the shell is probed away from that area, the predicted result will become much larger. Compared to the probing location, the poker size has little effect on the prediction results. For the cylindrical shell with measured imperfections, probing at the location with largest imperfection amplitude has achieved the most accurate prediction result. Besides, the predicted critical buckling loads obtained by probing at other locations are also acceptable. It is believed that for a general cylindrical shell without notable local defects, the smallest one of different predicted results obtained by probing a series of representative locations on the cylindrical shell could be regarded as the critical buckling load.


ABSTRACT: The behaviour of square steel tube confined reinforced concrete columns after fire exposure was studied experimentally and numerically in this paper. Eighteen stub columns were first heated following the ISO 834 standard fire including both heating and cooling phases, and were subsequently loaded to failure after cooling to ambient temperature. Failure modes, temperatures in specimens, axial load versus deformation curves and strains in steel tube were monitored and discussed. A finite element model was developed using the sequentially coupled thermal-stress analysis method and was validated against tests found in literatures and this study. Parametric study was performed to identify influences of key parameters, where are heating time, cross-sectional dimension, strengths of materials, steel tube to concrete area ratio and reinforcement ratio, on residual capacity and compressive stiffness. Finally, a simplified method is proposed for predicting residual cross-sectional capacity and compressive stiffness of square steel tube confined reinforced concrete columns after fire exposure.

Sadjad Pirmohammad and Sobhan Esmaeili-Marzdashti (Department of Mechanical Engineering, Faculty of Engineering, University of Mohaghegh Ardabili, Ardabil 179, Iran), “Multi-objective crashworthiness optimization of square and octagonal bitubal structures including different hole shapes”, Thin-Walled Structures, Vol. 139, pp 126-138, June 2019, https://doi.org/10.1016/j.tws.2019.03.004

ABSTRACT: This paper investigates the effects of hole shapes and dimensions on crashworthiness performance of the square and octagonal bitubal structures under impact loading. Several holes with three different shapes including rectangle, hexagon and ellipse are considered on the walls of the square and octagonal structures. For these structures, crashworthiness indicators SEA and PCF are numerically obtained.
using finite element code LS-DYNA. Based on the results, a significant improvement on the crashworthiness capacity is achieved by employing the technique of creating holes on the walls of structures; such that the hexagonal holes created on the square and octagonal bitubal structures improve the crashworthiness capacity by 60% and 42%, respectively in comparison to the corresponding conventional structures. Interestingly, all the holed structures show less PCF compared to those without hole. In the next phase, the hole dimensions are optimized using NSGA-II (non-dominated sorting genetic algorithm) and ANNs (artificial neural networks) methods to find the optimal structures. The SAW (simple additive weight) method is then implemented on the optimal structures, and the square and octagonal structures having the hexagonal holes are finally found as the best and superior energy absorbing devices. The effect of oblique loading on crushing behavior of the holed structures is also considered. According to the results, the holes created on the structure walls improve the crashworthiness capacity of structures under oblique loading, as well.

Ji-Hua Zhu, Zi-qi Li, Mei-Ni Su and Ben Young (First author is from: Department of Civil Engineering, Shenzhen University, Shenzhen, China), “Numerical study and design of aluminium alloy channel section columns with welds”, Thin-Walled Structures, Vol. 139, pp 139-150, June 2019, https://doi.org/10.1016/j.tws.2019.03.015

ABSTRACT: This paper presents a numerical investigation on aluminium alloy welded columns of channel section. Non-linear finite element models were firstly developed and validated against non-welded column test results. The materials considered in this study were aluminium alloys 6063-T5 and 6061-T6. The validated finite element models were used for parametric studies to generate numerical results for columns containing welds. In the finite element models, both ends of the columns were transversely welded to aluminium alloy end plates. Finite element models of welded columns were developed by dividing the column into two part: non-welded region and heat-affected zones. Material properties of non-welded aluminium alloys and heat-affected zone were adopted in the models. A total of 100 numerical results were newly generated from the parametric study. The numerical results were compared with design strengths predicted by the existing American, Australian/New Zealand, European and Chinese standards. The column strengths were also compared with the design strengths by the direct strength method (DSM) and the continuous strength method (CSM). Modified DSM and CSM approaches with the consideration of heat-affected zone softening effects were proposed in this study. Both modified DSM and CSM approaches were found to yield more accurate and consistent predictions for aluminium alloy welded columns. In addition, reliability analyses were performed to evaluate the reliability level of all the existing and newly proposed design rules for channel section columns containing transverse welds.


ABSTRACT: The local buckling behaviour and ultimate cross-sectional resistance of slender tubular elliptical profiles in bending are examined by means of numerical modelling. After successful validation of the numerical model against previous experimental results, a parametric study comprising 240 simulations was conducted in order to investigate the influence of cross-section aspect ratio, axis of bending, geometric imperfections and local slenderness on structural behaviour. The ultimate moments, moment–curvature relationships and failure modes obtained are discussed. It was found that, overall, postbuckling stability increases and imperfection sensitivity decreases with increasing elliptical hollow section (EHS) aspect ratio. A design method is proposed for Class 4 EHS members that reflects the reduction in resistance due to local buckling with increasing slenderness and extends the range of applicability of existing provisions. A reliability analysis was performed in accordance with EN 1990, indicating that the design methods for EHS in bending, in addition to previous design methods for EHS in compression, are suitable for use in the Eurocode framework with a recommended partial factor of unity.

ABSTRACT: In this study, three-dimensional problem of the theory of elasticity (3DPTE) for radially inhomogeneous (INH) transversally-isotropic thin hollow spheres is investigated using the asymptotic integration method. The basic relations and equilibrium equations for radially inhomogeneous transversally-isotropic thin hollow spheres are formed and inhomogeneous solutions (INHSs) and homogeneous solutions (HSs) are constructed. The built solutions completely reveal the qualitative structure of a three-dimensional stress-strain state of radially inhomogeneous transversally-isotropic spheres of small thickness and serve as an effective apparatus for solving boundary value problems, the basis for evaluating existing applied theories and for creating new, more refined applied theories. Asymptotic formulas are obtained that allow the calculation of the three-dimensional stress-strain state of spheres. New solution groups (boundary layer solutions) have been found that are absent in applied theories. The behavior of homogeneous solutions in the inner parts of the sphere and in the vicinity of conical sections has been studied, when the thin-walled parameter of the sphere tends to zero. The nature of the constructed homogeneous solutions is clarified. On the basis of the theoretical analysis, three types of the stress-strain state (SSS) in the radially inhomogeneous transversally-isotropic hollow spheres (RINHTIHSs) are considered: a penetrating stress state, a simple edge effect, and a boundary layer. Finally, numerical calculations are made and the influences of inhomogeneity on the stress distributions are investigated.


ABSTRACT: This paper reports an in-depth and extensive numerical investigation aimed at assessing the accuracy of the current Direct Strength Method (DSM) design curve in predicting the failure load of cold-formed steel columns collapsing in global modes, namely flexural or flexural-torsional modes. This study concerns fixed-ended columns with a wide variety of cross-section shapes: plain channels, lipped channels, double-fold (return) lipped channels, web-stiffened lipped channels, web/flange-stiffened lipped channels, lipped zed-sections, hat-sections, rack-sections and I-sections (formed by back-to-back plain channels). The first part of the work is devoted to plain channel columns and starts with a parametric study aimed at gathering failure loads of columns with continuously varying geometries and yield stresses, so that they (i) buckle in either major-axis flexural-torsional or minor-axis flexural modes and (ii) cover a wide slenderness range. These failure loads are then used to assess the quality of their predictions yielded by the codified global DSM design and to propose modifications to improve this quality. The second part of the work employs the modified DSM-based global design curves, as well as the current one, to predict a fairly large number of numerical failure loads of columns exhibiting the remaining eight cross-section shapes. This extensive parametric study shows that the failure load predictions provided by the proposed/modified DSM global strength curves (i) have very high quality and, for the columns considered, (ii) clearly outperform those yielded by the current design curve. In addition, the advantages and disadvantages of the proposed DSM global design curves are also discussed.


ABSTRACT: The force-displacement curve of circular tubes under lateral crushing load is typically divided into three stages. However, the plateau force actually shows a linearly increasing trend under compression load. As a matter of fact, a stable plateau force is remarkably important for the energy absorption devices. In an effort to overcome this drawback, this paper proposes an internally nested energy absorption system consisting of a circular tube and an elliptical tube, and it is promising to replace the single circular tube as the dominated impact protective structure in the helicopter seats. The experimental investigations of the circular tubes, the elliptical tubes and the nested circular-elliptical tube system (CETS) are carried out to study the mechanical behaviors of the tubes subjected to the lateral crushing load. In addition, an analytical model for the CETS is established on the basis of the rigid-perfectly plastic material model. The results indicate that the plateau force of the circular-elliptical tube system is extremely stable while the single circular or elliptical tubes has the plateau forces linearly increasing or decreasing. Besides, the 3D finite element model of the nested tube system is developed through LS-DYNA, and it is also validated by comparison with the experimental result of the CETS. Based on the numerical simulations, a parametric investigation is conducted to understand the effect of
the internal radius of the circular tube, the ovality of the elliptical tube, the number of elliptical tube and the impact velocity on the mechanical response and crashworthiness characteristics for the CETS.

Miguel Ormeno, Tam Larkin and Nawawi Chouw (Department of Civil and Environmental Engineering, Faculty of Engineering, the University of Auckland, New Zealand), “Experimental study of the effect of a flexible base on the seismic response of a liquid storage tank”, Thin-Walled Structures, Vol. 139, pp 343-346, June 2019, https://doi.org/10.1016/j.tws.2019.03.013

ABSTRACT: Previous studies have demonstrated that strong earthquakes can cause severe damage to storage tanks. In many countries tanks are built near the coast on soft soils. Because of the difference in stiffness between the tank (rigid) and the soil (flexible), the soft soil causes an elongation in the period of the impulsive mode of the soil-foundation-tank system and, therefore, this flexible base can have an important effect on the seismic response. Numerical studies by other researchers have shown the influence of a flexible base on the seismic response of storage tanks. However, experimental investigation on the effects of a flexible base using sand box on the key design parameter, i.e. stress developed in the tank shell, has not been reported. In this research shake table experiments were performed. Sand in a box is used to simulate the flexible base. Actual earthquake records scaled to the New Zealand design spectrum for Wellington City are used. The results showed that in comparison with the rigid base case (model placed directly on the shake table) the axial compressive stresses decreased. The experimental results are corroborated by a numerical model.


ABSTRACT: A generalized theory is formulated for the analysis of thin shells of general curvatures based on the variational form of the Hamiltonian functional in conjunction with tensor calculus. Simplifying approximations and subtle inconsistencies made at the early stages of common classical formulations are avoided herein, and hence, the present treatment leads to field equations and boundary conditions that are accurate and consistent. The theory is then specialized to circular cylindrical shells. The well-known field equations of Flugge and Donnell-Mushtari-Vlasov (DMV) theories are recovered as consistent approximations from the present theory. Closed form solutions are then developed for the present and past cylindrical shell theories by Flugge, Timoshenko, and DMV. A comparative study is conducted to assess and quantify the effects of approximations made in classical theories on the predicted displacements and stresses.


ABSTRACT: This study reports the formulation of a realistic aircraft wing model based on thin-walled composite beam theory. In this model, NACA 4-digit-series airfoils were selected for the wing-section. The circumferentially asymmetric stiffness lay-up was implemented and two different sets of coupling systems corresponding to the proposed model were utilized. The eigenvalue problem was solved by the extended Galerkin method and the natural frequencies were computed as a function of the ply angle. The results of the free vibration analysis along with the governing system of the proposed model contributes to the theory of anisotropic thin-walled beams, emphasizing the importance of thin-walled structures in the design of advanced aeronautical structures.


ABSTRACT: This paper presents a novel technique for the nonlinear dynamic instability analysis of graphene-reinforced composite (GRC) laminated plates resting on an elastic foundation and in thermal environments. The GRC layers are arranged in a piece-wise functionally graded (FG) pattern along the plate thickness direction and each layer of the plate contains different volume fractions of graphene reinforcement. The material properties of a GRC layer are assumed to be temperature-dependent and are estimated by the extended Halpin–
Tsai micromechanical model. The governing equations are based on a higher-order shear deformation plate theory with the geometric nonlinearity being defined by the von Kármán strain-displacement relationships. The plate-foundation interaction and thermal effects are also included. The novelty of this study is that the motion equation and the postbuckling equilibrium equation are derived by a two-step perturbation technique and are then solved simultaneously to determine the dynamic in-plane load and frequency uniquely for a given plate amplitude. The numerical illustrations reveal the nonlinear dynamic instability responses of FG-GRC laminated plates under different sets of thermal environmental conditions, from which results for uniformly distributed (UD) GRC laminated plates are obtained as comparators.


ABSTRACT: This work studies the nonlinear post-instability responses of in-plane bi-directional functionally graded (FG) simply-supported and clamped thin panels. The post-flutter responses of panels subjected to a supersonic airflow are considered as the dynamic case and the post-buckling responses as the static case. The effect of thermal and mechanical in-plane loadings on the panels’ stability and post-instability is analyzed. The first-order piston theory is used for the aerodynamic modeling and the classical plate theory (CPT) along with the nonlinear von-Karman’s strains for the structural modeling. The finite element method (FEM) is used for the analysis. The responses of the functionally graded panels are compared to those of the homogeneous panels. Magnesium reinforced by Silicon Carbide nanoparticles composite is considered in this work because of its high stiffness to weight ratio giving it a great potential for aerospace applications. The high stiffening effect of the nano-reinforcements allows the multi-dimensional material grading to maximize the panels’ performance using the minimum amount of the nano-reinforcement.


ABSTRACT: A unified semi-analytical method is presented to study free and forced vibrations of arbitrary shells of revolution stiffened by rings with T cross-section. Combined shells of revolution and rings with rectangular and L cross-sections are included in the titled structure. The ring-stiffened shell is firstly decomposed to several shell segments and rings with T cross-section according to intersections between the shell and rings, and shell segments are further divided into some narrower segments to be treated as conical shells. Rings with T cross-section are modeled as two cylindrical shells (left and right flanges) and one annular plate (web), rather than conventional curved beams. Conical segments, cylindrical segments and annular plates are uniformly analyzed by employing Flügge thin shell theory and expanding displacements as power series. To consider both classic and elastic boundary conditions, the artificial spring technology is employed to restrain displacements at edges. Then, boundary conditions at two edges and a set of continuity conditions of adjacent segments are assembled to the final governing equation. Through comparing free and forced vibration results of present method with the ones in the literature and calculated by finite element method, rapid convergence and high accuracy are demonstrated. Furthermore, effects of elastic boundary conditions and rings are discussed. Results reveal that mode shapes of shells are significantly affected by rings with T cross-section, and in-plane and out-plane deformations of the web of rings cannot be neglected, especially for rings with large height.


ABSTRACT: Thin-walled structural members have complex behavior. It is usual to interpret the complex behavior as the superposition of simpler behavior components, like global, distortional, local, in-plane shear and transverse extension. When the standard shell finite element method is employed for the analysis, the behavior components are not separated, and the results can be difficult to interpret due to the complexity of the deformations. The results are more meaningful if identified, i.e., if the participations of the behavior components are quantified. Methods for the formal identification of the deformations have already been
proposed, by using either the modes of generalized beam theory, or the basis functions of the constrained finite strip method. In this paper a newer and more general method, the constrained finite element method is used. Since this method can handle a wide range of thin-walled members, including members with holes, or members with varying cross-sections, or even stiffened plates, the identification can readily be applied to various thin-walled members. In the paper some particularities of the identification method are highlighted, as well as several sample examples are presented and discussed.

ABSTRACT: Cold-formed steel sections are used in many different shapes based on their applications. Recently, a new C-section known as SupaCee was introduced in Australia with higher flexural capacities compared to traditional channel sections. However, all cold-formed steel sections are vulnerable to web crippling failures due to their higher plate slenderness. Australian/New Zealand (AS/NZS 4600) and North American (AISI S100) Standards use a unified web crippling design equation with four coefficients while Eurocode 3 Part 1.3 uses different design equations to predict the web crippling capacities of cold-formed steel sections. The web crippling coefficients were developed based on the experimental studies undertaken since the 1940s. These experimental studies utilised different test set-ups and specimens lengths and hence the accuracy of predictions using these coefficients may be inadequate. No coefficients are available for unliped channel sections with fastened supports and high strength SupaCee sections while the same coefficients are used for lipped channels with fastened and unfastened supports. To address these shortcomings, the web crippling behaviour of unliped and lipped channel and SupaCee sections was experimentally investigated based on recently developed AISI S909 web crippling test guidelines. Finite element analyses were then performed to extend the range of cold-formed steel sections. Using the web crippling capacity results from both experiments and finite element analyses, new equations were proposed to determine the web crippling capacities of lipped and unliped channel and SupaCee sections. Suitable direct strength method based web crippling design equations were also developed. This paper presents the important details of several detailed web crippling studies undertaken recently including a suite of web crippling design equations that can be adopted in relevant cold-formed steel standards.

ABSTRACT: Cold-formed steel (CFS) built-up members are formed by connecting several single members by fasteners. This paper presents experimental, numerical and analytical studies on the effect of fastener configurations on the flexural rigidity of built-up sections. In this research, two zinc-coated steel C-sections are connected back-to-back to form a double-web built-up I-section, which is subject to weak-axis bending. A closed-formed expression for the flexural rigidity of built-up sections as a function of fastener stiffness, number and position of fasteners, and section geometry is then derived. This is validated against the tests and finite element modelling, and can be adapted more generally to determine the stiffness and global strength of CFS built-up members in bending.

Benjamin W. Schafer (Johns Hopkins University, USA), “Advances in the Direct Strength Method of cold-formed steel design”, Thin-Walled Structures, Vol. 140, pp 533-541, July 2019, https://doi.org/10.1016/j.tws.2019.03.001
ABSTRACT: Twenty years ago, the Direct Strength Method (DSM) was first proposed as an efficient alternative to traditional design methods for thin-walled cold-formed steel (CFS) structural members. DSM may be regarded as one implementation of a class of generalized slenderness methods that are used in structural design. The objective of this paper is to provide additional context on how DSM-based design fits within past design knowledge and summarize the current state of development and future potential of the approach. Although DSM is regarded as a relatively new member design approach, its fundamental principles have long been used to explore relationships between stability, material yielding, and strength. The first ten years of DSM development (1998–2008) focused largely on simple prismatic CFS members under single actions and was conducted by a small group of researchers. In the last ten years of DSM development both the scope of DSM-

ABSTRACT: This paper presents an experimental investigation on the cyclic behaviors of ultra-high performance steel fiber reinforced concrete filled thin-walled steel tubular columns under combined axial compression and cyclic lateral displacement loading. The failure modes, hysteretic behaviors, envelop diagrams, ductile performance, stiffness degradation and energy dissipation capacity were analyzed in detail. Notably, the cyclic behaviors of referenced high strength concrete and normal strength concrete filled thin-walled steel tubular columns were also studied to get a better illustration of the cyclic behaviors of ultra-high-performance steel fiber reinforced concrete filled thin-walled steel tubular columns. Furthermore, the effects of steel tube thickness, axial compression ratio, volume ratio of steel fiber and slenderness on the cyclic behaviors of ultra-high-performance steel fiber reinforced concrete filled thin-walled steel tubular columns were also investigated in detail. The test results indicate that the high strength concrete filled thin-walled steel tubular columns represent a poor cyclic behavior. However, replacing high strength concrete with ultra-high performance steel fiber reinforced concrete to infill thin-walled steel tubes can get an excellent cyclic behavior. Moreover, the cyclic behavior of ultra-high performance steel fiber reinforced concrete filled thin-walled steel tubular columns is also much better than that of normal strength concrete filled thin-walled steel tubular columns.


ABSTRACT: This paper presents finite element investigations on the structural behaviors of circular concrete-filled aluminum tubular (CFAT) stub columns under axial compression. The finite element models are developed by considering the nonlinearities of concrete and aluminum materials and the interactions between the two components. The predicted ultimate strengths, load-axial strain relationships and failure modes are compared to those from collected experimental data. Full range analysis on the load-deformation N-ε are conducted, where the investigations on the multi-axial stress conditions of the aluminum tube and the interaction stress between the aluminum tube and concrete core are included. The verified finite element models are used to carry out a series of parametric studies on key material and geometric properties. The ductility index DI and strain at ultimate strength εu are studied. Equations to determine εu for circular CFAT stub columns are proposed. The applicability of the existing design method for CFST to CFAT stub columns is investigated.


ABSTRACT: The use of bi-tubular structures has gained importance in the design of energy absorption systems for protection of passengers in train collisions. Therefore, it is critical to improve the crashworthiness performance of bi-tubular profiles. For this purpose, the effect of cross-section, bi-tubular clearance and holes as crush initiators is evaluated using finite element simulations. To get reliable outcomes, special emphasis was set on the progressive damage modelling of aluminum 6063-T5 by a Johnson-Cook (J-C) failure model. During
the cross-section study, bi-tubular arrangements based on polygonal and circular cross-section were evaluated by quasi-static compression loads. The results indicate that the circular shapes showed better crashworthiness performance or crush force efficiency (CFE) up to 12.28% respect to a square base structure. A 10.72% improvement in CFE was obtained when the non-dimensionalized clearance between profiles is increased from Lambda=20 to Lambda=40. The effect of holes on crashworthiness performance was evaluated by drilling holes at different locations both in the inner and outer profiles. The results show that the use of holes increased the crush force efficiency and energy absorption (E) capability even more than the effect of clearance alone. Improvements in the order of 2.50% and 12.96% for E, and CFE respectively were computed when holes were placed at the top end of a BC-3 profile with a non-dimensional clearance of Lambda=40. Considering all effects simultaneously, an increase of 24.6% and 26.31% for E, and CFE respectively was calculated. Finally, an application to a crash buffer in a railway transport system is considered. Likewise, its improved crashworthiness behavior is presented.

ABSTRACT: Arch structures made of double corrugated steel sheets, known as K-span, are used as self-supporting building roofs. The cold-rolling method of arch panel production causes the creation of deep-press formed transverse corrugation. The unusual profile shape significantly impedes the use of known design methods. In extreme cases, this might lead to the failure and collapse of K-span structures. This paper presents a method for testing full-size K-span structures using various measuring techniques, and provides a method of numerical analysis of the double corrugated structures. The results of the tests were compared with the results of the numerical analysis to assess the validity of the assumptions made for the calculations. A comparison of the test results and the numerical analyses helped to give practical guidelines for evaluation of the load capacity and stability of double corrugated K-span structures.

ABSTRACT: The multistable elastic behavior of a shallow dome with a cosine-curved profile is investigated in this work. The dome exhibits snap-through instability and could be used as a building block for energy dissipation mechanism in structures subjected to cyclic loading and high deformation demands. Numerical and experimental studies were carried on the geometric and material properties of the cosine-curved domes (CCD) under concentrated load at the apex. Finite element analyses (FEA), validated by experimental tests on 3D printed specimens, were conducted to study the controlling geometric and material properties of the CCD. Three types of response were recognized and discussed based on the force- and strain energy-displacement curves. Limitations on the geometric parameters that govern the recoverability of the original shape and the stability state upon load removal are also identified. In addition, empirical relations to estimate the limit-point load and displacement, and to characterize the snap-through response were developed. Good agreement was observed using the determined limits on the geometric parameters and the developed relations with the results from FEA and experimental tests.

ABSTRACT: The paper presents a general theoretical framework to investigate the dynamic behavior of rotating doubly-curved shell structures made of Functionally Graded Materials (FGMs). A clear advancement of the present formulation is the possibility to apply a rotating speed (angular velocity) about a general axis of the global reference system. It is important to underline that this aspect is innovative with respect to the previous studies proposed in the literature, in which the angular velocity is only applied about the revolution axis the shell. Furthermore, several Higher-order Shear Deformation Theories (HSDTs) are used to investigate the problem at issue. The results of various numerical applications are presented to discuss the effect of the choice of the axis of rotation, as well as the geometric features of the shells, on the dynamic response of the structures.
In particular, the analyses are performed to evaluate the critical value of rotating speed, which define the stiffness reduction of the structure. A five-parameter power law is developed to define the variation of the mechanical properties of the FGMs along the thickness of the structures. The accuracy of the current formulation, which includes the effects of both Coriolis and centripetal accelerations, is verified by means of the comparison with the results available in the literature. The solutions are carried out numerically by means of an efficient tool that allows to solve the strong formulation of the governing equations.


ABSTRACT: In recent years, externally bonded fibre reinforced polymer (FRP) material has gained popularity as an efficient means of strengthening existing civil engineering infrastructure. In the case of steel structures, FRP has frequently been deployed to strengthen against static and fatigue loads. However, the understanding of the effect of impact load on strengthened structures is still in its early stages. In parallel with this, most of the existing studies on impact have concentrated on small scale elements. Thus, the study presented here is aimed at examining the effectiveness of carbon fibre reinforced polymer (CFRP) in strengthening full-scale steel I-section columns against impact load. To achieve this aim, a non-linear finite element model built using ABAQUS was validated against experimental tests and then used to simulate the strengthening technique. The model included failure criteria of all investigated materials (steel, CFRP and adhesive material). Various parameters including boundary conditions, preloading level, kinetic energy, impact location and impact direction were examined. The CFRP strengthening technique was found to be highly effective in preventing column failure whether by global buckling failure or transverse shear failure. In addition the strengthened columns exhibited a reduced axial and transverse displacement by more than 70% in many cases.

Feng Zhou and Ben Young (First author is from: State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University, Shanghai, 200092, China), “Experimental investigation of concrete-filled single-skin and double-skin steel oval hollow section stub columns”, Thin-Walled Structures, Vol. 140, pp 157-167, July 2019, https://doi.org/10.1016/j.tws.2019.03.036

ABSTRACT: Both concrete-filled single-skin and double-skin steel tubular stub columns were investigated experimentally in this study. The skin of the composite columns was constructed using steel oval hollow section (OHS) tubes. A series of tests was performed to investigate the effects of the geometric dimension of steel OHS tube and concrete strength on the behaviour and strength of composite columns. The overall width-to-thickness ratio of the OHS tube sections ranged from 15.8 to 62.6. The structural performance of the composite columns was investigated using different nominal concrete cylinder strengths of 40, 70 and 100 MPa. The composite column lengths were chosen so that the length-to-width ratio generally remained at a constant value of 3 to prevent overall column buckling. The concrete-filled OHS tube specimens were subjected to uniform axial compression. The test strengths, load-axial shortening relationship and failure modes of the composite columns were presented in this paper. The test strengths were compared with the design strengths calculated using the American Specification and European Code for composite steel and concrete structures. It was shown that the design strengths do not agree well with the experimental results.


ABSTRACT: This paper presented axial compression tests on the behavior of the circular concrete filled steel tube stub columns with double inner square steel tubes (DIS-CFST). A total of 27 DIS-CFST stub columns with different eccentricity ratio (e), hollow area ratio (ψ) and concrete compressive strength (C) were tested. The study mainly investigated the failure modes, ultimate bearing capacity, load-strain curves, load-displacement curves, initial stiffness at elastic stage (k) and ductility of the DIS-CFST stub column. The failure mode of DIS-CFST stub columns observed from the tests was local buckling and no crack was observed on the surface of the specimens. It was found that concrete compressive strength had remarkable influence on ductility and ultimate
bearing capacity of DIS-CFST stub columns. However, eccentricity ratio had little influence on the behavior of DIS-CFST stub columns. Experimental results showed that when the hollow ratio was small, it had little effect on the ultimate load-carrying capacity of DIS-CFST stub columns. However, the ultimate bearing capacity of specimens significantly decreased when hollow area ratio was large. The eccentricity ratio, hollow area ratio and the concrete compressive strength had slight influence on initial stiffness at elastic stage. Furthermore, the ductility of DIS-CFST stub columns increased with the decrease of hollow area ratio. A simplified formula was proposed to calculate the ultimate bearing capacity of DIS-CFST stub columns. The predicted ultimate bearing capacities were in good agreement with DIS-CFST stub column test results. By comparing with the existing strength calculation formula, it can be concluded that the ACI code, EC4 and Han's method were more satisfied with the requirements of the design.


ABSTRACT: The thermoelastic response of aerospace structures is significantly influenced by structural nonlinearities and conventional design tools based on assumption of linearity prove to be insufficient. A nonlinear analysis of the thermoelastic response of aerospace structures opens up the possibility to capture the rich bifurcation behaviour of such panels. The primary objective of this paper is to study the impact of non-linearity and local geometric features, particularly corrugations, on the thermoelastic response and bifurcation characteristics of a hat-stiffened panel. The study derives its motivation from the SR-71 Blackbird that was designed with corrugations in the upper and lower wing skins. A representative hat-stiffened panel is created with corrugations on the skin face-sheet and stiffeners, similar to those on the SR-71 skin panels. The amplitude of these corrugations is varied and the panels are loaded till the bifurcation point is reached. The results show that in the absence of corrugations (at face-sheets) the panel experiences two bifurcation points. The first is similar to the bifurcation predicted from a typical linearized buckling analysis and is surrounded by stable equilibrium branches such that a small perturbation causes the panel to switch to this branch. The second bifurcation point is surrounded by unstable subcritical branches and a perturbation can cause violent snap-through. Adding a face-sheet corrugation causes the first bifurcation point to disappear and the temperature for the second bifurcation point to increase monotonically with the amplitude of corrugation. The displacement and stress at the panel mid-point for a given temperature also reduces with increasing corrugation amplitude. The corrugation in stiffeners does not provide any tangible benefit within the scope of this study.


ABSTRACT: The shear lag effect can significantly affect the performance of wide-box structures, and even becomes one of the most important influencing factors endangering structural safety. This paper develops a theoretical analysis method, which is designated as PM analysis for analyzing shear lag phenomenon in thin-walled box-section beam with arbitrary width of cantilever flange. In this method, the introduction of initial shear rotation (or initial shear strain) γ, due to the effect of web restraint on flanges, is innovatively proposed and further employed in describing the additional warping displacement in top lateral cantilever flanges, and a practical and straightforward procedure of coefficient α is designed (DP) based on the proposed assumptions. In addition, a modified method to PM-DP analysis is developed for improving the defects of the hypothesis of shear-lag warping displacements in top lateral cantilever flanges, that is, PM-DP(M) analysis. The differential equations for generalized displacement ω(x) and the standard magnitude of shear-lag warping displacement U(x) of the beam are deduced by means of the principle of minimum potential energy (MPE) and solved with the given boundary conditions. Numerous models of thin-walled box-section with arbitrary width of top lateral cantilever flanges under distributed load are chosen and built through a software program (ABAQUS). The results obtained from PM analysis (PM-LB, PM-DP and PM-DP(M)) are summarized into a series of curves indicating the distribution of normal stress and the displacements for various examples, and compared to those obtained from the finite element method (FEM). The study widely demonstrates the strong applicability and high precision of PM-DP(M) analysis, which can be considered as an ideal solution in predicting shear lag.
effect for thin-walled box-section beam with arbitrary width of cantilever flange and, possibly, be adopted as valuable reference for the design of related thin-walled structures.


ABSTRACT: This paper presents an analytical and numerical investigation of the relationship between the compressive load level and the natural frequency variation toward a vibration correlation technique for the buckling load calculation of imperfection-sensitive isotropic cylindrical shell structures. Firstly, a back-to-basic study is proposed and the linear equation between the applied load and the square of the loaded natural frequency is revisited. Such review considers the Flügge-Lur'e-Byrne's linear shell theory for the free vibrations of an isotropic unstiffened cylindrical shell under uniform axial loading. The demonstrated linear equation is rearranged for expressing the square of the applied load as a quadratic function of the square of the loaded natural frequency. The suggested formulation provides the analytical support to a novel vibration correlation technique that has been empirically proposed and experimentally validated for unstiffened cylindrical shells. Aiming a numerical verification based on finite element models, two cylindrical shells are defined. At first, the critical buckling load and the fundamental natural frequency for different load levels are determined and compared to the analytical results for validation of the numerical models. The finite element models are extended considering geometric nonlinearities, more realistic boundary conditions and three magnitudes of a benchmark measured initial geometric imperfection. The numerical results are considered for analyzing the variation of the natural frequency in the surroundings of buckling and for verifying the vibration correlation technique.


ABSTRACT: The shear stability of steel webs near the support section for long-span composite girders with corrugated steel webs is one of the main control factors for structural safety, which should be paid special attention to. Generally, concrete is poured on the inner side of corrugated steel webs to improve its shear stability, but encased concrete increases the weight of the girder, raises the difficulty of the construction process, and reduces the efficiency of the prestressing application. This paper proposes a new type of stiffened corrugated steel webs at the support area by adopting vertical or/and horizontal stiffeners instead of encased concrete. In order to explore the shear performance of proposed stiffened corrugated steel webs, experimental and numerical investigations were carried out in the present paper and the companion paper [1], respectively. Four steel I-girders with corrugated webs considering different stiffener arrangements were designed and tested under shear loading. The failure modes, shear strength and stiffness, strain distributions were obtained and analyzed in detail. The test results show that all specimens failed due to interactive shear buckling of corrugated steel web; shear buckling occurred between horizontal stiffeners and bottom flange for horizontal stiffened corrugated steel webs, but extended to the entire height for vertical stiffened corrugated steel webs, the stiffeners distorted associated with the deformation of corrugated steel web. Shear strength of corrugated steel webs can be improved by vertical and horizontal stiffeners. The vertical stiffeners do not affect the “accordion effect” of corrugated steel webs, but the horizontal stiffeners increase the axial stiffness of corrugated steel web in local area and resist bending moment together with top and bottom flanges. The shear strain of stiffened corrugated steel web still distributes uniformly along the height of the web. All the experimental results are then employed in the companion paper for the validation of finite element method and the evaluation of existing analytical models for predicting shear strength of un-stiffened and stiffened corrugated steel webs.

Jia-Bao Yan, Zhe Wang and Jian Xie (School of Civil Engineering/Key Laboratory of Coast Civil Structure Safety of Ministry of Education, Tianjin University, Tianjin, 300350, China), “Compressive behaviours of double skin composite walls at low temperatures relevant to the arctic environment”, Thin-Walled Structures, Vol. 140, pp 294-303, July 2019, https://doi.org/10.1016/j.tws.2019.03.047
ABSTRACT: Double skin composite (DSC) ice-resistant walls have been proposed for the Arctic oil platforms. This paper makes efforts to study the compressive behaviours of DSC walls at low temperatures of \(-80^\circ\text{C}–20^\circ\text{C}\). Seven DSC walls were tested at low temperatures to investigate the influences of different parameters on their compressive behaviours that included low temperature levels, thickness of steel faceplate, and spacing of connectors. The compressive behaviours of the DSC wall at low temperatures were reported and discussed in terms of failure mode, compressive force versus shortening behaviours, and load-strain behaviours. The influences of different parameters on compressive behaviours of DSC walls at low temperatures were reported and analysed. Theoretical models were developed to predict the ultimate compressive resistance of DSC walls at low temperatures. The accuracy of the developed theoretical models were checked through validations against reported seven test results.


ABSTRACT: Present manuscript is mainly arranged to take into consider the influences of nanofillers' aggregation, beam's shear deformation and various boundary conditions on the vibration frequency of multi-scale hybrid nanocomposites in the framework of finite element based Rayleigh-Ritz method. The constituent material is made from three phases, namely polymer matrix, macro-scale carbon fibers and nano-scale carbon nanotubes. Homogenization procedure is procured based on Eshelby-Mori-Tanaka approach incorporated with a micromechanical scheme to obtain the effective material properties via a two-step method. In addition, a new refined higher-order beam theory is introduced to govern shear stress and strain through the thickness direction. Furthermore, influences of different boundary conditions are included, too. The accuracy of the presented finite element formulations is examined by setting a comparison between the dimensionless frequency of multi-scale hybrid nanocomposite beams via both analytical and finite element solutions. Afterwards, parametric studies are adopted to put emphasize on the influence of various terms on the vibrational behaviors of nanocomposite beams. It is reported that influence of different parameters deeply depends on the magnitude of volume fraction of nanofillers inside the inclusions.

Mao Yang, Bin Han, Peng-Bo Su, Zi-Han Wei, Qi Zhang, Qian-Cheng Zhang and Tian Jian Lu (First author is from: State Key Laboratory for Mechanical Structure Strength and Vibration, Xi'an Jiaotong University, Xi'an, 710049, PR China), “Axial crushing of ultralight all-metallic truncated conical sandwich shells with corrugated cores”, Thin-Walled Structures, Vol. 140, pp 318-330, July 2019, https://doi.org/10.1016/j.tws.2019.03.048

ABSTRACT: Novel ultralight all-metallic truncated conical sandwich shells (TCSS) with corrugated cores are designed and fabricated using the molding process. Quasi-static axial compression tests are performed to investigate the crushing behaviors of the proposed structure, with focus placed upon its peak strength and energy absorption capacity as well as the interaction effect of its face-sheets and corrugated core during the crushing process. Detailed parametric study with three-dimensional finite element simulations is subsequently carried out to further explore the failure mechanisms as well as the influence of key geometrical parameters. Finally, the response surface models of specific energy absorption (SEA) and peak force (PF) are established with key design variables, and the Pareto fronts in terms of maximum SEA and minimum PF are obtained. Relative to monolithic conical shells having equal mass, the SEA of the TCSS is significantly greater while the PF is smaller, attractive for energy absorption applications demanding high levels of crashworthiness.


ABSTRACT: Recently, advanced materials whose properties vary within a continuous pattern have been put to use to design and manufacture modern structures. In the current investigation, size dependencies are captured in the nonlinear free vibration characteristics of micro/nano-beams made of bi-directional functionally graded materials (2D-FGM). With the aid of the nonlocal strain gradient elasticity theory and the variational principle, the size-dependent nonlinear differential equations of motion are derived within the framework of the refined
hyperbolic shear deformation beam theory. It is supposed that the material properties are distributed exponentially along longitudinal direction, and vary based on the power law function in lateral direction. Moreover, the deviation of the associated physical neutral plane from the mid-plane counterpart is taken into consideration. By employing a numerical solution methodology on the basis of the generalized differential quadrature method (GDQM) together with Galerkin technique and pseudo arc-length continuation method, the nonlocal strain gradient frequency-deflection responses of 2D-FGM micro/nano-beam are obtained corresponding to various values of longitudinal and lateral material property indexes and small scale parameters. It is revealed that the increment made by the strain gradient size dependency in the value of the nonlinear frequency is more than the reduction caused by the nonlocality, especially for the lower maximum deflection imposed to the 2D-FGM micro/nano-beam. Also, it is indicated that for lower values of the material property gradient indexes, the reduction in the nonlinear frequency caused by the lateral functionally graded pattern in the absence of the axial functionally graded pattern is more than that made by the vice versa case. However, for higher values of the material property gradient indexes, an opposite observation is seen.


ABSTRACT: In this paper, performance of the smart constrained layer damping (SCLD) treatment with elliptical geometrical plan form is investigated for controlling the vibrations of various types of doubly curved composite shells. The SCLD treatment is composed of a viscoelastic layer and an advanced constraining piezoelectric composite (PZC) layer attached at the top surface of the composite shell. A mesh free (MF) model of the smart composite shell has been developed based on the element free Galerkin approach to study its dynamic behaviour within the framework of a mixed layerwise displacement field theory considering transverse extensibility. Spherical, paraboloid and hyperboloid type composite shells with antisymmetric/symmetric cross-ply as well as general angle-ply lamination sequences are considered for the analysis. The numerical results demonstrated that the elliptical SCLD patches are more efficient in attenuating the vibration of the spherical and paraboloid laminated shells while the regular rectangular/square plan form patches are effective for the hyperboloid shells. The numerical results also indicate that the elliptical patches are having higher performance index in enhancing the active damping characteristics of the composite shells. Investigations are also carried out to analyze the effect of the variation in orientation of the piezoelectric fibers in the active PZC layers in attenuating the vibration of shells.

Wanxin Li, Xiyue An, Qing Zheng, Fan Yang and Hualin Fan (First author is from: Research Center of Lightweight Structures and Intelligent Manufacturing, State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing, 210016, China), “Hierarchical design, manufacture and crushing behaviors of CFRP tubular energy absorbers”, Thin-Walled Structures, Vol. 140, pp 416-425, July 2019, https://doi.org/10.1016/j.tws.2019.03.058

ABSTRACT: Hierarchical topology is introduced to construct weight-efficient carbon fiber reinforced polymer (CFRP) tubular energy absorbers through filling small-diameter tubes into large-sized tubes. Crushing behaviors of the thin-walled tubes and the hierarchical tubes are investigated through quasi-static compression experiments and compared with each other. Large-diameter and long thin-walled tubes always fail at brittle modes with limited energy absorption (EA). The hierarchical tubes are crushed progressively and have excellent EA, for the mean crushing force (MCF) exceeds half of the peak force (PF) and the crushing distance is larger than half of the tube length. The improvement in the EA is attributed to the interactions among substructures at different levels which induce a ductile crushing mode. Taking into account the priority of low density, the hierarchical CFRP tubes are weight-efficient absorbers.


ABSTRACT: This study presents an effort to clarify the effects of initial geometric distortions to the buckling capacity of stiffened panels through numerical experimentation. Four types of imperfections have been
considered, that is local (plate, web and stiffener) and global distortion types (column-like). These discrete types were considered as the factors that tend to affect the buckling capacity of the adopted finite element model. Statistical techniques of Design Of Experiments have been applied. A One Factor At a Time analysis along with a full factorial analysis have been performed for screening purposes, and the significant main and interaction effects have been evaluated. The Response Surface Method was finally employed so as to verify and narrow down the number of significant factors. From the four distortion types examined and for the particular involved collapse modes in the evaluated geometries, it was concluded that when the stiffened panel involves global distortion such that maximum global bending stress develops at the plate, then only local plate and web distortions are significant, while stiffener and global distortion may be neglected from the analysis. On the other hand, when global distortion maximizes the global bending stress at the stiffener top, then local web and this particular global distortion type have to be included.


ABSTRACT: Auxetic chiral structures consisting of circular ring nodes and tangentially connected ligaments are engineered systems that exhibit excellent flexibility, vibration attenuation, impact resistance performances. In this paper, the out-of-plane dynamic crash behaviors of anti-tetrachiral, hexachiral and hierarchical chiral structures are studied. The energy absorption efficiency, plateau stress, peak stress of chiral structures with different ligament length, node radius, ligament thickness, and level of structural hierarchy under different external crashing conditions are compared, and identical mass per area of different unit cell configurations are assumed. It is found that anti-tetrachiral structure is able to generate higher plateau stress and better energy absorption efficiency than hexachiral structures. Making use of the mechanical benefits of structural hierarchy, novel hierarchical chiral structures are proposed for improving the crash energy absorption abilities of chiral structures, and relations between crash energy absorption performances and unit cell geometries are explored, such as: energy absorption efficiency, plateau stress of chiral structures. Based on systematical analysis, optimized chiral and hierarchical chiral cellular structure can be designed for impact energy absorption in protective sandwich structures.


ABSTRACT: The material properties of aluminium alloys could be affected significantly as temperature rises. The present study aims to investigate the behaviour of aluminium alloy beams at elevated temperatures using finite element analyses. The newly developed numerical model was validated against a total of eight square hollow section beams subjected to three-point bending tests at elevated temperatures. The validated model was used to generate 120 numerical results in the parametric study. Three key parameters were considered, including cross-section slenderness ranging from 8 to 38, temperatures ranging from 24°C to 600°C and two aluminium alloys (6061-T6 and 6063-T5). Thus, a data pool containing a total of 128 experimental and numerical results was formed. The appropriateness of the design rules in the American Aluminium Design Manual, the Australian/New Zealand Standard, Eurocode 9 and the continuous strength method (CSM) for aluminium alloy beams at elevated temperature are assessed against the newly generated data pool. In comparison, the design strengths predicted by the four design methods are generally conservative, whereas the CSM approach is found to be the most accurate and consistent throughout the full temperature range. Additionally, reliability analysis has also been conducted to evaluate the reliability level of the aforementioned design methods for aluminium alloy beams at elevated temperatures.

Christopher P. Kohar, Abhijit Brahme, Fatemeh Hekmat, Raja K. Mishra and Kaan Inal (Primarily from: Department of Mechanical and Mechatronics Engineering, University of Waterloo, Waterloo, Canada N2L 3G1), “A computational mechanics engineering framework for predicting the axial crush response of aluminum
extrusions”, Thin-Walled Structures, Vol. 140, pp 516-532, July 2019, 
https://doi.org/10.1016/j.tws.2019.02.007
ABSTRACT: Automakers are developing new lightweight aluminum alloys for automotive structures to reduce vehicle weight. However, these alloys require extensive mechanical characterization for accurate calibration of a numerical model, which is often a painstaking task. Automakers are exploring alternative strategies to reduce the number of experiments required for characterizing these new alloys without sacrificing accuracy in predicting performance. The method of virtual experimentation through computational mechanics engineering (CME) with crystal plasticity is showing promise in satisfying this need. This work presents a CME framework for predicting the axial crush behavior of an aluminum alloy AA6060-T6 extrusion using only a single uniaxial stress-strain response and 2D electron backscatter diffraction (EBSD) scans. An anisotropic phenomenological model is generated using a 3D reconstructed microstructure and a calibrated crystal plasticity model. Additional mechanical characterization is performed to qualify the proposed CME framework. Finite element simulations that employ the CME framework are performed to evaluate the suitability of this methodology in quasi-static axial crush applications. Quasi-static axial crush experiments of the extrusion are performed to validate the finite element simulations and the CME framework. Simulations using the CME framework were capable of predicting the experimental crush response with 3–4%. The proposed CME framework can help automakers reduce the number of experiments needed for the development of components in large deformation, such as crush.

Baotong Li, Congjia Huang, Chengbin Xuan and Xin Liu (Primarily from: Key Laboratory of Education Ministry for Modern Design & Rotor-Bearing System, Xi’an Jiaotong University, Xi’an, 710049, PR China), “Dynamic stiffness design of plate/shell structures using explicit topology optimization”, Thin-Walled Structures, Vol. 140, pp 542-564, July 2019, https://doi.org/10.1016/j.tws.2019.03.053
ABSTRACT: The aim of this article is to present a novel and viable topological design approach for minimizing dynamic compliance of stiffened plate/shell structures subjected to time-harmonic loading with prescribed excitation frequency. In this method, the generalized incremental frequency technique (GIF) is introduced to transform the optimization problem into several sub-problems by making the prescribed excitation frequency located within different sub-intervals constructed by adjacent resonance frequencies. Based on this, a set of local optimum designs are identified by associating with the smallest value of dynamic compliance in each sub-interval, and then the optimized solution is selected from among these candidate solutions. Furthermore, the GIF technique is integrated into a Lagrangian-based topology optimization framework, where the stiffening topologies are represented explicitly by a set of geometric primitives such as line segments. In order to get an optimal layout solution, a special interpolation scheme called stiffness and mass transformation approach (SMTA) is presented to separate the line segments from the underlying FEM grids, so that they can move freely within the design domain. To demonstrate the benefits this method affords for dynamic design problems, three numerical examples are validated in detail. In each of the cases the optimization enables a significant reduction in the dynamic compliance. The proposed method allows for more flexibility in topology optimization, which is applicable for large-scale practical dynamic design problems.

ABSTRACT: Structural design rules for prestressed cold-formed steel beams, considering both the prestressing and imposed vertical loading stages, are presented herein. In the proposed approach, the cold-formed steel member is designed as a beam-column using linear interaction equations in conjunction with the Direct Strength Method (DSM), while the prestressed cable is designed by ensuring that its tensile capacity is not violated during the two loading stages. In the present paper, the design approach and the failure criteria, which define the permissible design zone for the prestressed system, are first introduced. The suitability of the design recommendations is then assessed by comparing a set of parametric finite element (FE) results for several combinations of prestress levels, beam geometries and cable sizes, with the corresponding design predictions. Finally, following reliability analysis, the implementation of the design recommendations is illustrated through a practical worked example.

ABSTRACT: Double skin composite (DSC) ice-resistant walls have been proposed for the Arctic oil platforms. This paper makes efforts to study the compressive behaviours of DSC walls at low temperatures of −80 °C−20 °C. Seven DSC walls were tested at low temperatures to investigate the influences of different parameters on their compressive behaviours that included low temperature levels, thickness of steel faceplate, and spacing of connectors. The compressive behaviours of the DSC wall at low temperatures were reported and discussed in terms of failure mode, compressive force versus shortening behaviours, and load-strain behaviours. The influences of different parameters on compressive behaviours of DSC walls at low temperatures were reported and analysed. Theoretical models were developed to predict the ultimate compressive resistance of DSC walls at low temperatures. The accuracy of the developed theoretical models were checked through validations against reported seven test results.

ABSTRACT: An efficient modelling technique based on one dimensional (1D) beam finite element analysis for buckling of thin-walled laminated composite beams having open/closed sections is proposed. The formulation derived has sufficient generality for accommodating arbitrary stacking sequences of the individual beam section walls, and includes all possible couplings between axial, shear, bending and torsional modes of deformation. The effects of transverse shear deformation of the section walls and out-of-plane warping of the beam section are considered where provision exists to restrain or allow warping deformation. The incorporation of shear deformation leads to a problem in the finite element implementation of the proposed beam kinematics, but this is successfully addressed adopting a novel modelling concept. Numerical results obtained for the sample cases of open sections I beams and closed section box beams are presented. The numerical results are benchmarked/compared to data available in open literature, and it is shown that the proposed model performs very well. Finally, a study of the effect of axial and end moment loading, acting alone or in combination, on the buckling response of thin-walled composite beams is presented.


ABSTRACT: For crashworthiness applications, hollow composite tubes have been proposed and studied as impact-bearing members in earlier studies to replace metal tubes and beams which resisted impact by bending. This study focusses on the effect of the addition of hollow glass microballoons (GMB) in composite tubes for compressive loading. Epoxy containing 0 to 0.3 volume fraction of GMB is used with woven glass fabrics to fabricate the specimens. The mean load and energy absorbed while progressively crushing the tubes are experimentally obtained. The variation of these properties with the addition of GMB is analyzed. It is found that the compression properties improve with the addition of hollow glass particles. To explain the different modes of energy dissipation, the basic mechanical properties of the GMB-filled composites are obtained by various mechanical tests. These results are also used in an energy-based model to predict the properties of the tubes under compression.


ABSTRACT: Novel steel-concrete-steel (SCS) sandwich composite walls with normal weight concrete (NWC) and J-hook connectors have been proposed for shear walls in buildings and protective walls in Arctic offshore platforms. Eight SCS sandwich walls with J-hook connectors and NWC were tested under monotonic compression. Investigated parameters in this testing programme included thickness of steel faceplate, spacing of J-hook connectors, strength of NWC core, and different types of connectors. Based on the reported test results, the influences of these parameters were analysed and discussed. Theoretical models were developed to predict compressive resistance of SCS sandwich walls with different types of connectors. The developed analytical models considered the confinement of steel faceplate on compressive strength of concrete core and proposed new buckling length coefficient for steel faceplate in SCS sandwich wall. The accuracies of the proposed analytical models were checked through validations against 50 test results reported by authors and other researchers. Finally, step-by-step design procedures were proposed to determine compressive resistance of SCS sandwich walls with different types of shear connectors.


ABSTRACT: Current work concentrates on large displacement dynamic analysis of super-elliptic (SE) shells made of functionally graded materials (FGMs) employing generalized differential quadrature (GDQ) technique. SE shells can be in quasi-rectangular, elliptical or cylindrical shell forms according to the parameters in super-ellipse formulation. In this paper, large displacements are considered through Green-Lagrange nonlinear strain-
displacement relationships derived for SE shells with full nonlinearity in transverse shear. Present solution is based on first-order shear deformation theory (FSDT). Virtual work principle and GDQ method are utilized to derive equation of motion and to express spatial derivatives existing in equation of motion, respectively. Newmark average acceleration method is employed in the solution of equation of motion. By solving various FGM super-elliptic (FGM-SE) shell problems, effects of FGM material properties (using different ceramic/metal pairs like Alumina/Steel (Al₂O₃/Steel), Zirconia/Aluminum (ZrO₂/Al), Alumina/Aluminum (Al₂O₃/Al), Zirconia/Monel (ZrO₂/Ni-Cu) and Silicon Nitride/Steel (Si.N./Steel)), SE geometric characteristics (ellipticity and ovality) and boundary conditions on dynamic response are investigated.


ABSTRACT: Concrete-infilled double steel corrugated-plate walls (CDSCWs) are composed of two steel corrugated-plates (SCPs) which are connected through bolts, and concrete filled the spacing formed between the two SCPs. Two vertical boundary elements are installed additionally at both sides of CDSCWs. On the one hand, the corrugated configuration of SCPs has great improvement on the load-bearing efficiency of CDSCWs; on the other hand, much higher bearing capacities and better seismic performance for CDSCWs are provided owing to the interactions among SCPs, bolts and infilled-concrete. This paper investigates the load-bearing mechanism and strength design formulae of CDSCWs under compressions. Since SCPs are prone to local buckling failure between two rows of bolts under the conditions of large vertical bolt spacing and small thickness of SCPs, this paper mainly focuses on the load-bearing mechanism of SCPs in CDSCWs under uniform compressions. The unilateral constraint on SCPs provided from infilled-concrete and the restraining effect on the flexural deformation of SCPs owing to bolts are considered. At first, series of finite element (FE) eigenvalue buckling analyses are conducted to study the elastic buckling behavior of SCPs subjected to uniform compressions. On the basis of Euler's formula, the formulae for predicting the elastic buckling stresses and corresponding normalized slenderness ratios $\lambda$ of SCPs are achieved respectively. The instability performance of SCPs under uniform compressions is then investigated through FE nonlinear analyses, and accordingly the stability coefficient $\phi$ is attained. The corresponding $\phi-\lambda$ curve is therefore established in order to calculate the ultimate bearing capacities of SCPs. In addition, the cooperative performance of material strengths between SCPs and concrete is analyzed numerically when CDSCWs reach their compressive ultimate strength. With this consideration, the design method for predicting the cross-sectional strength of CDSCWs under compressions is proposed. Moreover, a CDSCW specimen with I-section is tested under a compressive load. Its cross-sectional strength is investigated experimentally. The results of the experiment coincide with those of numerical simulation, this verifying the safety and validity of the design method for cross-sectional strength design of CDSCWs.


ABSTRACT: Residual stresses and distortions reduce the performance of welded structures. A lot of mechanisms were developed to minimize its consequences. Although, welding sequences (WSQ) effect in the residual stresses, measured by a portable XRD equipment in standard stiffened panels, were not deeply studied so far. In this paper, three sequences significantly changed the residual stresses, which are generated by the arc welding process due to the effect of the temperature, directly affecting the distortions. As a result a simple and inexpensive modification in the WSQ, the longitudinal and transversal compressive residual stresses were reduced by 59% and 86%, respectively. Distortions were also decreased by 68%. A higher welding velocity (100cm/min) and low heat input (0.64KJ/mm) were obtained by application of robotized FCAW. The results could prove the viability of using the portable XRD analyses in the shipbuilding industry.

ABSTRACT: Fifteen corrugated steel web I–beams were designed to investigate the shear buckling behavior and shear strength of corrugated steel webs with artificial corrosion pits. Different corrosion height, depth, and pit diameter, were considered in the shear loading tests. Critical buckling load and ultimate strength were compared with those calculated by existing formulas. In addition, Failure modes were discussed. Test results showed that corrosion volume decreased by 8% and bearing capacity decreased by nearly half compared with no corrosion. All corrugated steel webs were evenly sheared before the critical load was reached. Before reaching ultimate strength, the curve of vertical displacements and load is linear and the slope was affected by the corrosion. Perforation affected the failure modes of corrugated steel webs. Existing formulas yielded accurate and reliable results for uncorroded corrugated steel webs but cannot be used in the evaluation of the bearing capacity of corroded specimens. Corrosion volume, which was nonlinearly related to bearing capacity, was identified as an important factor that affects bearing capacity. Thus, corrosion volume must be considered in accordance with the actual working situation of corrugated steel webs. Future research should focus on the effect of perforation location and corrosion volume on ultimate strength to develop reliable designs for corrugated steel webs.


ABSTRACT: Compressive stresses present in the knuckle of ellipsoidal heads subjected to internal pressure. The presence of such stresses may make buckling possible. In this study, we combine experimental and numerical methods to investigate the buckling behavior of large-scale thin-walled ellipsoidal heads. Buckling experiments were conducted on three thin large-scale ellipsoidal heads with diameters up to 5m and thicknesses of 5.5mm. Finite element models of the ellipsoidal heads with measured initial shapes were generated to simulate the buckling behavior, which is compatible with the experimental observation that one or more buckles first occur at local positions in the knuckle and more ones form progressively with increasing pressure. Furthermore, the buckles become smaller or even disappear at relatively higher pressure, indicating that buckling is self-limited. These buckling behaviors are explained by changes in compressive stresses and shapes of ellipsoidal heads. In addition, we performed numerical simulation to investigate the effects of material properties, radius-to-height ratio, diameter-to-thickness ratio, and shape imperfection on buckling behavior.
https://doi.org/10.1016/j.tws.2019.04.032

ABSTRACT: Re-entrant anti-trichiral honeycomb is a typical auxetic material. The collapse process can be divided into three stages while its negative Poisson's ratio (NPR) effect under large deformation is still unclear. In the present paper, the NPR effects of re-entrant anti-trichiral honeycombs under large deformation are studied by numerical and theoretical method. Numerical results are verified by the experiments with respect to their deformation mechanism and stress-strain behavior. Theoretical formulas are derived to predict the NPR effect of the honeycomb under large deformation. The analytical predictions are in good agreement with the FEM results. It is revealed that the NPR effect of the honeycomb is magnified with the global strain in the second stage while is weaken in the third stage of the deformation process. The decrease of the ligament-ratio and the mean radius will result in more obvious NPR effect. Variation of cell-wall thickness doesn't have much impact on the Poisson's ratio in the second stage, while smaller cell-wall thickness will induce larger NPR in the third stage. The present work is supposed to shed light on the design and fabrication of re-entrant anti-trichiral honeycombs with desired Poisson's ratio.


ABSTRACT: In this paper, the nonlinear forced vibration of single layered graphene sheet including the pre-Stressed effect is studied based on nonlocal elasticity theory. The graphene sheet is located on a viscoelastic foundation based on Kelvin-Voigt model and exposed to thermo-magnetic-mechanical loads. A particle with constant velocity and concentrated load moves on the graphene sheet and applies mechanical shock to it. At first, using nonlinear strain-displacement relations, the geometrical nonlinearity is modeled. Besides, nonlocal plane theory and Hamilton's principle are utilized for deriving the governing equation. In the second step, using Galerkin method, the partial differential equation is transformed to the ordinary differential equation. Then, governing equation is solved based on multiple time scales method. Finally, frequency-response equations under sub-harmonic and super-harmonic stimulation are studied. Emphasizing the effect of nonlinearity, the results for the nondimensional nonlinear frequency versus nondimensional amplitude, the nondimensional phase angle and nondimensional velocity for single layered graphene sheet are plotted. At the end, numerical results are compared with results in the other researches. The results emphasize that the velocity of the nano particle and force amplitude are responsible to make resonance in the system based on a SLGS. Besides, force amplitude can be effective to intensify the effect of the mechanical shock in behavior of SLGS.


ABSTRACT: The aim of the work is to investigate the low-velocity impact of fully clamped rectangular multilayer sandwich plates with metal foam cores struck transversely by a heavy mass. Analytical models considering interaction of bending and stretching induced by large deflections are developed for the dynamic response of multilayer sandwich plates. Numerical calculations of multilayer sandwich plates under low-velocity impact are conducted and analytical models can capture the numerical results reasonably. The cases of three typical impact locations are considered. Effects of loading location, the multilayer factor and shape of the striker on the structural response are discussed. It is demonstrated that the present analytical model can reasonably predict the low-velocity post-yield behavior of rectangular multilayer sandwich plates with metal foam core struck by a heavy mass.


ABSTRACT: Spectral element method (SEM) is an accurate and efficient frequency domain-based method which has been frequently used in different analyses of various structures. In the present research, for the first time, this method is employed to deal with the wave propagation analysis of moderately thick rectangular plates with two piezoelectric layers attached on the top and bottom surfaces. The equations of motion are derived by taking into account the Mindlin plate theory assumptions and using the Hamilton's principle. The Maxwell's
equation is employed to obtain the governing equation of electric potential in the piezoelectric layers. The differential equations are transformed into the frequency domain by employing the discrete Fourier transform and then a closed-form solution for the Levy type plate attached to piezoelectric layers is introduced. The dynamic stiffness matrix for the smart plate is obtained by applying the exact dynamic shape functions. Accurate and efficient numerical algorithms are introduced to extract the natural frequencies and the dynamic response of the structure under impact loading. The validation of the presented method is accomplished by comparing the obtained natural frequencies and dynamic response with the existing results in the literature and also the results obtained by the Abaqus software. Also, the effects of boundary condition and thickness of the plate and piezoelectric layers on the results are investigated. Independence to the mesh structure and less computational time are the most important advantages of the SEM compared with similar numerical methods like the finite element method.


ABSTRACT: A comprehensive experimental and numerical study of concrete-filled double skin tubular (CFDST) stub columns is presented in this paper. A total of 23 tests was carried out on CFDST specimens with austenitic stainless steel circular hollow section (CHS) outer tubes, high strength steel CHS inner tubes, and three different grades of concrete infill (C40, C80 and C120). The ultimate load, load-deflection histories and failure modes of the stub columns are reported. The test results were employed in a parallel numerical simulation programme for the validation of the finite element (FE) model, by means of which an extensive parametric study was undertaken to extend the available results over a wide range of cross-section slendernesses, inner tube strengths and concrete grades. The experimentally and numerically derived data were then employed to assess the applicability of the existing European, Australian and North American design provisions for composite carbon steel members to the design of the studied CFDST cross-sections. Overall, the existing design rules are shown to provide generally safe-sided (less so for the higher concrete grades) but rather scattered capacity predictions. Use of an effective concrete strength is recommended for the higher concrete grades and shown to improve the consistency of the design capacity predictions.


ABSTRACT: The concept of local buckling of compressed isotropic cylindrical shells is developed in this paper. Buckling of axially compressed cylindrical shells under different types of local perturbations has been studied in many theoretical and experimental researches. Different methodologies, based on these studies, were suggested for design buckling load estimation. However, in most calculations and experiments only two classical boundary conditions were considered: fixed displacement of the shell edges in the axial direction or fixed and uniformly distributed compressive load. Both of them are hard or even impossible to realize in practical applications. In the present paper we studied the shell behaviour with 6 different types of boundary conditions, which included the above mentioned two types. We considered shell loading through rigid plates with different types of possible displacements (degrees of freedom) and through stiffening ribs at the edges of the shell. Two theoretical methods were applied: numerical (finite element method) and analytical (Pogorelov's geometrical method). Lateral force was applied as a perturbation and stability of the shell under load combination was studied. The results of calculations were compared with obtained experimental data for validation of numerical solutions. Then metastability and post-buckling behaviour of the structure was studied using theoretical and experimental methods. In particular the interval of existence and stability of post-buckling equilibrium states of the shells with one or several buckles was studied systematically. The post-buckling equilibrium paths and corresponding energy barriers for all mentioned types of boundary conditions were analyzed. Parametric analysis of boundary value problem allowed to establish the main (Batdorf) structure parameter. Formula for design buckling load was suggested and discussed.
ABSTRACT: The differences in the mechanical performance of prismatic and non-prismatic beams with concrete flanges and corrugated steel webs (CSWs) are numerically investigated in this paper with respect to their behaviour in bending, shear and shear buckling. With regard to the bending behaviour, it is found that the quasi-plane assumption is still valid for the non-prismatic beams with CSWs, similar to the prismatic beams with CSWs, at their elastic stage and their bending stiffness are mainly provided by the concrete flanges. This is attributed to the accordion effect of such webs. In terms of the shear behaviour, it is found that the inclined bottom flange shares a significant portion of the shear force in the non-prismatic beam with CSW, while the effective shear force carried by the CSW is greatly reduced; this phenomenon is called the Resal effect which is the most important reason leading to the shear performance difference between the prismatic and non-prismatic beams with CSWs. Thus, the traditional calculation assumption that the CSWs bear all the vertical shear force in the prismatic beams with CSWs is no longer applicable in calculating the shear stress in the non-prismatic cases. Additionally, it is noticed from two numerical cases, simulating the prismatic and non-prismatic beams with CSWs under end loading, that the average shear stress in the CSW of the non-prismatic beam decreases gradually from the free-end to the fixed-end with the increase of the hogging bending moment, while the shear stress in the CSW remains nearly constant in the prismatic beam. The numerical results, as well, show that the root cross-section, although it bears the maximum bending moment and shear force, is not the critical shear section of the CSW of the non-prismatic beam. Finally, considering the shear buckling behaviour, it is found that the shear buckling stress of the non-prismatic with CSW is much greater than that of an equal-weight prismatic beam with CSW through eigenvalue buckling analyses.

ABSTRACT: The steel-concrete composite structure using the high-strength steel (HSS) is featured with high strength, lightweight and economic benefits. In this study, a finite element model was established to simulate the compressive behavior of concrete-filled double-skin steel tubular (CFDST) stub column using high-strength steel. The material nonlinearity, the confinement effect and the contact behavior were considered. A total of four large-scale CFDST stub columns using HSS in the outer tube were tested under axial compression. The model was validated using both current and previous test results. The verified numerical model was then used to analyze the influences of various parameters, such as the yield stress of steel, the hollow ratio and the confinement factor. Furthermore, the feasibility of current design equations for CFDST columns using HSS was assessed. It was found that the HSS tube worked well with the sandwiched concrete, and the current methods could provide reasonable yet conservative predictions on the compressive strength of CFDST stub columns using HSS.

ABSTRACT: In this work, a finite element based optimization methodology is developed to obtain the optimal designs of thin-walled open cross-section columns for maximum buckling load. As a constraint for the optimization study, the total material volume of the column is kept constant. At first, an analytical formulation based on Bleich's (1952) approach, which considers the combined effect of both torsional and flexural buckling, is used to validate the finite element buckling load computation in ANSYS. Subsequently, these finite element buckling results are coupled with a Genetic Algorithm (GA) based optimization routine in MATLAB to obtain the optimal design of the cross-section of the columns. Optimal results are compared with a base model of the column having a cruciform cross-section. The optimization of the cross-sections results in remarkable enhancement, up to as high as 236%, in the maximum buckling load capacity compared to the base model.

ABSTRACT: The crash box is a structural component which is widely used in transport vehicles. It is designed to collapse and absorb kinetic energy in a low-speed collision. In this paper, we present a family of new origami crash boxes with rectangular, polygonal cross sections, and tapered shapes, through pre-folding the surface of thin-walled tubes according to a set of developable origami patterns. We have demonstrated through quasi-static impact experiments and numerical simulation that these origami crash boxes collapse into a diamond-shaped mode with a doubled number of traveling plastic hinge lines. The proposed optimal design leads to a maximum increase of 107.1% in terms of the energy absorption per unit mass and a maximum reduction of 68.3% of the initial peak force when compared with the conventional crash box. The substantial gain in overall energy absorption and the decrease in peak reaction force makes the proposed origami patterns attractive for energy absorption applications.


ABSTRACT: In this paper, an extensive numerical study is performed with the aim to investigate the elastic buckling behavior of simply supported cylindrically curved steel panels subjected to a pure shear load. The main objective is to understand the influence of geometrical parameters, such as curvature and aspect ratio, but also of the edge in-plane constraints. Finally, a new formula is proposed, which allows simple and accurate estimation of the critical shear stress of unstiffened curved panels with three different types of edge constraints, for various curvatures ($1 < Z \leq 100$) and various aspect ratios (up to 5).


ABSTRACT: The application of aluminium alloy members in building construction has considerably increased in recent years due to their appealing advantages such as corrosion resistance and high strength-to-weight ratio. However, the elastic modulus of aluminium is only one-third of that of steel, making aluminium members being susceptible to various buckling modes including web crippling. To date, only a limited amount of research study has been conducted to investigate the web crippling failure phenomenon in aluminium structural members, and no research has been carried out on the web crippling behaviour of roll-formed aluminium lipped channel sections. Hence, an experimental study was conducted to assess the web crippling behaviour and capacities of unfastened aluminium lipped channel sections under two flange load cases (End-Two-Flange (ETF) and Interior-Two-Flange (ITF)). Forty tests were performed with different bearing lengths, web heights and thicknesses. The results obtained from this study were then compared with the nominal web crippling strengths predicted using the design rules provided by the Australian, European and American Standards. The comparison showed that the current design equations are potentially unsafe and unreliable to estimate the capacity for aluminium lipped channel sections under both ETF and ITF load cases. Hence, suitable modifications were proposed to the available design equations based on the experimental results to accurately predict the web crippling capacities of aluminium lipped channel sections. Generally, it is shown that the web crippling results acquired from the modified equations agreed well with the test results.


ABSTRACT: Residual stresses and initial geometric imperfections have important effect on the buckling resistance of slender plated steel structures. Despite their large importance, the actual knowledge on residual stresses and exact geometric imperfections are limited, especially for corrugated web girders. In the accompanying paper [1] (Part 1) a finite element model of corrugated web girders is introduced and verified, which is able to virtually simulate the manufacturing process (cold-forming; cutting, welding) of corrugated web girders. The presented numerical model is able to determine the actual imperfection shape and residual stresses which are specific for the actual girder geometry and manufacturing method. The numerical model is
further developed for simulating geometrically and materially nonlinear analysis with imperfections (GMNIA) on the virtually manufactured specimens to determine the shear buckling resistance. The effect of manufacturing imperfections on the shear buckling resistance is evaluated for several different corrugation geometries and the obtained tendencies are evaluated and discussed in the current paper.


ABSTRACT: The treatment of cold-formed steel sections in design codes is very largely restricted to individual members under ideal conditions. More efficient design is possible if the complexities of the structural response caused by the thin plating and complex shapes, together with the actual conditions of load introduction and restraint arising from practical situations can be recognised. Traditionally this has only been possible by resorting to full-scale testing. This is, of course, time consuming and expensive; moreover, the impossibility of covering all variations of all the important problem parameters means that developing a comprehensive understanding of all aspects of the physical behaviour is unlikely. Numerical analysis offers the promise of an alternative approach. However, for this to be reliable there must be confidence that it accurately models the physical situation. For the past decade a programme of research has been underway aimed at the provision of a more complete understanding of the structural behaviour of cold-formed steel sections when employed in particular practical situations. Three such cases are addressed herein: purlins as used in the roofs of industrial buildings, beams used to support floors and columns forming part of a stud wall framing system. In each case the process has been to firstly identify all the important structural components including fastening arrangements, then to develop numerical models using ABAQUS that represent each of these physical features to a sufficient degree of accuracy, then to validate the models by comparison with all available test data, then to conduct parametric studies covering the full range of variables found in practice and, finally, to use the pool of results and the improved insights into behaviour as the basis for improved design approaches that, by more accurately capturing the key physical features, provide better predictions of performance. An important feature of this has been to ensure that the resulting design procedures were the simplest possible consistent with reliable predictions.


ABSTRACT: This paper presents the formulation of a three-dimensional beam finite element (FE) that accounts for cross-section warping and dynamic inertia effects. The model is the extension of an existing mixed formulation, originally developed for the static analysis of thin-walled beams, to the case of dynamic loading conditions.

Four independent fields are considered to derive the element governing equations, i.e. material rigid displacements, strains and stresses and an additional displacement field, describing the out-of-plane warping displacement of the beam cross-sections. The latter is independently interpolated in the element volume by including additional degrees of freedom (DOF) to the nodal translations and rotations classically considered in beam formulations.

To obtain a consistent form of the element mass matrix, the cross-section displacement shape functions are computed, relating the generalized cross-section displacement fields to the element nodal variables. In mixed FE formulations, these are not assigned a priori, as in displacement-based approaches, but are derived on the basis of material stiffness and element geometry, together with compatibility conditions. Thus, the Unit Load method is applied to deduce the expressions of the shape functions consistent with the force-based approach, assuming the simply-supported beam as reference element configuration.

As opposed to the original FE model, the additional warping DOFs are not condensed-out with the definition of the element quantities but are treated as additional global unknowns. This permits a correct description of the inertia effects and ensures continuity of the warping displacement fields between adjacent FEs.

Correlation studies are presented to validate the proposed model and investigate the effects of cross-section warping on the dynamic behavior of thin-walled structures. For selected specimens, the studies compare solutions obtained adopting the proposed beam element with those resulting from shell or brick FE models.
Modal decompositions and time-history analyses are conducted, assuming both linear elastic and nonlinear constitutive behavior for the latter.

Anders Bau Hansen, Jeppe Jönsson, “Displacement modes of a thin-walled beam model with deformable cross sections”, Thin-Walled Structures, Vol. 141, pp 576-592, August 2019, 
https://doi.org/10.1016/j.tws.2019.01.052

ABSTRACT: A novel one dimensional beam model for analysis of prismatic thin-walled beams with deformable cross sections is introduced and a novel cross section mode determination procedure, which leads to the three dimensional beam displacement modes, is derived. The first order beam model for linear analysis includes: shear deformations related to both Timoshenko and Mindlin-Reissner type shear deformations, the warping effects of torsion, cross section distortion with related warping effects, as well as the Poisson effect with transverse displacements due to normal stress. The generality of the model allows it to handle open, closed and multi-cell cross sections with branched walls. The cross section analysis procedure leads to two types of beam displacement modes referred to as distortional beam modes and fundamental beam modes, with exponential and polynomial variations along the beam axis, respectively. It turns out that each of the beam deformation modes consists of a sum of one to four cross section displacement fields each with an individual axial variation. The displacement modes can facilitate the formulation of an advanced thin-walled beam element. The beam displacement modes will be illustrated for an open and a closed cross section.


ABSTRACT: This paper provides a review of recent developments in research and design practice surrounding the structural use of stainless steel, with an emphasis on structural stability. The nonlinear stress-strain characteristics of stainless steel, which are discussed first, give rise to a structural response that differs somewhat from that of structural carbon steel. Depending on the type and proportions of the structural element or system, the nonlinear material response can lead to either a reduced or enhanced capacity relative to an equivalent component featuring an elastic, perfectly plastic material response. In general, in strength governed scenarios, such as the in-plane bending of stocky beams, the substantial strain hardening of stainless steel gives rise to capacity benefits, while in stability governed scenarios, the early onset of stiffness degradation results in reduced capacity. This behaviour is observed at all levels of structural response including at cross-sectional level, member level and frame level, as described in the paper. Current and emerging design approaches that capture this response are also reviewed and evaluated. Lastly, with a view to the future, the application of advanced analysis to the design of stainless steel structures and the use of 3D printing for the construction of stainless steel structures are explored.


ABSTRACT: The un-stiffened fiber reinforced polymer (FRP) beams under three-point bending often fail at compression web-flange junction due to low inter-laminar shear and transverse compressive strengths of web. Therefore, the objective of the present work is to study the effect of different stiffening elements on the flexural response of FRP I-beams. Various stiffening elements such as glass fiber reinforced polymer (GFRP) cover plates, cover angles, and bearing stiffeners are connected to the beam separately to examine their effect on the strength, stiffness and failure modes. This study also includes the strengthening of web-flange junction of FRP I-beams using carbon fiber layers with adhesive. It is observed that replacing the chopped strand mats with 45° and 90° unidirectional rovings increases the crushing strength of the beam. Strengthening of web-flange junction using carbon fiber layers or stiffening with short length bearing stiffeners under loading is observed to be most effective in preventing the failure of web-flange junction of FRP I-beams. Beams stiffened with short length bearing stiffeners have higher failure load than other stiffened beams. Strengthening of web-flange junction using wet carbon fiber layers is noted to be more effective than stiffening with GFRP cover angles. Since the stress concentration produced due to the sudden change in the cross-section of beams strengthened with carbon fiber reinforced polymer (CFRP) laminated cover angle is less than that for beams stiffened with GFRP cover angles.

ABSTRACT: Unstiffened I-beams are prone to local and premature failure. Stiffened beams having improper stiffening technique or size of stiffening element may have lesser failure load than that of unstiffened beams. In this paper, flexural characteristics of stiffened and unstiffened FRP I-beams is determined analytically and numerically; and verified with experimental investigation. There are no code provisions for designing of FRP beams with stiffening elements. Hence, equation to calculate the deflection of beams with different stiffening elements is derived using Castigliano’s theorem. In order to get the better understanding of failure of FRP beams, various formulae for beams without stiffening elements available in design manuals are incorporated in the analytical model for prediction of failure load and mode. Further, a failure criterion is recommended for prediction of failure load of beams with and without stiffening elements. The results obtained from analytical and finite element models give the good comparison of results with experimental investigation. Further, a parametric study is performed on beams having different flange width-to-thickness ratios (5–15), depth-to-thickness ratios (21–40), and length-to-depth ratios (3–11) with different sizes of stiffening elements. It is observed that failure load of beams increases up to certain length of bearing plate, later it becomes constant. Under flexural loading, bearing stiffeners of a beam is found to fail, if the length of bearing plate is less than the flange width of T-shaped bearing stiffener. Similarly, if the length of cover angle or carbon fiber layer provided is less than the length of bearing plate, then the failure load is equivalent to the beam with having bearing plate only. Carbon fiber angles are less effective than beam with cover angle for effective depth-to-thickness ratio more than 21.


ABSTRACT: This paper presents a detailed treatment of the formulation for buckling and free vibration analysis of Bi-Directional Functionally Graded (BDFG) Thin-Walled non-prismatic beams of generic open/closed cross section. The theory developed is limited to small strains, moderate deflections and small rotations. It is based on the assumption that the shear strain on the mid-surface contour of the cross section of the member is neglected. Using the membrane theory of shells rigorous expressions for strains are obtained by which the effect of nonlinear tapering is considered. The material properties are assumed to be graded both in the longitudinal and depth-wise directions of the plate segment of the thin-walled beams. The governing equations are developed defining the displacements with reference to any arbitrary point (say geometric centre) and get away with the usual shear centre and centroid. For computer solutions for classical buckling and vibration analyses, the Finite Element Method is used. Simpson’s rule of numerical integration is adopted for the computation of axial, coupled and bending rigidities as well as inertial properties of the plate segment and the Gaussian Quadrature of numerical integration is used for the computation of flexural stiffness, geometric stiffness and mass matrices of an element over the length of the beam. Critical buckling loads and the natural frequencies and their corresponding buckled and mode shapes for various examples are obtained by solving as an eigen-value problem and compared with the published results in the companion paper.


ABSTRACT: In the current study, deflections, buckling loads, natural frequencies and the corresponding mode shapes and forms for BDFG thin-walled tapered beams of generic open/closed/open-closed sections are examined using the finite element method. A tapered thin-walled beam finite element with the seven degrees of freedom at each node is investigated. A rigorous expression for strains based on the membrane theory of shells is considered. The flexural stiffness matrix, geometric stiffness matrix and the consistent mass matrices are developed in a companion paper. Using the present theory, one is able to investigate various torsional, flexural static and dynamic systems. Examples are presented and comparisons are made with the existing available literature. With the modifications of axial, coupled and bending rigidities one will be able to investigate composite beams with fibre reinforced composite laminates.

ABSTRACT: This paper concerns the underpinning system reliability calibrations that will enable the implementation of the next generation of system-based design-by-analysis method of steel rack frames, i.e., a design approach where analysis and capacity checks are carried out in a single step by using fully nonlinear analysis. The paper details the design framework of the new approach, referred to as the Direct Design Method (DDM), and derives system strength statistics for five typical configurations of rack frames using Monte-Carlo simulations, taking into account the randomness of geometric and material properties. The nominal models of rack frames are developed in accordance with the Australian Standard AS4084. The mean-to-nominal ratios (bias) and coefficient of variation of the system strengths are obtained, and will be used in the companion paper to derive the system resistance factors consistent with a given structural reliability.


ABSTRACT: This is the second of two papers introducing the underpinning structural analyses and reliability studies that implement the system-based design-by-analysis method of steel rack frames, referred to as the Direct Design Method (DDM). The present paper presents the reliability analyses and derivation of system reliability index (β) versus system resistance factors (ϕ) curves. Results are presented for nominal system strengths as per Australian Standard AS4084 for several nominal models, including models that exclude sectional imperfections, and models without member and sectional imperfections. The effect of model uncertainty is also assessed. A detailed example of the DDM applied to the design of a rack frame is presented and the benefits of the DDM are demonstrated when compared to the traditional design approach which is based on elastic analysis.


ABSTRACT: Thanks to the larger and more continuous confining stress provided by hollow steel tube, ultra-high-strength concrete-filled-steel-tube (UHSCFST) columns are advocated rather than conventional transverse steel confined ultra-high-strength concrete. However, during elastic stage, de-bonding occurs as the Poisson’s ratio of steel is larger than that of concrete, whereas in post-elastic stage, confining stress, strength and ductility of concrete decrease since the steel tube would buckle. Thus, the composite action cannot be fully developed. To overcome these problems, external confinement in the form of tie bars, steel rings and steel spirals are proposed in this paper to increase the confinement effect of UHSCFST columns. A series of uni-axial compression test has been conducted to study the behaviour of externally confined UHSCFST columns. Results showed that the proposed confining schemes can effectively improve the strength, elastic stiffness and ductility of UHSCFST columns. Moreover, rings and spirals are more effective than tie bars. Lastly, a modified theoretical model based on that developed previously by the authors was used to predict the ultimate load and axial load-strain behaviour of the tested columns, in which excellent agreement between the theoretical and experimental results has been obtained.


ABSTRACT: Thin-walled structure is widely used in automobile, aviation and other industrial fields due to its lightweight, high energy absorption efficiency and low cost. Four thin-walled hybrid multi-cell structures with circular and square sections are proposed in this paper. The energy absorption characteristics and crushing deformation of the hybrid structures are investigated by experimental testing and numerical analysis. Meanwhile, the theoretical models of mean crushing force and specific energy absorption of the hybrid structures are developed by simplified super folding element (SSFE) theory. It is found from the sensitivity analysis of parameters that the dimension of the external tube (D) and the wall thickness (T) of the structure have significant effects on energy absorption. Furthermore, the multi-objective optimization including multiple
surrogate models is performed to obtain optimal crashworthiness of the hybrid multi-cell structures. The results show that multiple surrogate models are more favorable and accurate for the crashworthiness design, and the hybrid multi-cell structure with the outer circle and inner square section (CS.) has the best crashworthiness performance. Finally, the multi-objective optimization solutions are analyzed and chosen by the normal boundary intersection (NBI) method to carry out the crashworthiness comparison with the typical multi-cell structures of the same mass, and the hybrid structure (CS.) outperforms multi-cell tubes with the single circular or square section.


ABSTRACT: An FRP (fiber-reinforced polymer) -confined concrete filled steel tube is formed by the combination of FRP material and a concrete filled steel tube, and it combines the advantages of FRP-confined concrete and a concrete filled steel tube (CFT); however, there is still no effective model to generally describe the complete stress-strain curve of a concrete filled FRP-confined steel tube. The stress-strain response of a concrete filled FRP-confined steel tube features the dual characteristics of both FRP confined concrete and steel confined concrete. In this paper, ninety-six test results of FRP confined circular CFT columns under axial compression were collected from different researchers. The steel tube confinement index is taken as an additional key influencing parameter on the strength and deformation, and calculation methods for the ultimate strain, ultimate stress, peak strain and peak stress of a concrete filled FRP-confined steel tube are established by taking into account the steel tube confinement index. Moreover, the stress-strain model was developed to describe the complete stress-strain curve consisting of the four stages of a concrete filled FRP-confined steel tube. The proposed model reflects the characteristics of the stress-strain behavior of a concrete filled FRP-confined steel tube with good accuracy and simplicity.


ABSTRACT: This paper is devoted to solving the stacking sequence optimization problem of symmetrical laminated composite cylindrical shells subjected to hydrostatic pressure. First, a conventional genetic algorithm (GA) coupled with a finite element analysis optimization method is developed to search for the best laminations with the maximum buckling pressure. These optimal laminations share similar extensional stiffness coefficient ratios \( A_{11}/A_{22} \) and bending stiffness coefficient ratios \( D_{11}/D_{22} \) because the two ratios of the optimal lamination fluctuate slightly around a specific value. Based on this phenomenon, a stiffness coefficient-based method (SCBM) is then proposed. The method is integrated with the GA and the stiffness coefficient calculation to identify the lamination whose stiffness coefficient ratios \( (A_{11}/A_{22} \text{ and } D_{11}/D_{22}) \) are closest to those obtained previously. The effectiveness of the SCBM is validated by comparison with the optimal results. The proposed method is then extended to more complex symmetrical laminations. Finite element analysis is also coupled with the GA as a control group. Comparisons reveal that the two methods lead to similar characteristic laminate patterns and maximum buckling pressures, which suggests that the SCBM works well for complex laminations. Moreover, the SCBM is found to be significantly more efficient because it only needs to calculate the stiffness coefficients rather than analyse the entire structure during the optimization.


ABSTRACT: In this paper, an extensive numerical study is performed with the aim to investigate the post-buckling behavior of simply supported cylindrically curved steel panels subjected to a pure shear load. The main objective is to understand the influence of geometrical parameters, such as curvature and aspect ratio, but also it is aimed to examine how the level of the constraint of the edges affects the ultimate shear resistance. Finally, a new set of formulas are numerically derived, which allow estimation of the ultimate shear reduction factor of unstiffened curved panels with three different types of edge constraints, for various curvatures (up to 50) and various aspect ratios (up to 5). Moreover, the formulas use a similar base form as the one available in EN 1993-1-5 for the prediction of the ultimate shear load of a flat panel.
ABSTRACT: In this paper, we evaluate various multi-cell design concepts to optimize the crash performances of thin-walled aluminum tubes. The crash performances of the tubes are evaluated by means of two metrics: the crush force efficiency (CFE) and the specific energy absorption (SEA). The CFE and SEA of the tubes are predicted through the use of the finite element analysis software LS-DYNA. Experiments are also conducted to validate the finite element models. Thirty different multi-cell design concepts are evaluated in terms of CFE and SEA, and the best design concept is selected for further evaluation. Next, we perform surrogate-based optimization of the selected design concept, upon which we find that optimum design for maximum CFE which utilizes smaller wall thickness values (except the wall thickness of the inner tube) and larger tube diameters than those of the corresponding ones for the optimum design for maximum SEA. Additionally, the optimized designs exhibit remarkable CFE and SEA performances.

ABSTRACT: Thin-walled cylindrical steel silos are one of the key structures for storage of materials in many industries and agricultural sectors. They are susceptible to instability under wind pressure when they are empty or partially filled. This paper investigates numerically the wind buckling behavior of three sample steel silos with stepped walls composed of isotropic rolled shells. Wind load vertical and circumferential distributions were adopted from Eurocodes. Two proposed circumferential pressure distributions for an isolated silo and a silo in a group with a closed roof were taken into consideration. Moreover, the effect of additional inward pressure, proposed by Eurocode, on buckling capacity of vented silos with a small opening was evaluated. Accordingly, comprehensive 3D finite element models were used and detailed linear and non-linear buckling analyses were conducted. The wind buckling capacity of sample structures considering multiple amplitudes of initial imperfections was also assessed. The results obtained suggest a considerable decrease in the buckling resistance of imperfect silos. Finally, Eurocode provisions for the wind buckling stress design of un stiffened cylinders with step-wise variable wall thickness were examined and the relevant conclusions have been made.

ABSTRACT: A highly efficient and accurate semi-analytical domain decomposition method for elastodynamic problems of functionally graded elliptic shells and panels with elastic constraints on the basis of the first-order shear deformation theory is presented. Firstly, according to the first-order shear deformation theory, the dynamic energy functional of elastic shell structure is established. Then, the multi-segment partitioning technique is used to segment the shell along the circumference and axis direction. Thirdly, the modified variational principle and least-squares weighted residual method are adopted to ensure the inherent continuity between segments. On this basis, the virtual springs are evenly arranged on each boundary to simulate the boundary forces, and then the desired boundary conditions can be simulated. The displacements of each shell domain are expanded as double Jacobi orthogonal polynomials in the circumferential and axial variable. Lastly, the piecewise matrices for a segment are assembled directly in a similar way to that of the finite element method, and the elastodynamic problems of functionally graded elliptic shells and panels are obtained by the variational operation with respect to generalized coordinate vectors. The numerical comparison shows high computational efficiency and accuracy of the present method. All the calculation results in this paper can be used as benchmark data for future scholars to study this structure.

ABSTRACT: The approach to solving two-dimensional nonlinear (linear) boundary-value problems for shallow shells using the complete systems and quasilinearization Newton-Kantorovich-Raphson methods is developed. With the complete systems method in linear case, the original two-dimensional boundary-value problem is reduced to this system of two interconnected one-dimensional problems, which is solved iteratively using the
Thin shells subjected to various boundary conditions. The vibration equation is obtained by using the Lagrange equation method. In constraint to obtain the potential energy of linear vibration analysis of symmetrically 3-layer composite thin circular cylindrical shells with arbitrary boundary conditions, the edges of the shell, which can be universally applicable to all geometrical parameters, material properties, imperfection, the elastic foundations, eccentrically oblique stiffeners, mechanical loads and temperature on the nonlinear dynamic response and nonlinear vibration of plates. The numerical results in this paper are compared with the results reported in other reports.


ABSTRACT: This paper presents a semi-analytical approach to investigate the nonlinear dynamic response and vibration of eccentrically oblique stiffened functionally graded plate resting on elastic foundation. The Lekhnitskii's smeared stiffener technique is improved by using a transformation technique for oblique stiffeners. Governing equations are solved by classical shell theory, Galerkin method, stress function with temperature-dependent material effects. The results show the influences of geometrical parameters, material properties, imperfection, the elastic foundations, eccentrically oblique stiffeners, mechanical loads and temperature on the nonlinear dynamic response and nonlinear vibration of plates. The numerical results indicate the influence of boundary conditions, geometric parameters, symmetrical lamination schemes and damping coefficients on the nonlinear amplitude-frequency characteristics of symmetrically 3-layer composite thin circular cylindrical shells are investigated. The numerical results indicate that the present method is powerful to calculate the nonlinear vibration response characteristics of symmetrically 3-layer composite circular cylindrical thin shells subjected to various boundary conditions.


ABSTRACT: Cruciforms are frequently used as energy absorption components in engineering structures. The kirigami cruciforms (KCs) are designed by kirigami approach to simplify the manufacture process and reduce the initial peak force. However, the mean crushing force of KC is less than half of that of conventional cruciform (CC), which is negative for energy absorption purpose. The weak interaction between two component plates (plates A and B) in KC (no material connection) is a crucial factor for the decrease of mean crushing force. Therefore, laser welding technology is employed to enhance the connection between plates A and B by applying welding lines on the intersection line between components. Detailed analyses concerning the welding lines and boundary constraints are conducted to investigate the effect of connection between plates A and B. The results show that the mean crushing force of KC is close to that of CC if these conditions are met: the location of welding line is at the center of intersection line, and the length of welding line is no less than 30% and 43% of the length of cruciforms without and with symmetric boundary constraints on outside flanges, respectively. The conclusions indicate that the energy absorption capacity of thin-walled structure can be tuned by adjusting the connection strength between components in an energy absorption system.


ABSTRACT: Considering the large-deformation hypothesis, the modeling and nonlinear vibration characteristics of symmetrically 3-layer composite thin circular cylindrical shells with arbitrary boundary conditions are analyzed by applying four sets of artificial springs. Firstly, by employing a set of orthogonal polynomials and trigonometric functions, the energy equations of the shells are derived with Donnell's nonlinear thin-shell theory. Then, the arbitrary boundary conditions are simulated by imposing the equivalent elastic constraint to obtain the potential energy of the edges of the shell, which can be universally applicable to all classical boundary conditions. The vibration equation is obtained by using the Lagrange equation method. In order to obtain correct numerical results, several comparisons of linear and nonlinear results are carried out to validate the approach method in the present study; meanwhile, the calculation convergence is checked. At last, the influence of boundary conditions, geometric parameters, symmetrical lamination schemes and damping coefficients on the nonlinear amplitude-frequency characteristics of symmetrically 3-layer composite thin circular cylindrical shells are investigated. The numerical results indicate that the present method is powerful to calculate the nonlinear vibration response characteristics of symmetrically 3-layer composite circular cylindrical thin shells subjected to various boundary conditions.

ABSTRACT: In this study, the traditional Temcor joint (TR-Temcor) is modified using a central hollow hexagonal prism and some front bolts. The Finite Element Analysis (FEA) model is established and verified by experiments. Then, a parametric analysis is carried out for the improved Temcor joint (IM-Temcor). To obtain the optimal parameters for the modified joint, the key factors, namely: number and location of the front bolts, bolt-hole deviation, pretension force in bolts, thickness of front plate and heat-affected zone caused by the welding work, are considered in the FEA models. The modified joint, with the optimized factors, is analyzed for different static load conditions, considering axial pressure, axial tension, pure bending, bending with axial force, and eccentric axial forces. The overall mechanical behavior of the joint, including the $M$-$Φ$ curves, initial stiffness, ultimate strength and deformation capacity, as well as the failure modes are identified. The results from the improved joint are compared with corresponding values from of the traditional Temcor joints. The results show that the central hollow hexagonal prism and front bolts significantly improves the stiffness and ultimate strength of the joint, especially when the joint is subjected to pure bending, bending with shear force, axial force, bending with certain axial force and eccentric force.


ABSTRACT: The semi-analytical solution for nonlinear stability analysis of imperfect doubly-curved laminated composite shallow shells with rotationally-restrained edges and under in-plane loading is presented. The nonlinear governing equations are established using the Galerkin method, and the arc-length and quadratic control method is implemented to capture the snapping phenomenon of the doubly-curved composite shells. The nonlinear load-displacement relationships of four special curvature radii of doubly-curved shell structures are obtained, and they are compared and validated with the numerical finite element solutions. A parametric study is conducted to evaluate the effects of the initial imperfection, edge rotationally-restrained spring stiffness, various load parameters, and curvature radius on the nonlinear stability behavior of doubly-curved shells. Finally, the computational efficiency and capability of the semi-analytical solution are demonstrated in comparison with the finite element analysis. The present semi-analytical solution can be effectively and efficiently used in simplified nonlinear stability analysis of complex doubly-curved composite shallow shells with periodic and restrained boundary conditions.


ABSTRACT: This paper focuses on the nonlinear dynamics near internal resonance of a truncated FGM conical shell. The FGM conical shell is subjected to the aerodynamic load and the in-plane excitation along the meridian direction. Material properties depend on the temperature and the constituent phases of the truncated FGM conical shell. The volume fractions are modified in the thickness direction based on a power-law function continuously and smoothly. The first-order piston theory is applied for the supersonic aerodynamic pressure. Based on the first-order shear deformation theory, von-Karman type nonlinear geometric assumptions, Hamilton principle and Galerkin method, the nonlinear equations of motion for the truncated FGM conical shell are derived. The averaged equations of the truncated FGM conical shell are obtained under the situation of 1:1 internal resonance and 1/2 subharmonic resonance by using the method of multiple scales. The frequency-response curves, the force-response curves, the bifurcation diagrams, the phase portraits, the time history diagrams, and the Poincare maps are obtained by using numerical calculations. The influences of the Mach number, the exponent of volume fraction and the in-plane excitation on the nonlinear resonant behaviors of the truncated FGM conical shell are investigated.
ABSTRACT: One of the most effective nondestructive methods to estimate the buckling load of imperfection sensitive thin-walled structures is vibration correlation technique (VCT). Although this technique can determine the buckling load for several types of structures without reaching the instability point, it is still under development for composite sandwich plates and shells. In this paper, experimental and numerical verification of VCT approach are presented for the estimation of the buckling load of the composite sandwich plates with iso-grid cores loaded in compression. In the experimental section, four specimens are designed and fabricated using a new silicone rubber mold, and hand lay-up technique. The modal test is performed on the first specimen by exciting the sandwich plates using the modal hammer method in the different applied loads. Then, the variation of the natural frequency with the applied compressive load is recorded up to actual experimental buckling load. Besides, numerical models, including nonlinear effects, are created in full details to calculate the variation of the natural frequencies with the applied load, and to be compared with the experimental results. Finally, the buckling test is carried out on all specimens to validate the experimental and numerical results of VCT approach. The results demonstrate that the maximum difference between the predicted buckling load using the VCT approach on the experimental and numerical results with an experimental buckling load is less than 5%. Also, VCT provides a reliable estimate of buckling load when the composite sandwich plates with iso-grid cores have been loaded up to at least 67% of the experimental buckling load.


ABSTRACT: In this paper modal decomposition of thin-walled structural members with rounded corners is discussed. Modal decomposition is a process which separates the characteristic behaviour types. If modal decomposition is applied in buckling analysis, pure uncoupled buckling modes can readily be analysed, such as pure global buckling, pure distortional buckling or pure local-plate buckling. Ability to calculate critical loads to a pure buckling mode is highly beneficial in the design of thin-walled structural members, for example in the design of cold-formed steel beams or columns. However, cold-formed steel profiles are always produced with rounded corners, and earlier studies showed that the now-used modal decomposition techniques of the constrained finite strip/element method sometimes fail to lead to reasonable results if the rounded corners are directly modelled in the analysis. In this paper a special version of the constrained finite strip method is presented and discussed. The proposed method introduces elastic corner elements, which makes it possible to perform the modal decomposition by the same process used for members with sharp corners, even if the rounded corners are directly modelled, still the results of pure buckling modes satisfy the engineering expectations. The theoretical background of the proposal is briefly summarized, then the elastic-corner approach is discussed by detailed analysis of sample examples as well as by an extended parametric study.


ABSTRACT: Thermal and mechanical buckling analysis of micro plate reinforced with functionally graded (FG) graphene nanoplatelets (GNPs) is studied in this paper based on modified strain gradient theory (MSGT). For description of kinematic relations, two higher order shear deformation theories including third order shear deformation theory and sinusoidal shear deformation theory are employed simultaneously. Size-dependency is accounted in governing equations of thermal buckling by application of modified strain gradient formulation including three micro length scale parameters. Distribution of graphene nanoplatelets along the thickness direction is assumed based on various known models including Parabolic, linear and uniform. Halpin-Tsai model and rule of mixture are used for calculation of the effective modulus of elasticity and Poisson's ratio, respectively. The outputs of this work are verified through comparison with existing numerical results based on various theories and methods. Thermal buckling loads are calculated based on analytical method in terms of significant parameters such as weight fraction of GNPs, various distribution of GNPs, three micro length scale parameters, some non-dimensional geometric parameters such as side length to thickness ratio and thickness to micro length scale ratio.

ABSTRACT: This paper introduces a novel hierarchical core structure to sandwich panel for bearing the blast loading, in which each vertex of a regular hexagonal cell was replaced with a smaller hexagonal unit. The finite element (FE) models of such hierarchical honeycomb sandwich panels were established and validated with the experiments under different impulse loads. The hierarchical honeycomb cores were compared with the regular honeycomb counterpart in terms of the peak deflection on the back facesheet, compression and specific energy absorption (SEA) of the core. The results showed that the maximum deflection at the back facesheet of the hierarchical honeycomb sandwich panels were smaller than the regular honeycomb counterpart for a higher level of blast load (specifically, the dimensionless impulse higher than 0.06). It was found that the structural hierarchical parameter gamma (i.e. the ratio of the newly-introduced smaller hexagonal edge length (L) to the regular hexagon edge length (L0)), had limited influence on the maximum deflection of back facesheet of the sandwich panel, but had a significant effect on the SEA of the cores.


ABSTRACT: Bistable structures, a class of highly geometrically nonlinear morphing structures, have two stable configurations that remain in their respective equilibrium positions without the continuous application of an external force. This paper aims to summarise, review, and assess the literature about the theoretical studies, driving methods, numerical simulations, experimental investigations, and fields of application of the structures. The theoretical models are separated into anisotropic and isotropic composites based on the properties of the material. The generalised methods to study the bistability of structures with various properties are presented. The driving methods used to trigger the snap of one equilibrium structure to the other include mechanical force, piezoelectric actuation, shape memory alloy actuation, thermal actuation, and magnetic actuation. Numerical simulations of the curing process during manufacture and of the morphing process, which includes the snap-through and snap-back of the bistable structure, are reviewed. Moreover, the experimental investigations of structures with unsymmetric and antisymmetric layups are also presented. Bistable composite laminates and their structures have been used in aerospace, bionics, energy harvesting, and other fields due to their unusual behaviour and morphing potential. This paper also highlights the remaining challenges and possible future work on bistable composite transition, from phenomenon to potential applications.


ABSTRACT: Extensive numerical results available in published articles reflect the importance of the effects of geometric parameters, material properties, end conditions, hygrothermal fields, etc. on the behavior of laminated composite and sandwich structures when exposed to environmental conditions. A critical review of available literature for the prediction of the behavior of laminated composites and sandwich structures under hygrothermal conditions is carried out and summarized under different categories namely: static, vibration, buckling, post-buckling and miscellaneous studies (transient, dynamic, impact studies). Each category is further discussed separately in details highlighting the important outcomes of the research. In addition to that, each category is again grouped on the basis of the type of theory used by different researchers in their work. The displacement fields, thermal fields and the method adopted in different papers are also summarized.


ABSTRACT: Thin-walled cold-formed (TWCF) steel members are widely used in aerospace, automobile and architecture industries. Among the various advantages, mainly associated with the relatively simple and very cheap techniques required for their production and shaping, it is important to mention the relevant high strength to weight ratio. Beside the benefits, it has to be pointed out that the TWCF member response is quite difficult to
be predicted because of the significant influence of local, distortional and overall buckling phenomena, owing to the frequent presence of open mono-symmetric cross-sections.

The present paper can be intended as a typical technical paper whose results are useful not only for research activities, but, especially, for the routine design. It summarises a study aimed at increasing the safety of two European approaches that should be potentially adoptable for designing TWCF steel members. The grade of reliability of these existing European procedures has been evaluated by predicting the performance of more than 240 TWCF members tested in laboratory, selected in the framework of 13 experimental studies, taken from the literature. Being the assessed load carrying capacity sometimes significantly greater than the characteristic-experimental one, suitable safety factors have been consequently calibrated and proposed for each cross-section type, to be directly adopted in routine design to match the requirements associated with the limit state philosophy. Finally, the strength of additional TWCF beam-column specimens has been predicted to assess the efficiency of the proposed coefficients for practical cases frequently encountered in routine design. A complete benchmark is proposed in Appendix A, where the application of the considered design procedures for one selected case is reported.


ABSTRACT: Steel I-girders with slender web are commonly used in the engineering practice. Previous research results proved that the current bending and shear interaction (M-V) check of the EN1993-1-5 does not always provide safe side resistance. The current research work focuses on the analysis of the M-V interaction behavior of longitudinally unstiffened and stiffened I-girders with slender web. Applicability interval of the current EN1993-1-5 based M-V interaction resistance model is determined and based on the executed numerical investigation a refined M-V interaction equation is proposed to ensure safe and economic design. The results of the numerical parametric study also proved that the flange contribution in the shear buckling resistance does not match the current design rules of the EN 1993-1-5. In a specific parameter range (girders with light flanges) the current design rule underestimates the flange contribution to the shear buckling resistance leading to conservative resistances. However, for I-girders with heavy flanges the current design method gives unsafe results. Therefore, the current paper presents an improved formula to the flange contribution ensuring better approximation of the computed resistances.


ABSTRACT: The paper presents an experimental investigation on cold-formed high strength steel tubular T-joints. The fabricated T-joints include brace members made up of square, rectangular and circular hollow sections, while chord members were made up of square and rectangular hollow sections. The nominal yield strengths of square and rectangular tubular members were 900 and 960 MPa, while the nominal yield strength of circular tubular members was 900 MPa. Two configurations of tubular joints were fabricated, first, where both brace and chord members were made up of square and rectangular hollow sections, and second, where circular hollow section braces were welded to square and rectangular hollow section chord members. The brace and chord members were joined together by automatic gas metal arc welding process. In total, 24 tubular T-joint tests were conducted where an axial compression was applied through the brace members of the T-joints, while the ends of the chord members were supported on rollers. The ratios of brace-to-chord width (β) ranged from 0.34 to 1, brace-to-chord thickness (δ) ranged from 0.52 to 1.27 and chord width-to-chord thickness (2δ) ranged from 20.63 to 38.55. The resistances and deformations of tubular T-joints were carefully examined. In order to evaluate the applicability of the existing design provisions for high strength steel tubular T-joints, test results were compared with the nominal strengths obtained from the Eurocode 3 (EC3) and CIDECT. It is shown that the existing design provisions are not capable of providing accurate and reliable predictions for the design of cold-formed high strength steel tubular T-joints made up of S900 and S960 steel grades.

ABSTRACT: Storage rack structures are pre-engineered light weight steel structures with standard details which can be quickly assembled because all building components arrive on site pre-fabricated in line with the agreed design. Since they are made using thin-walled perforated steel sections, mostly cold-formed, with mechanical joints, generally partial-strength, semi-rigid, and with a low structural redundancy, these structures are vulnerable to any action capable to induce a local damage of a member or connection. When heavily loaded, the local damage may spread progressively, generating an overall collapse or disproportional damages. Difficulties in predicting the structural behavior of storage pallet racks are amplified by the specific geometry of the structural components: members made by high slenderness thin-walled and open-section profiles (hence prone to global, local and distortional buckling problems), flexible beam-upright and baseplate connections with a non-linear behavior. Due to their peculiarities, additional modelling and design rules are required for these non-traditional steel structures and reference cannot be made to usual structural design recommendations and standards. In case of Selective Pallet Rack (SPR) structures, except for the earthquakes, collision of forklift trucks or other moving equipment with front upright is considered as one of the most frequent causes of local failure, with potential to develop into a progressive collapse. In the study, the robustness of SPR structures under accidental loading situations involving collision with forklift truck is assessed using both notional upright removal and explicit forklift impact approaches. Structural configurations are varied to consider different connection properties (upright base and beam-to-upright) and brace arrangements (spine bracing, top plan bracing). SPR structures are susceptible to global failure, especially if the spine bracing is in just a few spans and the rigidity of connections is low. The explicit modelling of the forklift impact provides the most accurate results, as the effects associated with the forklift impact are not properly captured when the response is evaluated using the dynamic analysis and notional upright removal approach. Non-linear static pushdown analysis can provide satisfactory results at the least computational effort, but the dynamic increase factors may require corrections.


ABSTRACT: In this research, the buckling behavior of thin walled composite shell with embedded shape memory alloy (SMA) wires is examined numerically. To model the SMA wire properties, constitutive equation of Brinson is used and a UMAT subroutine is developed to link with ABAQUS finite element (FE) model performed to simulate the buckling behavior of composite shells. To validate the FE modeling, some experimental specimens are fabricated by filament winding process and tested under axial compressive loading to analyze the buckling behavior of the structure. The results show that the numerical model has sufficient accuracy and the effect of tensile pre-strain and the number of embedded SMA wires on the buckling capacity of the cylindrical composite shell are investigated. As the results obtained, by embedding 4 SMA wires without pre-strain in composite shell, the critical buckling load increases about 35%. Also, by increasing the pre-strain and the number of SMA wires (more than 4), the stiffness of the structure and the magnitude of the critical buckling load are decreased.


ABSTRACT: Concrete-filled stainless steel tubular (CFSST) columns combine the advantages of composite action seen in concrete-filled steel tubular (CFST) columns with the durability benefits associated with stainless steel. An effective means of reducing the material usage in the outer stainless steel tube in CFSST columns is to embed an inner carbon steel profile. This enables the material costs to be reduced, while achieving similar load-bearing capacity and durability, as well as enhanced fire resistance. The behaviour of such steel reinforced composite columns, i.e. concrete-filled stainless steel tubular (CFSST) columns with outer square cross-sections and embedded carbon steel profiles, under ISO 834 standard fire conditions is investigated in this study by finite element (FE) analysis. Firstly, FE models are developed and validated against relevant published experimental data on CFSST and steel reinforced CFST columns under fire conditions. Based on the validated FE models, the
working mechanisms of the studied steel reinforced CFSST columns under fire conditions are investigated by analysis of the temperature field, failure modes, axial deformation versus time response and internal force distribution. The fire performance of the studied steel reinforced CFSST columns is also evaluated in comparison with CFST and CFSST columns with the same total cross-sectional area of steel or the equivalent cross-sectional load-bearing capacity at ambient temperature. Finally, with respect to fire resistance, the optimal ratio of the cross-sectional areas of the inner carbon steel profile to the outer stainless steel tube is investigated.

ABSTRACT: Concrete-filled steel tubular (CFST) truss is a type of composite structure with CFST chords and hollow tubular braces. CFST trusses have been increasingly used in large-scale structures such as towers, bridge girders, piers and arch ribs. The compression and flexural behaviour of CFST trusses are greatly improved compared to hollow tubular trusses due to the concrete infill in chords. With the complex configuration, nonlinear material interaction and sophisticated construction process, initial imperfections may largely affect the strength and stability of a CFST truss structure. Relevant studies in the past mostly focused on one single type of imperfection with assumed magnitude in CFST member whilst in reality a variety of combinations of steel and concrete imperfection exist. This paper develops a nonlinear analysis formwork with the reliability analysis of CFST truss with random imperfections based on on-site measurement data and Monte-Carlo (MC) simulations. Advanced nonlinear finite element analysis (FEA) that can account for the material interaction and confinement in CFST trusses is established and validated by reported test data. The flexural behaviour of CFST trusses with deterministic and probabilistic initial imperfections are evaluated and compared, based on which the reliabilities and related system resistance factors in regards to random initial imperfections are proposed.

ABSTRACT: In this study, a finite element model was established and validated to investigate the mechanical behaviour of the latticed-sleeved compression member with strip core. Failure mechanism of the latticed-sleeved compression member was studied based on the core moment distribution and the effects of three reinforcement methods to increase the ultimate bearing capacity were compared. A parametric study was performed to investigate the effects of essential factors on the mechanical behaviours of the latticed-sleeved compression members. A method was adopted to control global buckling of the latticed-sleeved compression members. Based on the latticed-sleeved compression member, a capacity-monitoring member was introduced to control buckling and monitor the bearing capacity of the key compression member. It is concluded that: the latticed-sleeved compression member has a greater resistance to buckling; mutual effects exist between the two failure modes, local buckling of the core segment and global buckling of the latticed-sleeved compression member; the gap between the core and sleeve, the sleeve stiffness and the core protrusion length above sleeve have effects on the mechanical behaviors of the latticed-sleeved compression members; the adopted method considering the mutual effects between the two failure modes can effectively control global buckling of the latticed-sleeved compression members; and the bearing capacity of latticed-sleeved compression member can be monitored through measuring the resultant axial force of the connecting bolts.

ABSTRACT: The behaviour of cold-formed lean duplex stainless steel columns at elevated temperatures was investigated. A numerical investigation on columns of square and rectangular hollow sections were performed at elevated temperatures ranged from 24 to 900 °C. A validated numerical model with material properties obtained from tensile coupon tests at elevated temperatures were used in the finite element analysis. A total of 180 numerical column strengths were compared with design column strengths predicted by existing design rules, which do not cover the lean duplex stainless steel material at elevated temperatures. Reliability analysis was carried out to assess the suitability of the existing design rules for lean duplex stainless steel columns at elevated temperatures. It is shown that the existing design rules are generally not suitable for predicting the column strengths, except for the American Specification and the modified direct strength method for stainless
steel. The modified direct strength method for stainless steel provides accurate and reliable predictions with relatively simple calculation procedure. Therefore, it is recommended that the modified direct strength method for stainless steel be used for design of cold-formed lean duplex stainless steel columns at elevated temperatures.


ABSTRACT: The aim of this work is to investigate the effects of kinematics approximation on post-buckling analysis of sandwich structures. To this end, a novel one-dimensional (1D) layer-wise model is proposed, where the core is approximated by Mac Laurin's polynomial functions, and the skins are modelled by Euler-Bernoulli beam theory. The resulting nonlinear equations are solved by the Asymptotic Numerical Method (ANM), in which the bifurcation indicator is introduced to precisely detect the bifurcation points and the corresponding instability patterns. By varying the polynomial order in the core, various kinematics models are generated automatically, and then evaluated in the post-buckling stage. According to the comparison results, we finally propose an optimized model that is valid in a wide range of geometric and material parameters.


ABSTRACT: This research aims to investigate the free vibration characteristics of a nanoplate sinking in an incompressible fluid, so that the plate is in touch with the fluid from its upper surface. The nonlocal continuum theory together with Gurtin-Murdoch elasticity theory are employed to examine the influence of size-dependency and surface energy effect, respectively. In order to model the fluid-plate interaction, the Navier-Stokes equation is utilized, and the motion equations are solved through implementing Galerkin weighted residual method. The results show that the impact of fluid on shifting the nanoplate natural frequencies to the lower values highly depends on the small-scale parameter. Furthermore, for certain value of the length-to-thickness ratio, while the effects of nonlocal and surface energy parameters are considered to be negligible, the natural frequencies of the submerged nanoplate significantly overestimate the values obtained in the presence of these parameters. This means that, in order to precisely predict the system natural frequencies, it is important to include the impact of size-dependency and surface energy in the mathematical formulation.


ABSTRACT: The wide application of aluminum alloys has been spread in the field of civil and building engineering due to their excellent performance and advantages. The companion paper (Part I) has described the eccentrically compressive loading tests and the verification of finite element (FE) models. In this paper, a parametric study about the 6082-T6 aluminum alloy columns of square and circular hollow sections (SHS-CHS) subjected to eccentric compression was performed using the verified FE models. The key parameters affecting the buckling behaviors and ultimate strength were investigated, including the regularized slenderness ratio, eccentricity, width-thickness ratio (for SHS columns) and diameter-thickness ratio (for CHS columns). The ultimate strength obtained from the previous loading tests and the finite element analysis (FEA) were compared with the design strength predicted by the current Chinese (GB 50429), European (Eurocode 9), American (AA-2010) design codes for aluminum alloy structures. In addition, the newer proposed design method – the direct strength method (DSM), were also investigated. It was found that these four design provisions were generally conservative for predicting the ultimate strength of the SHS and CHS columns for 6082-T6 aluminum alloy and DSM was shown to provide more accurate strength predictions than the current design codes. Finally, the optimal distribution types of the model error (ME) in the four design provisions were investigated and reliability analysis was conducted under different load ratios to evaluate the safety levels of the three current design codes and DSM. Revised Chines code was proposed to predict the ultimate strength of 6082-T6 aluminum alloy columns more precisely.

ABSTRACT: The vibrational behavior of multilayer functionally graded graphene platelets reinforced composite (FG-GPLRC) toroidal panels with elastically restrained against rotation edges is investigated. The first-order shear deformation theory (FSDT) of shells together with the finite element method (FEM) is employed to develop a general formulation and solution procedure. Nine-noded isoparametric shell elements with five degrees of freedom per node are used to discretize the spatial domain. After validating the approach, the influences of different distribution patterns of graphene platelets (GPLs) through the panel thickness, the geometrical parameters, and the elastic coefficients of the rotational springs are studied. It is shown that among the multilayer FG-GPLRC toroidal panels with different GPLs distribution patterns, the toroidal panels with X-type pattern have the highest frequency values whereas the minimum values belong to the shells with O-type and -type for the first and second frequency parameters, respectively. Also, the numerical results reveal that by increasing the GPLs volume fraction and the elastic coefficients of rotational springs, the frequency parameters increase, and these parameters have considerable effects on the frequency parameters. Also, the mode shapes of multilayer FG-GPLRC toroidal panels for different GPLs distribution patterns are depicted.


ABSTRACT: For the design of thin-walled spherical shells under external pressure empirical knockdown factors are applied. These knockdown factors are based on experimental results from the beginning of the 20th century and have been shown to be very conservative for modern shell structures. In order to determine less conservative and physically based knockdown factors for the design of spherical shells, different analytical and numerical design approaches have been developed. In this paper common as well as new shell design approaches are presented in detail and evaluated regarding the lower-bound buckling pressure. Among these design approaches are the reduced stiffness method, measured geometric imperfections and perturbation approaches. Important analysis and modeling details of each design approach are described, and test examples are given and validated. Advantages and disadvantages of each approach are listed, and design recommendations are given. Practical shell buckling design examples are demonstrated by means of a tori-spherical bulkhead and a deep-sea spherical pressure hull. In addition, a collection of about 700 experimental knockdown factors for spherical shells under external pressure is given in the Elsevier repository.


ABSTRACT: Aluminum alloys, which function as load-bearing components or decorative materials, have been commonly applied to architectural structures. In this study, a combination of experiments and finite element analyses was conducted to investigate the stability behaviors and ultimate strengths of the 6082-T6 aluminum alloy columns subjected to eccentric compression. Prior to the loading tests, tensile coupon tests and measurement of the initial geometric imperfections for the columns were performed. The buckling behaviors of 30 pin-ended specimens, including 11 extruded square hollow section (SHS) columns and 19 extruded circular hollow section (CHS) columns, were investigated and the observed failure modes of the tested columns included overall buckling, local buckling and the coupling modes. Meanwhile, the ultimate strengths, deflections and surface strains in whole process under eccentric compression were recorded. The finite element (FE) models of the tested columns were developed using the non-linear finite element analysis (FEA) software ABAQUS, and the geometric and material nonlinearities were considered in the FE models. The validation of the FE models was performed against the test results; it was observed that the proposed FE models are sufficiently accurate to predict the ultimate strengths and buckling behaviors of the tested columns.

ABSTRACT: This is the first research on the nonlinear vibration analysis of composite sandwich doubly curved shell with a flexible core integrated with a piezoelectric layer. By using the higher order shear deformable theory (HSDT) for the face sheets and the third-order polynomial theory for the flexible core, the strains and stresses are obtained. It is assumed a smart model including multiscale composite layers shell with a flexible core and magnetorheological layer (MR) that leading up by the nonlinearity of the in-plane and the vertical displacements of the core. Three-phase composite shells with polymer/Carbon nanotube/fiber (PCF) and polymer/Graphene platelet/fiber (PGF) and Shape Memory Alloy (SMA)/matrix either according to Halpin-Tsai model have been considered. The governing equations of multiscale shell have been derived by implementing Hamilton's principle and solved by multiple scalar method. For investigating the correctness and accuracy, this paper is validated by other previous researches. Finally, the effect of different parameters such as temperature rise, various distributions pattern, magnetic fields and curvature ratio are explored in detail.


ABSTRACT: The aim of the current work is to present a shear deformation theory which can model the free vibration of functionally graded nano-size beams made of two different types of materials (isotropic and anisotropic) resting on elastic foundation using a new shear strain shape function. The proposed model includes undetermined integral term and also contains both transverse shear and stretching effects. The size-dependent behavior of nano-size systems is captured via the nonlocal strain gradient theory. The governing equations of motion are obtained based on a virtual work of the Hamiltonian principle where an analytic technique based Navier series is established to solve the eigenvalue problem. From our knowledge, it is the first time that size-dependent dynamics of graded nanobeams made of anisotropic materials is investigated. The efficiency of the present model is verified by comparing the results of numerical examples with the different solutions found in the literature. It shows that the dynamic characteristics of the nanobeam are influenced by size effects, geometry, power-law index, exponential factor, and elastic foundation. Also, the possibility and accuracy of replacing a hexagonal model with isotropic one is investigated and discussed in detail.


ABSTRACT: Adoption of cylindrical shell structures for various load-resistance applications has enjoyed widespread acceptance in the field of civil, mechanical and aerospace engineering, mainly due to the exceptional structural efficiency of cylindrical shells to withstand significant longitudinal and circumferential in-plane loading without bending. However, where such in-plane loading conditions are compressive, cylindrical shells are likely to exhibit an unstable response characterized by localized out-of-plane deformation. Computerized numerical simulation is often required for accurate and efficient estimation of the strains and resultant stresses in cylindrical shells under loading, especially where the thickness of the shell is sufficient to evoke an inelastic buckling response in the structure. The buckling behavior of thin-walled cylindrical shells subjected to uniform axial compression has been studied in this paper using the finite element (FE) simulation method to assign respective material, geometric, loading and boundary properties to computer-generated cylindrical shell specimens. Extensive parametric analysis, consisting of approximately 720 FE runs, was then conducted based on a full-factorial empirical design, applying ample variations of the relevant parameters that influence the buckling response of axially-compressed cylindrical-shell structures. Nonlinear multiple regression techniques were then employed to derive the coefficients of nonlinear mathematical expressions, each developed as an arithmetic product of appropriate variable functions related to the respective functional sensitivities of the investigated parameters. Strain-hardening properties were incorporated into the mathematical expressions based on the shape constants of the Ndubuaku stress-strain model; which has proven to be remarkably useful for accurate parameterization of the stress-strain behavior over the full range of strains for a wide range of metallic materials, including materials with a well-defined yield plateau. Excellent predictions of FEA-derived values.
for the critical limit strain limit were obtained, and a simple statistical approach was presented to increase the conservativeness of the semi-empirical model as required.


ABSTRACT: Damage caused by corrosion is one of the main factors that diminish the performance of thin-walled structures such as pipelines. Using experimental and numerical methods, this study investigated the effects of corrosion depth and corrosion shape on the performance of corroded thin-walled steel pipes when subject to combined internal pressure and 4-point bending load. The effect of corrosion depth was studied using three API 5 L X52 grade pipe specimens with a nominal diameter of 8-inches (203 mm), and the effect of corrosion shape was investigated by testing five API 5 L X46 specimens with a nominal diameter of 6-inches (152mm), containing different corrosion shapes. It was found that increasing the corrosion depth drastically decreases the bending capacity of the corroded specimens. Also, it was observed that the specimens with circular and square corrosion shapes exhibited the same bending behaviour, and extending the corrosion along the circumferential direction of the pipe wall caused the most negative effect on the bending behaviour of the specimen.


ABSTRACT: This paper investigates the shear behaviour of Hybrid stainless steels (HSS) plate girders using the commercial FE software, Abaqus. Two types of stainless steel grades were adopted viz., Lean duplex stainless steel (LDSS) for web and Duplex stainless steel (DSS) for flanges. The FE results are presented in the form of shear capacity (V) and failure modes. Based on the study, it has been observed that web thickness (t) has higher positive influence on the shear capacity as compared to flange thickness (t). On the other hand, relative improvement in ductility could be seen when flange thickness is increased, in contrast to increase in web thickness (t). In general, three failure modes were observed in HSS plate girders viz., shear dominant failure mode, bending dominant failure mode and combined shear and bending dominant failure mode. Based on the present results, modified Eurocode and Direct strength method (DSM) design formulations have been proposed.


ABSTRACT: In this paper, the axisymmetric buckling of circular strain rate sensitive tubes subjected to axial impact is investigated theoretically and experimentally. The nonlinear governing equations are first derived in an incremental form. Then, the finite difference method is employed to solve the obtained equations implicitly for the case when a stationary tube is impacted by a striking mass. Experimental tests are performed by using a gas gun. The effect of linear and multi-linear approximation for strain hardening and strain rate on the shortening, buckling shape and axial force of steel tubes are investigated in which the strain rate is considered as a function of time. By applying the strain rate effect and using the multi-linear approximation for strain hardening, we showed there is a significant association between theoretical and experimental results of steel tubes. Also, using the nonlinear dynamic equations and newly developed inexact finite similitude theory it is revealed that the response characteristics of full-scale strain rate sensitive tubes can be predicted using small-scale strain rate insensitive tubes.


ABSTRACT: The present work discusses the development of a formulation for efficiently analyzing variable-stiffness plates operating in the post-buckling regime. The approach relies upon the combined use of a single-mode Koiter’s perturbation strategy along with a mixed variational formulation expressed in terms of Airy stress function and out-of-plane displacement, where the unknowns are approximated using global trial functions
A highly efficient numerical tool is achieved, which allows the initial post-buckling field to be analyzed with the ease of closed-form solutions, but a much wider field of employ in terms of elastic couplings, boundary and loading conditions. The quality of the predictions is illustrated by means of a comprehensive set of comparisons against results from the literature. Possible applications of the approach are shown, where the exploration of the design space offered by curvilinear fibers requires thousands of non-linear post-buckling analyses to be run.


ABSTRACT: A solution to the ‘modal decomposition problem’ encountered within the context of the stability analysis of thin-walled structural members is presented. The proposed method achieves decomposition of a randomly deformed shape into a number of constituent modes, which have the physical meaning of the classical local, distortional and global buckling modes, augmented with two additional classes of shear and transverse extension modes. The basis vectors of these five classes are created by defining sets of nodal forces which, when applied to the member in a first order linear elastic problem, generate shapes commensurate with specific mechanical criteria defining the local, distortional, global, shear and transverse extension modes. In a second step the basis vectors of a given class are used to define a constrained stability problem, where the solution is restricted to a linear combination of these basis vectors, in order to obtain the buckled shapes under a given loading. The full set of buckling modes spanning the five classes forms an orthonormal basis of the complete deformation space. Consequently, decomposition can be achieved by projecting the shape which is to be decomposed onto the basis vectors. Two examples are provided to illustrate the method.


ABSTRACT: This paper examined the effect of numerical modelling parameters on the accuracy and computational efficiency of Carbon Fibre Reinforced Polymer (CFRP) stiffened panels under Compression After Impact (CAI). Pristine and damaged CFRP stiffened panels were subjected to compression in Abaqus® software using Cohesive Zone Model (CZM) method. Various case studies were examined and the effect of the stiffness parameters of the cohesive elements was critically assessed. Moreover, the required number of cohesive zones to fully capture the damage mechanisms of the impacted and pristine panels under compressive loading was examined. The results showed that a wrong set of parameters can even lead to neglecting the induced damage and can cause severe convergence problems in the numerical model. The importance of the Overall Meshing Factor (OMF) was highlighted and a user-defined subroutine (USDFLD) was applied to capture the decrease in the load bearing capability of an impacted panel prior to the compressive loading, since CZM was found insufficient for this scope. The above-mentioned remarks illustrated the process of investigating the optimum numerical parameters set to achieve an accurate and efficient finite element modelling of the stiffened panels structural performance and maximum load-carrying capability, when subjected to CAI loading.


ABSTRACT: Nonlinear dynamic stability investigations for isotropic and composite cylindrical shells under pulsating axial loading are carried out through Finite Element analysis using numerical time integration. In particular, important characteristics of the geometrically nonlinear behaviour are systematically studied through Finite Element analysis. The results of the Finite Element analysis are compared with results obtained in earlier studies using semi-analytical procedures. In order to facilitate the evaluation and the comparison of these two complementary approaches, a modal projection procedure has been developed for the Finite Element analysis. Critical dynamic loads and frequency-response curves for isotropic and composite shells under pulsating loading obtained with the Finite Element analysis using numerical time integration are shown to be generally in good qualitative agreement with the results of earlier semi-analytical work. The analysis of the modal amplitude achieved via the modal projection procedure also makes it possible to study the interactions between...
contributing modes and to observe and interpret interesting phenomena such as the occurrence of travelling waves in the circumferential direction of the shell.


ABSTRACT: The goal of this paper is twofold. The first goal is to show that geometrically exact beam finite elements can be successfully employed to determine, accurately, the behaviour of steel I-section beams undergoing large displacements and finite rotations. For this purpose, a two-node geometrically exact beam element is presented and validated, which can handle arbitrary initial configurations (e.g. curved configurations), plasticity, geometric imperfections and residual stresses. The second goal is to employ the proposed element to assess the behaviour of I-section beams undergoing lateral-torsional buckling. In particular, the element is used to determine (i) elastic non-linear bifurcation loads (i.e., bifurcation loads accounting for pre-buckling deflections), (ii) large displacement elastic post-buckling paths including geometric imperfection effects and (iii) large displacement elastoplastic equilibrium paths accounting for geometric imperfections and residual stresses. Three support/loading cases are examined, namely: (i) simply supported beams under uniform moment, (ii) simply supported beams subjected to a mid-span vertical force and (iii) cantilevers subjected to a free end vertical force. Besides I-sections with standard height-to-width ratios, wider flange sections are also considered and it is demonstrated that, for the latter, the post-buckling behaviour is quite different from that of standard sections and an increase in the load carrying capacity is observed, which is not predicted by the current Eurocode 3 [1] provisions. Based on the results obtained, a set of relevant conclusions are drawn.


ABSTRACT: The evaluation of residual stress and its redistribution under cyclic loads are crucial to guarantee the integrity of welded components. In this paper, the effective parameters on welding residual stress relaxation are examined in thin cylindrical vessels due to cyclic pressure. First, the 3D finite element modeling is performed to evaluate the welding residual stress under cyclic pressure with various amplitudes and cycle numbers. Further, the model is verified using experimental stresses through the hole-drilling method. To study the plasticity behavior, two plasticity models are implemented: perfect plasticity and combined isotropic with kinematic hardening. It is concluded that the former leads to greater stress change. In addition, cyclic pressure causes redistribution and even change in the sign of the residual stresses, but this effect can be manifested as either stress relaxation or stress enhancement, depending on the initial residual stress. Moreover, the influence of various geometrical and loading parameters on stress modification is investigated through the Taguchi method. Statistical analysis reveals that an increase in thickness and diameter leads to a higher modified hoop stress, while an increase in maximum pressure leads to a lower modified hoop stress. On the other hand, the modified axial stress increases with an increase in thickness, and decreases with an increase in diameter. Analysis shows that thickness and maximum pressure are the most important parameters on the modified hoop and axial residual stresses, respectively. Finally, useful equations are proposed that can be used to calculate the modified residual stresses in terms of design factors.


ABSTRACT: The main structure of the central detector at the Jiangmen Underground Neutrino Observatory (JUNO) is a spherical shell structure, which has a giant acrylic spherical shell connected to a stainless-steel (SS) reticulated shell with 590 SS rods. The acrylic spherical shell is submerged into water and filled with detection liquid and prone to rotation subjected to considerable buoyancy. The stability against rotation of this super-deep underground spherical shell structure needs to be fully investigated. In this study, an effective and practical method consisting of parametric analysis and optimization procedure is proposed to improve the stability against rotation. Specifically, two indicators, namely, the critical loading multiplier and the rotation angle, are proposed to evaluate the stability against rotation of the acrylic spherical shell in linear and nonlinear stability analyses, respectively. Then, parametric analysis is performed to assess the sensitivity of the stability against
rotation to four parameters of interest (i.e., rod outer end constraints, liquid level difference, disc spring stiffness, and rod deviation). Based on the obtained parametric analysis results, the liquid level difference and disc spring stiffness are finally selected as design variables for the subsequent optimization process to further improve the stability against rotation. An efficient scheme combining design variable discretization and exhaustive method is adopted to identify the optimal variable values at which the acrylic spherical shell has good stability against rotation. The results indicate that the proposed method is efficient and effective for optimization of stability against rotation of such super-deep underground spherical shell structure. The proposed method is practical and easy to use for structural designers, and provides an efficient approach to the stability design of such rod-connected spherical shell structures.


ABSTRACT: Tanks, silos, and most large steel-shell structures consist of smaller pieces connected together during the manufacturing process. This causes several types of malformations on the shell walls. Furthermore, thin-walled members can be easily deformed in wall surfaces owing to the thickness of the structure. Fourteen thin-walled cylindrical shell specimens in two groups with different dent depths and various longitudinal dent numbers subject to hydrostatic pressure were tested in the present work. The models were designed to demonstrate how repairing dents by using carbon-fibre-reinforced polymer can recover lost capacity. The results of testing under different theories and codes were compared. This study shows the decreasing effects of the longitudinal dent number on the buckling capacity of the shells. Using carbon-fiber-reinforced polymer strips resulted in softening or stiffening behaviour in the models. Furthermore, to obtain the initial and overall buckling according to theoretical formulas, coefficients were predicted to obtain the initial, overall, and collapse buckling without an experiment for the models that were beyond the scope of the theories.


ABSTRACT: A unified analysis model for vibration characteristics of composite laminated annular sector plate, circular sector plate, annular plate and circular plate with various elastic boundary conditions is established based on the simplified plate theory (SPT) and two-dimensional (2D) improved Fourier-Ritz method. It has significant advantages in the study of free and forced vibration of thin-to-moderately thick rotary composite laminated plates. Under the current framework, the displacement admissible functions of the rotary plate are generally expressed as superposition of simple periodic functions, which includes the multiplication of two cosine functions and two complementary polynomials. The introduction of these polynomials can effectively eliminate jumping or discontinuity at the boundaries. The vibration characteristics of the rotary plate can be obtained by Rayleigh-Ritz energy technique. The present method shows fast convergence and good accuracy. The parameterization study on geometric parameters, material parameters and boundary conditions has been carried out to systematically reveal the vibration characteristics of rotary composite laminated plates, which can be the benchmark for the future research.


ABSTRACT: High-strength square concrete-filled double steel tubular (CFDST) slender beam-columns with a circular internal steel tube subjected to eccentric loads may undergo interaction local-global buckling. No computational studies on the interaction local-global buckling of slender square CFDST beam-columns have been reported and their behavior has not been fully understood. This paper describes a mathematical model for the simulation of the interaction local-global buckling behavior of square high-strength CFDST slender beam-columns under axial compression in combination with uniaxial bending. The mathematical model is formulated by the fiber approach, accounting for confinement provided by the internal circular steel tube, and geometric and material nonlinearities. An incremental-iterative numerical procedure is designed to quantify the local-global interaction buckling responses of slender CFDST columns. Efficient numerical solution algorithms implementing the inverse quadratic method are developed for solving the nonlinear equilibrium dynamic
functions of CFDST columns. The formulation proposed is verified by existing experimental data on CFDST columns as well as double-skin concrete-filled steel tubular (DCFST) slender columns. The developed computational model is employed to study the local-global interaction buckling behavior of CFDST columns made of high-strength materials with various important parameters. Simplified design models are proposed for determining the ultimate axial strengths of slender square CFDST columns under axial compression and the interaction curves of CFDST slender beam-columns loaded eccentrically. It is demonstrated that the computational and design models predict well the interaction local-global buckling behavior and strength of slender square CFDST beam-columns.


ABSTRACT: Laminated composite plates and shells have been widely used in aeronautical, mechanical, and naval structures. Stability is a major concern in the design of these structures due to their high slenderness. Therefore, it is necessary to properly analyze their post-critical behavior, assessing their sensitivity to initial imperfections and load-carrying capacity. This paper presents a methodology based on the Isogeometric Analysis to study the stability of laminated plates and shallow shells. In this formulation, the geometry and displacement field are described using NURBS basis functions. Appropriate integration schemes are used to avoid the locking problem for thin-walled plates and shells. The proposed formulation was applied in the stability analysis of various examples and excellent results were obtained. The influence of the composite layup and geometric imperfections on the buckling load and post-critical behavior is studied. New bifurcation solutions to a well-known laminated shell buckling benchmark problem are presented.


ABSTRACT: In this study, the axial impact behavior of empty and filled nested tubular structures is parametrically investigated both experimentally and numerically. The experiments are conducted by a drop test machine and the numerical studies are conducted using LS-DYNA software. The tubes are made of AL6063 aluminum alloy and a regular hexagonal honeycomb filler of ABSplus plastics. The external sizes of all specimens are held constant for meaningful comparisons. The primary objective of this study is to investigate the effects of using a honeycomb filler, increasing the numbers of tubes, and changing the lengths of the tubes on the nested tube structures. The results of single, double, triple, quadruple, and quintuple tubular structures, with and without the honeycomb filler, are compared in terms of collapse mechanism and common crashworthiness indicators, namely, peak crash force, specific energy absorption, and crash force efficiency. The results indicate that the honeycomb filler has a significant effect on the collapse mechanism of single and nested tubular structures, and the filled nested tube systems with fewer tubes are better than empty ones in terms of specific energy absorption and crash force efficiency. In addition, the energy absorption of the nested tubes could be increased in certain cases with the increase in the number of tubes and tube lengths increasing from the innermost to outermost tubes. Therefore, the double nested tube structures with a honeycomb filler are recommended for crash box designs.


ABSTRACT: This paper discusses the strength and stability of cold-formed welded hollow sections with and without stiffeners, as well as four different cross-section shapes, in terms of the “Overall Interaction Concept” (OIC). The studied types of cross-section are employed in various fields of the construction sector, and particularly in racking systems, where weight minimization is a specifically emphasized design objective. The scope of the study consists of an extensive experimental campaign, coupled with a comprehensive series of numerical tests. The results shown were developed in the framework of the European (RFCS) research project HOLLOSSTAB. The discussion of the results in terms of the OIC approach highlights its potential as a general
method for the cross-sectional design for hollow sections of various shape, loaded in various combinations of compression and bending.

Si-Wei Liu (1), Wen-Long Gao (1) and Ronald D. Siemian (2)
(1) School of Civil Engineering, Sun Yat-Sen University, Zhuhai, Guangdong, China
(2) Department of Civil and Environmental Engineering, Bucknell University Lewisburg, PA 17837, USA


ABSTRACT: Open-sections are often used in structural applications because of their material efficiency in providing members of high strength and stiffness. Although previous research has made significant progress in accounting for the effects when the shear-center and centroid are not coincident for such sections, the compression buckling strengths of non-symmetric sections, for example unequal-leg angles, are sometimes over- or under-predicted. This paper improves existing beam-column line-element formulations for accurately simulating the axial buckling behavior of arbitrarily-shaped open-sections. Detailed derivations are given and implemented within the educational software MASTAN2. Several verification examples are provided.

Miroslaw Ferdynus (1), Maria Kotelko (2) and Mariusz Urbaniak (2)
(1) Department of Machine Construction & Mechatronics, Lublin University of Technology, Poland
(2) Department of Strength of Materials, Lodz University of Technology, Poland


ABSTRACT: The paper presents results of the numerical and experimental study into crashworthiness performance and energy absorption capability of thin-walled square section columns with dents, subjected to axial impact load. Thin-walled aluminum tubes with four dents in the corners are under investigation. Energy absorption effectiveness of energy absorbing thin-walled structures is discussed. Finite Element parametric study into energy absorption capacity of structures under investigation is performed. Crushing behavior and some crashworthiness indicators are examined. Results of experimental impact tests carried out on aluminum tubes with dents of selected shape and position are presented. FE theoretical model and numerical results are confronted with those obtained from experimental tests. Some conclusions concerning optimal dent shape and position are derived.


ABSTRACT: Additive manufacturing, commonly known as 3D printing, is an evolutionary technology in the manufacturing industry. This technology has already been embraced by different industries, such as aerospace and biomedical engineering, and the recent advance in this technology has generated a vast of societal excitement for its future. Despite the exciting prospect of its application in civil engineering, additive manufacturing technology is still at a perceived stage for construction industry. The benefits and potential in construction industry are rarely known in the field at this stage. This paper aims to investigate the mechanical properties and structural performance of additively manufactured high strength steel tubular sections at the cross-sectional level through experimental program. The specimens were additively manufactured from H13 steel powder by selective laser melting (SLM) with three different scanning patterns, where the typical yield strength (0.2% proof stress) of the conventionally manufactured H13 steel is around 1650 MPa. The test program comprised tensile coupon tests, compression coupon tests, hardness tests, microstructural characterization as well as geometric imperfection measurements and stub column tests. The anisotropy on mechanical properties was examined through tensile coupon tests in both longitudinal and transverse directions. Compression coupon tests were also conducted to investigate the differential strength of material in tension and compression. The influences of scanning patterns on mechanical properties and structural behavior of as-printed high strength steel tubular sections stub columns were also investigated. The test results were used to assess the applicability of existing design provisions in the American Specification, Australian and New Zealand Standard
Yaqiao Zhu (1), Peng Shi (2), Yongtao Kang (3) and Baofa Cheng (4)
(1) School of Aviation and Aerospace, Tianjin Sino-German University of Applied Sciences, Tianjin, 300350, China
(2) School of Intelligent Manufacturing, Huanghui University, Zhumadian, Henan, 463000, China
(3) Altran Deutschland S.A.S. & Co. KG, Karnapp 25, 21079, Hamburg, Germany
(4) Advanced Manufacture Technology Center China Academy of Machinery Science and Technology, 18 Xue Qing Road, Haidian District, Beijing, 100083, China


ABSTRACT: This paper presents a new logarithmic higher order shear deformation theory (LHS-DT) based on isogeometric analysis (IGA) to study the static bending, free vibration, and buckling behaviors of functionally graded plates. The temperature change conditions are considered. In the LHS-DT fashion, shear stresses disappear at the top and bottom surfaces of the plates and shear correction factor vanishes. The requirement for C-continuity in terms of the LHS-DT is straightforwardly possessed with the aid of inherent high order continuity of non-uniform rational B-spline (NURBS), which serves as basis functions in our IGA formulation. The superior performance and accuracy of the proposed method is demonstrated through extensive numerical examples. The computed results of static bending, vibration and buckling from the proposed theory are in a very good agreement with reference solutions available in literature obtained by various plate theories and different solving method.


ABSTRACT: This paper proposes a novel polyurethane foam-filled energy absorption connector with advanced geometry to dissipate energy. Quasi-static loading tests of these connectors were first conducted to evaluate failure mechanisms and energy absorption performances. Numerical and analytical models which exhibited...
results consistent with those of the experiment were developed to predict and conduct an in-depth study of the energy absorption characteristics. The results revealed that most energy absorption parameters could be enhanced by filling polyurethane foam, increasing the armed plate thickness, and decreasing the height from the top of the armed plate to the intersecting point of the two arms. The findings from this work help understand the failure mechanism and energy absorption behaviour of the proposed connectors, and they will promote potential applications of these connectors in terms of dissipating blast or impact energy.

Vu Hoai Nam (1), Nguyen-Thoi Trung (1) and Le Kha Hoa (2)
(1) Division of Computational Mathematics and Engineering, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(2) Military Academy of Logistics, Hanoi, Viet Nam

ABSTRACT: This paper investigates the nonlinear buckling and postbuckling of functionally graded porous circular cylindrical shells reinforced by orthogonal stiffeners resting on Pasternak elastic foundations in thermal environment and under torsional load by an analytical approach. Shells are reinforced by closely spaced stringers and rings in which material properties of the shell and the stiffeners are assumed to be continuously graded in the thickness direction. Basing on the classical shell theory with von Karman geometrical nonlinearity and smeared stiffeners technique, the governing equations are derived. Using the Galerkin method with the three-term solution of deflection, the closed form to find critical load and post-buckling response are obtained. The effects of porosity coefficient, material, temperature, dimensional parameters, stiffener and foundation are analyzed.

Wanshi Hu, Harsh Bohra, Eyas Azzuni and Sukru Guzey (Lyles School of Civil Engineering, Purdue University, West Lafayette, IN, 47907, USA), “The uplift effect of bottom plate of aboveground storage tanks subjected to wind loading”, Article 106241, Thin-Walled Structures, Vol. 144, November 2019, https://doi.org/10.1016/j.tws.2019.106241

ABSTRACT: Because aboveground storage tanks are usually empty during construction, inspection and repair periods, they are more vulnerable to buckling due to wind loading than they are in use filled with liquid product. The uplift effect of the bottom plate of empty storage tanks due to wind pressure is investigated in this work. The buckling behavior of two sets of tanks were studied using finite element analysis (FEA): (1) tanks with bottom plate modeled directly in the analysis and (2) tanks without bottom plate but suitable boundary conditions applied in the analysis. Linear bifurcation analysis (LBA) and geometrically nonlinear analysis including imperfections (GNIA) are performed to obtain the deformation shapes and buckling capacities of tanks. The soil supporting the with-bottom tanks were modeled using nonlinear compression only springs connected to each node of the bottom plate. The buckling modes and the results from GNIA show that when a bottom is included into a tank FEA simulation, instead of fixed, the buckling pressure load will be substantially reduced for slender tanks having height to diameter ratio greater than 1/3. However, the broad tanks having height to diameter ratio less than 1/3 experience relatively small reduction in buckling load.


ABSTRACT: This study investigates buckling behaviors of functionally graded carbon nanotube-reinforced composites (FG-CNTRC) shells using a modified first-order enhanced solid-shell element formulation. On that account, a parabolic shear strain distribution through the shell thickness in the compatible strain part is proposed. In fact, the shear correction factors are no longer needed. Five kinds of single-walled carbon nanotubes (SWCNTs) distribution through the thickness of layers are considered, namely, uniform (UD) and functionally graded (FG) symmetric and asymmetric. The buckling behavior of FG-CNTRC plate under uniaxial compressive pressure and FG-CNTRC cylindrical shell under external pressure and axial compression are considered. Comparisons of our numerical results with those reported by other investigators are presented in
order to compare different formulations and to illustrate the performance of the developed solid-shell element. The result of the buckling behavior of CNTRC structure makes the present formulation appropriate for a wide range of structure plates and shells. Then, the effects of some geometrical and material parameters on the critical buckling load of shell structures are investigated.

Hadi Babaei (1), Yaser Kiani (2) and M. Reza Eslami (3)
(1) Mechanical Engineering Department, South Tehran Branch, Islamic Azad University, Tehran, Iran
(2) Faculty of Engineering, Shahrekord University, Shahrekord, Iran
(3) Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran


ABSTRACT: Current investigation deals with the small and large amplitude free vibrations of a curved beam (arch) resting on a nonlinear elastic foundation. The arch is made of a functionally graded material, where the properties are graded across the thickness. Uniform temperature elevation in the arch is also considered and material properties are assumed to be temperature dependent. The governing motion equations of the arch are established using a higher order arch theory which satisfies the traction free boundary conditions and the von Kármán type of non-linearity. The governing equations of the arch are solved for the case of an immovable pinned arch using the two step perturbation technique. Closed form expressions are given to estimate the nonlinear frequencies of the arch as a function of the mid-span deflection. Numerical results of this study are validated for the case of flat FGM beams on elastic foundation. Afterwards, novel numerical results are given to explore the influences of power law index, elastic foundation coefficients, length to thickness ratio, length to radius ratio, and the temperature effects.

Hairui Wang (1), Danyang Zhao (1), Yifei Jin (2), Minjie Wang (1), Zhong You (3) and Guangrui Yu (1)
(1) School of Mechanical Engineering, Dalian University of Technology, Dalian, 116024, PR China
(2) Department of Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL, 32611, USA
(3) Department of Engineering Science, University of Oxford, Oxford, Oxfordshire OX1 3PJ, UK


ABSTRACT: The study aims to investigate the effects of origami morphology and interval distribution on the mechanical behavior of origami-based and conventional tubes. Quasi-static axial crushing experiments have been conducted on six geometrical types of polymeric tubes with different morphology (including arrangement and patterns), uniform and non-uniform interval. The polymeric tubes having viscoelasticity are fabricated through a polymer blow molding approach, in which, the approach can ensure the integrated formation of these tubes and avoid the structural asymmetry caused by the machining process. The experimental results show that it is convenient to observe the collapsed position, plastic hinges, and collapsed modes from the crushed and incompletely recovered shapes of the polymeric tubes after 24-h unloading. The initial elastic stiffness and initial peak force of the origami-based tubes reduce dramatically as compared with those of the conventional tubes under the axial crushing. In addition, the origami morphology and interval distribution can cause the initial collapse and have a large effect on the final collapsed mode of the tube, while the effect of wall thickness on the collapsed mode can be negligible. Therefore, the origami morphology or non-uniform interval distribution of the origami-based tubes can be used as a geometrical defect to change the collapsed mode and as a trigger to orient the initial collapse in a certain position of the tube in engineering design.

Reza Shams (1), Abbas Niknejad (1,2), Abdul Ghanii Olabi (3,4) and Mohammad Zamani Nejad (1)
(1) Mechanical Engineering Department, Yasouj University, P.O. Box: 75914–353, Yasouj, Iran
(2) Mechanical Engineering Department, Meybod University, Meybod, Yazd, Iran
(3) Dept. of Sustainable and Renewable Energy Engineering, University of Sharjah, P.O. Box 27272, Sharjah, United Arab Emirates
(4) School of Engineering and Applied Science, Aston University, Birmingham, UK
ABSTRACT: This article presents a novel method to improve energy absorption performance of thin-walled circular tubes under quasi-static lateral loading through the preforming process. Desirable investigations are carried out by experimental tests and numerical simulations. Firstly, simple circular tubes are shaped into four different types (P1–P4) of preformed specimens, using a semi-cylindrical Teflon die and various blade-shaped indenters with semi-cylindrical nose. Then, the preformed specimens are laterally compressed between two rigid platens to perform flattening tests and their mechanical behaviors are investigated during the lateral flattening experiments, based on viewpoint of energy absorption. Some experiments are carried out and due to the test limitations, numerical simulations are performed, using the ABAQUS/Explicit software. In the following, based on the finite element analysis, various preformed specimens with different geometrical characteristics are simulated to investigate influences of wall thickness, preformed type and internal span of the specimen cross-section and also, effects of loading direction on energy absorption performance of the preformed specimens. Also, some simple circular tubes are flattened as the benchmark and results of four types of the preformed samples are compared with the corresponding benchmark. The obtained results illustrate that by shaping the simple circular tubes into the preformed specimen, a new hollow prismatic samples are produced that their energy absorption capability is 11.5 times of the corresponding value of the benchmark; consequently, the present article suggest the preformed specimens of various types instead of the corresponding simple circular tubes, as better energy absorber.

A. Mohammed (1) and S. Afshan (2)
(1) Brunel University London, London, UK
(2) University of Southampton, Southampton, UK


ABSTRACT: In this paper, the elevated temperature buckling performance and design of cold-formed square, rectangular and circular hollow section columns made of stainless steel is studied through a numerical modelling investigation. The finite element analysis software Abaqus was employed to perform the simulations, where the validity of the models was established by replicating the results of flexural buckling tests at both elevated and room temperatures from literature test programmes. In total, twelve square (SHS) and rectangular (RHS) hollow section columns tested at elevated temperature and eleven circular (CHS) hollow section columns tested at room temperature were simulated. Following this, a comprehensive numerical parametric investigation was performed to systematically assess the effect of variation of the governing parameters including the grade of stainless steel (austenitic, duplex and ferritic) and the elevated temperature member slenderness (Lambda=0.1–2.0) for all considered cross-section shapes with the addition of the aspect ratio of the cross-section (h/b=1.0 and 1.5) and the column axis of buckling (major and minor) for the SHS and RHS. The applicability and accuracy of the design methods recommended in EN 1993-1-2 and the Design Manual for Stainless Steel Structures were carefully assessed on the basis of the numerical flexural buckling performance results. New buckling formulations for the fire design of cold-formed stainless steel SHS/RHS and CHS columns were proposed, and their suitability was confirmed by means of reliability analysis.

Libin Duan (1), Zhanpeng Du (2), Haobin Jiang (1), Wei Xu (1) and Zhanjiang Li (3)
(1) School of Automotive and Traffic Engineering, Jiangsu University, Zhenjiang, 212013, China
(2) State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, 410082, China
(3) Nanjing YueBoo Power System Co., Ltd, Nanjing, 210019, China


ABSTRACT: In this study, a theoretical model is developed to reveal the bending collapse of top-hat thin-walled structures by dividing a top-hat thin-walled structure into a top-hat element and flat-plate element. A theoretical formula is also developed to describe the bending deformation and energy-absorption of the structures. The theoretical model is capable of predicting the bending collapse and energy-absorption of top-hat
thin-walled structures with different thickness and material specification. The accuracy and generality of the theoretical prediction model is validated by performing three-point bending tests and finite element simulations. Then, both theoretical prediction formulas and finite element analysis (FEA) based surrogate models are employed to perform the crashworthiness optimization of top-hat thin-walled structures. The results show that (i) the theoretical prediction model is capable of producing results that can be directly used to optimize the thicknesses, cross-sectional geometry, and material specifications for top-hat thin-walled structures, which will increase the efficiency and shorten the cycle time of crashworthiness design optimization for this type of structure; and (ii) steel-aluminum hybrid top-hat thin-walled structure has a larger energy-absorption capacity than high-strength steel without exceeding the initial weight, whereas a lightweight design is more feasible with an aluminum alloy than with high-strength steel without sacrificing the energy absorption of the baseline design.

Wenyuan Zhang (1), Ke Wang (1), Yong Chen (2) and Yukun Ding (1)
(1) Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin, 150090, China
(2) China Northeast Architectural Design & Research Institute Co., LTD, Shenyang, 110006, China

ABSTRACT: A new type of composite shear wall, composed of dual steel plates, vertical stiffening steel plates to connect the dual plates and concrete infilled in the vertical channels formed by these steel plates, is proposed. Fifteen specimens were tested under horizontal cyclic loads, along with a constant vertical axial force, to investigate their seismic behaviour. Specimen failure mainly included three modes: severe local buckling at the corners of the flange plates and boundary channels, damage of the concrete occurring in the middle and bottom of the shear wall and local buckling waves originating at the middle of the specimen. All the specimens exhibited a good deformation capacity: the ultimate drift ratios of the specimens reached an average value of 4.55%, and the ductility has an average value of 4.0. The test results indicated that the thickness of the shear wall and the number of channels in the shear wall have a significant effect on the ductility of the specimens. However, changing the number of channels in the walls has a negligible effect on the shear strength of the wall. Formulas to predict the maximum shear strength and initial stiffness of the shear wall are proposed, and it is verified that they can provide a satisfactory prediction for most specimens, with an error within 10%.

Ashkan Babazadeh and Mohammad Reza Khedmati (Department of Maritime Engineering, Amirkabir University of Technology, No. 424, Hafez Avenue, Tehran, 15916-34311, Iran), “Semi-analytical simulation of plastic collapse mechanism of cracked continuous unstiffened plates used in ship structure under in-plane...
ABSTRACT: The present study is undertaken based on a nonlinear finite element study carried out by the same authors for estimation of ultimate strength of cracked continuous unstiffened plates used in ship structures under in-plane longitudinal compression. Investigations show that in addition to the magnitude of ultimate strength, the deflection shape and plastic collapse mechanism will also change completely. Results show that deflection in the cracked half wave increases more rapidly than other half waves. Consequently generated half waves in a cracked plate will not have identical length and amplitude. This implies that the conventional plastic collapse mechanism cannot be used to predict the behavior of cracked plates in the post ultimate strength region. A new plastic collapse mechanism based on the FEM results is suggested and the principle of virtual work is used to derive the axial stress-deflection relation of the plate. However, due to inequality of the length and amplitude of generated half waves, the axial stress-deflection relation cannot be directly derived from the principle of virtual work. Therefore, in order to solve the virtual work equation, some auxiliary relations between the involved parameters are required. Auxiliary equations are derived using regression analysis based on FEM results. Finally, a semi-analytical formulation is derived to estimate post ultimate strength behavior of cracked plates. It is shown that the proposed semi-analytical formulation can predict both magnitude and slope of the stress-deflection curves with better accuracy compared to the conventional plastic collapse mechanism. The formulation can be used within the defined ranges of simulated crack lengths, slenderness and aspect ratios.

Cilmar Basaglia (1), Dinar Camotim (2) and Nuno Silvestre (3)
(1) Department of Structural Engineering, School of Civil Engineering, Architecture and Urban Design, University of Campinas, Av. Albert Einstein, 951, 13083-852, Campinas, Brazil
(2) CERIŠ, DECivil, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal
(3) DMEC, Department of Mechanical Engineering, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal


ABSTRACT: This paper reports the results of an investigation on the use of Generalised Beam Theory (GBT) to assess the buckling behaviour of steel cylindrical shells (pipes, tubes and pressure vessels) acted by combinations of axial compression and external lateral pressure. Initially, the derivation of an adequate GBT formulation is addressed. It (i) incorporates all the effects stemming from the presence of longitudinal and/or hoop stresses (the latter act in the circumferential direction), and (ii) takes into account the destabilising influence associated with the follower nature of the external pressure, which remains normal to the shell wall along the deformation process. Then, after numerically implementing the above formulation, by means of GBT-based beam finite elements, its application and capabilities are illustrated through the presentation and discussion of numerical results concerning the buckling behaviour of (i) pressure vessels and pipes acted by external pressure and (ii) tubes subjected to combinations of compression and external pressure. For validation purposes, most GBT results are compared with values either available in the literature or yielded by Ansys shell finite element analyses.

X.J. Gu (1), Y.X. Hao (1), W. Zhang (2) and J. Chen (3)
(1) College of Mechanical Engineering & Beijing Key Laboratory of Electromechanical System Measurement and Control, Beijing Information Science and Technology University, Beijing, 100192, PR China
(2) College of Mechanical Engineering, Beijing University of Technology, Beijing, 100124, PR China
(3) Architecture and Civil Engineering Research Center, Shenzhen Research Institute, City University of Hong Kong, Shenzhen, PR China


ABSTRACT: The initial geometric imperfections in manufacturing structure are unavoidable. Critical buckling load and dynamic instability of the rotating cantilever cross ply laminate thin walled twisted plate with exponential function type initial geometric imperfection are investigated for the first time. The mode shapes are
obtained by using Rayleigh-Ritz method and shallow shell theory including the influence of rotational speed and imperfection. Based on the Lagrange equations and the obtained mode shape function, motion equations considering the first three modes of the system are derived. The mode shapes, critical loads and dynamic instability obtained in present have been verified by comparing them with other researcher results. The detail studies about the effect of rotating speed, twisted angle, stacking sequence and imperfection factors of the rotating thin walled twisted plate subjected to the in-plane load on the static critical buckling load and dynamic instability are carried out.

Qihan Shen (1), Jingfeng Wang (1,2), Yanbo Wang (3) and Fengqin Wang (1)
(1) School of Civil Engineering, Hefei University of Technology, Anhui Province, 230009, China
(2) Anhui Civil Engineering Structures and Materials Laboratory, Anhui Province, 230009, China
(3) College of Civil Engineering, Tongji University, Shanghai, 200092, China

ABSTRACT: The partial CFRP (carbon fiber reinforced polymer) wrapping scheme is widely used for strengthening engineering practices to obtain a moderate improvement in strength, whereas detailed investigations on partially CFRP-wrapped thin-walled circular normal-strength concrete-filled steel tubular (NCFST) stub columns are seldom presented. This paper aims to conduct a series of numerical analyses to figure out the axial compressive performance of circular NCFST stub columns wrapped by CFRP belts partially. A nonlinear finite element (FE) modelling focused on the surface interaction as well as the CFRP and thin-walled hollow steel section (HSS) confinement effects on the concrete infill is developed via ABAQUS solver and the accuracy is validated against the existing experimental data. Following this, a systemic parametric investigation is developed to explore the impact of steel yield stress, concrete compressive strength, diameter: thickness ratio, CFRP wrapping ratio and number of CFRP layer, etc. on the axial compressive properties of the partially CFRP-wrapped thin-walled circular NCFST stub columns. Elaborate investigations on the surface contact action, stress-strain response, typical axial force versus axial shortening curve and failure modes are presented to better figure out the axial compressive behaviour of the type of composite column. A discussion on the effective wrapping scheme of the partially CFRP-wrapped thin-walled circular NCFST stub column imposed with axial compressive force is described as well. Finally, two types of design formulas in compliance with the unified theory and the tubed concrete method are proposed to assess the axial compressive resistance of the partially CFRP-wrapped thin-walled circular NCFST stub column. The research may provide a considerable and scientific basis for employing CFRP materials for the CFST structures.

Wei Li (1), Ying-Zhuo Gu (1), Lin-Hai Han (1) and Xiao-Ling Zhao (2)
(1) Department of Civil Engineering, Tsinghua University, Beijing, 100084, PR China
(2) Department of Civil and Environmental Engineering, The University of New South Wales (UNSW), Sydney, NSW, 2052, Australia

ABSTRACT: The grouted T-joint in offshore structure is usually subjected to low-velocity impact caused by ship collision. The behaviour of these joints under lateral impact loading is investigated. Tests on 12 specimens including eight grouted T-joints are conducted. The composite T-joint consists of grout-filled double-skin steel tubular chord and hollow steel section brace. The constant axially compressive load is applied along the axis of the composite chord and the impact load is applied along the axis of the hollow steel tubular brace. A finite element model is established and verified. The influences of various parameters on the T-joint behaviour are discussed.

Yao Sun (1), Zhanke Liu (2), Yating Liang (3) and Ou Zhao (1)
(1) School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
(2) School of Civil Engineering and Mechanics, Lanzhou University, Lanzhou, China
(3) School of Engineering, University of Glasgow, Glasgow, UK

ABSTRACT: The grouted T-joint in offshore structure is usually subjected to low-velocity impact caused by ship collision. The behaviour of these joints under lateral impact loading is investigated. Tests on 12 specimens including eight grouted T-joints are conducted. The composite T-joint consists of grout-filled double-skin steel tubular chord and hollow steel section brace. The constant axially compressive load is applied along the axis of the composite chord and the impact load is applied along the axis of the hollow steel tubular brace. A finite element model is established and verified. The influences of various parameters on the T-joint behaviour are discussed.
Jianxun Zhang, Yang Ye and Qinghua Qin (State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace Engineering, Xi’an Jiaotong University, Xi’an, 710049, China), “On dynamic response of rectangular sandwich plates with fibre-metal laminate face-sheets under blast loading”, Article 106288, Thin-Walled Structures, Vol. 144, November 2019, https://doi.org/10.1016/j.tws.2019.106288

ABSTRACT: This paper focuses on the analytical and numerical analyses to predict the dynamic response of fully clamped rectangular sandwich plates with fibre-metal laminate face-sheets and metal foam cores under blast loading. Based on the rigid-plastic material approximation with modifications, simple models are developed for the dynamic response of sandwich plates with fibre-metal laminate face-sheets. The so-called ‘bounds’ and the membrane mode solution for dynamic response of rectangular sandwich plates are obtained. The effects of the composite volume fraction, the ratio of metal layer strength to composite layer strength, relative density and relative strength on the dynamic response are discussed. The finite element calculation is carried out to study the dynamic response of the sandwich plates under blast loading. Good agreement is achieved between the analytical solutions and numerical results. This work provides the efficient method that reasonably captures dynamic response of the rectangular sandwich plates subjected to the blast loading.


ABSTRACT: The present paper reports a thorough experimental and numerical investigation into the compressive behaviour and load-carrying capacities of concrete-filled steel tube (CFST) stub columns with the outer tubes made of a newly developed high-chromium grade EN 1.4420 stainless steel. In comparison with the most commonly used stainless steel grades EN 1.4301 and EN 1.4404, the new grade EN 1.4420 possesses lower material price, but better corrosion resistance and higher strength, and thus has a greater potential for widespread use in composite construction. In this study, an experimental programme was firstly carried out on 15 CFST stub columns with high-chromium stainless steel tubes of five different cross-section sizes and concrete infill of three grades, as well as 5 (reference) bare high-chromium stainless steel tube stub columns. The test setup, procedure and results, including the ultimate loads, load–deformation histories and failure modes, were fully reported. The experimental investigation was supplemented by a numerical modelling study, where the developed finite element models were firstly validated against the experimentally obtained results and then utilised to perform parametric studies for the purpose of expanding the limited test data pool over a wider
range of cross-section sizes. The test and numerical results were utilised to evaluate the applicability of the codified provisions, established in North America, Europe and Australia, to the design of the new concrete-filled high-chromium stainless steel tube stub columns. Overall, the examined design codes were generally found to yield safe-sided but slightly conservative resistance predictions for the new high-chromium stainless steel composite stub columns. Modifications to the codified design provisions were then made, and shown to result in an improved level of design accuracy.

Artur Piekarczuk (1), Przemysław Więch (1) and Robert Cybulski (2)
(1) Instytut Techniki Budowlanej, Filtrowa 1, Warsaw, 00-611, Poland
(2) Department of the Theory of Building Structures, Silesian University of Technology, Akademicka 5, Gliwice, 44-100, Poland


ABSTRACT: K-span system double corrugated trapezoid sheet profiles are used in construction engineering as self-supporting arch roofs for buildings. Some cases of failures of such structures have been reported. Deep, transverse corrugations in the profile surface, formed as a result of manufacturing, make the use of standard designing methods difficult. The paper presents a scientific approach to determining the load-carrying envelope of double corrugated profiles under complex load. Tests are carried out on small fragments of individual profiles under simulated load and support conditions. The results of the tests indicate the significant influence of transverse notches on the formation of local instability, which results in a change of their geometric characteristics and profile load-carrying capacity.

Ran Feng (1,2), Chengdong Shen (3) and Junwu Lin (1)
(1) School of Civil and Environmental Engineering, Harbin Institute of Technology, Shenzhen, 518055, China
(2) State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou, 510640, China
(3) Anhui Provincial Architectural Design and Research Institute Co., Ltd, Hefei, 230002, China


ABSTRACT: Finite-element analysis (FEA) was performed in this study on the flexural behaviour of aluminium alloy circular hollow sections (CHSs) with circular through-holes subjected to gradient and constant bending moments. The non-linear finite-element models (FEMs) were established and verified by the corresponding experimental results. The material and geometrical non-linearities, as well as the initial geometrical imperfections, were taken into account in the FEMs. The validated FEMs were employed in an extensive parametric study on a total of 408 specimens, which have the cross-section slenderness ratio ($D/t$) and hole size ratio ($d/D$) ranged from 5 to 150 and from 0.2 to 0.8, respectively. The influences of the cross-section slenderness ratio and hole size ratio of the CHSs, as well as the quantity and location of the circular through-holes on the flexural strengths of aluminium alloy CHSs with circular through-holes, were carefully evaluated. The test and FEA flexural strengths are compared with the design flexural strengths determined by the modified direct strength method (DSM) and the modified continuous strength method (CSM) developed for aluminium alloy flexural members. The comparison indicates that the current design guidelines are conservative for aluminium alloy CHSs with circular through-holes in bending. Therefore, the design equations are proposed on the basis of the modified CSM for the flexural strengths of aluminium alloy CHSs with circular through-holes. A reliability analysis was carried out to evaluate the modified DSM, the modified CSM and the proposed design equations. It is demonstrated that the proposed design equations are of high precision and reliability for aluminium alloy CHSs with circular through-holes in bending.


ABSTRACT: The free vibration characteristics of the variable stiffness composite laminated plates containing embedded cutout of desired shapes is investigated. The circular, elliptical and quadrilateral perforation geometries are taken into account. In order to provide a strongly flexible calculation tool, an isogeometric
analysis formulation based on the non-uniform rational B-splines (NURBS) along with the Nitsche technique is developed based on the first order shear deformation plate theory. The effects of change in the mechanical properties of tow steered laminates throughout the geometry due to fibers following prescribed curvilinear paths are taken into account in the integration procedures. The accuracy and reliability of the calculations is shown through some representative comparisons. The effects of change in the cutout geometry, location and orientation in conjunction with the curvilinear fiber placement are studied.


ABSTRACT: Modern manufacturing processes and computational methods give the possibility to design shell structures with complex shapes. Such opportunity enables to use the structural advantages coming from their untypical geometries. In this paper the results of strength and stability analyses of a shell of revolution in the shape of Booth ovaloid are presented. The shell is proposed as an alternative for classical closed pressure hulls loaded with external pressure. The stress distribution along the meridian of the shell is provided as well as the buckling shapes, buckling loads and equilibrium paths. The influence of geometrical parameters of the lemniscate on the above mentioned results is discussed. The analysed shell is compared with the classical cylindrical pressure hulls as well as spherical shells, the advantages of the former are pointed out. Since the shape of the Booth lemniscate changes considerably depending on geometrical parameters it can be easily adopted to numerous applications.

Yuze Nian (1), Shui Wan (1), Xiayuan Li (1), Qiang Su (1) and Mo Li (2)
(1) School of Transportation, Southeast University, Nanjing, Jiangsu Province, 210096, PR China
(2) Department of Civil and Environmental Engineering, University of California, Irvine, CA, 92697, USA

ABSTRACT: Functionally graded structures are widely observed in nature and have been considered to have excellent mechanical properties. In this paper, a novel bio-inspired graded honeycomb-filled circular tube (BGHCT) is proposed to enhance structural energy absorption characteristics under lateral load. The graded honeycomb fillers are constructed using 3D printing techniques. To systematically explore the crashworthiness of BGHCT, the nonlinear finite element models are first developed in Abaqus (explicit) and validated against the experiments. Then graded honeycomb-filled circular tubes with axial and radial graded directions are compared with uniform honeycomb-filled counterparts (UHT). Parametric studies find that BGHCT exhibits superior capacity of energy absorption. Furthermore, various parameters, like effective filling length, thickness and yield stress of column wall, have a considerable effect on the crashworthiness of this novel structure. Lastly, multi-objective optimizations of BGHCT and UHT are carried out with the aim of simultaneously improving specific energy absorption (SEA) and reducing peak crushing force (PCF), based upon the Kriging modeling technique and non-dominated sorting genetic algorithm II (NSGA-II). The optimal design parameters are obtained for these honeycomb-filled structures. By comparison we find that energy absorption characteristics can be increased by up to 89.73%, and effective length filled structure has the best crashworthiness, followed by full graded honeycomb-filled structure. The study provides new insights into the transformation of natural biological inspiration into engineering applications for crashworthiness.

Jia-Bao Yan (1), Yan-Yan Yan (1), Tao Wang (2) and Zhong-Xian Li (1)
(1) School of Civil Engineering / Key Laboratory of Coast Civil Structure Safety of Ministry of Education, Tianjin University, Tianjin, 300350, China
(2) Key Laboratory of Earthquake Engineering and Engineering Vibration, Institute of Engineering Mechanics, CEA, Harbin, 150080, China

ABSTRACT: This paper firstly proposed steel-concretes-steel sandwich walls with J-hook connectors (SCSWJs) as protective structures in the Arctic offshore platforms. Followed, six large scale SCSWJs were tested under lateral cyclic loading to investigate their lateral seismic behaviours. The investigated parameters in
the testing program included spacing of J-hook, concrete core strength, thickness of steel faceplate, and aspect ratio. Seismic behaviours of SCSWJs were reported in details, and the effects of these parameters on their seismic behaviours were reported and discussed. The test results showed that the SCSWJ failed in flexure mode with characteristics of tensile yielding of side plate and steel faceplate, concrete crushing at the bottom toe, and outward local buckling of steel faceplates. Pinching effect was observed in the load versus lateral drift curves after the peak load due to premature local buckling of side plates and faceplates locating between the first and second row of J-hook from the bottom. This paper developed analytical models to predict the peak lateral resistance of SCSWJ. The validations against 12 results from six cyclic tests confirmed that the developed models offered reasonable but conservative predictions on the peak lateral resistance of SCSWJ. This study promotes the applications of the SCSWJ in the earthquake-prone Arctic regions.


ABSTRACT: According to the surface imperfections of rolling–welding cylinders, a finite element analysis (FEA) model for a cylinder with surface imperfections is proposed, namely, a statistic imperfections model. The maximum permissible geometry deviation values $e$ of statistic imperfections models are computed based on the shape reduced coefficient $\beta = 0.8$. Compared with the limited value of ASME Code sections VIII-1 and VIII-2, it is clear that the calculated value $e/t$ is positively correlated with the length–diameter ratio $L/D$ and diameter–thickness ratio $D/t$ and that the yield strength has a substantial influence on the maximum permissible geometry deviation values, which is not taken into account by Code VIII-2.

M.J. Khoshgoftar (Department of Mechanical Engineering, Faculty of Engineering, Arak University, Arak, 38156–88349, Iran), “Second order shear deformation theory for functionally graded axisymmetric thick shell with variable thickness under non-uniform pressure”, Article 106286, Thin-Walled Structures, Vol. 144, November 2019, https://doi.org/10.1016/j.tws.2019.106286

ABSTRACT: This paper studies Second order Shear Deformation Theory (SSDT), as a higher order shear deformation theory, for an axisymmetric functionally graded shell of revolution with variable thickness. According to symmetrical condition, there is not any displacement and any variation along the symmetric direction. The governing equations of proposed shell are derived by virtual work principle. As a special case, the governing equations are rewritten for a cylinder with variable thickness and non-uniform internal pressure. The comparison between current work, classical theory and First order Shear Deformation Theory (FSDT) are illustrated with some numerical results. Non-homogenous material, boundary condition effects, non-uniform pressure, arbitrary curvature with variable thickness and nonlinear displacement field are some advantages of current work. The optimum design of shell is the main goal of current approach that has a wide industrial application like aerospace engineering.


ABSTRACT: The combined loadings of the fragment impact and pool-fire caused by domino accidents in storage tank farms or oil depots can result in damage greater than that caused by a separate loading. However, due to the complexity of the combined loadings, these have not been well understood. In this study, the coupling effects of the fragment impact and adjacent pool-fire on the thermal buckling of a fixed-roof tank were numerically investigated. The effects of impact velocities, impact angles and fragment shapes on the failure mode and fire resistance of a fixed-roof tank were discussed. The results indicate that the coupling effects of the fragment impact and adjacent pool-fire were deeply different from those in which the fixed-roof tank was subjected to either fragment impact or adjacent pool-fire individually. The fire resistance and critical buckling temperature decreased for pre-damaged tanks comparing with no-pre-damaged tanks. Besides, the local buckling mode triggered by the adjacent pool-fire was depended on the impact dent zone caused by the fragment impact. Moreover, the fire resistance and critical buckling temperature reduced with the increase of
the impact velocity, structural stability of the fragment and the decrease of the impact angle. This study can be used to understand the vulnerability and obtain the critical failure criterion of the large storage tanks under the coupling effects of multiple accidents, and optimize the steel structure design of oil tanks for resisting projectiles and pool-fires in tank farms to reduce the possibility of storage tank accidents.

Sahil Goyal (1), C.S. Anand (1), Sunil Kumar Sharma (1) and Rakesh Chandmal Sharma (2)
(1) Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University Uttar Pradesh, Noida, India
(2) Mechanical Engineering Department, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India
ABSTRACT: This paper aims to fabricate star polygon thin walled energy absorption structure that tends to relapse the intensity of set in decelerations during impact while escalating the amount of energy absorbed. The crashworthiness topology optimization is used for structural optimization of various foam-filled tubes. The relative advantages of 14 configurations are discussed, and the effects of filling five types of foam into the best configuration of the star-shaped tube over an empty one is investigated. Specific Energy Absorption, Peak Crush Force and response of weight of the members during frontal impact are the main dimensions parameters of the member's performance. Numerical simulation is carried out using the explicit dynamics of Ansys 17.1, and obtained results are compared with experimental results conferring crash behavior and energy absorption characteristics. Based on results, the suited configuration with required performance in crashworthiness is suggested, which shall be incorporated in automobiles for safety consideration of passengers during an impact. The results show an increment of 40% in Specific Energy Absorption suggesting a better choice of a particular type of foam over a hollow tube.

Boshan Chen (1), Krishanu Roy (1), Asraf Uzzaman (2), Gary M. Raftery (1), David Nash (2), G. Charles Clifton (1), Pouya Pouladi (1) and James B.P. Lim (1)
(1) Department of Civil and Environmental Engineering, The University of Auckland, New Zealand
(2) Department of Mechanical and Aerospace Engineering, The University of Strathclyde, 75 Montrose Street, Glasgow, G1 1XJ, United Kingdom
ABSTRACT: The use of cold-formed steel (CFS) channel sections are becoming popular as the load-carrying members in building structures, and such channel sections often include web openings for the ease of installation of services. Traditional web openings are normally punched, and are unstiffened which can restrict the size and spacing of web openings. Recently, a new generation of CFS channel sections with edge-stiffened web openings has been developed, and is widely used in New Zealand. However, no experimental investigation has been reported in the literature for such channel sections under compression. In this paper, a total of 75 results comprising 26 axial compression tests and 49 finite element analysis results are reported on the compression resistance of CFS channel sections with both edge-stiffened and unstiffened web openings. For comparison, channel sections without web openings were also tested. For all specimens, initial imperfections were measured using a laser scanner. A nonlinear elasto-plastic finite element model was also developed, and the results showed good agreement with the test results. A parametric study was conducted using the validated finite element model to investigate the effect of opening spacing and column length on compression resistance of channel sections. It is shown that for the case of a channel section having seven edge-stiffened web openings, the compression resistance increased by as much as 22%, compared to a plain channel section. For comparison, the same section having unstiffened web openings had a 20% reduction in compression resistance, compared to a plain channel section.

ABSTRACT: In this study, the postbuckling analysis of functionally graded graphene platelets reinforced composite (FG-GPLRC) cylindrical shells is presented. The continuous uniform and functionally graded distribution of GPLs is considered through the thickness direction of the shell. In order to present the effective mechanical properties of GPL-reinforced composites the modified Halpin-Tsai micromechanical model is taken into account. On the basis of first-order shear deformation shell theory and von Karman geometrically nonlinear relations, the nonlinear governing equations are present in the context of the variational formulation. Employing the Fourier series and variational differential quadrature (VDQ) numerical approach, the semi-analytical solution methodology is further presented. The pseudo arc-length continuation method in conjunction with a load disturbance approach was utilized to solve the nonlinear governing equations and trace the postbuckling path. Note that based on the proposed formulation, the mode changes and secondary buckling can be considered through the postbuckling path. The results indicate that in addition to geometrical parameters, distribution patterns and weight fractions of GPLs have significant effects on the buckling and postbuckling characteristics of FG-GPLRC cylindrical shells.


ABSTRACT: A complex structural system can be described by a collection of individual rigid and/or flexible components in combination with a set of kinematic constraints. Moreover, their configuration can be described by redundant coordinates yielding to singular system matrices. Therefore, the calculation of frequencies and modes using a classical modal analysis is not longer applicable. In this work, we propose a variational-consistent framework, which is able to deal with structural systems with singular matrices and relies on a null-space projection. Finally, the effectiveness of the proposed framework is tested successfully by complex examples (single- and multibody systems) containing rigid bodies, geometrically exact beams and solid-degenerate shells.

F. Xie (1), T. Liu (2) and Q.S Wang (1)
(1) State Key Laboratory of High Performance Complex Manufacturing, Central South University, Changsha, 410083, PR China
(2) Light Alloy Research Institute, Central South University, Changsha, 410083, PR China

ABSTRACT: Free vibration characteristics of parallelogram laminated thin plates under multi-points supported elastic boundary conditions are studied by improved Fourier series method (IFSM) in this paper. The parallelogram thin plate region is first transformed into the unit square region. Artificial virtual springs are introduced to simulate various boundary constraints. In the study, to remove the jumps or discontinuities problem on the boundary, an IFSM is used to express all allowable displacement functions of parallelogram laminated thin plates. All energy equations of thin plates are established by the classical thin plate elasticity theory. Then the Rayleigh-Ritz method is used to solve the problem. The innovation of this paper lies in the combination of non-uniform boundary constraints and coordinate transformation. By comparing a large number of numerical results with the finite element method, the results show that the method has high stability, accuracy, and rapid convergence. Moreover, the parametric research of vibration characteristics of the parallelogram laminated thin plate is also studied. The method can easily obtain the free vibration peculiarities of parallelogram laminated thin plates under multi-points supported elastic boundary constraints, including its natural frequencies and modal shapes.

Rade Vignjevic (1), Ce Liang (1), Kevin Hughes (1), Jason C. Brown (2), Tom De Vuyst (3), Nenad Djordjevic(1) and James Campbell (1)
ABSTRACT: The Heat Treatment Forming and in-die Quench (HFQ) process allows for manufacturing of more complex geometries from Aluminium sheets than ever before, which can be exploited in lightweight automotive and aerospace structures. One possible application is manufacturing thin walled beams with corrugated internal reinforcements for complex geometries.

This work considers different internal reinforcements (C-section and corrugated) to improve the energy absorption properties of thin walled rectangular beams under uniaxial and biaxial deep bending collapse, for loading angles ranging from 0 to 90 deg, in 15° increments. Using LS-DYNA simulations experimentally validated through unreinforced metallic tubes under quasi-static bending collapse, the finite element results demonstrate the stabilising effect of the reinforcements and an increase in the buckling strength of the cross section.

Corrugated reinforcements showed a greater potential for increasing specific energy absorption (SEA), which was supported by investigating key geometric parameters, including corrugation angle, depth and number. This favourable response is due to an increased amount of material undergoing plastic deformation, which consequently improves performance of the beam undergoing post buckling and deep collapse. This concept is applicable to vehicle and aircraft passive safety, with the requirement that the considered geometries are manufacturable from Aluminium Alloys sheet only, using the HFQ process.

References listed at the end of the paper:

1 D. Kecman, Bending Collapse of Rectangular Section Beams in Relation to the Bus Roll over Problem, Cranfield University (1979)
13 A. Teter, Z. Kolakowski, Buckling of thin-walled composite structures with intermediate stiffeners, Compos. Struct., 69 (4) (2005), pp. 421-428
14 M. Obst, D. Kurpisz, P. Paczos, The experimental and analytical investigation of torsion phenomenon of thin-walled cold formed channel beams subjected to four-point bending, Thin-Walled Struct., 106 (2016), pp. 179-186
A new formula to predict buckling pressure of steel ellipsoidal heads under internal pressure

ABSTRACT: Buckling is a critical failure mode of ellipsoidal head under internal pressure. This study focuses on the prediction of buckling pressure of steel ellipsoidal heads subjected to internal pressure. First, finite element model of ellipsoidal head is generated, taking into account the effects of material and geometrical nonlinearity. The plastic bifurcation buckling pressure of ellipsoidal head is determined by nonlinear FEM. Second, we study the effects of diameter-thickness ratio, radius-height ratio, yield strength, strain hardening and attached cylinder on buckling pressure. Based on FE results of the models with elastic-perfectly plastic material, we propose a formula to predict buckling pressure of perfect ellipsoidal head. In addition, we summarize experimental results on the buckling of twenty-one ellipsoidal heads which cover different geometrical parameters, material types, and methods of fabrication. Eleven out of twenty-one ellipsoidal heads were tested by the authors recently. Finally, based on the formula for perfect ellipsoidal heads, a new formula is developed for the buckling pressure of actual ellipsoidal heads after considering a reduction factor that accounts for the effect of initial shape imperfection. The reduction factor depends on the methods of head fabrication, i.e. whether cold pressing and spinning or assembly of formed segments. It is shown that the new formula has comprehensive advantage in accuracy and applicability in comparison with other formulae.
This was done through numerical investigations followed by a parametric study which are reported herein in...
details. A wide range of roll-formed ALC sections covering web slenderness ratios ranged from 28 to 130, inside bent radii ranging between 2mm and 8mm, bearing lengths ranged from 50mm to 150mm, and three sheeting aluminium alloy grades (5052-H32, 5052-H36 and 5052-H38) were considered in the parametric study. The acquired web crippling database was then used to assess the consistency and accuracy of the current design rules used in practice. It was found that the web crippling capacity determined by the current international specifications are unsafe and unreliable, whereas the predictions of the recently proposed equations agree very well. Furthermore, a Direct Strength Method (DSM)-based capacity prediction approach was proposed and then validated against the web crippling database acquired here as well as the experimental and numerical data for cold-formed steel lipped channel sections used in the literature.

J.P. Magrinho (1), G. Centeno (2), M.B. Silva (1), C. Valllellano (2) and P.A.F. Martins (1)
(1) IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal
(2) Department of Mechanical and Manufacturing Engineering, University of Seville, Camino de los Descubrimientos s/n, 41092, Sevilla, Spain


ABSTRACT: This paper is focused on the external thin-walled tube inversion using different die fillet radii and is aimed at analysing its formability limits by local buckling, necking and fracture in principal strain space. The investigation draws from a methodology that was recently developed by the authors for general tube forming and focuses on the specificities that characterize its application to the deformation conditions of external tube inversion. Strain loading paths and formability limits at the onset of buckling, necking and fracture are determined by combination of experimental strain analysis with digital image correlation (DIC), thickness measurements, force-displacement evolutions and finite element modelling. Results show the paramount importance of the curling radius on the formability limits of external tube inversion. This information is relevant for designing energy absorbers based on external tube inversion and the novelty of the paper stems from the use of experimental techniques commonly employed in metal forming to the analysis of formability and failure in typical deformation modes of energy absorbers.


ABSTRACT: Unitized curtain wall systems made of aluminium frame infilled glass panes are commonly used to form the building envelopes in many buildings. The vertical framing members of such systems known as mullions are extruded aluminium sections with complex geometries. These mullions must transfer the wind load acting on the building envelope to the main structural system. This paper presents a detailed numerical study on the member moment capacities of long span mullion sections subject to wind suction loading. Validated finite element models of the mullions developed to predict their section moment capacities were extended to predict the member moment capacities. The procedures adopted in developing the finite element models and the analysis results are given in this paper. Mullions of different cross-section geometries with varying member slenderness used in both the captive and structural glazing systems were considered. In addition, the performance of open and hollow mullion sections was investigated. Lateral restraints provided by the glass panels to the mullions were simulated in the models while the effect of providing lateral restraint at the mid-span of the mullion through bracing was also investigated. The finite element analysis results were compared with the predicted capacities of Aluminium Association Design Manual and Eurocode 9 Part 1-1 design rules and suitable recommendations were made in relation to their applicability for mullion sections. Improved mullion sections reinforced with cold-formed steel stiffeners were proposed and their potential use in real world applications was discussed.

ABSTRACT: The paper analyzed the free vibration of functionally graded porous spherical shell (FGPSS) based on Ritz method. The energy method and first-order shear deformation theory (FSDT) are adopted to derive the formulas. In this paper, the displacement functions are improved on basis of domain decomposition method, in which the unified Jacobi polynomials are introduced to represent the displacement functions component along meridional direction, and the displacement functions component along circumferential direction is still Fourier series. In addition, the spring stiffness method is formed a unified format to deal with various complex boundary conditions and continuity conditions. Then the final solutions can be obtained based on Ritz method. To prove the validity of proposed method, the results of the same condition are compared with those obtained by FEM, published literatures and experiment. The results show that the proposed method has advantages of fast convergence, high calculation efficiency, high solution accuracy and simple boundary simulation.

Xu-hao Huang (1), Li Bai (1), Jian Yang (1), Fei-liang Wang (1), Jue Zhu (2) and Qing-feng Liu (1)
(1) State Key Laboratory of Ocean Engineering, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, 200240, PR China
(2) Faculty of Mechanical Engineering and Mechanics, Ningbo University, Ningbo, 315211, China

ABSTRACT: In the present work, the distortional buckling behaviour of simply supported columns and beams made from channel sections with longitudinal web ribs is investigated when subjected to axial compression and/or pure bending. The effect of stiffening ribs on the critical buckling stress of such members is studied using finite strip method (FSM). An analytical model, namely, the stiffened plate buckling model (SPBM), is developed. Based on this model, the closed form analytical solution is obtained and the formulae for calculating the critical distortional buckling stresses are derived. The analytical solution is then validated by comparing the critical distortional buckling stress with those obtained in finite strip method (FSM). An excellent agreement from the comparison is found. The present model has the potential to be adopted in the development of the designed model of such sections in engineering practices.

Yachuan Sun (1), Zhen Liu (1), Bingfei Li (1), Longlei Dong (1) and Fang Ren (2)
(1) State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, People's Republic of China
(2) Science and Technology on Reliability and Environment Engineering Laboratory, Beijing Institute of Structure and Environment Engineering, Beijing, 100076, People's Republic of China

ABSTRACT: A novel theoretical method is developed to determine the snap-through boundaries of thin-walled plates under thermal and acoustic load. By accounting for the correlation between the acoustic load probability distribution and the extreme points of the stiffness curves, an analytic snap-through boundary is derived in the parameter plane of the buckling coefficient and the sound pressure level. The accuracy of this method is verified by finite element analysis and existing literature. The effect of influence factors was investigated in detail. This work should provide a basis for structural safety evaluation and design optimization.

Luís Vieira (1), Rodrigo Gonçalves (2) and Dinar Camotim (1)
(1) CERIS, DECivil, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal
(2) CERIS and Departamento de Engenharia Civil, Faculdade de Ciências e Tecnologia, Universidade NOVA de Lisboa, 2829-516, Caparica, Portugal

ABSTRACT: This paper presents the results of an investigation concerning the influence of corners with standard radii in the local buckling behaviour of thin-walled rectangular hollow section (RHS) members subjected to combinations of axial force and biaxial bending. The calculation of the half-wave length leading to the minimum critical bifurcation load is performed by means of a Generalized Beam Theory (GBT) specialization, developed taking advantage of the assumption that the stress resultants are uniform along the member length. This assumption makes it possible to obtain semi-analytical solutions, adopting half-wave sinusoidal amplitude functions for the GBT cross-section deformation modes, and leads to a numerical implementation that (i) is able to quickly solve a large number of problems and (ii) provides physical insight into the critical buckling mode mechanics, through a shell-like stress resultant-based energy criterion, as well as the modal decomposition features of the GBT semi-analytical solutions. Members with cross-sections belonging to the EN10219-2 database are analysed and their critical buckling coefficients are compared with those provided by available analytical expressions and/or currently included in steel design codes, namely Eurocode 3 and the North American Specification for Cold-Formed Steel Members. Analytical expressions are developed to take into account the (usually) beneficial influence of the rounded corners to the RHS member critical buckling stress.

G. J. Nie (1) and R. C. Batra (2)
(1) School of Aerospace Engineering and Applied Mechanics, Tongji University, Shanghai, 200092, China
(2) Department of Biomedical Engineering and Mechanics, M/C 0219, Virginia Polytechnic Institute and State University, Blacksburg, VA, 24061, USA


ABSTRACT: The reduction in the stress concentration factor (SCF) around a circular hole in an infinite panel by adding an isotropic functionally graded incompressible material (FGIM) lining is analytically investigated. We assume that the shear modulus varies only in the radial direction either as a power-law function or an exponential function. For a panel subjected to far field uniaxial tension, the problem is solved by superposing the solution of two independent problems – one of biaxial tension and the other of pure shear loading. The former has a closed-form solution and latter's solution is either closed-form or in the form of the Frobenius series which depends on the functional form of the shear modulus. We also study tailoring the FGIM shear modulus in the radial direction to achieve a desired value of the SCF. For the biaxial tension loading, the required shear modulus variation is explicitly obtained, but for the uniaxial tension loading the approximate variation is numerically found. Numerical results for a few example problems reveal that the SCF strongly depends upon the sign of the shear modulus slope at the hole periphery. The FGIM lining alleviates the SCF at the hole periphery and in some cases migrates the point of the maximum hoop stress to the panel interior. Thus not only the SCF but also the maximum hoop stress in the panel interior must be considered in the panel design. The analytical results presented here should serve as benchmarks for verifying the accuracy of approximate/numerical solutions for a panel with a circular hole.


ABSTRACT: This paper presents an efficient computation method for matrices in the isogeometric analysis (IGA) of laminated composite plates, based on the First order Shear Deformation Theory (FSDT). In the method, the stiffness matrix, mass matrix and geometric stiffness matrix for static, vibration and buckling analyses are adapted into tensor-product forms and 2D integrals of the matrices are decomposed into Kronecker product of 1D integrals, which leads to the improvement of computational efficiency. Several experiments that apply the method to the static analysis and design optimization of laminated composite plates are presented in this paper to demonstrate its effectiveness. The first experiment studies the case that the domain parameterization has a diagonal Jacobian matrix (rectangular plate), and the result shows that the computation
time of global matrices is drastically reduced while their accuracy is not affected compared with traditional computation methods. The second experiment is about the case of non-diagonal Jacobian matrix. The results of circular plate, annular plate and square plate with complicated cutout show that the matrices calculation is also remarkably sped up when its model is formed in NURBS. Although the tensor-decomposition incurs certain approximation in the second case, the results still show high accuracy. The third and fourth ones study the computation efficiency of design optimization, respectively about the constant-stiffness and variable-stiffness designs when the proposed method is applied to the analysis in each iteration. All the experiments prove the high efficiency of the proposed method.


ABSTRACT: It is known that the foam-filled tubes offer significant improvement in energy absorbing owing to the interaction between the foam filler and the tube wall during axial folding deformation. In this study, an experimental investigation was carried out to clarify the interaction. For this purpose, two main specimen configurations, namely uniform density foam-filled (UDF) and radially-graded density foam-filled (RGDF), were prepared by filling aluminium tubes with PVC foam (60 and 100 kg/m³) and tested under axial compression. The experiments revealed that application of radially-graded foam filling to the tube enhanced energy absorption capacity (EAC). EAC of the RGDF and UDF specimens were 48% and 40% higher respectively than that of the base tube. Moreover, the specific energy absorption (SEA) value for the RGDF filled tube was found as 23.8 J/g while it was 21.5 J/g for the UDF filled specimen. From the experimental results, two main influence effectively increased the absorbed energy such as the axial resistance of the foam filler and the squeezed foam between inward parts of tube folds. It was concluded that if a proper foam filling design is applied the contribution of the foam squeezed between inward tube folds would have a noticeable effect on the EAC with higher SEA.


ABSTRACT: This is the first research on the nonlinear vibration of smart viscoelastic composite doubly curved sandwich shell with flexible core and MR layers with different distribution patterns. By using Reddy's third order shear deformation theory (TSST), the strains and stresses are obtained. This smart model including multiscale composite layers, flexible core and magnetorheological layer (MR). According to the Halpin-Tsai model three-phase composites layers have been considered. The governing equations of the multiscale doubly curved shell have been derived by implementing the Hamilton's principle. For investigating correctness and accuracy, this paper is validated by other previous studies. The results of this work are validated through the comparison with the results available researches. Finally, the influence of different parameters such as temperature rise, various distributions pattern, magnetic fields, and curvature ratios on nonlinear frequency response are investigated in the details. The results presented that the multiscale doubly curved sandwich shell with flexible core show a complex behavior.

Han Huang and Shucai Xu (State Key Lab of Automotive Safety and Energy, Tsinghua University, Beijing, 100084, PR China), “Crashworthiness analysis and bionic design of multi-cell tubes under axial and oblique impact loads”, Article 106333, Thin-Walled Structures, Vol. 144, November 2019, https://doi.org/10.1016/j.tws.2019.106333

ABSTRACT: Creatures in nature adapt to the environment by a long-term evolution, they often obtain the optimization structures for hunting and self-defence. One such example is a marine crustaceans named Odontodactylus scyllarus (O. scyllarus) has hammer-like dactyl clubs, which can bear high-velocity impacts and absorb the impact energy efficiently. In this paper, a novel bionic multi-cell tube (BMT) with three layers of circular columns was designed, inspired by dactyl clubs structure of O. scyllarus. The crashworthiness of BMTs with different bionic-cell numbers were investigated under axial and oblique loads using nonlinear finite element (FE) method through LS-DYNA. Secondly, a complex proportional assessment (COPRAS) method
was used to select the best possible sectional configuration under multiple loading angles. According to this method, the BMT with five cells (BMT-5) was determined to be the best design based on multicriteria process. Finally, a metamodel-based multiobjective optimization method based on polynomial regression (PR) metamodel and multiobjective particle optimization (MOPSO) algorithm were employed to optimize the dimensions of the BMT-5, where $F_\text{cr}$ and $EA$ were taken as objectives and wall thickness $t$ and middle circle diameter $D$ regarded as the design variables. The multiobjective optimization results showed that the BMT-5 has variant optimal solutions under different single loading angles. The optimal solutions of mutliobjective optimization under the multiple loading angles was highly dependent on the selection of weighting factors for different loading cases. Further research is required to investigate the crashworthiness analysis of BMTs under lateral impact.

Sherif S. Sorour (1), Mostafa Shazly (1) and Mohammad M. Megahed (2)
(1) Mechanical Engineering Department, the British University in Egypt, El-Sherouk City, Cairo, Egypt
(2) Mechanical Design and Production Engineering Department, Cairo University, Giza, Egypt


ABSTRACT: The fabrication of pipe bends using rotary pipe bending (RPB) process results in geometrical imperfections as described by cross-sectional ovality and wall thickness variations which affect the pipe bends performance during service. Previous studies whether ignores these imperfections (Ideal pipe bend (IB)) or assume these imperfections in their analysis (Assumed shape bend (AS)). The objective of the present work is to investigate, using non-linear finite element analysis, the effect of the residual stresses and the presence of the inherited geometrical imperfections (low ovality) obtained from RPB process of 90° pipe bends on their load carrying capacities as compared with the IB and AS models. RPB process with basic tooling configuration is first simulated to obtain the as-fabricated 90° pipe bend. The results of this step were verified against published experimental results and analytical solutions, and compensated for springback. The pipe bend was then subjected to different combinations of loads (in-plane moment and internal pressure) to construct a comparative limit load diagram. Within the scope of our study, results have shown that the presence of the residual stresses remarkably reduces the pipe bend load-carrying capacity. IB model results in non-conservative results as geometrical imperfections lower the load carrying capacity of the pipe bend, while the AS model has been found to be invalid for cases where a mandrel is used in RPB process.

A.H. Sofiyev (1), B. Esencan Turkaslan (2), R.P. Bayramov (3) and M.U. Salamci (4)
(1) Department of Civil Engineering of Engineering Faculty of Suleyman Demirel University, Isparta, Turkey
(2) Department of Mechanical Engineering of Engineering Faculty of Suleyman Demirel University, Isparta, Turkey
(3) Department of Automobile Transportation and Organization of Transport of Azerbaijan Technical University, Baku, Azerbaijan
(4) Department of Mechanical Engineering, Faculty of Engineering, Gazi University, Ankara, Turkey


ABSTRACT: In this study, an effective analytical solution for the stability problem of functionally graded (FG) carbon nanotube reinforced composite (CNTRC) conical shells (CSs) exposed to external lateral and hydrostatic pressures is presented. The materials of functionally graded carbon nanotube reinforced composite conical shells (FG-CNTRC-CSs) are graded in the thickness direction according to linear distributions of the volume fraction of CNTs. The effective material properties of CNTRC-CSs are calculated using the extended mixture rule. The basic equations of CNTRC-CSs are derived using modified Donnell-type shell theory based on the first order shear deformation theory (FSDT). By using Galerkin method, the expressions for the critical external pressures of FG-CNTRC-CSs are obtained. The accuracy and reliability of existing solutions is confirmed by numerical examples and comparison with the results based on the FSDT and classical shell theory (CST) in the literature. Finally, numerical calculations are performed to demonstrate the effects of various graded profiles and volume fraction of CNTs and variation of CSs geometry on the critical external pressures for FG-CNTRC-CSs.
Anders Bau Hansen (1,2) and Jeppe Jönsson (2)
(1) NIRAS A/S, Sortemosevej 19, DK-3450, Allerød, Denmark
(2) Technical University of Denmark, Department of Civil Engineering, Brovej Building 118, DK-2800 Kgs, Lyngby, Denmark
ABSTRACT: Using energy principles, a thin-walled beam element is introduced for the analysis of beams with deformable cross-sections that are prone to distortion. The beam element is based on previously attained semi-analytical displacement solution modes of an advanced thin-walled beam model. The first-order beam element for linear analysis handles shear deformations related to both Timoshenko and Mindlin-Reissner type deformations, warping effects of torsion, cross-section distortion including associated warping effects, as well as the transverse displacement effect from normal stress. The formulation can handle both open and closed cross-sections without special attention. The formulation of the displacement solution modes and the stiffness integration of the products of the advanced displacement modes using the Hadamard product are described. The paper also presents the transformations between modal degrees of freedom and element displacement degrees of freedom. Four examples show the beam element capabilities and good agreement with results obtained using the shell and solid elements of a commercial finite element program. The kinematic assumptions that the thin-walled beam model accommodates leads to local shear stress transfer at corners. This transfer of shear stresses is not normally seen in thin-walled beam formulations or shell models. However, the shear transfer is verified through examination of a finite element model using solid elements.

Weiqiang Wang (1), Chengqing Wu (1,2), Jun Li (1), Zhongxian Liu (2) and Xudong Zhi (3)
(1) Centre for Built Infrastructure Research, School of Civil and Environmental Engineering, University of Technology Sydney, NSW, 2007, Australia
(2) Tianjin Key Laboratory of Civil Structure Protection and Reinforcement, Tianjin Chengjian University, Tianjin, 300384, China
(3) Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin, 150090, China
ABSTRACT: This study investigates the lateral impact behavior of double-skin steel tubular (DST) members with ultra-high performance fiber-reinforced concrete (UHPFRC). A total of six specimens were prepared and tested under lateral impact loading. In addition to UHPFRC filled DST members, normal strength concrete (NSC) filled DST member was also tested for comparison. Other investigated parameters in this study include the impact energy, the outer steel tube thickness, the inner steel tube thickness, and the presence of axial force. The test results demonstrate that the UHPFRC filled DST members exhibit significantly higher lateral impact resistance capacity than the NSC filled DST member. The impact energy and the outer steel tube thickness significantly affect the lateral impact behavior of UHPFRC filled DST members, while the influence of inner steel tube thickness is insignificant. With the applied axial force in this study, the influence of axial force is also insignificant. Afterwards, numerical model was developed and validated by the present test results. Based on the validated numerical model, the mid-span bending moment distributions and the stress wave propagations were investigated. Finally, parametric analyses were carried out to investigate the influences of different parameters on the lateral impact behavior of UHPFRC filled DST members.

Jie Liu (1), Haifeng Ou (1), Rong Zeng (2), Jiaxi Zhou (2), Kai Long (3), Guilin Wen (1) and Yi Min Xie (4)
(1) Center for Research on Leading Technology of Special Equipment, School of Mechanical and Electric Engineering, Guangzhou University, Guangzhou, 510006, PR China
(2) College of Mechanical and Vehicle Engineering, Hunan University, Changsha, 410082, PR China
(3) State Key Laboratory for Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing, 102206, China
(4) Centre for Innovative Structures and Materials, School of Engineering, RMIT University, Melbourne, 3001, Australia

ABSTRACT: Using a two-dimensional (2D) metal sheet to design structures exhibiting different dynamic properties can show prolonged promising for actual engineering. In this study, a Miura tube is first designed and fabricated by using a five-step strategy. The structure is constructed by carefully stacking two identical brass Miura sheets into one tube. A finite element (FE) model with high-fidelity has been developed to predict the natural frequencies (NFs) of the Miura tube and simulation results have been compared with the data from experiments. The dynamic responses of the Miura tube are then numerically investigated by using the verified FE model. Finally, a multi-objective optimization strategy is developed to optimize the Miura tube in order to maximize the fundamental frequency and minimize the dynamic displacement simultaneously. Results show that the dynamic properties of the Miura tube, made from one same metal sheet, can be significantly altered in a wide range by simply changing its geometric parameters. Moreover, the proposed structure can be easily fabricated from a single thin sheet made of one material and simultaneously owns better mechanical properties than the Miura sheet.

Ho-Jun Lee (1), Hong-Gun Park (1) and In-Rak Choi (2)
(1) Dept. of Architecture and Architectural Engineering, Seoul National Univ., 1 Gwanak-ro, Seoul, 151-744, South Korea
(2) Dept. of Architectural Engineering, Hoseo University, Asan-si, Cheongcheongnam-do, 31499, South Korea


ABSTRACT: An experimental research was conducted for the eccentric compression behavior of concrete-encased-and-filled steel tube (CEFT) columns with high-strength circular steel tube. Five eccentrically loaded columns and one concentrically loaded column were tested under monotonic axial compression. The parameters of the test specimens included axial-load eccentricity, tie spacing, and the use of concrete encasement. In addition to conventional perimeter ties, U-cross ties were used to prevent the premature spalling of thin concrete encasement as well as local buckling of longitudinal rebars. Although early vertical cracking occurred at the compressive face, the outer concrete significantly contributed to the stiffness and strength of the composite column without the premature failure. The test strengths were compared with the predictions of current design codes, addressing contributions of the whole encasement. The CEFT specimens showed substantial ductility even after the concrete crushing, owing to the increased resistance of the high-strength circular steel tube and confined infill concrete. To verify overall behavior of the test specimens, nonlinear numerical analysis using a fiber model was performed.

Tianli Chen (1), Mingzhou Su (1), Chiling Pan (2), Li Zhang (1) and Huimeng Wang (1)
(1) School of Civil Engineering, Xi’an University of Architecture and Technology, Xi’an, 710055, China
(2) Department of Construction Engineering, Chaoyang University of Technology, Taiwan 400, China


ABSTRACT: Local buckling may occur in the straight portion of a corrugated steel plate (CSP) pipe-arch with a deep wave section that is used in a buried structure. In this study, the soil support of the pipe-arch structure is considered, and the local buckling of the straight portion of the CSP is investigated. The corresponding theoretical formulae are derived using the Rayleigh-Ritz method. The simplified mechanical model with the soil support is used for derivation. Then, the finite element models for the invert of the pipe-arch with several waves are established to analyze the actual rotational restraints of the straight portion. The influences of plate thickness, corrugation, aspect ratio and curvature on the local buckling load of the invert are investigated. The relationships of plate thickness and local buckling load for three types of deep corrugations are obtained. These relationships reveal that the actual rotational restraints are negative, i.e., the straight portion provides restraint for the corrugated portion. Based on numerical simulations, the theoretical formulae are modified to account for the actual rotational restraints of the straight portion. Then, the finite element model of the global pipe-arch structure is built. The corresponding analysis matches well with the revised formula, which validates the modified derivation. Finally, according to the yield criterion, a reasonable limit value for the width-to-thickness
ratio for the straight portion of the CSP is suggested. This limit can be used to prevent local buckling of CSP buried pipe-arch structures in practice.


ABSTRACT: This paper presents and discusses numerical results on the (i) elastic post-buckling behaviour and (ii) imperfection sensitivity of simply supported cylindrical steel panels under uniform compression. The results presented are obtained by means of a geometrically non-linear Generalised Beam Theory (GBT) formulation previously reported by the authors, which can include arbitrary member initial geometrical imperfections. The modal decomposition features of GBT enables extending the knowledge on the mechanics underlying these structural elements, which cannot be obtained with standard shell finite element analysis. The work begins by describing the GBT buckling analysis of four curved panels with distinct curvatures. Then, post-buckling results are presented and discussed for each of the four panels geometries, by considering (i) two distinct critical-mode initial geometrical imperfections shapes and (ii) five distinct amplitudes to assess the imperfection sensitivity – if the “sign” of the initial geometrical imperfection is relevant, ten amplitudes are considered. These results provide the evolution, along the equilibrium paths, of relevant modal displacement profiles, modal participation diagrams and deformed configurations. For comparison and validation purposes, shell finite element results are also reported.

Bin Qin (1), Rui Zhong (2), Qiangyun Wu (1), Tiantian Wang (1), and Qingshan Wang (2)
(1) Key Laboratory of Traffic Safety on Track, Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha, 410075, PR China
(2) State Key Laboratory of High Performance Complex Manufacturing, Central South University, Changsha, 410083, PR China

ABSTRACT: In this research, an analytical Jacobi-Ritz method for the free vibration analysis of composite laminated rectangular plate subject to arbitrary boundary conditions is proposed. The theoretical model is constructed in the framework of the first-order shear deformation theory (FSDT), and the multi-segment partitioning strategy is introduced. The boundary condition as well as the interface continuity condition is dealt with through the artificial spring technique. The displacement functions for every separated plate segment are expanded in the way of Jacobi polynomials along both the length and width orientations. And all the undetermined coefficients are decided through the Ritz method. The solution exhibits excellent convergence performance and shows stable features. The reliability and precision of the proposed methodology are validated by comparison with results from literature, where general boundary conditions are taken into account. Furthermore, parameterized study of the composite laminated rectangular plate is conducted, the results of which can be benchmark results for the future study.

Michael C.H. Yam (2,3), Ke Ke (1,2), Angus C.C. Lam (4) and Qingyang Zhao (1,2)
(1) Hunan Provincial Key Laboratory for Damage Diagnosis of Engineering Structures, Hunan University, Changsha, China
(2) Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong, China
(3) Chinese National Engineering Research Centre for Steel Construction (Hong Kong Branch), The Hong Kong Polytechnic University, Hong Kong, China
(4) Department of Civil and Environmental Engineering, University of Macau, Macau, China

ABSTRACT: This paper reports a numerical study on the local web buckling strength and behaviour of single-coped beam with slender web (SCBSW). First, finite element (FE) models of SCBSW connections were developed, and the effectiveness of the modelling techniques was validated by the results of full-scale SCBSW connection tests conducted by the authors and those in the literature. Subsequently, an extensive parametric investigation covering a wide range of web slenderness ratio, cope geometries and rotational stiffness of the
connection was conducted. A database of the FE results of 243 SCBSW models connected with a rotationally rigid support was developed. The analysis results show that all of the models were governed by local web buckling, and post-buckling behaviour of the SCBSW connections was confirmed. The interaction among the slender web, cope configurations and rotational stiffness of the connections on the structural behaviour and local web buckling capacity of SCBSW connections was characterised. A practical approach for evaluating the local web buckling strength of end-plate type SCBSW connecting with a rotationally rigid support was developed using the available FE results. The post-buckling behaviour and the interactive effect among the slender web and the other essential factors were considered in the proposed method. The proposed method produces reasonable predictions of the local web buckling strength of SCBSW connections with a rotationally rigid support comparing with those predicted by the FE results and the available test data, which may offer a basis for a full-fledged design guide for SCBSW.

J.J. Tang (1), H. Wu (2), S.T. Ke (3) and Q. Fang (1)
(1) State Key Laboratory for Disaster Prevention & Mitigation of Explosion & Impact, Army Engineering University of PLA, Nanjing, 210007, China
(2) Research Institute of Structure Engineering and Disaster Reduction, Tongji University, Shanghai, 200092, China
(3) Department of Civil Engineering, Nanjing University of Aeronautics and Astronautics, Yudao Road 29, Nanjing, 210016, China


ABSTRACT: As the highest and largest building in the nuclear power plant, the large-scale cooling tower is more likely to suffer the accidental or deliberate impact of the commercial aircraft, while few related studies have been conducted. By adopting the missile-target interaction method, the dynamic responses of the large-scale cooling tower under the impact of typical medium and large commercial aircrafts, i.e., Airbus A320 and A380, are numerically evaluated. Firstly, the refine finite element (FE) models of Chinese Chaohu hyperbolic cooling tower as well as the above two aircrafts are established by using the HyperMesh program. Then, by comparing with the classic Meppen-II-4 impact test (the fourth shot of the second series of Meppen impact tests) of large deformable missile and the modified Riera force function, the validations of concrete and aircraft models are verified respectively. Furthermore, the explicit dynamic analysis program LS-DYNA is used to perform the numerical simulations of the cooling tower collided by the two typical aircrafts. The whole impact processes are reproduced, and the impact force, damage and failure of the shell concrete, velocity of the aircraft are examined and discussed. Finally, the parametric influences of the impact velocity, angle, and position of two aircrafts on the damage and failure of cooling tower are further performed.

Zhixiang Li, Wen Ma, Ping Xu and Shuguang Yao (Key Laboratory of Traffic Safety on Track, Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha, China), “Crushing behavior of circumferentially corrugated square tube with different cross inner ribs”, Article 106370, Thin-Walled Structures, Vol. 144, November 2019, https://doi.org/10.1016/j.tws.2019.106370

ABSTRACT: In this paper, new designed circumferentially corrugated square tubes (CCSTs) with cosine and triangular corrugation cross-sectional profiles, respectively, are proposed for energy absorption. Three types of cross inner ribs, namely, crisscross, X shape and star shape, are introduced to induce the deformation of CCSTs. Quasi-static crushing test and finite element simulation were used to investigate the crushing performance of the CCSTs. The results showed that all triangular profile CCSTs can not deform stably, and only the crisscross inner rib can induce the deformation of CCSTs to deform progressively. The performance of cosine profile CCSTs with crisscross inner rib (i.e., CTC_C) under different geometric parameters was therefore further studied. It was found that the CTC_C develops four different deformation modes, and the ordered progressive mode II (OPM II) showed better energy absorption efficiency than the other modes. Finally, a theoretical model based on Simplified Super Folding Element method was presented to predict the mean crushing force of CTC_C deforming with OPM II. By comparing with the experimental and FE results, the theoretical model was proved to be very accurate.

Shuguang Yao, Yanfei Huo, Kaibo Yan and Ping Xu (Key Laboratory of Traffic Safety on Track, Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha, China), “Crushing behavior of circumferentially corrugated square tube with different cross inner ribs”, Article 106370, Thin-Walled Structures, Vol. 144, November 2019, https://doi.org/10.1016/j.tws.2019.106370

ABSTRACT: In this paper, new designed circumferentially corrugated square tubes (CCSTs) with cosine and triangular corrugation cross-sectional profiles, respectively, are proposed for energy absorption. Three types of cross inner ribs, namely, crisscross, X shape and star shape, are introduced to induce the deformation of CCSTs. Quasi-static crushing test and finite element simulation were used to investigate the crushing performance of the CCSTs. The results showed that all triangular profile CCSTs can not deform stably, and only the crisscross inner rib can induce the deformation of CCSTs to deform progressively. The performance of cosine profile CCSTs with crisscross inner rib (i.e., CTC_C) under different geometric parameters was therefore further studied. It was found that the CTC_C develops four different deformation modes, and the ordered progressive mode II (OPM II) showed better energy absorption efficiency than the other modes. Finally, a theoretical model based on Simplified Super Folding Element method was presented to predict the mean crushing force of CTC_C deforming with OPM II. By comparing with the experimental and FE results, the theoretical model was proved to be very accurate.

ABSTRACT: Thin-walled structures are universally used as energy-absorption devices for their great crashworthiness characteristics and light weight. In this paper, a novel tubular configuration is introduced with a gradually decreasing amplitude of the corrugation profile in the axial direction, namely, a hybrid corrugated tube (HCT), to improve the energy-absorption capacities of ordinary corrugated tubes (OCTs). Based on the validated finite element (FE) models, the effects of geometric parameters of the HCTs on crashworthiness are investigated. The numerical results show the HCTs exhibit advantages on the energy absorption capability compared to OCTs, and the crashworthiness indicators and deformation modes of the HCTs depend strongly on the wavelength and constant corrugation ratio. The strengths of the HCTs gradually increases as the compression progresses, and when the constant corrugation ratio increases, the strengthening effect gradually weakens. By comparing OCTs and HCTs with the same wavelengths and deformation modes, it can be found that in the HCTs, the $SEA$ values increase by 21%–57%, the $F_m$ values increase by 15%–45%. The lower is the constant corrugation ratio, the more obvious are the increase in the $EA$, $SEA$, $F_m$ values. Finally, a multi-objective optimization is conducted to obtain the optimized HCT configuration for maximizing the $SEA$ and minimizing the $F_m$. The optimal HCTs are of even more superior crashworthiness and great potential as an energy absorber.


ABSTRACT: Aluminium honeycomb sandwich panels are an interesting lightweight structural solution for several applications such as marine structures, aerospace, automotive and aeronautics. In many of these applications, in-service conditions produce fatigue loadings: as a result, safer use of aluminium honeycomb sandwich structures requires a deep knowledge of their fatigue response, which was seldom studied in previous literature. The aim of the current study is to evaluate the fatigue response of aluminium honeycomb sandwich panels subjected to three-point bending loading conditions. The experimental investigation was performed on a commercial aluminium honeycomb sandwich structure with an overall thickness of 11 mm. A preliminary static analysis was performed both under three and four point bending conditions. The static tests allowed the identification of the static bending strength and the absence of a significant strain rate influence. Crashworthiness parameters were evaluated and a slight better performance was found under four point bending. The combination of static tests with Computed Tomography analysis resulted in the observation of the phenomena involved in static bending response of aluminium honeycomb sandwich structures, which are mainly dependent on cell walls buckling. Fatigue tests were conducted under three-point bending conditions. The influence of boundary conditions on fatigue life and on collapse modes were investigated by considering different supports spans. For one condition the $S$-$N$ curve was obtained and its equation was compared to literature results. Two different collapse mechanisms were observed depending on the supports span: for larger supports span a fracture of the tensioned skin was observed, whereas lower supports span produced core shear. The former mode differred significantly from static failure with the same boundary conditions. In both cases, failure occurred suddenly and this should be taken into consideration in industrial applications. An analytical model was applied to predict fatigue collapse modes and limit loads. A fatigue failure map describing the relationship between supports span, collapse modes and fatigue limit loads was obtained, in order to provide a quantitative tool for aluminium honeycomb sandwich structures design. The fatigue failure map was able to accurately predict the experimental results.

Jiayue Zhai (1), Yufei Liu (1), Xinyu Geng (1), Wei Zheng (1), Zhijun Zhao (2), Chengbo Cui (1) and Meng Li(1)
(1) Qian Xuesen Laboratory of Space Technology, China Academy of Space Technology, Youyi Street No. 104, Haidian, Beijing, 100094, China
ABSTRACT: Honeycomb structures have been extensively employed as energy absorption devices. This paper proposes a kind of energy absorption structure known as the pre-folded honeycomb, which is made from conventional honeycomb with a pre-folded trace. The folding mode and energy absorption performance of the pre-folded structure under in-plane impact load were investigated both numerically and experimentally. Furthermore, the response surface method was chosen to find the optimal pre-folded honeycomb structure for the purpose of maximizing the specific energy absorption. The results demonstrate that the proposed method is effective in solving crashworthiness design-optimization problems. Additionally, the numerical results show that the in-plane structural strength of pre-folded honeycomb is nearly 8 times higher than that of conventional honeycomb.

B.A. Selim (1,2), Zishun Liu (1) and K.M. Liew (2)
(1) International Center for Applied Mechanics State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China
(2) Department of Architecture and Civil Engineering, City University of Hong Kong, Kowloon, Hong Kong, China


ABSTRACT: To the best of our knowledge, this is the first trial to study the active vibration control of functionally graded multilayer graphene nanoplatelets (GPLs) reinforced composite plates integrated with piezoelectric layers. The theoretical formulation of the composite plates with piezoelectric layers is developed utilizing the element-free improved moving least-squares Ritz (IMLS-Ritz) method in association with the higher-order shear deformation theory (HSDT). Four GPLs distributions across the thickness of the GPLs reinforced composite layer are considered. For all distributions, the effective Young's modulus is calculated by the modified Halpin-Tsai model while the effective Poisson's ratio and mass density are estimated by the rule of mixture. Natural frequency results for GPLs reinforced composite plates with piezoelectric layers are presented considering various essential parameters including GPLs volume fractions, GPLs distribution patterns, plate's total thickness to width ratio, piezoelectric layer thickness to total plate's thickness ratio as well as boundary conditions. Additionally, the effects of these parameters on natural frequency increment between open and closed-circuit conditions are discussed. For active vibration control results, a constant velocity feedback controller is used considering two positions of piezoelectric sensor and actuator layers: the sensor and actuator layers are placed at two opposite sides or they are placed at the same side of the plates.

Hui Zhao (1), Rui Wang (1), Chuan-Chuan Hou (2) and Dennis Lam (3)
(1) School of Civil Engineering, Taiyuan University of Technology, Taiyuan, 030024, China
(2) School of Transportation Science and Engineering, Beihang University, Beijing, 100191, China
(3) Faculty of Engineering and Informatics, University of Bradford, Bradford, BD7 1DP, UK


ABSTRACT: This paper presents an experimental and numerical study on the impact performance of circular concrete-filled double skin steel tubular (CFDST) members with external stainless steel tube. Austenitic 304 stainless steel was used for all the test specimens. Taguchi approach was employed for the parametric design of the experimental program. The testing parameters were the impact height, hollowness ratio and axial load level. 18 specimens were tested under transverse impact loading to obtain the failure patterns, the time histories of impact force and mid-span deflection, as well as the strain developments in the stainless steel tube. Finite element (FE) models were then established and verified against the test results, in which the strain rate effects of the stainless steel, the carbon steel and the infilled concrete were considered. The validated FE model was then employed to investigate the whole dynamic response of CFDST members with outer stainless steel tube subjected to impact. The impact resistance of the stainless composite member was also compared with that of the CFDST member with an external carbon steel tube.
Jianbin Cao, Zhusuo Zhang and Yanfei Guo (State Key Laboratory for Manufacturing and Systems Engineering, School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an, 710049, P.R. China), “A finite element based state-space approach for vibration analysis of slender explosive clad pipe with partial contact defect”, Article 106359, Thin-Walled Structures, Vol. 145, December 2019, https://doi.org/10.1016/j.tws.2019.106359

ABSTRACT: An efficient modeling method is presented in this paper for vibration analysis of explosive clad pipe with partial contact defect (PCD). The principal purpose is to study the effects of the PCD on the vibration characteristics of explosive clad pipe and to explore effective techniques for detecting the PCD. The slender explosive clad pipe is regarded as two parallel elastic beams continuously joined by a virtual Winkler/Pasternak type viscoelastic layer, and the virtual layer is capable to describe the non-uniform bonding state such as the PCD. By means of finite element method and the standard linear solid (SLS) model, a state-space model of explosive clad pipe with inhomogeneous bonding state is developed for the fields of axial displacement and transverse displacement. The model can reflect the PCD pipe system under different boundary conditions and describe damping behavior of bonding interface. Experiments and numerical examples available in the literature demonstrate the accuracy and reliability of proposed approach. Finally, numerical results are presented and show that the PCD have significant effect on the natural frequencies and forced response in high-frequency domain. A potential method for identifying the length and position of the PCD in explosive clad pipe is also discussed in this paper.

H.N.R. Wagner (1,2), C. Hühne (1,3), R. Khakimova (4)
(1) Technische Universität Braunschweig, Institute of Adaptronics and Function Integration, Langer Kamp 6, 38106, Braunschweig, Germany
(2) Siemens Mobility GmbH, MO MM R&D SYS ITV IXL, Ackerstr. 22, 38126, Braunschweig, Germany
(3) German Aerospace Center (DLR), Institute for Composite Structures and Adaptive Systems, Lilienthalplatz 7, 38108, Braunschweig, Germany
(4) Fraunhofer Institute, Open Hybrid LabFactory e.V., Hermann-Münch-Straße 2, 38440, Wolfsburg, Germany


ABSTRACT: Thin-walled conical shells are used as adapters between cylindrical shells of different diameters in launch-vehicle systems or as tailbooms in helicopters. A major loading scenario for conical shells is pure bending. The buckling moment of these shells is very sensitive to imperfections (geometry, loading conditions) which results in a critical disagreement between theoretical and experimental results for conical shells under pure bending. The design of these stability critical shells is based on classical buckling loads obtained by a linear analysis which are corrected by a single knockdown factor (0.41 - NASA SP-8019) for all cone geometries. This practice is well established among designers and hasn't changed for the past 50 years because the buckling behavior is till today not very well understood. Within this paper a reduced stiffness analysis for conical shells under pure bending is performed. Data of previous experimental testing campaigns are used to validate the new design criteria for different conical shell geometry configurations. The results show that the application of the new design recommendation for conical shell structures results in increased knockdown factors for the buckling moment which in turn may lead to a significant weight reduction potential. All ABAQUS-Python scripts and the results generated for this article are deposited in the Elsevier repository.

Zhichao Li, Subhash Rakheja and Wen-Bin Shangguan (School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou, 510641, China), “Study on crushing behaviors of foam-filled thin-walled square tubes with different types and number of initiators under multiple angle loads”, Article 106376, Thin-Walled Structures, Vol. 145, December 2019, https://doi.org/10.1016/j.tws.2019.106376

ABSTRACT: A finite element model of a thin-walled foam-filled square tube is developed for estimating its energy absorption characteristics. The crush behavior of the foam-filled tube is experimentally evaluated under axial loading and the measured force-deflection properties are used to examine validity of the model. The validated model is subsequently applied to study the effects of types and number of crush initiators on the energy absorption characteristics of the foam-filled thin-walled square tubes subjected to loading at different angles. It is shown that initiators can yield improved collision performance of the foam-filled thin-walled square
tubes, when a reasonable number of crushing initiators are introduced. The energy absorption performances of the foam-filled structure with different types and quantities of crushing initiators are calculated and ranked. The results showed best performance when a set of four-corner-holes along the axial direction of the tubes is added. Based on the model results, a multi-objective optimization method is proposed for deriving an optimal design of the tube with a set of four-corner-holes for enhanced crashworthiness performance.

A. Paul Praveen (1), Vasudevan Rajamohan (1), Ananda Babu Arumugam (2) and Sameer S Rahatekar (3)
(1) School of Mechanical Engineering, Vellore Institute of Technology (VIT), Vellore, India
(2) Department of Mechanical Engineering, SET, Sharda University, Greater Noida, UP, India
(3) School of Aerospace, Transport and Manufacturing, Cranfield University, United Kingdom

ABSTRACT: This study investigates numerically and experimentally the effect of longitudinal ribbon reinforcement in conventional honeycomb structure on the various dynamic characteristics of a hybrid composite sandwich plate. Longitudinal strips are considered to be embedded along the transverse directions at various locations of a honeycomb core material without and with carbon nanotubes (CNT) reinforcement in a composite sandwich plate. The governing differential equations of motion of the various hybrid honeycomb composite sandwich plate configurations with strips inserted in conventional honeycomb structures as core layer having top and bottom face composite layers are derived using higher order shear deformation theory (HSDT) and solved numerically using a four noded rectangular finite element. Further, experimental investigations are performed by fabricating the various strips embedded hybrid honeycomb core material with and without CNT reinforcement to evaluate the shear and loss moduli using the alternative dynamic approach. The efficacy of the developed finite element formulation is demonstrated by comparing the experimental and numerical results obtained in terms of natural frequencies and loss factors for the various prototypes of honeycomb composite sandwich plates. Also, the effect of variation in CNT content and thickness of longitudinal ribbon reinforcement in conventional honeycomb core material and ply orientation of the face sheets on the various dynamic properties of hybrid composite structures are studied under various end conditions. This study proposes that the ribbon reinforcement location and the addition of CNTs in honeycomb core materials strongly influence the stiffness, damping and transverse vibration displacements of the ribbon reinforced hybrid composite sandwich plates.

Ali Binazir (1), Hassan Karampour (1), Adam J. Sadowski (2) and Benoit P. Gilbert (1)
(1) Griffith School of Engineering and Built Environment, Griffith University, Gold Coast Campus, QLD, 4222, Australia
(2) Department of Civil and Environmental Engineering, Imperial College London, UK

ABSTRACT: Subsea pipelines and PIP systems experience large bending moments during installation and operation. However, unlike single-walled pipelines, the behaviour of PIPs under bending has been only marginally addressed. In the current study, the bending response of PIP systems with diameter-to-thickness ratio \((D/t)\) of 15–40 is investigated. Linear bifurcation analyses (LBA) and geometrically nonlinear analyses (GNA) are conducted on PIPs of varying lengths. Analytical expressions are provided to predict the classical and nonlinear limit moments of PIPs, and are compared to existing expressions for single-walled pipelines. Ultimate bending moments of PIPs are obtained from physical four-point bending tests and are compared against geometrically and materially nonlinear analyses (GMNA). The finite element results show that in PIPs with centralizers, the limit moments (GNA) drop slightly, however, the ultimate moments (GMNA) remain unchanged. A parametric study of the effect of geometry and material properties of the inner and outer pipes on the ultimate moment of PIPs is presented. It is understood that the ultimate moments of PIPs with thick tubes are predominantly influenced by the material nonlinearities rather than ovalization of the tubes.

Jagath Narayana Kamineni and Ramesh Gupta Burela (Multi-Functional Composites Lab, Mechanical Engineering Department, Shiv Nadar University, Greater Noida, UP, 201314, India), “Constraint method for

ABSTRACT: In this work, a new methodology is developed for constructing the stiffened panel structure. Here we introduce the constraint method to integrate the stiffener and plate. The geometric nonlinear analysis is performed to analyze the stiffened panel behavior in terms of load-deformation response curve. Variational Asymptotic Method (VAM) is applied to analyze composite flat stiffened panels. The VAM development begins with the 3-D nonlinear strain energy functional which splits into a 1-D through-the-thickness analysis and a 2-D plate analysis. The 2-D constitutive law that is an output of 1-D analysis is used as an input to perform the 2-D nonlinear plate analysis. The integration of skin and the stiffener technique is implemented by introducing a constraint matrix. At the skin and stiffener interface, the developed constraint matrix is used in realization of 3-D displacements of stiffener and skin are same. The proposed approach is simple and reliable to address the complexity in analyzing stiffened structures. This methodology is developed using a computational symbolic tool Mathematica and the implemented computer program named as NASSVAM (Nonlinear Analysis of Stiffened Structures using Variational Asymptotic Method). The obtained results from NASSVAM are compared and showed good agreement with the 3-D FEA results.

S. Mohsenizadeh and Z. Ahmad (School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Malaysia), “Auxeticity effect on crushing characteristics of auxetic foam-filled square tubes under axial loading”, Article 106379, Thin-Walled Structures, Vol. 145, December 2019, https://doi.org/10.1016/j.tws.2019.106379

ABSTRACT: This paper treats energy absorption and crushing characteristics of auxetic foam-filled square-section tubes under axial loading condition. The influence of auxeticity effect on the structural collapse was experimentally investigated to quantify the interaction effect between Poisson's ratios of foam (ranging from −0.31 – 0.03) and square tube walls under quasi-static and dynamic loadings. The validated computer simulation technique was employed to conduct a series of parametric study in order to evaluate the influence of tube parameters on the energy absorption responses. It is evident that negative Poisson ratio effectively influences the crushing response and energy absorption capability of auxetic foam-filled square tubes. Moreover, it was found that increasing the auxeticity level of foam filler enhances crashworthiness performance of foam-filled structures under both quasi-static and dynamic loading conditions. The primary outcome of this study is a design guideline for the use of auxetic foam in different ranges of Poisson's ratio as a core for an energy absorber device where impact loading is expected.

Amit H. Varma (1), Soheil Shafaei (1) and Ron Klemencic (2)
(1) Lyles School of Civil Engineering, Purdue University, West Lafayette, USA
(2) Magnuson Klemencic Associates, Seattle, WA, USA

ABSTRACT: Concrete-filled composite plate shear walls (CPSW) consist of a concrete (infill) wall sandwiched between two steel plates that are connected to each other using ties and anchored to the concrete infill using these embedded ties or shear connectors. Steel modules consisting of plates, ties and shear connectors are prefabricated in the shop, transported to the field, and assembled first. The erected modules serve as falsework for construction activities and stay-in-place formwork for concrete casting. This is a primary advantage and appeal of this system. However, there is a lack of knowledge regarding the structural behavior of empty steel modules (before and during concrete casting). This paper presents the results of analytical, numerical, and experimental investigations conducted to evaluate: (i) the structural behavior of empty steel modules under their own self-weight, (ii) the stability and axial load capacity of steel modules for construction loads and activities, and (iii) the effects of concrete casting (hydrostatic pressure) in terms of the deflections and stresses induced in the steel plates. The results indicate that the effective shear stiffness of the empty modules governs their structural behavior as well as their stability. The effective shear stiffness can be estimated using the finite element method (verified using test results), or conservatively using mechanics-based equations presented in this paper. The effective shear stiffness is governed by plate slenderness, defined by the tie spacing and plate thickness, and the relative flexural rigidity of the steel plates and the connecting ties. These parameters can be designed to limit the flexibility and the critical buckling stress of the empty modules. The paper also provides
equations for calculating the out-of-plane displacement and stresses induced in the steel plates by the concrete casting hydostatic pressure.

Habib Ahmadi and Kamran Foroutan (Faculty of Mechanical Engineering, Shahrood University of Technology, Shahrood, Iran), "Nonlinear vibration of stiffened multilayer FG cylindrical shells with spiral stiffeners rested on damping and elastic foundation in thermal environment", Article 106388, Thin-Walled Structures, Vol. 145, December 2019, https://doi.org/10.1016/j.tws.2019.106388

**ABSTRACT:** This paper presents the nonlinear vibration of multilayer FG cylindrical shells reinforced by spiral FG stiffeners surrounded by damping and elastic foundation in thermal environment. The primary, superharmonic and subharmonic resonances of spiral stiffened multilayer FG cylindrical shell are analyzed. It is assumed that the material properties are dependent to temperature. The linear elastic foundation is based on the Winkler and Pasternak model. In order to model the stiffeners, the technique of smeared stiffener is utilized. With regard to classical plate theory of shells, von Kármán equation and Hook law, the relations of stress-strain is derived for shell and stiffeners. According to the Galerkin method, the discretized motion equation is obtained. The primary, superharmonic and subharmonic resonances in presence of thermal environment are analyzed by using the method of multiple scales. The influence of the material parameters, temperature, elastic foundation and various geometrical characteristics on the primary, superharmonic and subharmonic resonances is investigated.


**ABSTRACT:** The lateral-torsional buckling of steel beams with welded slender I-shaped sections, or Class 4 sections according to Eurocode 3 classification, is investigated in this paper. While the response of non-Class 4 section beams has been extensively studied in the literature, welded slender section beams have received less attention to date.

Finite element (FE) models for non-linear analyses were developed and validated against 64 experimental tests available in the literature considering both material and geometrical imperfections. Subsequently, an extensive parametric study covering a wide range of sections and member geometries was carried out.

The existing rules from Eurocode 3 and a proposal based on a consistent derivation of the Ayrton-Perry formulation, developed for compact and semi-compact sections (sections of Class 1, 2 and 3), were presented and their accuracy was then evaluated using the numerical data generated.

As demonstrated, due to high width-to-thickness ratio of section's constituent plates, the coupled interaction between the local buckling and the lateral-torsional buckling affects the stability of the beams, but the design provisions deliver insufficient account of said interaction thus resulting in highly scattered predictions when compared against the numerical results, mostly yielding lower values of resistance than that obtained numerically.

To improve this condition, a novel concept, named the effective section factor (E.S.F.), was further developed to account with the coupled interaction by grouping the behaviour of beams with Class 4 sections into different ranges of E.S.F.

Finally, enhanced design formulae for the estimation of the ultimate strength of the beams was proposed based on the developed E.S.F. concept, providing more accurate capacity prediction.


**ABSTRACT:** In this paper the elastic buckling of longitudinally stiffened plates are discussed in the light of modal deformations. Though in the analysis and design of cold-formed steel members it is a widely used approach to decompose the deformations into global, distortional, local and other deformation modes, this approach has not been used for stiffened plates yet. In this paper a large number of stiffened plates are analysed with varying the plate width and thickness, the type, size and number of stiffeners. The investigated plates are subjected to uniform or linearly varying uniaxial compression as well as shear loading. Linear buckling analyses
are performed by enforcing various combinations of constraints, by using the constrained finite element method (cFEM). Regular unconstrained analyses are also completed, and the buckled shapes are identified with the help of cFEM, by calculating the participations from the characteristic deformation types. The results and tendencies are systematically and comprehensively evaluated. The completed studies reveal that though the geometric parameters and the load type have effect on the results, in the buckling modes with significant stiffener displacements the role of distortional and global modes is always crucial. This finding might have implication on the design, too. This question is discussed in detail in a companion paper, in which the Eurocode-based design of uniformly compressed stiffened plates with closed stiffeners are investigated.

Muhammad Ziad Haffar (1), Balázs Kövesdi (2) and Sándor Ádány (1)
(1) Department of Structural Mechanics, Budapest University of Technology and Economics, Hungary
(2) Department of Structural Engineering, Budapest University of Technology and Economics, Budapest, Hungary


ABSTRACT: Buckling resistance of longitudinally stiffened orthotropic plates is highly important in the design of steel bridges. The current calculation method of Part 1.5 of Eurocode 3 is based on the concept that the behaviour can be superposed from plate-like and column-like behaviours. Recent results indicate uncertainties in the application of the current method, e.g., if applied to plates with closed stiffeners. It is also known that the critical buckling stress is dependent on how it is calculated: by using a shell finite element model or by using the equations from Annex A of the relevant code part. The two calculation methods can lead to significant differences in the critical stress, which then mirrored in the resistance. Some results indicate that shell finite element calculation of the critical stresses can lead to resistance overestimation, especially when closed stiffeners are used. However, the reasons of the differences between the numerically and analytically calculated critical stresses are not yet fully clarified. Therefore, in the current paper the elastic critical buckling stress and buckling resistance of longitudinally stiffened plates are discussed. The paper presents the results of an extensive numerical research program focusing first on the critical buckling stress, then on the buckling resistance of plates with closed stiffeners. Reasons of the experienced differences between the critical stresses are explained in full detail. Moreover, possible enhancement of the resistance prediction is indicated.

Ghanim Mohammed Kamil (1), Qing Quan Liang (1) and Muhammad N.S. Hadi (2)
(1) College of Engineering and Science, Victoria University, PO Box 14428, Melbourne, VIC, 8001, Australia
(2) School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW, 2522, Australia


ABSTRACT: Slender rectangular thin-walled concrete-filled steel tubular (CFST) columns in composite building structures exposed to fire may experience the interaction of local and global buckling. Numerical investigations on the interaction buckling responses of such columns under fire exposure have been rarely reported. This paper describes a fiber-based computational model for the prediction of the fire-resistance and interaction responses of local and global buckling of concentrically-loaded slender CFST columns made of rectangular sections exposed to fire. The thermal analysis is undertaken to calculate the distribution of temperatures in the column cross-section considering the effects of the air gap between concrete and steel, exposure surface emissivity as well as moisture content in concrete. The local and post-local buckling models proposed previously for steel tube walls at elevated temperatures are incorporated in the inelastic analysis of cross-sections to model the progressive post-local buckling. The global buckling analysis of slender CFST columns exposed to fire accounts for the effects of material and geometric nonlinearities as well as local buckling. Efficient computational procedure and solution algorithms are developed to solve the nonlinear equilibrium dynamic functions of loaded slender CFST columns exposed to fire. Independent experimental and numerical results on slender CFST columns are utilized to validate the computational model. The interaction behavior of local and global buckling and fire-resistance of slender rectangular CFST columns are investigated. It is shown that the developed computational model provides a reasonably accurate and efficient method for the
prediction of the interaction buckling responses as well as the fire-resistance of slender CFST columns subjected to axial loading and fire.

Anton Köllner (1), Melanie Todt (2), Gregor Ganzosch (3) and Christina Völlmecke (1)
(1) Institute of Mechanics, Stability and Failure of Functionally Optimized Structures Group, Technische Universität Berlin, Einsteinufer 5, 10587, Berlin, Germany
(2) Institute of Lightweight Design and Structural Biomechanics, Technische Universität Wien, Getreidemarkt 9, 1060, Vienna, Austria
(3) Institute of Mechanics, Continuum Mechanics and Material Theory Group, Technische Universität Berlin, Einsteinufer 5, 10587, Berlin, Germany


ABSTRACT: The effect of pre-stress on the buckling behaviour of geometric unit cells of collinear square lattices is investigated experimentally and numerically. The geometric unit cells are manufactured using fused deposition modelling. Manufacturing strategies are presented which incorporate fibres subjected to pre-stress within the unit cell. The effect of pre-stressed fibres is analysed by comparing the compressive behaviour of unit cells with and without fibre reinforcement. The buckling behaviour of the unit cells is also investigated numerically by employing a parametric study within Abaqus varying the pre-stress in the fibres. The experimental test series shows that the addition of pre-stressed fibres to the system results in an increase in buckling and maximum load of 260%–480% and 220%–350% respectively. The increase strongly relates to the manufacturing quality, i.e. the bonding between the lattice material and the fibres, where a sufficient bonding yields significantly larger loads. The experimental findings on the qualitative and quantitative buckling behaviour correspond well with results obtain from the numerical study.


ABSTRACT: The hot-press molding technique was developed to fabricate the Y-frame sandwich core from carbon fiber reinforced polymer composite. The three-point bending tests were conducted to investigate mechanical behavior of the Y-frame sandwich core. The effects of the relative density on the mechanical behavior of the Y-frame sandwich core were revealed by the experiments. The bending load-displacement curves were recorded, which indicated that the bending properties of the Y-frame sandwich core were strongly influenced by the relative density. The bending failure load and the value of P/delta were analytically predicted. The discrepancy between the experimental results and the predictions was analyzed. Furthermore, the analytical prediction also revealed that the value of P/delta was dependent on the span length of the composite Y-frame sandwich core.

Wenbin Ye (1), Zhongcheng Li (2), Jun Liu (1), Quansheng Zang (1) and Gao Lin (1)
(1) State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, Dalian, 116024, China
(2) China Nuclear Power Design CO., LTD (Shenzhen), Shenzhen, 518029, China


ABSTRACT: This paper develops a high-performance semi-analytical numerical model to analyze the bending responses of the angle-ply composite laminated cylindrical shells with the fiber reinforced layers using the scaled boundary finite element method (SBFEM). As the thin-walled structures, the angle-ply composite laminated shells are assumed to be made of orthotropic materials in the cylindrical coordinate system. Both the geometric and basic variables are discretized by utilizing the two-dimensional (2D) high order spectral elements in the curved surface domain of the shells. According to the exact three-dimensional (3D) theory of elasticity rather than the approximate shell theories, the weak form of the partial differential governing equations for each layer of the composite laminated cylindrical shells in the cylindrical coordinate system are transformed into ordinary differential equations using the SBFEM. In the circumstances, there are no variables about the curved
surface of shell in the SBFEM governing equations for each lamina, so that it can be analytically solved on the basis of the dual variable approach and the precise integration technique (PIT). Employing the interface continuity conditions of displacement between the layers, the complete SBFEM model with respect to the global stiffness matrix of the composite laminated cylindrical shell can be obtained. Unlike the general layerwise theories, which supposes that the basic variables varied linearly with the thickness coordinate, the through-thickness distributions of the displacement field in each discrete layer is assumed to be a quadratic polynomial with respect to the radial coordinate in this paper, thus the through-thickness stress field can be described more accurate. Numerical examples for solving the bending problem of composite laminated cylindrical shells are presented. As a result, the numerical efficiency, accuracy and applicability of the proposed formulations are confirmed by the comparison of the published results involving the distributions of the displacements and stresses through the thickness and along the circumferential direction for different staking configurations, geometric properties and boundary conditions.

Xie Lei (1), Qi Yujun (2), Bai Yu (1), Qiu Chengyu (1), Wang Hao (3), Fang Hai (2) and Xiao-Ling Zhao (4)
(1) Department of Civil Engineering, Monash University, Clayton, Victoria, 3800, Australia
(2) College of Civil Engineering, Nanjing Tech University, Nanjing, 211800, China
(3) Centre for Future Materials, University of Southern Queensland, Toowoomba, QLD, 4350, Australia
(4) Department of Civil and Environmental Engineering, The University of New South Wales (UNSW), Sydney, NSW, 2052, Australia


ABSTRACT: Sandwich structures were built up by two glass fibre reinforced polymer (GFRP) thin-walled panels and square hollow sections (SHS) in between through adhesive bonding or mechanical bolting. Experiments in compression were conducted in order to understand the failure modes including global and local buckling, load-bearing capacities, load-displacement curves and load-strain responses. Accordingly the effects of different connection methods and different spacing values between the SHS sections were clarified. Sudden debonding failure between GFRP panels and inner SHS columns was found on adhesively bonded specimens; while mechanically bolted specimens showed evident lateral deformation and progressive failure until the ultimate junction separation failure on the GFRP SHS columns. Local buckling was found on GFRP thin-walled panels of specimens with a larger spacing between the two SHS sections. Finite element analysis and analytical modelling were performed to estimate the load-displacement curves and the critical stress for the local buckling on GFRP thin-walled panels, where consistent agreements with experimental results were received.

Junxian Zhou (1), Ruixian Qin (2) and Bingzhi Chen (2)
(1) School of Mechanical Engineering, Dalian Jiaotong University, Dalian, 116028, Liaoning, PR China
(2) School of Locomotive and Rolling Stock Engineering, Dalian Jiaotong University, Dalian, 116028, Liaoning, PR China


ABSTRACT: Multi-cell design and graded thickness are two efficient strategies for improving the mechanical behaviors of metallic thin-walled tubes. This paper combines these two strategies to present a novel multi-cell structure with a double surface gradient (DSG) and to address the energy absorption characteristics of the new tube subjected to axial compression. A mathematical formulation for the mean load was derived through theoretical analysis of the multi-cell structure's folding mechanism, and two vital parameters were proposed. Afterwards, comprehensive numerical simulations were conducted to validate the formulation and to investigate effects of the DSG on the mechanical properties. The results demonstrated that the combination of the DSG strategy and the multi-cell structure led to a greater energy absorption capacity. Finally, the key factor of the DSG design in promoting the energy absorption efficiency was analyzed. To achieve a higher promotion, an approach of rationalizing the sectional material distribution of the DSG tube was attempted and proven valid. All these achievements shed a light on the multi-cell and graded thickness effects on mechanical properties.
ABSTRACT: This paper presents a numerical-experimental research to evaluate the effect of corrosion in panels subjected to uniaxial compression and subsequent repair. The effects of corrosion are approximated by a uniform reduction in the plating's thickness. Currently, repairing a corroded offshore structure involves the change of the hull plating, which is excessively expensive and, therefore, other alternatives should be investigated in order to extend its useful life. The experimental study considers a set of five panels with an average scale of 1:3.5, representing a typical intact panel of a VLCC (Very large Crude Oil Carrier) converted into a FPSO (Floating Production Storage and Offloading) platform and two different plating reduction thickness levels. These experiments are reproduced through a numerical model that considers geometric and material nonlinearities. The geometrical imperfections in the surfaces of plates and stiffeners are reconstructed from measurements using techniques of laser scanning and optical capture. Thickness distributions are measured with an ultrasonic sensor in several predetermined panel sections points. True stress vs true strain curves for all panel's elements are obtained by tensile tests and employed in the numerical model. Once the numerical model is validated, the effect of the axial load eccentricity, the supported element load redistribution due to changes in the thickness, and the effects of the inclusion of intermediate repair on the plate are studied. The results show that the inclusion of an intermediate light stiffener allows recovering the panel load capacity and prolonging the useful life of offshore platforms. Likewise, it is concluded that the selection of the repair should be based on the local strength recovery of the plate, which is most affected.

Ghanim Mohammed Kamil (1), Qing Quan Liang (1) and Muhammad N.S. Hadi (2)
(1) College of Engineering and Science, Victoria University, PO Box 14428, Melbourne, VIC, 8001, Australia
(2) School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW, 2522, Australia


ABSTRACT: The repair of fire-damaged thin-walled rectangular concrete-filled steel tubular (CFST) columns in engineering structures after fire exposure requires the assessment of their residual strength and stiffness. Existing numerical models have not accounted for the effects of local buckling on the post-fire behavior of CFST columns with rectangular thin-walled sections. This paper describes a nonlinear post-fire simulation technique underlying the theory of fiber analysis for determining the residual strengths and post-fire responses of concentrically loaded short thin-walled rectangular CFST columns accounting for progressive local buckling. The post-fire stress-strain laws for concrete in rectangular CFST columns are proposed based on available test data and implemented in the theoretical model. An innovative numerical scheme for modeling the progressive local and post-local buckling of CFST thin-walled columns is discussed. The nonlinear post-fire simulation model is verified by experimental data and then used to investigate the significance of local buckling, material strengths and width-to-thickness ratio on the post-fire responses of CFST stub columns. The proposed post-fire computer model is shown to be capable of predicting well the residual stiffness and strength of concentrically loaded thin-walled CFST columns after fire exposure. A design formula is proposed that estimates well the post-fire residual strengths of CFST columns. Computational results presented provide a better understanding of the post-fire behavior of CFST columns fabricated by thin-walled sections incorporating local and post-local buckling.

Sheng Jin (1,2), Zhanjie Li (3), Fang Huang (1), Dan Gan (1,2), Rui Cheng (1,2 and Gaofeng Deng (4)
(1) School of Civil Engineering, Chongqing Univ., Chongqing, 400045, China
(2) Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education, Chongqing, 400045, China
(3) Department of Engineering, SUNY Polytechnic Institute, Utica, 13502, USA
(4) General Architectural Planning & Design Research Institute of Chongqing University Co., Ltd., China


ABSTRACT: This paper presents a numerical-experimental research to evaluate the effect of corrosion in panels subjected to uniaxial compression and subsequent repair. The effects of corrosion are approximated by a uniform reduction in the plating's thickness. Currently, repairing a corroded offshore structure involves the change of the hull plating, which is excessively expensive and, therefore, other alternatives should be investigated in order to extend its useful life. The experimental study considers a set of five panels with an average scale of 1:3.5, representing a typical intact panel of a VLCC (Very large Crude Oil Carrier) converted into a FPSO (Floating Production Storage and Offloading) platform and two different plating reduction thickness levels. These experiments are reproduced through a numerical model that considers geometric and material nonlinearities. The geometrical imperfections in the surfaces of plates and stiffeners are reconstructed from measurements using techniques of laser scanning and optical capture. Thickness distributions are measured with an ultrasonic sensor in several predetermined panel sections points. True stress vs true strain curves for all panel's elements are obtained by tensile tests and employed in the numerical model. Once the numerical model is validated, the effect of the axial load eccentricity, the supported element load redistribution due to changes in the thickness, and the effects of the inclusion of intermediate repair on the plate are studied. The results show that the inclusion of an intermediate light stiffener allows recovering the panel load capacity and prolonging the useful life of offshore platforms. Likewise, it is concluded that the selection of the repair should be based on the local strength recovery of the plate, which is most affected.

ABSTRACT: The objective of this paper is to develop a constrained shell Finite Element Method (cFEM) based on a force approach for elastic buckling analysis of thin-walled members. The new cFEM is able to separate the general deformation of thin-walled members into the three fundamental deformation mode classes, namely Global (G), Distortional (D), and Local (L), to enable the modal decomposition and identification. In this paper, four force-based mechanical criteria are defined to separate these mode classes. These mechanical criteria are implemented with the general shell finite element formulation without any special treatment of the element formulation. The constraint matrices of the G, D, and L mode classes are then constructed. Numerical examples are presented to demonstrate the capabilities of the new cFEM in modal decomposition and identification. In particular, the modal decomposition and identification results are compared with the cFSM solutions. Applicability of the new cFEM to other shell FE formulation and different loading conditions are illustrated. All these numerical examples demonstrate the potential of the developed cFEM in taking advantages of the modeling capability of the existing shell FE method.


ABSTRACT: The axial splitting of thin-walled tube is usually considered as an efficient deformation mode to dissipate impact energy thanks to its large stroke ratio. However, the low crushing force and the unstable deformation process, such as crack merging and branching, significantly limit its application in crushworthiness design. In this paper, we propose to enhance the deformation stability through introducing initial kerfs on the inner and outer surfaces of the circular steel tube in its axial direction to guide the propagation of cracks during the splitting process, thus we can improve the crushing force via a significant increase in tube wall thickness. To demonstrate the feasibility of the proposed method, quasi-static compressive experiments on single tube (inner radius \( r=55 \text{mm} \), wall thickness \( t=5 \text{mm} \)) and doubled tube (consisted of two tubes with wall thickness \( t=5 \text{mm} \)) with kerf depth \( \delta=0.5 \text{mm} \) split by a radiusied die are performed, which exhibit stable deformation processes and high steady-state compression forces (103.32 kN for single tube, and 216.44kN for doubled tube). Then, finite element simulations are conducted to model the tested samples. It is found that the experimentally observed deformation processes are well captured by simulations, and the relative errors of numerical steady-state compression forces in comparison to experimental results are 0.39% (single tube) and 1.90% (doubled tube), respectively. Finally, based on the validated numerical model, the influence of tube and die dimensions on its crushworthiness performance is discussed. It is observed that the axial load significantly depends on kerf depth, crack number, and tube thickness. The curling radius is nearly not affected by kerf depth, but it almost linearly depends on die radius. Moreover, the tube with larger wall thickness has a higher specific energy absorption.

R.R. Kumar (1), T. Mukhopadhyay (2), S. Naskar (3), K.M. Pandey (1) and S. Dey (1)
(1) Department of Mechanical Engineering, National Institute of Technology Silchar, India
(2) Department of Aerospace Engineering, Indian Institute of Technology Kanpur, Kanpur, India
(3) Whiting School of Engineering, Johns Hopkins University, Baltimore, USA


ABSTRACT: This paper quantifies the influence of uncertainty in the low-velocity impact responses of sandwich plates with composite face sheets considering the effects of obliqueness in impact angle and twist in the plate geometry. The stochastic impact analysis is conducted by using finite element (FE) modelling based on an eight nodded isoparametric quadratic plate bending element coupled with multivariate adaptive regression spline (MARS) in order to achieve computational efficiency. The modified Hertzian contact law is employed to model contact force and other impact parameters. Newmark’s time integration scheme is used to solve the time-dependent equations. Comprehensive deterministic as well as probabilistic results are presented by considering the effects of location of impact, ply orientation angle, impactor velocity, impact angle, face-sheet material property, twist angle, plate thickness and mass of impactor. The relative importance of various input parameters
is determined by conducting a sensitivity analysis. The results presented in this paper reveal that the impact responses of sandwich plates are significantly affected by the effect of source-uncertainty that in turn establishes the importance of adopting an inclusive stochastic design approach for impact modelling in sandwich plates.


ABSTRACT: Thin-walled structures such as those used for space launch vehicles are prone to buckling when axial load is applied. These structures can be designed as imperfection-sensitive structures in the form of unstiffened shell structures or else as imperfection-tolerant structures by applying frames and stringers to the shell structure. Weight-Strength-Curves can be applied to compare structural concepts from a pure technological point of view, where neither costs of manufacturing nor the manufacturing signature are taken into account. Within this paper, a cost model for unstiffened isotropic shell structures based on the assembly output of multiple panels is introduced. Furthermore, a relation between the manufacturing process and the load carrying capacity of an isotropic shell structure is derived. On this basis a coupled structural and economical design procedure is evolved. In a final step, an example is introduced in order to illustrate the application of the coupled design procedure and to derive a structure which is optimized with regard to its structural mass and manufacturing costs. Based on this example it is shown that the chosen panel size affects not only the manufacturing costs, but also the load carrying capacity.

Jixiang Xu (1), Yige Tong (1), Jianping Han (1), Zhaolong Han (2,3) and Zhanjie Li (4)
(1) Department of Civil Engineering, Lanzhou University of Technology, Lanzhou, 730050, China
(2) State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
(3) School of Naval Architecture, Ocean & Civil Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
(4) Department of Engineering, SUNY Polytechnic Institute, Utica, NY, 13502, USA


ABSTRACT: The objective of this paper is to computationally investigate the fire resistance of earthquake-damaged thin-walled tubular T-joints stiffened with internal rings at elevated temperatures. An earthquake can cause severe damage to the T-joints, thus may lead to the reduction of fire resistance after that. Additionally, given the needs in improving the performance of T-joints using stiffeners, the behaviors and fire performance of these stiffened T-joints under post-earthquake fire (PEF) is of great interests. A computational model, validated with the existing experimental results, is established to conduct the analysis of the fire resistance behavior of the stiffened tubular T-joints under PEF. Then, by using this model, the stiffening strategies for tubular T-joints using 1 internal ring, 2, and 3 internal rings, are evaluated along with the unstiffened case to investigate their effectiveness in improving the fire resistance capability under PEF. Later, a parametric study is performed for the stiffened T-joints with 3 internal rings under PEF using the validated computational model. 24 finite element models are analyzed under different damage levels, by considering the following key geometric parameters: the diameter ratio (β), the wall thickness ratio (γ) of the T-joint's chord and brace members, the diameter-thickness ratio (α) of the chord member, and the thickness ratio η of ring-stiffener and chord along with the damage variable (D̄) to account for the level of the T-joint being damaged. The results on different stiffening strategies and the parametric study reveal that the significant influence of the damage variable and the sensitivities of other influencing parameters. The findings from this study provide needed evidence for potential design recommendations for post-earthquake fire resistance of stiffened tubular T-joints.

Amirreza Sadighi (1), Arameh Eyvazian (2), Masoud Asgari (1) and Abdel Magid Hamouda (2)
(1) Research Laboratory of Passive Safety Systems, Faculty of Mechanical Engineering, K. N. Toosi University of Technology, P. O. Box: 19395-1999, Tehran, Iran
(2) Department of Mechanical and Industrial Engineering, Qatar University, P.O. Box 2713, Doha, Qatar

ABSTRACT: In this paper, tubes with different axial corrugations were studied under axial loading. Accordingly, a new axially half-corrugated thin-walled tube was developed to improve the energy absorption characteristics. The forming process of the corrugations on the tubes has also been described. Comprehensive experimental and numerical analysis have been conducted in order to investigate the effects of various geometrical parameters on crushing behavior of the structure. It has been shown that by the use of the new axially half corrugated tube, there is much more efficient crushing via a more uniform force-displacement result as well as a considerable improvement in other crashworthiness characteristics. Subsequently, a numerical study has been conducted on the same tubes to both have the numerical results validated and assure the repeatability and reliability of the experimental results. An efficient model in axial loading has been obtained which is offering a perfect concertina form. The obtained model deforms through an inversion mode causing an extra frictional force between the inverted part and the tube itself, resulting in a considerable increase in SEA, mean force, and consequently CFE.


ABSTRACT: It is well-known that the buckling response of thin-walled structures is greatly affected by initial geometrical imperfections. In this study, the uncertainty in such geometrical imperfections is modelled by a non-probabilistic field model that is a reasonable and convenient alternative to the probabilistic random field representation of uncertainties with limited samples. After representing the bounded field uncertainty as a function of a reduced set of uncorrelated uncertain coefficients using the series expansion method, the buckling assessment problem of thin-walled plates is then constructed to minimize the critical buckling load under the non-probabilistic field description of imperfections and the volume constraint of plates. The optimization problem is solved effectively using a standard gradient-based algorithm with adjoint-variable sensitivity analysis. Numerical examples are given to demonstrate the validity and applicability of the proposed model for assessing both the critical buckling load and the worst imperfection pattern in thin-walled plates.


ABSTRACT: This paper investigates the buckling behaviors of thin rectangular functionally graded carbon nanotubes reinforced composite (FG-CNTRC) plate subjected to the arbitrarily distributed partial edge compression loads. Three distribution types of carbon nanotubes (CNTs) are considered and the effective material properties of carbon nanotube reinforced composite are given according to the extended rule of mixture, in which the distribution uncertainty of CNTs is also taken into account. Based on the differential quadrature method (DQM) and work equivalent method, the pre-buckling in-plane stress distribution of thin rectangular FG-CNTRC plate are determined firstly. Then the accurate critical buckling loads and buckling modes of FG-CNTRC plate are consequently obtained. By comparing with the results in published literatures, the feasibility and accuracy of present numerical method are validated. Finally, the systematic parametric studies are carried out to elaborate the effects of distribution type, volume fraction and distribution uncertainty of CNTs as well as the distribution width, position and distribution type of partial edge compression loads on the buckling behaviors of thin rectangular FG-CNTRC plate for the first time.

ABSTRACT: The mechanical property of anti-trichiral honeycombs under large deformation along the x-direction are studied by both experiments and theoretical analysis. It's shown that the elastic-plasticity bending occurs in the ligaments besides the plastic hinges, which is very different from the deformation mode under the y-directional compression reported previously. Based on the cells’ deformation mechanism observed in experiments, an analytical model is established to derive the Poisson's ratio and the crushing stress of the anti-trichiral honeycomb. The theoretical predictions are verified by the experimental results. It is shown that the crushing stress increases with the wall thickness t, but decreases with the ligament's length L. As for the Poisson's ratio, it increases with L, but decreases with the honeycomb's deformation, while the ligament's wall thickness t makes no difference to it. Moreover, it is revealed that the negative Poisson's ratio effect of the anti-trichiral honeycomb under the x-directional compression is stronger than that under the y-directional compression, while the superiority of the crushing stress along these two directions depends on the cell's geometry parameters.


ABSTRACT: In this paper, a numerical investigation is carried out for determining the influence of imperfections on the lateral-torsional buckling of welded I-shaped slender section beams. The buckling resistance of unrestrained beams is calculated with nonlinear shell-element based FE analysis, including material and geometrical imperfections. The sensitivity to global and plate imperfections, as well as residual stresses, is presented for different amplitudes and shapes of geometrical imperfections and distributions of residual stresses available in the literature. The recommendations outlined in this work shall help the choice of these parameters on future numerical simulations and extend the observations of other authors in the context of studies for beams with non-slender sections.

The comparison of the numerical results with the predictions of the North American design code, AISC360-16, and the European design code, Eurocode 3, suggests that the AISC360-16 provides an upper limit for the beam’s resistance and the Eurocode 3 a lower bound, mainly because residual stresses have a greater impact in the load-carrying capacity on the studied beams. Thus, these findings are expected to promote future developments and amendments to said design codes.

Finally, this investigation also supports the need of more realistic definition of imperfections, especially for the case of residual stresses, and justifies a more comprehensive experimental campaign on the subject.

Cuong-Le Thanh (1,2), A.J.M. Ferreira (5) and Magd Abdel Wahab (3,4)
(1) Soete Laboratory, Faculty of Engineering and Architecture, Ghent University, Technologiepark Zwijnaarde 903, Zwijnaarde, B-9052, Belgium
(2) Faculty of Civil Engineering and Electricity, Open University, Ho Chi Minh City, Viet Nam
(3) Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(4) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(5) Departamento de Engenharia Mecanica, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal

ABSTRACT: In this article, a refined modified couple stress theory based on isogeometric analysis to capture the small-scale effect on laminated composite micro-plates is developed for the first time. Based on Hamilton's principle, the weak form for composite plate is established by using the Reddy's third order shear deformation theory without shear correction factor and the refined modified couple stress theory. Unlike the modified couple stress theory, which contains only one material length scale parameter, the proposed theory contains three
material length scale parameters. To confirm the accuracy of the proposed method, several examples are presented, discussed and compared to references' solutions. In addition, cut-out complicated shapes are analyzed to show the influences of the small-scale effect on free vibration behaviors of laminated micro-plates. An increase in the material length scale parameter leads to decrease in the deflection, stresses and increase in frequencies and critical buckling load factor. The presented numerical results show the great efficiency of the NURBS-based isogeometric analysis for capturing the small-scale effect of the composite laminated micro-plates.

Pattamad Panedpojaman (1), Thaksin Thepchatri (2) and Suchart Limkatanyu (1)
(1) Department of Civil Engineering, Faculty of Engineering, Prince of Songkla University, Songkhla, 90110, Thailand
(2) Department of Civil Engineering, Chulalongkorn University, Phayathai Road, Pathumwan, Bangkok, 10330, Thailand

ABSTRACT: A calculation of the elastic buckling load for cellular columns with multiple circular openings is required to determine their axial load capacity. Due to the complexity of column geometry and shear effects, the available methods to analyze the elastic buckling load are limited. This study proposes a method of calculation the elastic buckling load about the major axis of a pin-ended cellular column. The analysis is based on simplification of the column geometry and uses an effective length of shear force transfer across openings in the columns. The shear force in the column causes additional deformations of the web-post and the Tee section of cellular columns. The buckling load is derived by using differential equations of total curvature of the buckling curve, which is the sum of curvatures due to moment and shear forces. The proposed buckling load estimate is validated by comparisons with finite element analysis. A parametric study of the column geometry effects on shear, such as the section ratios, the opening ratios, the spacing ratios and the slendernesses, was also conducted. The shear effects clearly increases with open area fraction in the web, and with the section ratios. It was found that the spacing ratio affects the buckling load more than the opening ratio. Overall, the shear effects degrade the buckling load by less than 20% when the slenderness exceeds 50 compared to the Euler buckling load.

Qusay Al-Kaseasbeh (1,2) and Iraj H.P. Mamaghani (2)
(1) Dept. of Civil and Environmental Engineering, Mutah University, Mutah, Al-Karak, 61710, Jordan
(2) Dept. of Civil Engineering, Univ. of North Dakota, Grand Forks, ND, 58202, USA

ABSTRACT: Thin-walled steel tubular circular columns are becoming an increasingly attractive choice as cantilever bridge piers due to their architectural, structural and constructional advantages. This paper aims to evaluate the strength and ductility of thin-walled steel tubular circular columns with uniform thickness (BC) and graded thickness (BGC) under bidirectional cyclic lateral loading in the presence of constant axial force. The analysis is carried out using a finite-element model (FEM) which is substantiated based on the experimental results in the literature. Then, the proposed BGC column with size and volume of material equivalent to the BC column is investigated. As a part of this research, a comprehensive parametric study is carried out to investigate the effects of main design parameters including: radius-to-thickness ratio parameter \( \alpha \), column slenderness ratio parameter \( \lambda \), magnitude of axial load \( (P/P) \), and number of loading cycles \( N \) on the strength and ductility of both BC and BGC columns under bidirectional cyclic lateral loading. Finally, design formulae of ultimate strength and ductility of BC and BGC columns are derived.

Dafni Pantousa (1) and Luis A. Godoy (2,3)
(1) Marie-Curie Research Fellow, Faculty of Engineering and Physical Sciences, University of Southampton, UK
(2) Institute for Advanced Studies in Engineering and Technology, IDIT CONICET/UNC, FCEFyN, Universidad Nacional de Córdoba, Córdoba, Argentina
(3) Mechanical and Aerospace Engineering Department, West Virginia University, Morgantown, WV, USA

ABSTRACT: This paper addresses the thermal buckling behavior of tanks having a fixed roof, as employed to store fuel in the oil industry. The study is performed based on finite element analyses of the shell, including linear analysis, linear bifurcation analysis, and geometrically and constitutive nonlinear analysis, in order to elucidate the mechanics of stress redistribution at pre-buckling and buckling states. Based on previous works, the roof is modeled as a conical shell with an equivalent uniform thickness. The results show that the stress field due to a uniform temperature around the circumference is considerably different from that obtained for a non-uniform field as modeled in cases of temperatures due to an adjacent fire: Under uniform temperatures around the circumference the shell does not provide vertical restrain and buckling is dominated by hoop action; whereas displacement constraints are present under a non-uniform temperature, leading to buckling dominated by meridional stresses. Contrary to what has been suggested, the tank under uniform temperature cannot be taken as an upper bound to the buckling of a tank under an adjacent fire. In the evaluation of critical temperatures, the influence of geometric relations \(H/D\) (height to diameter) and \(R/t\) (radius to thickness) are independent of each other. It is shown that the problem is not imperfection-sensitive. Finally, thermal buckling mode and critical temperatures are strongly dependent on the \(H/D\) ratio of the cylindrical shell.

Yong-jing Wang (1), Zhi-jia Zhang (1), Xiao-min Xue (2) and Ling Zhang (1)
(1) State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an, 710049, PR China
(2) Department of Civil Engineering, Xi'an Jiaotong University, Xi'an, 710049, PR China


ABSTRACT: The vibration characteristics of sandwich panels with a hierarchical composite honeycomb sandwich core were investigated in this study. An orthotropic constitutive model of the hierarchical composite honeycomb sandwich core was used to propose an equivalent model (two-dimensional model). Two-dimensional (2D) and the three-dimensional (3D) finite element models as well as modal tests were used to predict the natural frequencies and mode shapes of the sandwich panels. The prediction results obtained using the equivalent model were consistent with the experimental and 3D finite element analysis results. Subsequently, a redesigned sandwich panel, with a hierarchical cross-honeycomb sandwich core, was manufactured to implement the multifunctional characteristics such as fluid flow and installation of microelectronic devices. To compare the vibration characteristics of the panel with a hierarchical cross-honeycomb sandwich core with those of a panel with a hierarchical square-honeycomb sandwich core, a dimensionless frequency parameter, \((\omega \text{-sub-1}/\omega)\), was proposed. The frequency parameter had different sensitivities to the geometric parameters, \(i.e.,\) the face-sheet thickness ratio, wall-sheet thickness ratio, and relative density of the filling foam.

Di Wang, Lei Wu, Yun Zhu, Xian Wang and Yueming Li (State Key Laboratory for Strength and Vibration of Mechanical Structures, Shaanxi Key Laboratory of Environment and Control for Flight Vehicle, School of Aerospace Engineering, Xi'an Jiaotong University, Xi'an, 710049, PR China), “Vibration of a plate coupled with fluid considering the effects of stress and deformation under hydrostatic load”, Article 106413, Thin-Walled Structures, Vol. 145, December 2019, https://doi.org/10.1016/j.tws.2019.106413

ABSTRACT: The effects of inner stress and geometric deformation caused by hydrostatic load on the vibration of a bottom plate-fluid coupled system are studied in detail. The Von Karman nonlinear strain displacement relationship and the Hamilton's principle are utilized to formulate the two sets of governing equations: nonlinear static equations under hydrostatic load and linear vibration equations of the plate-fluid coupled system considering the hydrostatic load effect at the nonlinear static position. A two-step theoretical approach is developed based on the equations. Experimental and numerical researches are carried out to validate the theoretical approach, and the natural frequencies derived by the three approaches coincide well. The results show that with the fluid height increasing, the natural frequencies of the plate decrease sharply at the very beginning, then increase constantly except that the fundamental frequency continues to decrease slowly. That means the added mass effect is the dominating effect when the fluid height is low, and the stiffening effect of the hydrostatic load plays a more important role with the fluid getting higher. The stress and deformation effects
are considered respectively and compared in detail. Models with different fluid-plate size ratios are studied. Moreover, the hydrostatic load effect on the hydroelastic vibration responses of the plate is also analyzed.

David Henriques (1), Rodrigo Gonçalves (1) and Dinar Camotim (2)  
(1) CERIS and Departamento de Engenharia Civil, Faculdade de Ciências e Tecnologia, Universidade NOVA de Lisboa, 2829-516, Caparica, Portugal  
(2) CERIS, DECivil, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal


ABSTRACT: This paper reports the latest developments concerning the use of Generalised Beam Theory (GBT) in the field of steel-concrete composite beams. In particular, a GBT-based finite element is presented that uses a linear visco-elastic material law to capture, accurately and efficiently (with a very low computational cost), the effects of concrete creep, as well as cross-section distortion and shear lag in complex cross-sections (combining closed cells and open branches). It is shown that the versatility of the GBT approach makes it possible to obtain accurate solutions with a fairly small number of cross-section deformation modes (cross-section DOFs), leading to significant computational savings with respect to standard shell finite element models. Several numerical examples are presented, to illustrate the capabilities and potential of the proposed GBT-based finite element.


ABSTRACT: In this paper, the crushing behavior of hybrid metal-composite conical tube under dynamic loading is studied. An efficient analytical solution for FML conical tubes consist of any number of metal and laminated composite layers is developed. In the analytical analysis, the mean collapse load of structures subjected to axial loading was predicted while its accuracy is validated via experimental tests and numerical simulation. Numerical simulation of the structure is also done using explicit dynamic finite element software in order to investigate the effects of different parameters on crushing characteristics of various structures. On the other hand, new values for failure energies of fiber reinforced composites are proposed in the failure evolution criteria in the finite element model. It leads to good agreement between FE simulations and experimental test other. Moreover, a comprehensive parametric study has been done in order to investigate the effect of various parameters including semi-apical angle, ply pattern of laminated composite, diameter of tube, wall thickness and material properties of tubes on energy absorption capacity and crashworthiness characteristics of various considered specimens. Finally, the crashworthiness capacity (SEA and CLE) with respect to semi-apical angle and ply pattern of laminated composite optimized in order to obtain a desired collapse mode. Based on the obtained results the optimized structure is determined. Also, crushing behaviors of various specimens predicted beyond the tested configurations using response surface methodology (RSM).

Haichao Li (1), Gao Cong (1), Lei Li (2), Fuzhen Pang (1) and Jicai Lang (1)  
(1) College of Shipbuilding Engineering, Harbin Engineering University, Harbin, 150001, PR China  
(2) Department of Naval Architecture, Ocean &Marine Engineering, University of Strathclyde, Glasgow, UK


ABSTRACT: The paper investigated the free vibration of combined spherical-cylindrical-spherical (CSCS) shell with non-uniform thickness based on Ritz method. The energy method and first-order shear deformation theory are adopted to derive the formulas. The displacement functions are improved on base of domain decomposition method, in which the unified Jacobi polynomials are introduced to represent the displacement functions component along axial direction. The displacement functions component along circumferential direction is still Fourier series. In addition, the spring stiffness method is formed to be a unified format to deal with general boundary conditions. Then the final solutions are obtained by using Ritz method. To prove the validity of this method, the results of the same condition are compared with those obtained by FEM, published
lithatures and experiment. In addition, some meaningful examples are provided to reveal the free vibration characteristics of stepped spherical-cylindrical-spherical shell. The results of this paper can be used as the reference data for future research in related field.


ABSTRACT: Rectangular Levy-type plates restrained using point-supports have wide engineering applications. However, the analytical solutions for the buckling behaviour of such plates are not well developed. This paper presents the derivation and application of analytical solutions for the buckling analysis of Levy-type rectangular plates with arbitrarily positioned single or multiple point-supports, which may be located on free edges or within the interior domain. Two general approaches, the impulse function approach (IFA) and the flexibility function approach (FFA), are developed to obtain the critical buckling coefficients ($K_c$) and buckled shapes of point-supported rectangular plates. In the IFA, the shear or moment distribution is expressed using a Fourier expansion of the impulse function whereas in the FFA a flexibility function, with zero values of the deflection at the point-support locations and sufficiently large values over the rest of the plate, representing the fictitious elastic distribution, is used to modify the plate support conditions. These approaches are employed in both one-dimensional (1D), and two-dimensional (2D) forms. The developed methods can be adopted to analyse any rectangular Levy-type plate subjected to uniaxial or biaxial loads restrained by arbitrarily positioned point-supports. The IFA and FFA results are validated with finite element method solutions obtained using Abaqus software. Several examples of buckling behaviours, including primary Levy-type plates, edge point-supported plates, as well as single and two interior point-supported plates are provided as guidelines for future design purpose.

Yancheng Cai (1), Wai-Meng Quach (2) and Ben Young (3)
(1) Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, China
(2) Department of Civil and Environmental Engineering, The University of Macau, Macau, China
(3) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China


ABSTRACT: The structural behavior of concrete-filled hot-finished (HF) and cold-formed (CF) steel elliptical tubular stub columns was investigated and is presented in this paper. A series of tests was conducted on HF and CF steel elliptical tubular sections infilled with three different concrete grades, namely C40, C80 and C100. The tested HF and CF steel elliptical hollow sections (EHS) had an aspect ratio of 2 with the same nominal section dimension of 200×100×6.5 mm. The test specimens were subjected to uniform axial compression. The initial local geometric imperfection measurements, ultimate loads and failure modes of the concrete-filled HF and CF EHS stub columns are presented. An extensive numerical study accounting for the confinement effect, as well as the non-linearities of materials, geometry and contacts was also performed. After a successful model validation against test results, a parametric investigation was conducted by considering a wide range of the cross-section dimensions and section slenderness of HF and CF EHS with different grades of the infilled concrete. A total of 111 concrete-filled HF and CF EHS specimens were carefully designed and analyzed by using the validated numerical model. The behavior of concrete-filled HF and CF EHS stub columns was investigated, including the maximum load, end shortening, strength enhancement index and ductility index. Effects of section strength factor and column sectional characteristics on the stub-column behavior were also investigated. Furthermore, the experimental and numerical results were used to assess the suitability of the design equations specified in the current American Specifications (AISC and ACI) and European Code (EC4) for the compressive resistance of the concrete-filled HF and CF EHS stub columns. It was found that the predictions from the current international design specifications were overall conservative for both concrete-filled HF and CF EHS stub columns. Generally, the predictions by EC4 were less conservative but more scattered than those predicted by AISC and ACI specifications for the concrete-filled HF and CF EHS stub columns.

ABSTRACT: Mass efficient thin-walled rectangular hollow section (RHS) struts have been shown to be susceptible to local–global mode interaction and exhibit sensitivity to imperfections. Material nonlinearity may increase the imperfection sensitivity of such members further and affect the final failure mode. Nonlinear finite element (FE) models for welded inelastic thin-walled RHS struts with pre-defined local and global geometric imperfections alongside residual stresses are developed within the commercial package Abaqus and validated against two independent experimental studies. Based on the validated FE model, the effects of material nonlinearity and residual stresses from welding on the ultimate load, mechanical behaviour and the imperfection sensitivity of struts are investigated. A simplified method to determine the initial geometric imperfection amplitude introduced in the FE model with residual stresses explicitly modelled within the ECCS framework is proposed for the first time. The experimental and numerical results in conjunction with existing experimental results from the literature are employed in the companion paper for the assessment of the Effective Width Method and Direct Strength Method, which also forms the basis for a new set of design recommendations.


ABSTRACT: The second part of the study on the local–global mode interaction in thin-walled inelastic rectangular hollow section struts focuses on design guidance. Based on the validated finite element (FE) model from the companion paper, a framework for fully automating FE model generation, submission and post-processing for geometric and material nonlinear analysis with imperfections is first presented. The ultimate load data for specimens with different cross-section aspect ratios, cross-sectional slenderness, global slenderness and welding options are generated. The current design rules for thin-walled welded RHS struts are assessed using the numerical results and existing experimental results from the literature by means of structural reliability analysis in accordance with the methodology presented in Annex D of Eurocode EN1990. A modified Direct Strength Method (DSM) relationship is then proposed and it is demonstrated to provide superior ultimate load predictions than the current guidelines.


ABSTRACT: An extensive numerical study of Class 4 section beams at elevated temperature is described in the paper. The study focuses on welded I-section beams of slender web and flange and covers beams of constant height as well as beams with significant web taper ratio. The numerical parametric study extends previous test results significantly in terms of various temperatures, section slenderness for flange and webs considering also combination of more stocky flanges with a slender web, various beam slenderness and moment distribution along the beam. Based on the numerically calculated resistances, a simple design rule was developed for both constant and web tapered members. The proposed model is believed to be predicting the beam capacity accurately with formulas simple enough to be used and accepted by structural engineers.

References listed at the end of the paper:

1 V. Z. Vlasov, Тонкостенные упругие стержни. Gosudarstvenoe izdavateljstvo fiziko-matematičeskoj literaturi, Moscau (1940)
References listed at the end of the paper:

1. Jie Wu (1), Junying Zhu (1), You Dong (2) and Qilin Zhang (1)
1 College of Civil Engineering, Tongji University, 1239 Siping Road, Shanghai, 200092, PR China
2 Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, PR China


ABSTRACT: There is a lack of investigation on the nonlinear stability analysis of large steel hyperbolic cooling towers considering imperfection sensitivity. In this paper, nonlinear stability analysis of 150m-height steel hyperbolic cooling towers was assessed. Models with five structural systems were established, including two types of reticulated shells (i.e., single-layer and double-layer shells) and three forms of girders (i.e., triangular, rectangular grid, and square pyramid grid). Additionally, geometrically and material nonlinear stability analyses for more than 220 cases were conducted considering various distributions and amplitudes of imperfections. The results showed that the five hyperbolic steel cooling towers are of relatively low imperfection sensitivity, which is different from most other thin-walled shells, and the imperfection sensitivity of rectangular grid is high, while triangle grid and square pyramid grid are of low imperfection sensitivity. In addition, structures with double-layer reticulated shells are more sensitive to imperfection than those with single-layer ones. It is recommended that the design of steel cooling towers can give priority to the scheme of single-layer reticulated shell with triangular grid. Furthermore, the imperfection amplitude of H/300 could reasonably represents the most unfavorable instability state for this type of structures.

References listed at the end of the paper:

1 R. Harte, W.B. Krätzig, Large-scale cooling towers as part of an efficient and cleaner energy generating technology, Thin-Walled Struct., 40 (7) (2002), pp. 651-664, 10.1016/S0263-8231(02)00018-6
16 S. Ke, L. Xu, Y. Ge, Sensitivity analysis and estimation method of natural frequency for large cooling tower based on field measurement, Thin-Walled Struct., 127 (2018), pp. 809-821, 10.1016/j.tws.2018.03.012
25 J.W. Hutchinson, J.M.T. Thompson, Nonlinear buckling interaction for spherical shells subject to pressure and probing forces, J. Appl. Mech., 84 (2017), Article 061001, 10.1115/1.4036555
30 P. Hao, B. Wang, K. Du, G. Li, K. Tian, Y. Sun, Y. Ma, Imperfection-insensitive design of stiffened conical shells based on equivalent multiple perturbation load approach, Compos. Struct., 136 (2016), pp. 405-413, 10.1016/j.compstruct.2015.10.022
This article investigates the nonlinear vibration behavior of multiscale composites nanoshells subjected to hygrothermal environment and resting on elastic foundations. The novelty and contribution of this article is considering a multiscale doubly curved sandwich nanoshell. Three-phase composite nanoshell

Mahsa Karimiasl (1), Farzad Ebrahimi (1) and Vinyas Mahesh (2)

(1) Department of Mechanical Engineering, Faculty of Engineering, Imam Khomeini International University, Qazvin, Iran
(2) Department of Aerospace Engineering, Indian Institute of Science, Bangalore, 560012, India


ABSTRACT: This article investigates the nonlinear vibration behavior of multiscale composites nanoshells subjected to hygrothermal environment and resting on elastic foundations. The novelty and contribution of this article is considering a multiscale doubly curved sandwich nanoshell. Three-phase composite nanoshell...
composes of polymer-Carbon nanotube-fiber (PCF) and polymer-Graphene platelet-fiber (PGF) according to Halpin-Tsai model. Various distributions patterns such as U (uniform), X, A and O are considered. The classical shell theory and nonlocal strain gradient theory including von Kármán strain–displacement relationships are employed to build the size-dependent governing equations. The governing equations of multiscale nanoshell have been implemented by Hamilton's principle and solved by homotopy perturbation method. For investigating correctness and accuracy, this paper is validated by other previous researches. Finally, the effects of different parameters such as temperature rise, various distributions patterns and curvature ratio have been investigated.

References listed at the end of the paper:
1 N.D. Duc, P.H. Cong, N.D. Tuan, P. Tran, N. Van Thanh, Thermal and mechanical stability of functionally graded carbon nanotubes (FG CNT)-reinforced composite truncated conical shells surrounded by the elastic foundations, Thin-Walled Struct., 115 (2017), pp. 300-310
33 B. Akgöz, Ö. Civalek, Vibrational characteristics of embedded microbeams lying on a two-parameter elastic foundation in thermal environment, Compos. B Eng., 150 (2018), pp. 68-77
35 M. Mohammadmehr, S. Shahedi, High-order buckling and free vibration analysis of two types sandwich beam including AL or PVC-foam flexible core and CNTs reinforced noncomposite nano-faced shell using GDQM, Compos. B Eng., 108 (2017), pp. 91-107
41 H. Wu, J. Yang, S. Kitipornchai, Dynamic instability of functionally graded multilayer graphene nanocomposite beams in thermal environment, Compos. Struct., 162 (2017), pp. 244-254
45 B. Karami, M. Jahghorban, A. Tounsi, Variational approach for wave dispersion in anisotropic doubly-curved nanoshells based on a new nonlocal strain gradient higher order shell theory, Thin-Walled Struct., 129 (2018), pp. 251-264
48 F. Tornabene, S. Brischetto, 3D capability of refined GDQ models for the bending analysis of composite and sandwich plates, spherical and doubly-curved shells, Thin-Walled Struct., 129 (2018), pp. 94-124
49 B. Akgöz, Ö. Civalek, Effects of thermal and shear deformation on vibration response of functionally graded thick composite microbeams, Compos. B Eng., 129 (2017), pp. 77-88
52 H.S. Shen, A comparison of buckling and postbuckling behavior of FGM plates with piezoelectric fiber reinforced composite actuators, Compos. Struct., 91 (3) (2009), pp. 375-384
54 M. Rafiee, J. Yang, S. Kitipornchai, Large amplitude vibration of carbon nanotube reinforced functionally graded composite beams with piezoelectric layers, Compos. Struct., 96 (2014), pp. 716-725
ABSTRACT: The present article proposes an advanced Ritz formulation with 3D capabilities for the analysis of thin-walled metallic and composite beam structures. Various set of admissible functions such as: Legendre, Chebyshev and algebraic polynomials, as well as hybrid functions are employed. The investigation is carried out by using the method of power series expansion of displacement components based on 2D-Taylor polynomials. The governing equations (GEs) are derived in their weak form via Hamilton’s Principle and are solved by using the Ritz method. Convergence and stability of both cross-section and admissible functions have been thoroughly analysed. The high level of accuracy of the proposed formulation has been comprehensively examined in three selected case studies: (i) slender beams with arbitrary boundary conditions, and both solid and thin-walled cross-sections; (ii) a fully-clamped three-layer non-homogenous circular cylindrical shell; (iii) a fully-clamped functionally graded material (FGM) box resting on two-parameter elastic foundation.

References listed at the end of the paper:

1. L. Euler, De Curvis Elasticis, Methodus Inveniendi Lineas Curvas Maximi Minimive Proprietate Gaudentes, Sive Solutio Problematis Isoperimetrici Lattissimo Sensu Accepti, Series 1, vol. 24, Opera Omnia, Bousquet, Geneva (1744)
2. D. Bernoulli, De vibrationibus et sono laminarum elasticarum, Commentarii Academiae Scientiarum Imperialis Petropolitanae, 13 (1751), p. 105
4. S.P. Timoshenko, On the correction for shear of the differential equation for transverse vibrations of prismatic bars, Philos. Mag. Ser., 6 (1921), pp. 742-746
25 R. Schardt, Eine erweiterung der technischen biegetheorie zur berechnung prismaticer faltwerke(Extension of the engineer's theory of bending to the analysis of folded plate structures), Stahlbau, 35 (1966), pp. 161-171
29 D. Camotim, C. Basaglia, On the behaviour, failure and direct strength design of thin-walled steel structural systems, Thin-Walled Struct., 81 (2014), pp. 50-66
32 R. Gonçalves, D. Camotim, GBT deformation modes for curved thin-walled cross-sections based on a mid-line polygonal approximation, Thin-Walled Struct., 103 (2016), pp. 231-243
35 N. Silvestre, Generalised beam theory to analyse the buckling behaviour of circular cylindrical shells and tubes, Thin-Walled Struct., 45 (2007), pp. 185-198
36 R. Bebiano, N. Silvestre, D. Camotim, Local and global vibration of thin-walled members subjected to compression and non-uniform bending, J. Sound Vib., 345 (2008), pp. 509-553
37 C. Basaglia, D. Camotim, H.B. Coda, Generalised beam theory (GBT) formulation to analyse the vibrational behaviour of thin-walled steel frames, Thin-Walled Struct., 127 (2018), pp. 259-274
40 E. Carrera, M. Petrolo, Refined one-dimensional formulations for laminated structure analysis, AIAA J., 50 (2012), pp. 176-189
41 E. Carrera, F. Miglioretti, M. Petrolo, Computations and evaluations of higher-order theories for free vibration analysis of beams, J. Sound Vib., 331 (9) (2012), pp. 4269-4284
43 A. Alesadi, S. Ghazanfari, S. Shojaea, B-spline finite element approach for the analysis of thin-walled beam structures based on 1D refined theories using the Carrera unified formulation, Thin-Walled Struct., 130 (2018), pp. 313-320
44 A. Pagani, M. Boscolo, R.J. Banerjee, E. Carrera, Exact dynamic stiffness elements based on one-dimensional higher-order theories for free vibration analysis of solid and thin-walled structures, J. Sound Vib., 303 (23) (2013), pp. 6104-6127
50 M. Dan, A. Pagani, E. Carrera, Free vibration analysis of simply-supported beams with solid and thin-walled cross-sections using higher-order theories based on displacement variables, Thin-Walled Struct., 98 (2016), pp. 478-495
53 F.A. Fazzolari, Quasi-3D beam models for the computation of eigenfrequencies of functionally graded beams with arbitrary boundary conditions, Compos. Struct., 154 (2016), pp. 239-255
55 F.A. Fazzolari, Natural frequencies and critical temperatures of functionally graded sandwich plates subjected to uniform and non-uniform temperature distributions, Compos. Struct., 121 (2015), pp. 197-210
71 W.L. Li, M.A. Daniels, A fourier series method for the vibration analysis of elastically supported plates arbitrarily loaded with springs and masses, J. Sound Vib., 252 (4) (2002), pp. 768-781
73 W.L. Li, Vibration analysis of rectangular plates with general elastic boundary supports, J. Sound Vib., 273 (3) (2004), pp. 619-635
74 D. Zhou, Natural frequencies of rectangular plates using a set of static beam functions in Rayleigh-Ritz method, J. Sound Vib., 189 (1996), pp. 81-87

Nguyen Dinh Duc (1,2), Seung-Eock Kim (2), Duong Tuan Manh (1) and Pham Dinh Nguyen (1)
(1) Advanced Materials and Structures Laboratory, VNU, Hanoi - University of Engineering and Technology, 144 Xuan Thuy, Cau Giay, Hanoi, Viet Nam
(2) National Research Laboratory, Department of Civil and Environmental Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul, 05006, South Korea

ABSTRACT: This work aims to study the effect of oblique stiffeners on the nonlinear static and dynamic buckling behaviors of S-FGM cylindrical panels based on the classical shell theory (CST) with the geometrical nonlinearity in von Kármán Donnell sense. The dynamic critical buckling load is obtained by Budiansky-Roth criterion. The cylindrical panels are reinforced by oblique stiffeners on the top layer, and supported by elastic foundations on the bottom layer. Numerical results are given to evaluate effects of inhomogeneous, dimensional parameters, temperature increment, compressive pressure, oblique angles of stiffeners, the imperfection of original shape, and elastic foundations to the nonlinear static and dynamic response of S-FGM cylindrical panels in the thermal environment.

References listed at the end of the paper:
10 H.T. Hu, J.S. Yang, Buckling optimization of laminated cylindrical panels subjected to axial compressive load, Compos. Struct., 81 (3) (2007), pp. 374-385
13 K. Magnucki, Elastic buckling of a cylindrical panel with symmetrically varying mechanical properties – analytical study, Compos. Struct., 204 (2018), pp. 217-222
17 A.H. Sofiyev, N. Kuruoglu, Buckling and vibration of shear deformable functionally graded orthotropic cylindrical shells under external pressures, Thin-Walled Struct., 78 (2014), pp. 121-130
21 F. Tornabene, E. Viola, Static analysis of functionally graded doubly-curved shells and panels of revolution, Meccanica, 48 (4) (2013), pp. 901-930
30 S.M. Chorfi, A. Houmat, Nonlinear free vibration of a functionally graded doubly curved shallow shell of elliptical plan-form, Compos. Struct., 92 (2010), pp. 2573-2581
31 H. Matsunaga, Free vibration and stability of functionally graded shallow shells according to a 2D higher-order deformation theory, Compos. Struct., 84 (2) (2008), pp. 132-146
33 M.H. Hajmohammad, R. Kolahchi, M.S. Zarei, M. Maleki, Earthquake induced dynamic deflection of submerged viscoelastic cylindrical shell reinforced by agglomerated CNTs considering thermal and moisture effects, Compos. Struct., 187 (2018), pp. 498-508
ABSTRACT: Based on Reddy’s third order shear deformation shell theory and Galerkin method, this paper introduces analytical solutions to study nonlinear buckling behaviors of imperfect carbon nanotube reinforced composite cylindrical panels on elastic foundations in thermal environments. The panels are reinforced by single-walled carbon nanotubes and the eccentrically longitudinal and transversal stiffeners. The effects of geometrical parameters, eccentrically stiffeners, elastic foundations, initial imperfection, temperature increment and nanotube volume fraction on the mechanical behaviors of the nanocomposite cylindrical panels are also examined in numerical results. Some comparisons with results of other authors show the accuracy of the present theory and approach.

References listed at the end of the paper:
36 D.O. Brush, B.O. Almroth, Buckling of Bars, Plates and Shells, McGraw-Hill, Mc (1975)

H.N.R. Wagner (1,2), C. Hühne (1,3) and I. Elishakoff (4)
(1) Technische Universität Braunschweig, Institute of Adaptronics and Function Integration, Langer Kamp 6, 38106, Braunschweig, Germany
(2) Siemens Mobility GmbH, MO MM R&D SYS ITV IXL, Ackerstr. 22, 38126, Braunschweig, Germany
(3) German Aerospace Center (DLR), Institute for Composite Structures and Adaptive Systems, Lilienthalplatz 7, 38108 Braunschweig, Germany
(4) Department of Ocean and Mechanical Engineering, Florida Atlantic University, Boca Raton, FL, USA


ABSTRACT: This article contains examples to demonstrate the use of different design concepts for cylindrical shells under axial compression. The examples are based on shells which were manufactured according to electroplating, machining, welding (isotropic cylinders) and prepreg hand layup on a mandrel (composite cylinders). Three of the four shell series are characterized by pure elastic buckling and one shell series buckled in the elastic-plastic region. All relevant data for the numerical analysis are described in the article and summarized in the Elsevier repository of this article (geometry, material, measured imperfection data and Python-ABAQUSS scripts).

The design concepts are based on the geometric imperfection signatures, probabilistic and deterministic lower-bound methods. The design concepts are representative for the development of design approaches for imperfection sensitive shells from the early 1980 to the late 2010 and are validated with experimental data. Recently developed design lower-bound curves for axially loaded cylinders are presented and compared with currently used design criteria like the Eurocode EN 1993-1-6 and the NASA SP-8007. The results of this article show that the design of imperfection sensitive cylinders has been significantly improved in the last 30 years. References listed at the end of the paper:


4 J. Arbocz, The Effect of General Imperfections on the Buckling of Cylindrical Shells, PhD thesis, California Institute of Technology, Pasadena, California, USA (1968)

5 M. Ellinger, B. Geier, Gerechnete Nachbeullasten als untere Grenze der experimentellen axialen Beullasten von Kreiszylindern, Stahlbau, 41 (1972), pp. 353-360


22 J. Arbocz, The imperfections data bank, a means to obtain realistic buckling loads, Ramm E. Buckling of Shells (1982)


29 C. Hüne, R. Rolfs, E. Breitbart, J. Teßmer, Robust design of composite cylindrical shells under axial compression — simulation and validation, Thin-Walled Struct., 46 (2008), pp. 947-962


31 M. Biagi, F. Del Medico, Reliability-based knockdown factors for composite, Thin-Walled Struct., 46 (12) (2008), pp. 1351-1358


34 I. Elishakoff, Probabilistic resolution of the twentieth century conundrum in elastic stability, Thin-Walled Struct., 59 (2012), pp. 35-57


69 Dassault SystemesABAQUS 613 — Software Package (2013).


72 J. Croll, Towards simple estimates of shell buckling loads, Stahlbau, 1 & 2 (1975).


84 H. Wagner, C. Hühne, S. Niemann, K. Tian, B. Wang, P. Hao, Robust knockdown factors for the design of cylindrical shells under axial compression: analysis and modeling of stiffened and unstiffened cylinders, Thin-Walled Struct., 127 (June 2018), pp. 629-645.


93 J. Rotter, A. Hussian, Length effects in the buckling of imperfect axially compressed cylinders, Proc. SDSS International Colloquium on Stabilitiy and Ductility of Steel Structures, Timisoara, Romania (2016).


Qinghua Han (1,2,3), Chenxi Wang (3), Ying Xu (1,2,3), Xiaoning Zhang (3) and Yiming Liu (3)
ABSTRACT: Previous studies on the mechanical performance of AH (assembled hub) joints mainly focused on the axial capacity and the bending capacity of the joint system. However, the joint system in latticed shells is subjected to combined axial forces and bending moments in practice. In this paper, the mechanical performance of joints under eccentric load is investigated experimentally and numerically. The eccentric bearing capacity, as well as the failure mechanism of the novel joint system, are derived and compared with the axial loading and pure bending conditions. The correlation curve with 95% guaranteed rate is determined by non-linear regression analysis. On this basis, a combined non-linear spring model is established to simulate the mechanical performance of joints in single-layer cylindrical shells for stability analysis. The results indicate that for orthodox type cylindrical latticed shells with diagonals or crossed cables, the stability reduction factor can reach a range of up to 0.8 to 0.96. However, for cylindrical latticed shells with lamella grids or three-way grids, the stability reduction factor is less than 0.62. This situation can be improved by strengthening the joint system or reducing the intersection angles of members. When the intersection angle decreases from 90° to 60°, the stability reduction factors of lamella shells will increase by 34%–47%. This means that cylindrical shells with AH joints have sufficient stability to meet engineering requirements by rational design.

References listed at the end of the paper:
24 Q. Han, Y. Liu, Y. Xu, Stiffness characteristics of joints and influence on the stability of single-layer latticed domes, Thin-Walled Struct., 107 (2016), pp. 514-525
26 P. Feng, H. Qiang, L. Ye, Discussion and definition on yield points of materials, members and structures, Eng. Mech., 34 (3) (2017), pp. 36-46
27 Eurocode3: Design of Steel Structures, EN- 1993-1-1, European Committee for Standardization.

Zaigen Mu and Yuqing Yang (School of Civil and Resource Engineering, University of Science and Technology Beijing, Beijing, 100083, China), “Experimental and numerical study on seismic behavior of obliquely stiffened steel plate shear walls with openings”, Article 106457, Thin-Walled Structures, Vol. 146, January 2020, https://doi.org/10.1016/j.tws.2019.106457

ABSTRACT: To study the influence of frame-to-plate connections and oblique channel-shaped stiffeners on the seismic behavior of steel plate shear walls (SPSWs), cyclic quasi-static tests were carried out on two one-bay two-story specimens. One specimen was diagonally stiffened with two rectangular openings, and the other was multi-obliquely stiffened with one rectangular opening. The bearing capacity, ductility, degradation characteristics, and energy dissipation of two specimens were analyzed. Furthermore, following the test program, the stress distribution, deformation and fracture tendency of the two specimens were simulated by the finite element (FE) software ABAQUS and validated by the experimental results. The experimental results show that the channel-shaped stiffeners make full use of the larger flexural and torsional stiffness and improve the bearing capacity, stiffness, and elastic buckling load of the structures. Moreover, the oblique stiffeners have an obvious bracing effect, so the web of the middle beam is subjected to shear yield at the opening segment, which is similar to the link in the eccentrically braced frame. The inelastic mechanism is transferred from the steel plate to the link. In the plastic stage of the structure, the stiffened plate is basically elastic, and the seismic energy is mainly consumed by the link. Therefore, this kind of steel plate shear wall needs to consider the additional effect of the stiffeners on the boundary elements. The reasonable design of the link segment enables the frame to have enough strength to support the stiffened plate as well as avoid premature yielding at the link.

References listed at the end of the paper:
4 E. Alavi, F. Nateghi, Non-linear behavior and shear strength of diagonally stiffened steel plate shear walls, Int. J. Eng., 22 (4) (2009), pp. 343-356
8 M.A. Sigariyazd, A. Joghataie, N.K.A. Attari, Analysis and design recommendations for diagonally stiffened steel plate shear walls, Thin-Walled Struct., 103 (2016), pp. 72-80
References listed at the end of the paper:


ABSTRACT: In this paper, a finite element analysis based systematic parametric study has been conducted on perforated Lean Duplex Stainless Steel semi-elliptical hollow section members subjected to torsion. Upon validation of finite element modelling procedure with experimental results, a parametric study was conducted on members with single circular perforation, on either flat or curve element of semi-elliptical hollow section. The diameter of the perforation was varied from 10% to 90% of the flat element length. Five different failure modes were identified for perforated members and reported in this study. The finite element results generated from the parametric study were further used to propose design equations. Initially, design equations for unperforated members were proposed in three different formats – (a) Direct Strength Method, (b) European code and (c) Deformation Based Method (in line with Continuous Strength Method). A reduction factor, expressing as a function of both cross-section slenderness and perforation diameter, was incorporated to extend these proposed design equations to perforated members. Efficacy of all proposed design rules were assessed by conducting reliability analysis.

References listed at the end of the paper:
2 B. Rossi, Discussion on the use of stainless steel in constructions in view of sustainability, Thin-Walled Struct., 83 (2014), pp. 182-189
5 Y. Huang, B. Young, Experimental investigation of cold-formed lean duplex stainless steel beam-columns, Thin-Walled Struct., 76 (2014), pp. 105-117
6 Y. Huang, B. Young, Material properties of cold-formed lean duplex stainless steel sections, Thin-Walled Struct., 54 (2012), pp. 72-81
8 Y. Huang, B. Young, The art of coupon tests, J. Constr. Steel Res., 96 (2014), pp. 159-175
9 K. Sachidananda, K.D. Singh, Structural behaviour of fixed ended stocky Lean Duplex Stainless Steel (LDSS) flat oval hollow column under axial compression, Thin-Walled Struct., 113 (2017), pp. 47-60
11 Y. Huang, B. Young, Structural performance of cold-formed lean duplex stainless steel columns, Thin-Walled Struct., 83 (2014), pp. 59-69, 10.1016/j.tws.2014.01.006
13 Y. Huang, B. Young, Experimental and numerical investigation of cold-formed lean duplex stainless steel flexural members, Thin-Walled Struct., 73 (2013), pp. 216-228
14 J.K. Sonu, K.D. Singh, Shear characteristics of lean duplex stainless steel (LDSS) rectangular hollow beams, Structure, 10 (2017), pp. 13-29
ABSTRACT: In this paper a mixed finite element based on Generalised Beam Theory (GBT) is proposed to analyse the first-order behaviour of naturally curved beams with circular axis (without pre-twist) and having deformable thin-walled cross-sections. The element applies the assumed strain concept to the longitudinal strains terms that are not present in straight members and cause locking. The additional strain DOFs are condensed out and therefore the stiffness matrix of the mixed element shares the DOFs of the standard (displacement-based) GBT finite element. The superior predictive capacity of the proposed mixed element with respect to the standard element with reduced integration is demonstrated through several examples involving complex global-distortional-local cross-section deformation.

References listed at the end of the paper:

1 R. Schardt, Eine erweiterung der technischen biegetheorie zur berechnung prismatischer faltwerke, Stahlbau, 35 (1966), pp. 161-171 (German)
2 R. Schardt, Verallgemeinerte Technische Biegetheorie, Springer Verlag, Berlin, Germany (1989) (German)
6 J. Cai, Obtaining the modal participation of displacements, stresses, and strain energy in shell finite-element eigen-buckling solutions of thin-walled structural members via generalized beam theory, Thin-Walled Struct., 134 (2019), pp. 148-158
7 L. Duan, J. Zhao, GBT deformation modes for thin-walled cross-sections with circular rounded corners, Thin-Walled Struct., 136 (2019), pp. 64-89
8 M. Nedelcu, GBT formulation to analyse the buckling behaviour of isotropic conical shells, Thin-Walled Struct., 49 (7) (2011), pp. 812-818
9 N. Peres, R. Gonçalves, D. Camotim, First-order generalised beam theory for curved thin-walled members with circular axis, Thin-Walled Struct., 107 (2016), pp. 345-361
10 E. Winkler, Die Lehre von der Elasticitaet und Festigkeit, H. Dominicus, Prague (1868)
11 V. Vlasov, Tonkonteneye Sterjni, Fizmatgiz, Moscow, Russia (1958)
12 N. Peres, R. Gonçalves, D. Camotim, GBT-based cross-section deformation modes for curved thin-walled members with circular axis, Thin-Walled Struct., 127 (2018), pp. 769-780
ABSTRACT: Triangular lattices were hierarchically incorporated into a regular hexagonal honeycomb to substitute each vertex of the regular honeycomb. To investigate the crushing behaviors of the newly constructed vertex-based hierarchical honeycombs, finite element (FE) analyses were carried out subsequently for both in-plane and out-of-plane crushing. Effect of the hierarchical organizational parameter on deformation mode, crushing response and energy absorption capacity were discussed respectively. The results showed that the hierarchy significantly affected the crushing behaviors of the honeycomb differently for in-plane and out-of-plane crushing. The hierarchy had a far greater influence on the deformation mode for in-plane crushing than out-of-plane crushing. Compared with that of the regular honeycomb, hierarchy not always improved the honeycomb in terms of plateau stress and specific energy absorption (SEA). The maximum plateau stress and SEA of the hierarchical honeycombs increased by up to approximately 127% and 109% respectively under crushing along L direction (in-plane ribbon direction); 122% and 108% respectively under crushing along W direction (in-plane width direction); and 30% and 34% respectively under crushing along T direction (out-of-plane direction).

References listed at the end of the paper:


ABSTRACT: Above-ground pipeline systems are subject to a wide range of deformations, such as ovalization and warping, particularly in the neighborhood of a support. A structural analysis, which can fully evaluate these transversal and local effects, can currently be carried out only using shell or solid finite-element models. However, the complete finite-shell element model of a long-distance pipeline system requires a significant amount of time to be modeled and solved. In contrast, generalized beam theory (GBT) has attracted attention as an alternative modeling technique, and it can easily model a pipeline system using beam-finite elements, but with all transversal and local effects. In order to obtain a feasible application of GBT for above-ground pipeline systems, this study presents an extension of GBT with semi-continued arbitrary support to hollow circular cross-sections. The numerical formulation is an alternative recursive approach based on the master-slave method to create a multi-freedom constraint among the high modes of GBT and the springs, which represent the support conditions. An example of its application illustrates the proposed approach and is compared with a complete finite-shell element models.

References listed at the end of the paper:
2 V. Vlasov, Thin-Walled Elastic Beams, Israel Program for Scientific Translations (1961)
6-8: NOTE: Journal name not given in these citations.
6 N. Silvestre, Generalized beam theory to analyse the buckling behaviour of circular cylindrical shells and tubes, vol. 45 (2007)
8 G. Taig, G. Ranzi, F. D’Annibale, An unconstrained dynamic approach for the generalised beam theory, vol. 27 (2014), pp. 879-904
9 N. Silvestre, D. Camotim, Influence of shear deformation on the local and global buckling behaviour of composite thin-walled members, J. Loughlan (Ed.), Proceedings Of the 4th International Conference On Thin-Walled Structures, IOP Publishing Ltd (2003), pp. 659-668
12-16: NOTE: the journal name is not given in these citations.
12 D. Camotim, N. Silvestre, C. Basaglia, R. Bebiano, GBT-based buckling analysis of thin-walled members with non-standard support conditions, vol. 46 (2008), pp. 800-815
19 J. Jönsson, M. Andreassen, Distortional buckling modes of semi-discretized thin-walled columns, Thin-Walled Struct., 51 (2012), pp. 53-63
X.W. Chen (1), E. Real (2), H.X. Yuan (1) and X.X. Du (1)
(1) Hubei Provincial Key Laboratory of Safety for Geotechnical and Structural Engineering, School of Civil Engineering, Wuhan University, Wuhan, 430072, PR China
(2) Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya, Barcelona, 08034, Spain


ABSTRACT: This paper aims to develop design methods for the shear strength of welded stainless steel I-shaped members. The current American AISC Design Guide 27 has been published for Structural Stainless Steel, and it refers to the specification ANSI/AISC 360-16 for structural steel buildings for the shear strength without considering tension field action (TFA). All the available test data on stainless steel plate girders were collected from literatures and employed to assess the provisions in the Design Guide 27, as well as the codified ones in Eurocode 3 Part 1.4. Based on the test results and obtained comparisons, two new proposals for unstiffened webs or webs with transverse stiffeners widely spaced (without TFA), and for interior webs with stiffeners spaced at $3h$ or smaller (considering TFA) were developed and presented to match the format of the expressions in ANSI/AISC 360-16 for stainless steel webs under shear. Reliability analysis was further performed to calculate the Load and Resistance Factor Design (LRFD) resistance factors determined by the new proposals and to further justify the target factor in AISC Design Guide 27 for structural stainless steel.

References listed at the end of the paper:
10 N.R. Baddoo, P. Francis, Development of design rules in the AISC design guide for structural stainless steel, Thin-Walled Struct., 83 (2014), pp. 200-208
13 I. Arrayago, E. Real, E. Mirambell, Experimental study on ferritic stainless steel RHS and SHS beam-columns, Thin-Walled Struct., 100 (2016), pp. 93-104
18 A. Olsson, Stainless Steel Plasticity-Material Modeling and Structural Applicatio, [PhD Dissertation], Lulea University of Technology, Sweden (2001)

NOTE: In Refs. 21-24 the Journal name is not given. Maybe it is Thin-Walled Structures.
24 SEI/ASCE 8-02, Specification for the Design of Cold-Formed Stainless Steel Structural Members, ASCE (2002).
32 The Steel Construction Institute, Design Manual for Structural Stainless Steel, (fourth ed.) (2017), Berkshire, UK.


ABSTRACT: This study presents a novel non-local model for the stress analysis of sandwich plates with a functionally graded core using Peridynamic Differential Operator (PDDO) and Refined Zigzag Theory (RZT). The through-thickness material properties of the functionally graded cores were tailored by means of mixing rules. The PDDO converts the equilibrium equations of the RZT from the differential form into the integral form. This makes the PDDO capable of solving the local differential equations accurately. The RZT is very suitable for the stress analysis, especially for thick and moderately thick plates. It contains only seven kinematic variables and eliminates the use of the shear correction factors. A typical sandwich structure consists of a soft core and stiff orthotropic face-sheets. The mismatch of the stiffness at the core and face sheet interfaces results in an increase in the interfacial shear stresses, leading to the core-face sheet delamination. The interfacial stresses can be mitigated by functionally grading the material properties of the core through the thickness. The PD-RZT stress and displacement predictions were compared with the analytical solutions by using the uniform and non-uniform mesh discretizations and good agreements were achieved. It was observed that the functionally graded cores offered some advantages with respect to the classical cores and minimized the stress concentrations at the interface of the core and the face sheets.

References listed at the end of the paper:
6 H.T. Thai, S.E. Kim, A review of theories for the modeling and analysis of functionally graded plates and shells, Compos. Struct., 128 (2015), pp. 70-86.
13 S. Pandey, S. Pradhyumna, Analysis of functionally graded sandwich plates using a higher-order layerwise theory, Compos. B Eng., 153 (2018), pp. 325-336
14 N.N. Huang, Influence of shear correction factors in the higher-order shear deformation laminated shell theory, Int. J. Solids Struct., 31 (1994), pp. 1227-1263
17 J.L. Mantari, E.V. Granados, A refined FSDT for the static analysis of functionally graded sandwich plates, Thin-Walled Struct., 90 (2015), pp. 150-158
23 R.S. Khabbaz, B.D. Manshadi, A. Abedian, Nonlinear analysis of FGM plates under pressure loads using the higher-order shear deformation theories, Compos. Struct., 89 (2009), pp. 333-344
28 A. Barut, E. Madenci, A. Tessler, C0-continuous triangular plate element for laminated composite and sandwich plates using the (2,2)-refined zigzag theory, Compos. Struct., 106 (2013), pp. 835-853
42 A. Karamanli, Bending behaviour of two directional functionally graded sandwich beams by using a quasi-3d shear deformation theory, Compos. Struct., 174 (2017), pp. 70-86

ABSTRACT: The work herein presented is devoted to the prediction of the ultimate response of high-yielding low-hardening aluminium alloy beams subjected to a moment gradient. To this scope, a wide parametric analysis has been performed by the ABAQUS computer program to investigate the response parameters characterising the ultimate behaviour of I-beams. The parameters affecting the ultimate performances of aluminium alloy I-beams subject to local buckling under non-uniform bending are the flange slenderness, the flange-to-web slenderness ratio and the non-dimensional shear length. The flange slenderness parameter is directly related to the occurrence of local buckling either in the elastic or in the plastic range. The flange-to-web slenderness ratio accounts for the interactive buckling of the plate elements constituting the member section. The non-dimensional shear length accounts for the longitudinal stress gradient due to non-uniform bending. These non-dimensional parameters define entirely the geometry of the three-point bending scheme usually adopted for evaluating the rotation capacity of metal members. The results of the parametric analyses are expressed by the moment-rotation curves whose response parameters are the subject of empirical formulations. The final goal is the setting up of formulations to predicting both the maximum bending resistance and the rotation capacity of aluminium beams made of high-yielding low-hardening alloys.

References listed at the end of the paper:
4 G. De Matteis, G. Brando, Metal shear panels for seismic protection of buildings: recent findings and perspectives, Ingegneria Sismica, 33 (3) (2016), pp. 5-27
37 Z. Li, B.W. Schafer, Buckling analysis of cold-formed steel members with general boundary conditions using CUFSM: conventional and constrained finite strip methods, Proceedings of the 20th International Specialty Conference on Cold-Formed Steel Structures, 2010 (2010), pp. 17-31

Fariborz Mirzaie (1), Andrew T. Myers (1), Angelina Jay (3), Abdullah Mahmoud (4), Eric Smith (5) and Benjamin W. Schafer (6)
References listed at the end of the paper:

17 P.A. Berry, R.Q. Bridge, J.M. Rotter, Imperfection measurement of cylinders using automated scanning with a laser displacement meter, Strain, 32 (1) (1996), pp. 3-8
ABSTRACT: This paper presents the behavior of fiber-reinforced polymer (FRP)-confined concrete-filled stainless steel tube (CFSST) stub columns under axial loading. Six CFSST stub columns and 18 FRP-confined CFSST stub columns were tested. Typical failure modes and load–displacement curve were obtained. The effects of the number of carbon FRP (CFRP) wrapping layers and the thickness of the stainless steel tube were analyzed. In contrast to the uniform outer buckling of CFSST specimens, all FRP-confined CFSST specimens were found with the first explosive rupture of the CFRP wrap in the midheight region. Typical axial load–displacement curve exhibited four stages, namely, elastic, secondary ascending, repeated fracture, and post-fracture stages. All CFSST and FRP-confined CFSST specimens underwent substantial hardening after the yielding of composite sections. With the confinement of wrapped CFRP, the load-bearing capacity of FRP-confined CFSST specimens was increased by up to 71.35%, and the energy absorption capacity was also enhanced considerably. Test results indicated that the improvement in the load-bearing capacity approximately increased linearly with the number of CFRP wrapping layers, and the load-bearing capacity increased with confinement ratio (math/math). Based on the trend line of the increase in load-carrying capacity versus confinement ratio (math/math), a simplified method was proposed to predict the capacity of FRP-confined CFSST stub columns. This simplified method conservatively predicted the experimental results, warranting its further application in the field of engineering.

References listed at the end of the paper:

ABSTRACT: The research introduces a unified method to investigate the dynamic behavior of spherical caps with uniform and stepped thickness distribution under different edge constraints. In the framework of thin shell theory, the mathematical model of spherical cap is proposed. By combining the multi-section partition technique and
Rayleigh-Ritz method, the vibration characteristics of spherical caps can be obtained. The spherical cap is partitioned into sections along the meridian direction, in which the displacement components of spherical caps along meridian and circumferential direction are respectively represented by Jacobi polynomials and Fourier series. Based on the virtual boundary spring stiffness technique, different edge conditions can be easily simulated. The comparison with FEM, modal test and published literatures prove the accuracy and dependability of current method. The impacts of geometric parameters and edge constraints on the vibration characteristics of spherical cap are also discussed.

References listed at the end of the paper:
8 Y.-C. Wu, P. Heyligier, Free vibration of layered piezoelectric spherical caps, J. Sound Vib., 245 (3) (2001), pp. 527-544
27 H. Li, et al., Free vibration characteristics of functionally graded porous spherical shell with general boundary conditions by using first-order shear deformation theory, Thin-Walled Struct., 144 (2019), p. 106331
30 H. Li, et al., Free vibration analysis for composite laminated doubly-curved shells of revolution by a semi analytical method, Compos. Struct., 201 (2018), pp. 86-111
ABSTRACT: Thin shells are increasingly finding new applications under the sea. In this study, we consider a thin-walled shell-of-revolution assembly comprising a deep spherical shell dome (deeper than a hemisphere) axisymmetrically and tangentially joined to a steep-sided conical shell, the whole being a closed shell structure intended for stationary deployment beneath the surface of the sea in relatively shallow water. The closed shell structure, which might serve as an underwater observatory, is intended to operate at a constant depth, anchored to the seabed against flotation forces, with the thin steel shell walls being required to withstand the external hydrostatic pressure of the surrounding water. We use shell theory to investigate the discontinuity stresses that occur at the junction of the spherical shell and the conical shell, and employ FEM to explore the buckling behaviour of the thin shell. While discontinuity stresses are relatively small, they may influence the lower buckling modes of the shell, which are found to be largely confined to the region of the cone that is adjacent to the junction. Considerations are extended to a doubly-curved variant of the cone in the form of a paraboloid of revolution. As expected, double curvature enhances buckling capacity and also influences the mode shapes.

References listed at the end of the paper:

2 A. Zingoni, Liquid-containment shells of revolution: a review of recent studies on strength, stability and dynamics, Thin-Walled Struct., 87 (2015), pp. 102-114
3 W. Flugge, Stresses in Shells, Springer-Verlag, Berlin (1973)
7 A. Zingoni, Discontinuity effects at cone-cone axisymmetric shell junctions, Thin-Walled Struct., 40 (10) (2002), pp. 877-891
10 W. Pietraszkiewicz, V. Konopinska, Junctions in shell structures: a review, Thin-Walled Struct., 95 (2015), pp. 310-334

19 L.A. Godoy, Buckling of vertical oil storage steel tanks: review of static buckling studies, Thin-Walled Struct., 103 (2016), pp. 1-21
25 A. Zingoni, N. Enoma, Strength and stability of externally pressurised spherical-conical shell assemblies, Eighth International Conference on Thin-Walled Structures (ICTWS 2018) (2018), Lisbon, Portugal, July 24-27
31 A. Zingoni, Simplification of the derivation of influence coefficients for symmetric frusta of shells of revolution, Thin-Walled Struct., 47 (2009), pp. 912-918
35 A. Zingoni, Group-theoretic insights on the vibration of symmetric structures in engineering, Phil. Trans. R. Soc. A, 372 (2014), 20120037
36 Y. Chen, J. Feng, Q. Sun, Lower-order symmetric mechanism modes and bifurcation behavior of deployable bar structures with cyclic symmetry, Int. J. Solids Struct., 139/140 (2018), pp. 1-14


ABSTRACT: Although the use of longitudinal stiffeners in cold-formed steel members in compression is known to increase their ultimate strength at ambient temperatures, it is expected that the rigidity of such stiffeners and the strength of steel decreases when the cold-formed steel members are exposed to high temperatures. Therefore, this paper presents and discusses the results of an experimental investigation on the structural response of cold-formed steel columns with intermediate and edge stiffeners under fire conditions for assessing mainly their critical temperatures, critical times (fire resistance) and failure modes. The main variables studied included the: (a) cross-section shape, (b) boundary conditions, (c) edge stiffener configuration and (d) stiffness of the surrounding structure to the thermal elongation of such columns. Additionally, European fire design predictions (EN 1993-1-2:2005) were compared with the experimental results, in order to observe their accuracy. Finally, based on the findings of this research work it is obvious the advantage of using CFS sections with double edge fold stiffeners over the sections with single edge fold stiffeners. Moreover, built-up sections had lower critical temperatures than those for single sections, but with slightly higher fire resistance.
time. Furthermore, existing analytical methods have been shown to be incapable to predict sufficiently realistic
the complex buckling behaviour of restrained CFS columns under fire conditions.

References listed at the end of the paper:

1 P. Natário, N. Silvestre, D. Camotim, Computational modelling of flange crushing in cold-formed steel sections, Thin-Walled Struct., 84 (2014), pp. 393-405
8 M.R. Haidarali, D.A. Nethercot, Local and distortional buckling of cold-formed steel beams with both edge and intermediate stiffeners in their compression flanges, Thin-Walled Struct., 54 (2012), pp. 106-112
9 J.-H. Zhang, B. Young, Numerical investigation and design of cold-formed steel built-up open section columns with longitudinal stiffeners, Thin-Walled Struct., 89 (2015), pp. 178-191
15 H.D. Craveiro, J.P.C. Rodrigues, L. Laím, Cold-formed steel columns made with open cross-sections subjected to fire, Thin-Walled Struct., 85 (2014), pp. 1-14
21 AISI S100, Specifications for the Cold-Formed Steel Structural Members. Cold-Formed Steel Design Manual, American Iron and Steel Institute, Washington, USA (2012)
22 M. Rusthia, A.D. Ariyanayagam, M. Mahendran, Fire design of LSF wall systems made of web-stiffened lipped channel studs, Thin-Walled Struct., 127 (2018), pp. 588-603
23 S. Cheng, L.-y Li, B. Kim, Buckling analysis of partially protected cold-formed steel channel-section columns at elevated temperatures, Fire Saf. J., 72 (2015), pp. 7-15
24 S. Cheng, L.-y Li, B. Kim, Buckling analysis of cold-formed steel channel-section beams at elevated temperatures, J. Constr. Steel Res., 104 (2015), pp. 74-80
25 S. Gunalan, M. Mahendran, Fire performance of cold-formed steel wall panels and prediction of their fire resistance rating, Fire Saf. J., 64 (2014), pp. 61-80
30 A.S. Mota, Fire Resistance of Cold-Formed Steel Columns with Sigma Cross-Sections, MSc Thesis in Civil Engineering, Faculty of Sciences and Technology, University of Coimbra, Portugal (2016) (in Portuguese)
Announcing the launch of our new product, the "SmartGauge" system, designed to revolutionize the measurement industry.

The SmartGauge is a cutting-edge solution that combines high-precision sensors with advanced data analysis software to deliver unparalleled accuracy and efficiency in various applications. It is designed to meet the needs of professionals in sectors such as manufacturing, construction, and research.

Key Features:
- High-precision sensors for accurate measurements
- User-friendly interface for easy operation
- Customizable software for specific requirements
- Real-time data analytics for informed decision-making

Applications:
- Manufacturing: Quality control, process optimization
- Construction: Structural integrity checks, building compliance
- Research: Material science, environmental monitoring

Benefits:
- Increased productivity and efficiency
- Enhanced product quality and safety
- Cost savings through reduced waste and errors

Order now and experience the future of precision measurement technology. Contact us for a free consultation to explore how the SmartGauge can benefit your business. 

SmartGauge - Precision at your fingertips.
geometric imperfections depending on welding variables. Manufacturing imperfections are calculated for several girders with different corrugation profiles. The obtained tendencies are evaluated and discussed in the current paper (Part I). In the accompanying paper [1] (Part 2) the effect of manufacturing imperfections are analysed on the shear buckling resistance of corrugated web girders. The whole numerical simulation process from manufacturing simulation to resistance determination is presented, and their advantages in the design are demonstrated.

References listed at the end of the paper:
4 A. Bergfelt, L. Leiva, Buckling of Trapezoidally Corrugated Webs and Panels, IABSEReports (1986), pp. 67-74
8 M.F. Hassanein, A.A. Elkawas, A.M. El Hadi, M. Elchalakani, Shear analysis and design of high-strength steel corrugated web girders for bridge design, Eng. Struct., 146 (2017), pp. 18-33, 10.1016/j.engstruct.2017.05.035
28 K. Masubuchi, Residual Stresses and Distortion, Welding, Brazing Solder, vol. 6 (1993),
37 W.Y. Wang, G.Q. Li, Y. Ge, Residual stress study on welded section of high strength Q460 steel after fire exposure, Adv. Steel Constr., 11 (2015), pp. 150-164
51 J. Bradac, Using welding simulations to predict deformations and distortions of complex car body parts with more welds, Mach. Technol., 4 (2012), pp. 29-32
52 J.A. Goldak, Web Based Simulation of Welding and Welded Structures, (2013)
54 A. Robertson, J. Svedman, Simulation of Welding a Gear Wheel Using FEM, Chalmers University of Technology (2013)
59 M. Rhodin, Calculation of Welding Deformations in a Pipe Flange, Chalmers University of Technology (2012)


ABSTRACT: Plastic forming technology is a low-cost and high-efficiency way to produce doubly curved sandwich plate from a flat plate. However, there are various potential forming defect modes which may affect the formability of sandwich plate. This paper is focused on the defect-free plastic forming of all-metal sandwich
plates with bi-directionally trapezoidal cores, an approximate theoretical model for predicting the global buckling of sandwich plate was developed and the formability of sandwich plate with different geometric parameters were investigated analytically, experimentally and by numerical simulations. The results show that the forming defect mode which dominates the formability of a specified sandwich plate depends on the geometric parameter of the sandwich plate, the formability of the thin sandwich plate with small size core cells is limited by global plastic buckling, while that of the relative thick sandwich plate with relative large size core cells is limited by skin wrinkling and skin dimpling. Significant trends are found that the sandwich plates with thick skins have superior forming performance compared to those with thin ones, and that the limit forming radius is decreased greatly with the decrease of the characteristic sizes of core cell unit. Multi-point forming experiments on bi-directionally trapezoidal sandwich plates were performed, and the numerically simulated results and theoretically analyzed results on the formability were demonstrated finally.

References listed at the end of the paper:
1 M. He, W. Hu, A study on composite honeycomb sandwich plate structure, Mater. Des., 29 (2008), pp. 709-713
23 S. Yiatsos, O. Marangos, M.A. Wadie, C. Georgiou, Localized buckling in sandwich struts with inhomogeneous deformations in both face plates, Compos. Struct., 133 (2015), pp. 630-641
Kai Wei(1,2), Qidong Yang (1), Xujing Yang (1), Yong Tao (3), Haiqiong Xie (4), Zhaoliang Qu (5) and Daining Fang (5)

(1) State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, Hunan, 410082, PR China
(2) State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi’an Jiaotong University, Xi’an, Shaanxi, 710049, PR China
(3) College of Aerospace Engineering, Chongqing University, Chongqing, 400044, PR China
(4) School of Advanced Manufacturing Engineering, Chongqing University of Posts and Telecommunications, Chongqing, 400065, PR China
(5) Institute of Advanced Structure Technology, Beijing Institute of Technology, Beijing, 100081, PR China


ABSTRACT: In order to balance the strength and weight, 3D lightweight metallic kagome lattice sandwiches were fabricated by selective laser melting with 304 stainless steel (SS) and Co-Cr-Mo (CCM) alloy. Systematical experiments, numerical modeling and theoretical prediction for compression and bending behaviors were conducted. The experimentally measured strengths are very close to the theoretical predictions, demonstrating the excellent mechanical properties. The numerical modeling can capture the stress-strain, load-deflection curves, and the failure mode is the strut buckling initiated from the plastic hinges with high stress level. The CCM alloy kagome lattice sandwich presents non-synchronous deformation. The buckling of the struts near bottom facesheets always arises first, and is followed by the subsequent buckling of the struts near up facesheets. The strength and modulus of CCM alloy are higher than those of 304 SS, resulting in relative high values of strength and load capacity for CCM alloy kagome lattice sandwich. In contrast, the superior plasticity of 304 SS enables relative high plastic deformation ability of 304 SS kagome lattice sandwich. The kagome lattice sandwiches provide a solution to effectively balance the strength and weight, as they present lower density than engineering alloys and higher strength than honeycombs, foams and pyramid lattice sandwich.

References listed at the end of the paper:

3 G. Sun, T. Pang, C. Xu, et al., Energy absorption mechanics for variable thickness thin-walled structures, Thin-Walled Struct., 118 (2017), pp. 214-228
8 K. Wei, Y. Peng, K.Y. Wang, et al., Three dimensional lightweight lattice structures with large positive, zero and negative thermal expansion, Compos. Struct., 188 (2018), pp. 287-296
33 I. Ullah, M. Brandt, S. Feih, Failure and energy absorption characteristics of advanced 3D truss core structures, Mater. Des., 92 (2016), pp. 937-948

Shenghui Yi, Xiaqiao He and Jian Lu (Centre for Advanced Structural Materials, City University of Hong Kong Shenzhen Research Institute, 8 Yuexing 1st Road, Shenzhen Hi-Tech Industrial Park, Nanshan District,

ABSTRACT: A localized nanostructuring approach is proposed to manufacture bistable metallic shells and improve bistable properties of conventional cylindrical bistable shells. The stable configurations and transition processes of bistable shells based on three different mechanisms are experimentally and numerically investigated. Compared to conventional bistable cylindrical shells produced by plastically bending, the bistable shells with a nanostructured region can have much higher load bearing capacities and stiffness, and consume more energy before shape transition, no matter in a domelike shape or a cylindrical shape. Numerical modelling is developed using two equivalent inelastic strains for the plastic bending deformation and accumulated plastic deformation in nanocrystallization process. For nanostructured bistable shells, the internal stress fields are found to play important roles for the transition features, which are considerably affected by eccentric loading, while the eccentric loading has little effect on transition processes of the cylindrical bistable shells made by plastically bending. The influences of the size of the nanostructured region, the plate thickness and different nanostructuring processes on the bistable behaviors are further experimentally studied. In addition, the bistable properties of the bistable shells based on different mechanisms after thermal treatment from 200°C to 700°C are investigated. The applied nanostructuring process largely improves the bistable properties of bistable metallic shells, which can sustain severe environment of high temperature (about 500°C).

References listed at the end of the paper:
4 C.G. Diaconu, P.M. Weaver, F. Mattioni, Concepts for morphing airfoil sections using bi-stable laminated composite structures, Thin-Walled Struct., 46 (6) (2008), pp. 689-701
5 S. Daynes, X. Lachenal, P.M. Weaver, Concept for morphing airfoil with zero torsional stiffness, Thin-Walled Struct., 94 (2015), pp. 129-134
12 M. Gigliotti, M. Minervino, J. Grandier, M. Lafarie-Frenot, Predicting loss of bifurcation behaviour of 0/90 unsymmetric composite plates subjected to environmental loads, Compos. Struct., 94 (9) (2012), pp. 2793-2808
References listed at the end of the paper:

rocket shells, fusion reactor vessels.

The obtained results that are validated with other studies, have the valuable applications in nuclear reactors, frequencies, the dynamical responses as time history and phase plane graphs, Poincaré map are given in detail. The obtained results that are validated with other studies, have the valuable applications in nuclear reactors, rocket shells, fusion reactor vessels.

Dinh Gia Ninh (1,2,3), Nguyen Duc Tien (2,3), Vu Ngoc Viet Hoang (2,3) and Dao Huy Bich (4)

(1) Department of Aerospace Engineering, Embry-Riddle Aeronautical University, Daytona Beach, FL 32114, United States

(2) Department of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Viet Nam

(3) Group of Materials and Structures, HUST, Hanoi, Viet Nam

(4) Department of Mathematics, Mechanics and Informatics, Vietnam National University, Hanoi, Viet Nam


ABSTRACT: The analytical approach is presented to study the nonlinear vibration of W-Cu sandwich shell containing heavy water surrounded by an elastic foundation under thermo-mechanical loads. The cylindrical shell is assumed to be made of Tungsten and Copper, continuously graded in the thickness direction. The fluid in the shell is heavy water which is assumed to non-viscous and incompressible. The nonlinear vibration of the full-filled fluid shell using Flügge-Lur'e-Bryrne theory is investigated through the Galerkin method. The natural frequencies, the dynamical responses as time history and phase plane graphs, Poincaré map are given in detail. The obtained results that are validated with other studies, have the valuable applications in nuclear reactors, rocket shells, fusion reactor vessels.

References listed at the end of the paper:


5 T. Shmatko, A. Bhaskar, R-functions theory applied to investigation of nonlinear free vibrations of functionally graded shallow shells, Nonlinear Dyn., 93 (2018), pp. 189-204


12 H.S. Shen, Nonlinear vibration of shear deformable FGM cylindrical shells surrounded by an elastic medium, Compos. Struct., 94 (2012), pp. 1144-1154

13 J. Yang, H.S. Shen, Nonlinear bending analysis of shear deformable functionally graded shells subjected to thermo-mechanical loads under various boundary conditions, Compos. B Eng., 34 (2003), pp. 103-115


22 Y. Yang, Y. Wei, A unified approach for the vibration analysis of cylindrical shells with general boundary conditions, Acta Mech., 229 (2018), pp. 3693-3713


Yongqiang Li, Mao Zhou, Tao Wang and Yingjie Zhang (College of Science, Northeastern University, Shenyang, 110819, China), “Nonlinear primary resonance with internal resonances of the symmetric rectangular honeycomb sandwich panels with simply supported along all four edges”, Article 106480, Thin-Walled Structures, Vol. 147, February 2020, https://doi.org/10.1016/j.tws.2019.106480

ABSTRACT: The nonlinear primary resonances of symmetric rectangular honeycomb sandwich panels with simply supported boundaries along all four edges are studied. The nonlinear governing equations of the symmetric rectangular honeycomb sandwich panel subjected to transverse excitations are derived by using Hamilton's principle and Reddy's third-order shear deformation theory. These nonlinear partial differential equations are reduced into nonlinear ordinary differential equations by the Galerkin method. Based on the homotopy analysis method, the average equations of the primary resonance are obtained. For all the three primary resonances cases, the frequency-response curves of primary resonance are constructed. Comparison studies on the forced vibration of cubic non-linearity system are conducted to verify the correctness and accuracy of the homotopy analysis method. Effects of thickness-to-length ratio, width-to-length ratio and transverse excitation on the nonlinear primary response have been investigated for honeycomb sandwich panels.


ABSTRACT: Double-corrugated-plate shear wall (DCPSW), which is composed of two identical corrugated plates and assembled by connecting bolts, is an innovative type of lateral force resistant device for high-rise building structures. In this paper, the shear resistant behavior of the DCPSW is investigated via tests and additional finite element (FE) parametric study. First, the test results of two DCPSW specimens subjected to monotonic in-plane shear loads are reported. Second, FE models are introduced to perform simulations on the shear resistant behavior of the test specimens; it is seen that the numerical results fit well with the test results, and hence the FE models for simulations of the DCPSWs are validated. Then, an additional parametric study is presented by changing the geometrical parameters including aspect ratio, bolt column number, corrugation amplitude and dimensions of boundary elements of the DCPSWs. As a result, the effects of these parameters on...
the shear resistant behavior of the DCPSWs are further revealed. It is shown that the ultimate shear resistance of the DCPSWs increases with the increase of aspect ratio, bolt column number and corrugation amplitude, yet the dimensions of the boundary elements have little effect on the shear resistance of the embedded corrugated plates. Finally, by analyzing the results of the parametric study, some design remarks are concluded to provide valuable references for the design of the DCPSWs in practice.


ABSTRACT: In this paper, an efficient simple numerical method, known as energy-based collocation, is presented to analyze the nonlinear behavior of a geometrically imperfect composite plate subjected to compressive in-plane load while taking into account progressive damage phenomena. This method is based on the energy approach, in which the plate is discretized into the Legendre-Gauss-Lobatto points. The nonlinear governing equations are based on the First-order Shear Deformation Theory (FSDT) and the assumptions of large deflection. The system of nonlinear algebraic equations is solved using the quadratic extrapolation technique. Plates with various boundary conditions and different ranges of thickness are investigated. Hashin and Rotem failure criteria are established to predict failure. Several properties degradation models are proposed for the developed failure mechanism and description of ply degradation. The analysis is performed by a computer program developed based on FORTRAN language. The accuracy of the developed procedure is assessed by comparing numerical results taken from previous works.

Erdong Wang (1), Qing Li (2) and Guangyong Sun (1,2)
(1) State Key Laboratory of Advanced Design and Manufacture for Vehicle Body, Hunan University, Changsha, 410082, China
(2) School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Sydney, NSW, 2006, Australia

ABSTRACT: Structural responses, deformation modes, blast resistance and energy absorption of foam core signify some major functional characteristics for design of sandwich panels. This study aimed to address these issues by investigating uniform and graded foam core configurations. First, an experimental study was performed and the testing results of blast-loaded sandwich panels were analyzed. Second, a numerical model was developed and validated by comparing the simulation results with the experimental results in terms of deformation modes and back facesheet deflection. Third, the blast resistance of sandwich panels was comprehensively studied based upon the developed numerical models. Due to the high attenuation ability of the shock induced stress wave, the foam core with descending gradient of layer density across the thickness direction provided the highest blast resistance of all the core configurations considered here and its advantage could be further improved by enlarging the density difference of the core layer. While keeping total facesheet thickness unchanged, a relatively thick back facesheet is beneficial to enhance the blast resistance under relative low blast intensity. Finally, an optimization study was performed to improve the blast resistance of graded core sandwich panels. For the single objective optimization, the maximum back facesheet deflection of the optimum design decreased by 24.58% in comparison with that for the initial baseline design. For the multiobjective optimization, the optimal designs obtained from the Pareto solution can significantly enhance weight efficiency without compromising the resistance.

Vipulkumar Ishvarbhai Patel (1), Qing Quan Liang (2) and Muhammad N.S. Hadi (3)
(1) School of Engineering and Mathematical Sciences, La Trobe University, Bendigo, VIC, 3552, Australia
(2) College of Engineering and Science, Victoria University, PO Box 14428, Melbourne, VIC, 8001, Australia
(3) School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW, 2522, Australia

ABSTRACT: Concrete-filled aluminum tubular (CFAT) columns have the advantages of a lightweight, high resistance to corrosion, good appearance and ease of maintenance over concrete-filled steel tubular (CFST) columns. However, experimental and computational studies on the performance of CFAT columns have rarely been reported. This paper concerns with the fiber-based numerical analysis, structural behavior, and design of circular high strength CFAT stub columns loaded concentrically. A new concrete confinement model for computing the lateral pressures on the concrete core in CFAT circular columns is proposed and implemented in the computational model. The numerical analysis procedure is given for the determination of the nonlinear load-strain behavior of CFAT stub columns. The available experimental results of circular CFAT columns are used to assess the accuracy of the developed model. The computer model is employed to ascertain the significance of various geometric parameters in addition to material strengths on the responses of CFAT stub circular columns. The design equation based on Liang-Fragomeni's expression is proposed for quantifying the ultimate axial strengths of axially compressed CFAT short columns. The verification reveals that the computer modeling approach accurately quantifies the ultimate loads and nonlinear load-strain performance of CFAT columns with circular sections. The proposed design equation yields good calculations of the ultimate axial strengths of CFAT columns.

Shaoyu Zhao (1), Zhicheng Yang (2), Sritawat Kitipornchai (1) and Jie Yang (3)
(1) School of Civil Engineering, The University of Queensland, St Lucia, Brisbane, QLD, 4072, Australia
(2) College of Urban and Rural Construction, Zhongkai University of Agriculture and Engineering, Guangzhou, 510225, China
(3) School of Engineering, RMIT University, PO Box 71, Bundoora, VIC, 3083, Australia


ABSTRACT: This paper investigates the dynamic instability of a functionally graded porous arch reinforced with uniformly distributed graphene platelets (GPLs) under the combined action of a static force and a dynamic uniform pressure in the radial direction. The relationship between the elastic modulus and mass density of the material is determined by the closed-cell cellular solids under Gaussian Random Field scheme. The governing equation is derived based on classical Euler-Bernoulli theory. Galerkin approach is used to derive the Mathieu-Hill equation from which the dynamic unstable region is obtained using Bolotin method. A comprehensive parametric study is conducted to examine the effects of GPL weight fraction and dimensions, porosity distribution, pore size, static force, and arch geometry and size on the dynamic stability characteristics of the arch. Numerical results show that the porous arch's resistance against dynamic instability can be considerably improved by using symmetrically non-uniform porosity distribution and the addition of a small amount of GPLs.

Z.G. Wang (1), H. Wu (2), Q. Fang (1) and J. Wu (3)
(1) State Key Laboratory of Disaster Prevention & Mitigation of Explosion & Impact, PLA Army Engineering University, Nanjing, 210007, China
(2) Research Institute of Structural Engineering and Disaster Reduction, College of Civil Engineering, Tongji University, Shanghai, 200092, China
(3) School of Urban Rail Transportation, Shanghai University of Engineering Science, Shanghai, 201620, China


ABSTRACT: Ultra-high performance cementitious composite filled steel tube (UHPCC-FST) has been widely applied as the load bearing members for long-span bridges, which are the potential bomb explosion attack targets in terroristic activities. This paper aims to experimentally study the residual axial capacity of UHPCC-FST columns under contact explosion by conducting the field contact detonation and the subsequent axial compression tests. Firstly, five UHPCC-FST cylinder columns are fabricated with the column height, outer diameter and core concrete compressive strength being 2000 mm, 203 mm and 131.5 MPa, respectively.
Secondly, three of which are tested under contact explosion with the TNT charge weights of 1 kg, 2 kg and 3 kg, in which the impact craters are formed and the integrity of the columns is maintained under 1 kg and 2 kg TNT explosions, while the outer steel tube is seriously ruptured and the core UHPCC is fully crushed for 3 kg TNT explosion. Furthermore, the original axial capacity of intact columns and the residual axial capacity of blast-damaged columns are evaluated though the axial compression tests, and the relationships between the axial load and axial/lateral displacement are derived. It indicates that, (i) both the intact and blast-damaged columns under axial compression show diagonal shear failure, the local bulging of steel tube is induced due to the low confinement of steel tube and high compressive strength of UHPCC; (ii) the quantitative dependence of column damage index on the charge weight is determined.

Hugo Elizalde (1), Diego Cárdenas (2), Juan Carlos Jáuregui-Correa (3), Marcelo T. Piovan (4) and Oliver Probst (5)

(1) Tecnológico de Monterrey, School of Engineering and Sciences, Calle del Puente 222 Col, Ejidos de Huipulco Tlalpan, CP14380, Ciudad de México, Mexico
(2) Tecnológico de Monterrey, School of Engineering and Science, General Ramón Corona 2514, CP 45138, Zapopan, Mexico
(3) Universidad Autónoma De Querétaro, Cerro de Las Campanas, s/n, Las Campanas, 76010, Santiago de Querétaro, QRO, Mexico
(4) Centro de Investigaciones en Mecánica Teórica y Aplicada, Universidad Tecnológica Nacional – Fac. Reg. Bahía Blanca, 11 de abril 461, 8000, Bahía Blanca, Argentina
(5) Tecnológico de Monterrey, School of Engineering and Sciences, Av. Eugenio Garza Sada 2501 Sur, Monterrey, CP 64849, Mexico


ABSTRACT: This paper presents a unified theory for the vibrational analysis of thin-walled composite beams (TWCB) with arbitrary planar axial curvature, variable cross section, and general composite material layup, allowing for the accurate modelling of a large class of composite beams with an accuracy normally achievable only through shell-type finite-element (FE) models, but at a fraction of the numerical cost. The kinematic description is based on the Frenet-Serret frame field, providing a transparent path for transforming the equations of motion from rectilinear to curved TWCB while fully accounting for curvature gradient terms, thereby allowing for the treatment of highly curved geometries. Additional innovations include the use of a novel formulation increasing the accuracy for cases with significant axial-bending-torsional structural coupling, as well as a computationally efficient Isogeometric Analysis (IGA) formulation. The new method has been applied to modal and transient analysis of several test cases where conventional TWCB models are found to yield limited accuracy. The results obtained are almost indistinguishable from those obtained with a full-sized shell-based FE model, at a computational cost which is about two orders-of-magnitude smaller.


ABSTRACT: This paper proposes a scheme for distributed piezoelectric actuator layout-design to improve active vibration control performance of thin-walled smart structures. The aim of the design is to maximize the energy transformation from actuator to structure so that better control performance will be achieved under a control strategy. The system performance index (SPI) is used to measure energy transformation. The layout-design problem is formulated by combining the topology optimization technique and the SPI. The pseudo-densities of piezoelectric materials are used as design variables and a penalty function is applied on piezoelectric materials so that a clear result can be obtained. Based on the chain rule and the adjoint method, and with the help of solving Lyapunov function, the sensitivity analysis is conducted. The optimization model is solved by nonlinear programming method. Once the optimized layout is obtained, the linear quadratic regulator (LQR) control strategy is applied and vibration suppression can be achieved. The method is load-independent. External loads and control strategy are not considered in layout-design so that a single layout can be obtained.
Yet for all that, the optimized layout can achieve excellent performance in a wide range of load cases. Two numerical examples and two engineering applications demonstrate the validity of the proposed method.


ABSTRACT: Although it is well known that initial deflections have a significant influence on load-bearing capacity of unstiffened square box section columns under axial compression, their quantitative influence is not clear. In this study, 378 finite element models were analyzed to reveal the quantitative influence of local and overall initial deflections on load-bearing capacity. In the parametric analyses, nine combinations of the amplitude of the local and overall initial deflections were considered. In addition, normalized width-thickness and slenderness ratios were varied with ranges from 0.3 to 1.8 and from 0.3 to 1.5, respectively. As a result, the initial deflection influence coefficient was proposed to describe the quantitative influence on load-bearing capacity and formulated as functions of the local and overall initial deflections, normalized width-thickness and slenderness ratios. The accuracy of the proposed formula was verified through the comparison with the FEA results including additional 108 FEA results with normalized slenderness ratio of 0.9 and 1.2.

Chenpu Guo (1), M. Elchalakani (1), A. Karrech (1), M.R. Bambach (2) and Bo Yang (3)
(1) School of Civil Environmental, and Mining Engineering, University of Western Australia, Australia
(2) School of Civil Engineering, University of Sydney, Australia
(3) School of Civil Engineering, Chongqing University, Chongqing, 400045, China

ABSTRACT: The current slenderness limits are significantly different in international design codes for cold-formed Circular Hollow Sections (CHS) under pure bending. This paper aims to use the Finite Element (FE) method to understand the behaviour of cold-formed CHS under pure bending and to propose new design rules. The model is calibrated by comparing its predicted load-deflection curves with previously published experimental data. In total, 21 specimens were modelled with diameter-to-thickness ratios ranging from 13 to 122. The current slenderness limits in the present international steel specifications were examined using the FE model and their suitability for cold-formed CHS is discussed. The effect of section slenderness on rotation capacity has been examined where the predicted variation of rotation capacity against section slenderness has been compared to the experimental results. A new equation for the amount of initial geometrical imperfection as a function of section slenderness has been developed and proposed for design purposes. The ovalisation deformation ratio and the critical strain at local buckling were determined and compared for compact, non-compact and slender sections. The progressive bending deformations of CHS at 10 critical steps have been presented and compared for the three cross sectional types, in particular at the maximum moment and bending rotation. In general, a good agreement has been obtained between the predicted strengths and ductilities using the current FE models and those of the experimental data of cold-formed CHS.

Yuan Du, Liping Sun, Shuo Li and Yuhui Li (College of Shipbuilding Engineering, Harbin Engineering University, Harbin, 150001, PR China), “Vibration analysis of truncated spherical shells under various edge constraints”, Article 106544, Thin-Walled Structures, Vol. 147, February 2020,
https://doi.org/10.1016/j.tws.2019.106544

ABSTRACT: By means of combining Flügge's thin shell theory and energy method, a generalized approach to investigate vibration characteristic of truncated spherical shell subjected to various edge constraints is proposed. The truncated spherical shell is devided into different sections along the meridian line, in which the displacement function of truncated spherical shell along meridian and circumferential line are respectively represented by Jacobi polynomials and Fourier series. Various edge constraints can be simulated on the basis of virtual spring stiffness method in the current research. Finally, the solutions can be derived by mean of Ritz method. The dependability and exactness of current method have been proved by the comparison between
current method, FEM and related literatures. The dimensionless frequency parameters of different truncated spherical shell under various edge constraints are displayed. In addition, the influence of geometric dimensions and boundary constraints on frequency parameters are also discussed.


ABSTRACT: For the preliminary structural design of aircraft, spacecraft and marine vessels, computationally efficient and sufficiently accurate computational methods are necessary. The present work contributes to this field by deriving a new closed-form analytical solution for the local buckling analysis of omega-stringer-stiffened composite panels. Hereby, the plates of the assembly are modelled separately and include the stiffener foot. The principle of the minimum potential energy is used in a Ritz-like approach and leads to an explicit analytical formulation of the critical buckling load. The compliance to geometric and dynamic boundary conditions is ensured. The panel is uniaxially loaded and investigated for different geometrical and material configurations. For the verification of the presented method, a finite element analysis is performed as well as a solution of the Lévy type is obtained. Very good agreement of the new closed-form analytical approach with finite element analyses is shown in numerical studies for technical relevant areas of the design space.

Regina Khakimova (1), Richard Degenhardt (2,3) and Dirk Wilcken (2)
(1) Fraunhofer IWU, Hermann-Münch-Straße 2, 38440, Wolfsburg, Germany
(2) DLR, Institute of Composite Structures and Adaptive Systems, Lilienthalplatz 7, 38108, Braunschweig, Germany
(3) PFH, Private University of Applied Sciences Göttingen, Composite Engineering Campus Stade, Germany

ABSTRACT: Thin-walled cylindrical structures are widely used in aerospace, offshore, civil and other engineering fields. Parts of space launcher transport systems are one example for the application of such shells. Buckling of thin-walled structures is a very important phenomenon to be considered during their design phase. This is true not just because such structures are often imperfection sensitive (geometry, boundary conditions, load introduction, thickness, etc.) but also due to operational requirements set on these thin-walled structures which often lead to the need for introducing cutouts to accommodate access panels, doors and windows. These cutouts constitute an additional factor that influences the overall stability and needs to be understood in order to enable a safe operation and an effective design of these structures. The study deals with buckling experiments on two axially compressed, unstiffened CFRP cylindrical shells with circular unreinforced cutouts, performed by DLR. Moreover, a FE model is described that is validated with the experimental results. The objective of the study is to investigate the effect of the size of the cutouts on the buckling characteristics of the tested shells.

Shengwen Tu and Jian Shuai (Faculty of Safety Science and Ocean Engineering, China University of Petroleum (Beijing), 102249, Beijing, China), “Numerical study on the buckling of pressurized pipe under eccentric axial compression”, Article 106542, Thin-Walled Structures, Vol. 147, February 2020, https://doi.org/10.1016/j.tws.2019.106542

ABSTRACT: Pipeline transport is one of the main solutions for oil and gas transmission and distribution. The pipeline in service may be subjected to complicated loads (internal pressure, tension or compression, bending and their combination) when crossing complex geohazard regions. In this study, the compressive strain capacity of pressurized pipelines under eccentric axial compression is investigated numerically. Meanwhile, the effects of the internal pressure, pipe diameter-to-wall-thickness ratio (D/t) and the material strain hardening capacity on the compressive strain capacity are studied. It has been found out that under eccentric axial compression, the buckling behavior of pipes depends on the internal pressure, D/t and material strain hardening capacity. The compressive strain capacity increases with the increase of the internal pressure and the strain hardening capacity; while the diameter-to-wall-thickness ratio displays a negative effect.
Weiliang (1,2), Xing Hu (3), Ying Zheng (3) and Dean Deng (3)
(1) College of Mechatronics & Automotive Engineering, Chongqing Jiaotong University, Chongqing, 400074, China
(2) State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin, 150001, China
(3) College of Materials Science and Engineering, Chongqing University, Chongqing, 400045, China
“Determining inherent deformations of HSLA steel T-joint under structural constraint by means of thermal elastic plastic FEM”, Article 106568, Thin-Walled Structures, Vol. 147, February 2020,
https://doi.org/10.1016/j.tws.2019.106568
ABSTRACT: The inherent strain method is a powerful and efficient tool to simulate welding deformation, so it recently becomes the mainstream way to estimate the total welding distortion of large complex welded structures. When using this method to predict welding deformation, the simulated result strongly depends on the accuracy of the inherent deformations of each typical joint involved in the welded structure. During welding process, the constraint condition usually has a significant influence on the inherent deformations of a welded joint. In the current study, the influence of different constraint conditions on the inherent deformations of atypical high strength low alloy steel thin-plate T-joint was investigated experimentally and numerically. Meanwhile, the welding deformation of a simple thin-plate stiffened-panel structure was calculated by using the inherent deformations of T-joints with different constraint conditions. Based on the simulated results, the influence of the inherent deformations of T-joints with different restraint conditions on the total welding deformation of the stiffened-panel structure was clarified. In addition, a newly method was proposed to obtain the inherent deformations of a welded joint with structural constraint condition.

Bing Du, Jun Xie, Han Li, Changcai Zhao, Xin Zhang and Xiaoming Yuan (Key Laboratory of Advanced Forging & Stamping Technology and Science (Yanshan University), Ministry of Education of China, Qinhuangdao City, 066004, PR China), “Determining factors affecting sheet metal plastic wrinkling in response to nonuniform tension using wrinkling limit diagrams”, Article 106535, Thin-Walled Structures, Vol. 147, February 2020, https://doi.org/10.1016/j.tws.2019.106535
ABSTRACT: In thin plate plastic forming, the efficient, accurate prediction and control of wrinkling is a basic requirement. Because there is no clear means of determining the main strain space curve (similar to the fracture forming limit diagram) when establishing the critical wrinkling state, this work used diagonal tensile plate tests to verify a numerical simulation of plastic wrinkling in thin plates. This model included a buckling mode
As for the effect of temperature distribution patterns in the columns on the member critical temperature, it was one of the important factors that could be detrimental to the fire resistance even with a low load ratio. It was also found that creep deformation associated with the low heating rate decreased the fire resistance of the columns considerably. For those columns with an applied load ratio lower than 0.6, the load ratio led to a significant decrease in the member critical temperatures. The test results indicated that increasing the ambient temperature was tested first. The effects of heating rate, load ratio, and temperature distribution pattern on the fire responses of the columns were investigated in the fire tests. The test results showed substantial improvements from a crashworthiness viewpoint. The obtained interesting results showed the high potential of the BESO algorithm for the design of thin-walled square tubes subjected to an axial crushing load was carried out to enhance its crashworthiness performance, utilizing the modified Bidirectional Evolutionary Structural Optimization (BESO) procedure. In this way, by systematic searching, topology optimization finds the best material layout for the structure to satisfy the objective function. In each iteration, a new pattern of material-void through the tube walls can trigger various folding mechanisms. Thus, the energy absorption history trend might not be smooth and the ultimate pattern proposed by the algorithm is less likely to be the optimal one. With an emphasis on the BESO hypothesis regarding direct removal and addition of elements, the modified BESO algorithm excavated the optimal design in two steps. First, material-void patterns were produced, considering specific energy absorption as the element efficiency criterion. Then, the pattern with the least material usage which satisfies an energy absorption constraint was selected as the optimal design. Such an optimum layout also boosts the tube performance respecting peak crushing force, since the embedded voids through the structure serve as a crush initiator. The optimization code was developed in MATLAB, which was automatically integrated with ABAQUS software performing the nonlinear crushing analysis. To validate the finite element model, an experimental investigation was carried out on a simple square tube. Having performed the topology optimization and some fine-tuning process, the topologically optimized tube was constructed and experimentally tested. Results showed 16.21% weight reduction enriched with 36.57% enhancement in the peak crushing force by sacrificing less than 3.5% energy absorption, which represents substantial improvements from a crashworthiness viewpoint. The obtained interesting results showed the high potential of the BESO algorithm for the design of thin-walled structures under large deformation and out-of-plane buckling.

Jingjie Yang, Weiyong Wang, Yu Shi and Lei Xu (School of Civil Engineering, Chongqing University, Chongqing, 400045, China), “Experimental study on fire resistance of cold-formed steel built-up box columns”, Article 106564, Thin-Walled Structures, Vol. 147, February 2020, https://doi.org/10.1016/j.tws.2019.106564

ABSTRACT: Cold-formed steel built-up box columns are commonly used in mid-rise cold-formed steel buildings to resist applied loads. Numerous studies have been conducted to evaluate the load-bearing capacity of the columns at ambient temperature but there is very limited research on the fire resistance of the built-up columns. In this paper, a full-scale experimental investigation on fire responses of sixteen axially loaded cold-formed steel built-up box columns was conducted. As a benchmark, the load-bearing capacity of the columns at ambient temperature was tested first. The effects of heating rate, load ratio, and temperature distribution pattern on the fire responses of the columns were investigated in the fire tests. The test results indicated that increasing the load ratio led to a significant decrease in the member critical temperatures, which consequently reduced the fire resistance of the columns considerably. For those columns with an applied load ratio lower than 0.6, they were expected to have member critical temperatures higher than 500 °C. Moreover, with thin-walled steel and no fire protection the column temperatures increased quickly, leading to failure in no more than 12 min in a fast fire even with a low load ratio. It was also found that creep deformation associated with the low heating rate was one of the important factors that could be detrimental to the fire resistance and member critical temperature. As for the effect of temperature distribution patterns in the columns on the member critical temperature, it was obtained by an eigenvalue buckling analysis as the initial shape defect in a dynamic explicit numerical simulation of the plastic deformation of the test pieces. This permitted calculation of the true instability morphology of the test piece and avoided the difficulty associated with simulating plastic deformation wrinkling morphologies using existing static implicit or dynamic explicit numerical simulation algorithms. The morphology and characteristics of the critical wrinkling limit diagram (WLD) associated with nonuniform tension were investigated. The effect of the specimen thickness and boundary conditions on the WLD in the main strain space were also examined and the effects of various processing parameters on crease resistance were established. Finally, the effectiveness of the WLD established in this work was verified based on using non-contact full-field strain measurements to examine the plastic wrinkling of thin plates. This research provides a means of establishing the critical wrinkling line for various conditions.


ABSTRACT: In this study, topology optimization of a thin-walled square tube subjected to an axial crushing load was carried out to enhance its crashworthiness performance, utilizing the modified Bidirectional Evolutionary Structural Optimization (BESO) procedure. In this way, by systematic searching, topology optimization finds the best material layout for the structure to satisfy the objective function. In each iteration, a new pattern of material-void through the tube walls can trigger various folding mechanisms. Thus, the energy absorption history trend might not be smooth and the ultimate pattern proposed by the algorithm is less likely to be the optimal one. With an emphasis on the BESO hypothesis regarding direct removal and addition of elements, the modified BESO algorithm excavated the optimal design in two steps. First, material-void patterns were produced, considering specific energy absorption as the element efficiency criterion. Then, the pattern with the least material usage which satisfies an energy absorption constraint was selected as the optimal design. Such an optimum layout also boosts the tube performance respecting peak crushing force, since the embedded voids through the structure serve as a crush initiator. The optimization code was developed in MATLAB, which was automatically integrated with ABAQUS software performing the nonlinear crushing analysis. To validate the finite element model, an experimental investigation was carried out on a simple square tube. Having performed the topology optimization and some fine-tuning process, the topologically optimized tube was constructed and experimentally tested. Results showed 16.21% weight reduction enriched with 36.57% enhancement in the peak crushing force by sacrificing less than 3.5% energy absorption, which represents substantial improvements from a crashworthiness viewpoint. The obtained interesting results showed the high potential of the BESO algorithm for the design of thin-walled structures under large deformation and out-of-plane buckling.
found that the member critical temperatures for specimens with non-uniform temperature distribution were slightly higher than those with uniform temperature distribution.

M.A. Eltaher (1,2), S.A. Mohamed (3) and A. Melaibari (1)
(1) Mechanical Engineering Department, Faculty of Engineering, King Abdulaziz University, P.O. Box 80204, Jeddah, Saudi Arabia
(2) Mechanical Design & Production Department, Faculty of Engineering, Zagazig University, P.O. Box 44519, Zagazig, Egypt
(3) Department of Engineering Mathematics, Faculty of Engineering, P.O. Box 44519, Zagazig, Egypt


ABSTRACT: This article investigates the static stability and mode-shapes of composite laminated beams under varying axial in-plane loads. The kinematic displacement field is described by unified higher order shear deformation theory. Six functions are assumed to describe the distribution of axial in-plane load, which are one constant function, two-linear functions, and three-parabolic functions. The Hamilton's principle is proposed to get the equilibrium equations of unified composite laminated beams. An efficient numerical differential quadrature method (DQM) is proposed to solve the govern equations. The obtained equations are solved as an eigenvalue problem to find critical buckling loads and their corresponding mode shapes. The validation studies are compared with published works. Numerical results illustrate effects of in-plane load type, beam thickness, orthotropy ratio, fiber orientations, and boundary conditions on the critical buckling loads. The effect of axial load functions on the buckling mode shapes is presented for the first time. These effects play very important role on the static stability and mode-shapes of composite beam structures. The proposed model may be important in design of aircraft, civil and ship-building when non-uniform in-plane compressive load is important.

Yongqiang Li (1,2), Mao Zhou (1) and Meng Li (3)
(1) College of Science, Northeastern University, Shenyang, 110819, China
(2) Key Laboratory of Ministry of Education on Safe Mining of Deep Metal Mines, Northeastern University, Shenyang, Liaoning, 110819, China
(3) Research Institute of Economics and Management, Southwestern University of Finance and Economics, Chengdu, 611130, China


ABSTRACT: In this paper, free vibration of thin rectangular plates with cut-outs for different boundary conditions is analyzed by using the discrete singular convolution (DSC) method. First, the entire plate configuration is divided into appropriate sub-domains. The edges involved with cut-outs in each sub-domain are treated as free boundary conditions and the Taylor series expansion method is adopted for solving. Then, the convergence of the DSC method is tested and the frequency parameters were validated by comparing with the exact solutions by Leissa. At last, the influence of rectangular and U-shaped cut-outs structure parameters on the natural frequency is studied.

Jun He (1), Sihao Wang (2), Yuqing Liu (2), Dalei Wang (2) and Haohui Xin (3)
(1) School of Civil Engineering, Changsha University of Science and Technology, Hunan, China
(2) Department of Bridge Engineering, Tongji University, Shanghai, China
(3) Civil Engineering and Geosciences, Delft University and Technology, Netherlands


ABSTRACT: For long-span composite bridges with corrugated steel webs, the encased concrete near the intermediate support section increases the weight of the girder, reduces pre-stressing efficiency, and causes difficulties in the construction process. The authors in the companion paper [1] proposed a corrugated steel web with vertical or/and horizontal stiffeners to replace or shorten the length of concrete encasement. In parallel with experimental study described in the companion paper, this paper further investigates the shear performance of proposed stiffened corrugated steel webs by numerical and analytical methods. Firstly, finite element (FE)
models considering material nonlinearity, welding residual stress, and geometric imperfection were established and validated against the experimental results. Then the effects of web thickness, corrugation depth, height and thickness of stiffeners on shear strength and failure modes were analyzed based on the validated FE models. Finally, both experimental and numerical shear strength were used to evaluate the applicability of existing calculation methods proposed by different scholars to predict the shear capacity of stiffened corrugated steel web. The comparisons reveal that calculation methods proposed by Hassanein & Kharoob [2] and Leblouba et al. [3] predict the shear capacity of pure corrugated steel web more accurately, and all existing calculation methods underestimate corrugated steel web with vertical stiffeners. Therefore, the analytical model for accurately predicting shear strength of stiffened corrugated steel web need to be developed, which will be investigated in subsequent studies.


ABSTRACT: An experimental investigation into the cross-sectional behaviour of hot-finished high strength steel tubular sections, to support the assessment and development of structural design guidance, is presented. Two grades of quenched and tempered high strength steel – S690 and S770 and eight cross-sections – seven square hollow sections (SHS) and one rectangular hollow section (RHS), covering a wide range of local slenderness, were examined. This test programme consisted of twelve tensile coupon tests, five stub column tests and 30 short beam-column tests, with various initial loading eccentricities employed to achieve a spectrum of compression and bending combinations. Local geometric imperfection measurements were carried out on each test specimen using 3D laser-scanning, and a rational approach to analysing the local imperfection distributions using the scanned data was subsequently proposed. Following the experimental study, the current Eurocode 3 cross-section design provisions were evaluated through comparisons with the results from the present research and additional results from the literature. The experimental results and findings from the present study provide a basis for the development of numerical models and the enhancement of existing design methods in the future.

Hanwen Lu (1), Airong Liu (1), Mark Andrew Bradford (2) and Yong-Lin Pi (1,2)
(1) Guangzhou University-Tamkang University Joint Research Centre for Engineering Structure Disaster Prevention and Control, Guangzhou University, Guangzhou, Guangdong, China
(2) Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, The University of New South Wales, UNSW, Sydney, NSW, Australia

ABSTRACT: An arch under a central in-plane point load may lose its stability in an out-of-plane buckling mode when the load attends a certain value. This paper presents a theoretical study for the out-of-plane buckling of elastic circular arches under a central radial point load using an energy method and an experimental study for the out-of-plane buckling load of elastic circular aluminium arches under a central radial point load. Six circular aluminium arches of doubly symmetric I-sections having different rise-to-span ratios, different load heights and different boundary conditions are tested by applying a radial point load to the crown of the arch. With specially designed supports that can simulate different in-plane boundary conditions, an ingenious loading device and high-precision real-time displacement measurement, the elastic out-of-plane buckling loads of tested arches are accurately recorded. Comparisons show that agreements of test results against theoretical solutions are very good. The influences of the slenderness ratio, in-plane boundary conditions and the load height on the out-of-plane buckling are also investigated and it is found that they influence the out-of-plane buckling load of circular arches significantly.

E. Ozyurt (School of Mechanical, Aerospace and Civil Engineering, University of Manchester, UK and Department of Civil Engineering, Gümüşhane University, Gümüşhane, TR, Turkey), “Finite element study on axially loaded reinforced Square Hollow Section T-joints at elevated temperatures”, Article 106582, Thin-Walled Structures, Vol. 148, March 2020, https://doi.org/10.1016/j.tws.2019.106582
ABSTRACT: This study numerically investigates the elevated temperature resistance of collar plate and doubler plate reinforced Square Hollow Section (SHS) T-joints subjected to brace axial compressive load. The extensive numerical simulations were performed to examine the effects of the geometrical parameters of main members and reinforcing plate on the fire resistance of reinforced SHS T-joints after verification of the numerical models based on the available test results. The corresponding unreinforced joints were also analysed as reference resistance at five different temperature levels (20 °C, 400 °C, 500 °C, 600 °C, and 700 °C). Results indicate that the elevated temperature capacity of SHS T-joints can be significantly increased by using a collar plate or a doubler plate. Although the initial stiffness of the doubler plate reinforced joints was higher than the collar plate reinforced joints, their capacity was similar to each other. Also, the fire resistance of the reinforced joints mainly depended on the brace-to-chord width ratio and reinforcing plate thickness to chord wall thickness ratio. However, there was no beneficial effect on the fire resistance of reinforced joints when the thickness of the reinforcing plate was greater than 1.5 times the chord wall thickness. Moreover, there was an insignificant effect of half-width to thickness ratio of the chord, reinforcing length and reinforcing type as long as the required limit values of the reinforcing length and width were used based on the Eurocode 3 EN 1993-1-8. It is worth mentioning that modifying the steel yield strength in the ambient temperature design method to calculate the capacity of the reinforced SHS T-joints at elevated temperatures may be unsafe. A new design method was developed to predict the capacity of a collar plate and doubler plate reinforced SHS T-joints subjected to brace compressive load in fire.

Zhe Xing (1), Merih Kucukler (2) and Leroy Gardner (1)
(1) Department of Civil and Environmental Engineering, Imperial College London, London, SW7 2AZ, UK
(2) School of Engineering, University of Warwick, Coventry, CV4 7AL, UK
ABSTRACT: The local buckling behaviour and design of stainless steel plates in fire are investigated in this paper. Finite element models of stainless steel plates able to mimic their response in fire are created and validated against experimental results from the literature. Parametric studies are then performed and the results are utilised to assess the current design provisions set out in the European structural steel fire design code EN 1993-1-2; shortcomings in the prediction of the local buckling response of stainless steel plates in fire are revealed. A new effective width based design approach able to reflect the variation in strength and stiffness of stainless steel at different temperature levels in the determination of the local plate slenderness and thereby the ultimate resistances of stainless steel plates in fire is put forward. The proposed approach is shown to provide significantly higher levels of accuracy and reliability relative to the current provisions in EN 1993-1-2 for a wide range of plate slendernesses, elevated temperature levels, stainless steel grades and loading conditions. The design rules proposed for the local buckling assessment of stainless steel plates at elevated temperatures in this paper are due to be incorporated into the upcoming version of the European steel fire design standard EN 1993-1-2.

Y.B. Zhang (1), B. Zhao (1), J.H. Hu (1), W J. Chen (1), X.W. Deng (2), Z.Y. Yu (2), C Xie (3) and F.J. Peng(3)
(1) Space Structure Research Center, Shanghai Jiao Tong University, Shanghai, 200240, PR China
(2) Department of Engineering Mechanics, Shanghai Jiao Tong University, Shanghai, 200240, PR China
(3) Shanghai Institute of Aerospace System Engineering, Shanghai, 201109, PR China
ABSTRACT: The pretensioned rectangular membrane is a basic structural component that is widely used in various spacecraft, and requires experimental ground verification before being launched into orbit. However, the dynamic calibration of the membrane is a considerable challenge, because the dynamic response is sensitive to the air resistance effect. A grid membrane can be intuitively thought of as being insensitive to a great extent and proposed as a dynamic equivalent structure. The dynamic equations of the two structures are respectively formulated, and the dynamic equivalent methodology of the two structures is formulated by making the corresponding coefficients of the two equations equal to one another. In the simulations, the frequencies of the two structures under the same vibration amplitude are essentially identical. A low vacuum chamber and biaxial
extension frame are developed for experimental validation. In the experiment, the dynamic response of the grid membrane in air shows a fine consistency with the rectangular membrane in low vacuum. Therefore, the proposed dynamic equivalent methodology is demonstrated to be valid, and the grid membrane can be used as a substitute structure for the rectangular membrane in order to reduce the air resistance effect.

Vuong Nguyen Van Do (1), Yang-Kyu Lee (2) and Chin-Hyun Lee (3)
(1) Applied Computational Civil and Structural Engineering Research Group, Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(2) Department of Civil and Environmental Engineering, Daelim University College, 29, Imgok-ro, Dongan-ku, Anyang-si, Gyeonggi-do, 13916, Republic of Korea
(3) The Graduate School of Construction Engineering, Chung-Ang University, 84, Huksuk-ro, Dongjak-ku, Seoul, 06974, Republic of Korea

ABSTRACT: Bézier extraction based isogeometric finite element analysis method coupled with a new hybrid type higher-order shear deformation theory (HSDT) is presented for the static bending and buckling analysis of functionally graded carbon nanotube reinforced composite (FG-CNTRC) plates. By mapping non-uniform rational B-spline basis functions to Bézier element in the forms of Bernstein polynomial basis via the Bézier extraction operator, the isogeometric analysis (IGA) can be implemented in the conventional finite element (FEM) framework. This study focuses on the introduction of the Bézier extraction based IGA combined with the HSDT for the static analysis through the formulation and implementation of the second-order derivatives of the Bézier element basis functions, which has hardly been attempted in the open literature. Compared to the conventional FEM based on first-order shear deformation theory, the present IGA method based on the HSDT surmounts the shear locking without exploiting the shear correction factor. The proposed isogeometric approach is thus believed to be more accurate and effective and achieves higher convergence as the polynomial order increases. Performance accuracy of the Bézier extraction based isogeometric approach is first evidenced by comparing the computed results with the reference solutions, followed by the illustrative examples to further explore the flexural and buckling behavior of FG-CNTRC plates with various reinforcement patterns.


ABSTRACT: The estimation of the critical buckling loads and eigenfrequencies are among the most common problems of mechanical engineering. These parameters are very important measures to avoid the loss of stability of the designed structures. In this work a progressive analytical model of doubly curved shells will be presented and applied to a delaminated spherical shell. The equations are derived using an improved version of the Sanders shell theory and the System of Exact Kinematic Conditions (SEKC). The solution method is based on the Lévy formulation. With this method the governing partial differential equation (PDE) can be reduced to an ordinary differential equation (ODE) with the use of Fourier-series. The resulting set of equations are solved using a variant of the state-space method which is able to solve systems with non-constant system matrix.

Tao Liu (1), Ailun Wang (1,2), Qingshan Wang (2) and Bin Qin (3)
(1) Light Alloy Research Institute, Central South University, Changsha, 410083, PR China
(2) State Key Laboratory of High Performance Complex Manufacturing, Central South University, Changsha, 410083, PR China
(3) Key Laboratory of Traffic Safety on Track, Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha, 410075, PR China
ABSTRACT: The wave based method (WBM) is used to analyze the free vibration characteristics of functionally graded material (FGM) cylindrical shell with arbitrary boundary conditions. The motion relationship is described by the first-order shear deformation shell theory (FSDST). The displacement components and transverse rotations are expressed as wave function expansions. In accordance with the dynamic relationship, the final governing equation and global matrix are assembled by incorporating the boundary conditions. The natural frequency of the system is obtained by solving the determinant of the global matrix. By comparing the results with those in the literature, the validity of the proposed method is verified. In addition, the influences of power-law exponents and boundary conditions on natural frequencies are analyzed. The effects of geometric parameters including the ratio of thickness to radius and the ratio of length to the radius on natural frequencies are discussed. The purpose of this paper is to demonstrate the ease of application of the WBM for the free vibration of FGM cylindrical shells with arbitrary boundary conditions. Furthermore, the advantage of the WBM are: (1) the global matrix is easy to construct; (2) different boundary conditions can be conveniently adjusted; (3) it is with high computational efficiency and precision.

Jiafeng Song (1), Shucai Xu (2), Shengfu Liu (1), Han Huang (2) and Meng Zou (1)
(1) Key Laboratory for Bionics Engineering of Education Ministry, Jilin University, Changchun, 130022, China
(2) State Key Lab of Automotive Safety and Energy, Tsinghua University, Beijing, 100084, China

ABSTRACT: Thin-walled structures are widely used as strengthened parts or energy absorbers in vehicle bodies. Thus, the collapse behaviors and mechanical properties of thin-walled columns under static and dynamic loads have drawn much attention. During vehicle side crash accidents, the contact parts of vehicles usually deform in the bending collapse mode. Thus, it is significantly important to investigate the collapse behaviors of these parts under the lateral impact. In this study, a new type of Bionic Column with Groove (BCG) was designed, with the inspiration from the lodging resistance features and lightweight of cornstalks. To understand the crashworthiness of BCGs under the lateral impact, we first experimentally established and validated the finite element models of BCGs and Circular Column (CC) under the lateral loading. The simulations agreed well with the experimental tests. Then, the crashworthiness of CC and the BCG were compared, and BCG2-90 outperformed normal CC in specific energy absorption (SEA), bending strength (BS) and crushing force efficiency (CFE). Parametric analyses showed the parameters of the bionic groove significantly affected the crashworthiness of BCG2-90. Finally, a response surface method showed the SEA, BS, and CFE of the optimal design increased by 93.10%, 50.96%, and 15.05% compared with CC respectively. Moreover, the mass reduction relative to CC was 2%. The results from the optimization demonstrate BCG is superior over CC in overall crushing behavior under the lateral impact.


ABSTRACT: The ring on ring (ROR) bending test is an ASTM standard (C1499) for characterizing the equibiaxial flexural strength of ceramics. This simple test protocol induces biaxial flexure by applying an out of plane uniaxial load via a small loading ring, to a plate or disc shaped specimen, simply supported on a larger ring. The main objective of this paper is to apply this test method to analyze the biaxial flexural failure of woven fabric composite plates. Ring on ring bending tests are conducted on square shaped plate specimens of epoxy/carbon plain woven composites, until failure. Experiments reveal interesting similarities and differences when compared to ceramics. First it is seen that while for ceramics the bottom surface fractures under biaxial tension, for woven composites the top surface fractures under biaxial compression. The failure pattern however, is similar to ceramics, and consists of several radial kink bands which initiate near the center and propagate outwards towards the specimen edges. Subsequent numerical stress analysis of the test reveals that the stress state in the region of the plate encompassed by the loading ring is almost exactly equibiaxial. This is primarily because the test method induces pure bending and because the two in-plane principal moduli are equal to each other, and much larger than all the other moduli. This implies near axisymmetry of the stress state despite material orthotropy. This aspect is seen to enable a simple determination of the biaxial flexural strength using the in-situ measured principal strains. It also implies that this biaxial flexural strength could be a good
approximation of the equibiaxial compressive strength for the woven composite, directly measuring which is usually a challenging task. Conditions for the suitability of this test method are explored via further numerical modeling.

Nan-ting Yu (1,2), Boksun Kim (2), Long-yuan Li (2), Wei-jian Hong (1) and Wei-bin Yuan (1)
(1) College of Architecture and Civil Engineering, Zhejiang University of Technology, Hangzhou, 310023, PR China
(2) School of Engineering, Computing and Mathematics, University of Plymouth, Plymouth, PL4 8AA, UK


ABSTRACT: Thin-walled channel beams are easily punched with circular holes on the web to allow the access for services such as plumbing pipes and electric wires. The presence of the holes can alter the stress distribution in the member and reduce the cross-sectional property. Consequently, it changes its buckling mode. Since perforated cold-formed steel beams are usually placed between main structural frame and corrugated roof, the most common loading case is the uniformly distributed transverse load. Recent work by Chen and Li has given the solution for distortional buckling of channel-, zed- and sigma-sections subject to the uniformly distributed transverse load. This paper is an extension of Chen and Li’s research to explore the distortional buckling behaviour of perforated cold-formed steel beams with holes. The effect of perforations on the critical stress is evaluated. A new model is deduced to predict the critical stress of distortional buckling by reducing the stiffness of the vertical spring. The Rayleigh-Ritz method is used to solve eigenvalue problems. In order to validate the analytical model, finite element analyses have been performed by using ANSYS. When the beam is longer than 3500 mm, the critical stress computed from the analytical model matches well with the critical stress acquired from the finite element analyses.


ABSTRACT: A novel semi-analytical method is presented for buckling analysis of stiffened laminated composite plates with rotationally-restrained edges and under compression and in-plane shear loading. The equivalent model with variable stiffness for stiffened plates is developed, and the Heaviside function is uniquely used to establish the variable stiffness of the stiffened plates along two orthogonal directions. The characteristic equation based on the governing equations of stiffened plates is solved by the Galerkin method. Buckling behavior of stiffened laminated composite plates is obtained and compared with those from both the real geometry and equivalent models by numerical finite element method. Accuracy of the present semi-analytical method is also verified by comparing its predictions with available solutions in literature. A parametric study is conducted to evaluate effects of stiffener geometry, load parameter, and edge rotationally-restrained spring stiffness on buckling behavior of stiffened plates. Finally, practical application of the present semi-analytical method is demonstrated, considering the cross-sectional geometries and material properties of stiffeners, number of stiffeners, and buckling behavior of stiffened plates.

Feng Zhou (1,2) and Ben Young (3,4)
(1) State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University, Shanghai, 200092, China
(2) Department of Structural Engineering, Tongji University, 1239 Siping Road, Shanghai, 200092, China
(3) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China
(4) Formerly, Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, China


ABSTRACT: This paper describes an investigation of web crippling behaviour of aluminium alloy plain and lipped channels with flanges restrained. A total of 340 data is presented that include 52 test results and 288 numerical results. A series of tests was conducted on plain and lipped channels fabricated by extrusion using
6063-T5 and 6061-T6 heat-treated aluminium alloys under end-two-flange (ETF) and interior-two-flange (ITF) loading conditions. The concentrate loads were applied by means of bearing plates. The flanges of the channels were either bolted (fastened) to one or two bearing plates. A finite element model was developed and verified against the experimental results. Geometric and material non-linearities were included in the finite element model. It was shown that the finite element model closely predicted the web crippling strengths and failure modes of the tested specimens with flanges restrained. Hence, the finite element model was used for an extensive parametric study of cross-section geometries, and the web slenderness value ranged from 24.0 to 207.3. The test results and the web crippling strengths predicted from the finite element analyses were compared with the design strengths obtained using the American, Australian/New Zealand and European specifications for aluminium structures. A unified web crippling equation with new coefficients for aluminium alloy channels with flanges restrained under ETF and ITF loading conditions is proposed in this study. Since two failure modes of web buckling and web yielding were also observed in the aluminium plain and lipped channels with flanges restrained, design rules of web crippling strengths are also proposed by considering the lesser of the web buckling strength and web yield strength.


ABSTRACT: In this paper, an equivalent damage model is proposed to quickly predict the compression after impact (CAI) strength of composite laminates and stiffened panels. Low-velocity impact (LVI) and CAI tests at various energy levels are carried out on laminates. Based on the measured impact damage sizes, the model simplifies the damage area into concentric circles with different stiffness and strength properties by adopting the soft inclusion method. Progressive failure analysis and virtual crack closure technique (VCCT) are used to simulate the intra-laminar and inter-laminar failure of impacted laminates under axial compression in commercial finite element software ABAQUS. The predicted failure modes and CAI strength of laminates are in good agreement with the experiment results from this paper and the literature at various impact energies, which proves the validity of the model. Whilst the numerical model achieves high computational efficiency, the effect of mass scaling on computational efficiency and accuracy is evaluated, which provides a reference for the parameter choice in engineering application. The model is further applied to predict the compressive failure load of the stiffened composite panel with skin bay impact damage as a practical application, showing this modelling approach is also suitable to composite structures.

Jialin Liu (1), Longhe Xu (1) and Zhongxian Li (2)
(1) School of Civil Engineering, Beijing Jiaotong University, Beijing, 100044, China
(2) Key Laboratory of Coast Civil Structure Safety of China Ministry of Education, Tianjin University, Tianjin, 300072, China

ABSTRACT: A new type of steel plate shear wall with self-centering energy dissipation braces (SPSW-SCEDB) was developed. Validation tests of the wall plate and the pre-pressed spring self-centering energy dissipation (PS-SCED) braces were conducted and a single-bay, single-story, 1:3-scale SPSW-SCEDB specimen was designed, fabricated, and tested under cyclic loadings. The results demonstrated that the SPSW-SCEDB exhibited a stable flag-shaped hysteretic response with high initial stiffness, appreciable ductility, and excellent self-centering and energy dissipation capabilities due to the synergistic effects of the wall plate and the PS-SCED braces. The proposed theoretical equations of the compressive force of the wall plate, the ultimate lateral load capacity, and the remaining restoring force of the SPSW-SCEDB were verified. The PS-SCED braces reduced the stiffness degradation of the wall plate and improved the lateral force resistance and the stability of the SPSW-SCEDB system. The wall plate provided more energy dissipation than the PS-SCED braces. The remaining restoring force of the PS-SCED braces should be as small as possible to maximize the energy dissipation of the PS-SCED braces while ensuring that it overcomes the compressive force of the wall plate.
ABSTRACT: FRP tube could serve as formwork in new constructions and the square cross-section is convenient for connections. This paper presents an experimental and theoretical study on seawater sea sand concrete (SWSSC)-filled glass/carbon/basalt FRP square hollow section (SHS) stub columns and beams. FRP SHS includes fibres oriented in $\pm 15^\circ$, $\pm 40^\circ$ and $\pm 75^\circ$ with respect to the longitudinal axis so that the hoop and axial strengths are comparable. Both unfilled FRP SHS and SWSSC-filled FRP SHS were tested under axial compressive, three-point or four-point bending loads. SWSSC-filled FRP columns failed by FRP rupture, whereas the failure mode for beams was the crushing of compressive flanges. In this paper, the stress-strain behaviour of columns and moment-strain curves of beams were discussed and compared to the corresponding SWSSC-filled stainless steel (SS) SHS specimens. It was found that existing stress-strain models, which were originally derived for rectangular concrete confined by FRP wrap, cannot precisely capture the stress-strain response of SWSSC-filled FRP columns. Existing models are improved to more accurately predict the ultimate axial strains and stress-strain relationship. A theoretical model is proposed to estimate the moment capacity of SWSSC-filled FRP beams with reasonable accuracy.

Y.M. Wang (1,2), Y.B. Shao (1), C. Chen (1) and U. Katwal (2)
(1) School of Civil Engineering and Architecture, Southwest Petroleum University, Chengdu, 610500, PR China
(2) Centre for Infrastructure Engineering, Western Sydney University, Penrith, NSW, 2751, Australia


ABSTRACT: To improve the resistance of I-girder with concrete-filled tubular flanges and flat-plate web to web shear buckling, corrugated plate is used to replace the conventional flat-plate web to produce a new composite I-girder. To investigate the resistance improvement of the new composite I-girder, i.e., with concrete-filled tubular flanges and corrugated web, experimental tests are currently carried out. Two composite I-girder specimens with flat-plate and corrugated webs, respectively, are designed and tested. Both specimens have a short-span and are subjected to shear action through applying a three-point loading at the mid-span. The test results indicate that no member global buckling occurs for the I-girders both with flat-plate web and with corrugated web attributed to the larger out-of-plane flexural stiffness of the concrete-filled tubular flanges. The composite I-girder with flat-plate web fails due to shear buckling of the web. Because the resistance of the corrugated web to shear buckling is higher, yielding strength, rather than shear buckling of the web, is observed in the composite I-girder with corrugated web. Such different failure modes cause the I-girder specimen with corrugated web to have a much higher load carrying capacity.

M. Javani (1), Y. Kiani (2) and M.R. Eslami (1)
(1) Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran
(2) Faculty of Engineering, Shahrekord University, Shahrekord, Iran


ABSTRACT: An analysis on thermal buckling of composite laminated annular sector plates reinforced with the graphene platelets is examined in this research. It is assumed that the graphene platelets fillers are randomly oriented and uniformly distributed in each ply of the composite media. Effective elasticity modulus of the nanocomposite media is extracted utilizing the modified Halpin-Tsai procedure which takes into account the size effects of the graphene fillers. Using the von Kármán type of geometrical nonlinearity and first order shear deformation plate theory, the governing equilibrium equations for the buckling of nanocomposite plates in sector shape under uniform temperature rise are established. Stability equations are obtained using the adjacent equilibrium criterion and solved by means of the generalized differential quadrature method. Numerical examples are given to study the effects of boundary conditions, weight fraction of the graphene platelets, and distribution pattern of the graphene platelets on critical temperature and the fundamental buckled shapes.
Results represent that, with introduction of a small amount of graphene platelets into the isotropic matrix of the composite media, the critical buckling temperature of the plate may be enhanced.

Xiaofei Cao (1,2), Dengbao Xiao (1,2), Ying Li (1,2), Weibin Wen (3), Tian Zhao (1), Zihao Chen (1,2), Yongbo Jiang (1,2) and Daining Fang (1,2)
(1) Beijing Key Laboratory of Lightweight Multi-functional Composite Materials and Structures, Institute of Advanced Structure Technology, Beijing Institute of Technology, Beijing, 100081, PR China
(2) State Key Laboratory of Explosion Science and Technology, Beijing Institute of Technology, Beijing, 100081, PR China
(3) School of Civil Engineering, Central South University, Changsha, 410083, PR China

ABSTRACT: Dynamic compression properties of the modified rhombic dodecahedron (RD) lattice structures were investigated by using a Split Hopkinson Pressure Bar (SHPB) system. All the deformation processes were recorded and a digital image correlation (DIC) technique was employed to analyse the strain distribution during the compression process. Experimental results indicated that the modified lattice structure showed better compressive strength, plateau stress and energy absorption when compared with the original one under both quasi-static and dynamic loading conditions. The effect of the shape parameter on the deformation mechanisms of the RD lattice structure was discussed, where three different deformation modes were observed. Finite element analysis was also conducted to simulate the dynamic response of the modified lattice structure. The finite element results are in good agreement with the experimental results. Then, a mode classification map was plotted and discussed based on the numerical results.


ABSTRACT: This paper focuses on the development of beam-column flexural stiffness reduction factor ($\tau_{MN}$) applicable to the in-plane stability design of stainless steel beam-columns and frames with compact cold-formed square and rectangular hollow sections. The proposed $\tau_{MN}$ accounts for the deleterious influence of material non-linearity, residual stresses and member out-of-straightness. The use of a Geometrically Non-linear Analysis (GNA) with the proposed $\tau_{MN}$ eliminates the need for member buckling strength checks and thus, only cross-sectional strength checks are required. The proposed approach, aligned to AISC standards, is aimed at facilitating greater and more efficient use of stainless steel.

Two types of $\tau_{MN}$ are proposed: analytical and approximate. The analytical $\tau_{MN}$ accounts for the deleterious influence of material non-linearity, residual stresses and member out-of-straightness. The use of a Geometrically Non-linear Analysis (GNA) with the proposed $\tau_{MN}$ eliminates the need for member buckling strength checks and thus, only cross-sectional strength checks are required. The proposed approach, aligned to AISC standards, is aimed at facilitating greater and more efficient use of stainless steel.

Petr Hála (1), Michal Frydrýn (2), Petr Máca (3) and Radoslav Sovják (1)
(1) Experimental Centre, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29, Prague 6, Czech Republic
(2) Department of Forensic Experts in Transportation, Faculty of Transportation Sciences, Czech Technical University in Prague, Horská 3, 128 03, Prague 2, Czech Republic
(3) Institute of Concrete Structures, Technische Universität Dresden, Faculty of Civil Engineering, 01062, Dresden, Germany

ABSTRACT: Even though the number of deadly traffic incidents is decreasing, the proportion of motor vehicle crash deaths involving a collision with fixed objects is not. To address this issue, a novel load-bearing energy-absorbing system comprised of brittle blocks with thin-walled cellular structures is presented here, laying the foundation for the assessment of the system's crashworthiness. Six brittle hexagonal cellular structures were subjected to quasi-static and impact tests. The crushing process, force-displacement curves, and a wide range of indicators of crashworthiness were examined. Samples with different levels of crashworthiness were identified and several observations that could guide future crashworthiness design are given. Our findings show that relatively small changes in the design can lead to production of blocks with distinguishable levels of crashworthiness.

Jelena Dobrić (1), Jovana Ivanović (1) and Barbara Rossi (2,3)
(1) University of Belgrade, Faculty of Civil Engineering, Serbia
(2) University of Oxford, Department of Engineering Science, United Kingdom
(3) KU Leuven, Department of Civil Engineering, Belgium


ABSTRACT: In this paper, the structural stability of cold-formed stainless steel plain channel columns under axial compression is investigated. Reliable finite element models for channel section columns are first developed and validated against experiments conducted on stainless steel lipped channel specimens. This is followed by a parametric study in which columns made of austenitic, ferritic and duplex stainless steel are assessed. The considered cross-section classes and column lengths cover the entire range of global slenderness. The effects of material and geometrical nonlinearity are considered in the numerical analysis. The numerically generated data are then employed to evaluate the accuracy of the current European and Australian design codes EN 1993-1-4 and AS/NZS 4673 respectively, for predicting the flexural and flexural-torsional column buckling resistance. The results show a necessity to improve the current buckling curve used to predict the flexural buckling resistance of plain channel section columns, currently adopted in EN 1993-1-4, whose use may lead to unsafe predictions, especially for the austenitic grade.


ABSTRACT: This study investigates the ultimate shear strength of unstiffened slender web in prismatic tapered steel beams using newly proposed buckling coefficients raised in the preceding research conducted by the authors [1]. An experimental program is performed using three specimens that are selected to fail in shear without any significant flexural deformations. A three dimensional numerical finite element model is established considering both material and geometrical non-linearities. The finite element model is successfully calibrated to simulate the experimental tests. New procedures are proposed to predict the ultimate shear strength which is validated against the existing experimental results. The developed finite element models are used to expand the validation range of the proposed method to include the practical ranges within the relevant specifications limits.

Jiankun Yang (1), Claudio M. Paz (1), Segen F. Estefen (1), Guangming Fu (2) and Marcelo Igor Lourenço (1)
(1) Subsea Technology Laboratory, COPPE, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
(2) School of Petroleum Engineering, China University of Petroleum (East China), Qingdao, China


ABSTRACT: Combining both thermal insulation and structural strength in the core, sandwich pipes (SP) are a promising alternative for conventional single wall pipes in deep-water applications. The ultimate strength of SPs under external pressure has always been a major concern in the design process. An insightful understanding of the collapse pressure and post-buckling behavior of SPs is critical not only for safe application, but also for
optimized design. This paper and its companion paper present a comprehensive study on the collapse pressure of SPs with strain-hardening cementitious composite (SHCC).

Part 1 presents experiments investigating the collapse under external pressure of SPs composed of two steel tubes and the strain-hardening cementitious composite (SHCC) core. The experimental results were employed in correlation studies with the finite element model using the ABAQUS software; good agreement was reached. The proposed numerical model was used in a parametric study for simulating collapse in 6000 different practical configurations. The influence of the geometric parameters and material properties of the SP on its ultimate structural strength under external pressure and post-buckling behavior was systematically analyzed. The results revealed some interesting phenomena not previously reported. For example, assuming frictionless inter-layer conditions, the collapse pressure of an SP with an SHCC core decreases with increasing steel layer thickness. The reasons behind these phenomena were thoroughly discussed and the special behavior of an SP with an SHCC core subjected to external pressure is reported.

The results developed in this paper were utilized in Part 2: A suitable prediction equation, where different equation forms are evaluated and one prediction equation is recommended for the design of an SP with an SHCC core.


**ABSTRACT:** A comprehensive study on the collapse pressure and post-buckling behaviour of a sandwich pipe (SP) with a core of strain-hardening cementitious composite (SHCC) was carried out in Part 1 of two companion papers. The results in the Part 1 paper show that an SP with an SHCC core has a different collapse mechanism from an SP with a polypropylene core. Because of its weak inter-layer adhesion and a relatively hard core, the collapse pressure and the characteristic response of an SP with an SHCC core are more influenced by its strongest layer than by the summed strength of all its layers. Since this behaviour has never been reported before, current prediction equations for the collapse pressure of SP systems cannot capture the special behaviour of an SP with an SHCC core. Therefore, utilizing the available prediction equations for an SP with an SHCC core may lead to unreliable estimates. This Part 2 paper is dedicated to addressing the challenge by proposing a suitable prediction equation.

Based on the extensive simulation results carried out by the numerical model verified by experiments in the Part 1 paper, supervised machine learning techniques were applied to support the regression of different equation forms, which come from three sources: (a) equation forms proposed by previous researchers, (b) equation forms found by the automatic machine learning software EUREQA, and (c) equation forms proposed by us. Further, the performances of the equation forms in predicting accurate results for the collapse pressure were compared. Based on the comparative performances and accuracy, an equation was recommended for the design of SPs under external pressure.

Zaid Al-Azzawi (1), Tim Stratford (2), Michael Rotter (2) and Luke Bisby (2)
(1) College of Engineering, University of Anbar, P.O. Box 55/ Ramadi, 55431, Baghdad, Anbar, Iraq
(2) School of Engineering, The University of Edinburgh, AGB Building, The King’s Buildings, Mayfield Road, Edinburgh, EH9 3JL, UK


**ABSTRACT:** This paper presents the theoretical part of an experimental study aimed for proposing a novel FRP strengthening technique to strengthen the webs of steel plate girders against breathing fatigue reducing the critical stresses and consequently increasing the life expectancy of the bridge. The proposed technique is economic, easy to install and is also designed for increasing the ultimate capacity of the strengthened specimens by up to 88% while maintaining the typical ductile shear failure of the steel plate girders, which is something not common with other strengthening techniques.

A non-linear finite element model is developed and an extensive parametric study has been performed to propose a new design method for shear buckling of the new composite section including a simplified approach to determine the orthotropic mechanical properties of the proposed FRP section.
ABSTRACT: In this paper, a parameter-free optimization method is presented for optimizing the cross-sectional shape of thin-walled structures, which are often demanded at the early stage in structural designs. The thin-walled cross section is minimized subject to constraints of sectional properties including torsion constant, moment of inertia, and shear center. The optimization problem is formulated as a shape optimization problem, and a boundary integral equation method is employed to solve the problem. The results show that the proposed method is effective and efficient in optimizing the cross-sectional shape of thin-walled structures.
of area, centroid and shear center of the cross section. The problem is formulated as a distributed shape optimization problem, and the shape gradient function is derived using the Lagrange multipliers and the material derivative method. The H1 gradient method, which was proposed as a gradient method in a Hilbert space, is applied to determine the smooth optimal shape. The constraint conditions are satisfied using a linearised constraint equation. The validity of this parameter-free method is verified through several design examples for obtaining the optimal shape of a thin-walled cross section under the constraints of sectional properties.


ABSTRACT: The buckling behavior of the windings of pulsed magnets is analyzed systematically for the first time. The buckling analysis of a pulsed magnet is a complicated problem from the material properties to the geometry and the Lorentz force load. Each layer of the magnet is a composite of a helical conductor winding and a layer of orthotropic fiber. Pulsed magnets are compressed axially and expanded radially simultaneously by the Lorentz force, which is distributed in the whole magnet. The structural properties of the windings are discussed by the linear buckling analysis at first, where the Lorentz force is replaced by axial compressed force applied at the ends of cylinders. Then a more comprehensive analysis that includes all the above factors is presented by the nonlinear buckling model in the ANSYS software. The results show that pulsed magnets have a high risk of buckling. The results also indicate many other valuable conclusions, and even some conclusions will subvert the traditional cognition for the pulsed magnet designing. All these results will promote the pulsed magnet technology, and lay the foundation for the theory of pulsed magnets of ultra-high field.

H. Nikkhah (1), A. Baroutaji (2), Z. Kazancı (3) and A. Arjunan (2)
(1) Faculty of Engineering, School of Mechanical Engineering, University of Mohaghegh Ardabili, Ardabil, Iran
(2) Faculty of Science and Engineering, School of Engineering, University of Wolverhampton, Telford, UK
(3) Advanced Composites Research Group, School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast, UK

ABSTRACT: Mimicking anatomical structures like bone can aid in the development of energy absorbing structures that can achieve desirable properties. Accordingly, this study presents the analysis of tubular nested designs inspired by Haversian bone architecture. Based on this design philosophy, a total of 18 nested tube designs with various geometrical configurations were developed. Within each design, the effect of reinforcement walls on the crashworthiness performance is also analysed. A finite element model, validated using quasi-static experimental tests, was used to study the crashworthiness performance and progressive deformation of the nested system. Based on the results, a multi-criteria decision-making method known as Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) was employed to determine the most suitable cross-section that features high energy absorption and low impact force. Consequently, the study identified a nested tube configuration that exhibits superior crashworthiness and high energy absorbing characteristics. The bio-inspired design methodology presented in this study allows the exploitation of variable nested geometries for the development of high-efficiency energy absorbing structures.


ABSTRACT: This paper aims to better understand the influence of longitudinal web stiffeners in the structural behavior of cold-formed steel purlins. A set of specimens with stiffened web and plain web cross-sections were tested on predominantly shear, combined bending and shear, and bending only. Numerical analyses carried out in CUFSM and ANSYS investigated the buckling behavior of the sections, allowing the determination of elastic
critical stresses and the calculation of the resistance for the tested specimens by Direct Strength Method (DSM). Numerical results showed that the intermediate web stiffeners improve the buckling strength in loading cases of pure bending and pure shear. Experimental and numerical data were used to evaluate the interaction between bending moment and shear force, and showed that the circular interaction diagram was conservative and the results were closer to the trilinear interaction diagram. The comparison between experimental data and DSM predictions demonstrated that DSM provides accurate estimates for shear and flexural strengths of purlins with stiffened web cross-section.

Pouya Taraghi (1), Hossein Showkati (1) and Tadeh Zirakian (2)
(1) Department of Civil Engineering, Urmia University, Urmia, Iran
(2) Department of Civil Engineering and Construction Management, California State University, Northridge, CA, USA

ABSTRACT: Thin-walled conical shells are extensively used in a variety of engineering applications. The major concern in the design of these thin-walled structures is the buckling failure. One potential strategy for improving the buckling stability performance of conical shells may be the employment of carbon fiber reinforced polymer (CFRP) composite materials for reinforcement purposes. On this basis, a detailed numerical study is conducted on the buckling performance of CFRP-strengthened conical shells under uniform external pressure and reported in this paper. To this end, numerous conical shell models with different slenderness ratios, strengthened circumferentially and meridionally at different locations and directions using CFRP stripes with 0, 45, and 90 fiber orientations are investigated through linear and nonlinear buckling analyses using ABAQUS finite element software. The results and findings of this research are indicative of effectiveness of the reinforcing CFRP laminates in increasing the stiffness and buckling strength of such structures. Specifically, the circumferential reinforcement of the bottom third region using [45/90] reinforcing CFRP stripes is found to be the superior approach for improving the buckling stability performance of conical shells.

G. Tiwari (1), N. Khaire (1), M.A. Iqbal (2), P.K. Gupta (2) and N.K. Gupta (3)
(1) Department of Mechanical Engineering, Visvesvaraya National Institute of Technology, Nagpur, 440010, India
(2) Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, 247667, India
(3) Supercomputer Education and Research Centre, Indian Institute of Science, Bangalore, 560012, India

ABSTRACT: The ballistic resistance and energy absorption characteristics of the thin hemispherical shells were evaluated against ogive and blunt nosed projectile impact with varying span and configuration of the shell. The span diameter of the 1100-H12 aluminium shell was varied as 68, 100, 150 and 200 mm whereas the configuration of the shell was varied as monolithic and double layered (0.5/0.5, 0.33/0.67 and 0.67/0.33) which was hit at the crown by 19 mm diameter, 50.8 mm length and 52.5 g mass projectile. Three dimensional numerical simulations were carried out through commercially available finite element code ABAQUS. The accuracy of the numerical model was validated by comparing the numerical result of monolithic shell with experimental result conducted through the pressure gun. Numerical simulation result were further employed to extract the total energy absorption in plastic deformation by computing the strain energy in stretching in polar, radial, elevation and shear directions of the shell by using a user defined programme written in python. The influence of projectile nose shape, incidence velocity of the projectile and configuration of the hemispherical shell on the mechanics of failure, ballistic resistance, ballistic limit and energy dissipation characteristics were studied. The double layer hemispherical target showed better performance against ogive nosed projectile however opposite behaviour was observed against blunt nosed projectile.

Daisuke Shiomitsu (1) and Daisuke Yanagihara (2)
(1) Department of Maritime Engineering, Graduate School of Engineering, Kyushu University, Japan
(2) Department of Marine Systems Engineering, Faculty of Engineering, Kyushu University, Japan

ABSTRACT: Ring-stiffened cylindrical shells are often used in offshore and submergible structures, it is important for the structural safety to estimate the buckling strength of those under extremely high water pressure. Although the buckling strength can be accurately calculated using the finite element analysis (FEA), the estimation by more easy way is required at an initial stage of the structural design. This paper proposes two formulas for the local shell and stiffener-tripping buckling strength of the ring-stiffened cylindrical shells under external pressure. One can estimate the tripping buckling strength only and is derived assuming the tripping buckling as buckling of only the flange-beam supported by springs and considering effects of the cylindrical shape and torsional stiffness which are not included in a conventional formula. The other can estimate both the shell and tripping buckling strength and is considered interaction of buckling deflection between a cylindrical shell and ring-stiffeners and influence of stresses acting on the web which are not included in conventional formulas. Based on the principle of minimum potential energy, the formula is derived using the functions to express the buckling deformation in the cylindrical shell and ring-stiffeners. The buckling strength estimated by the two proposed formulas is compared with that by existing conventional formulas and the finite element analysis, and this study discusses the influence of new considerations on the shell and tripping buckling strength. From the results, it is found that the second formula can deal with any buckling mode and has greatly high accuracy compared with other conventional formulas.


ABSTRACT: In this paper, the low-velocity impact of metal foam-filled circular tubes are investigated. Based on the quasi-static method, an analytical model is developed to predict the plastic behaviors of the fully clamped metal foam-filled circular tube under the low-velocity impact. Effects of local denting and filled foam strength on the overall bending of the foam-filled tube are considered. Finite element analysis are conducted to study the dynamic response of clamped metal foam-filled circular tube. Good agreement is achieved between the analytical and numerical results. The effect of the filled foam on the dynamic response of the foam-filled tube is discussed. It is demonstrated that the present analytical model is valid to predict the low-velocity of foam-filled circular tubes.

Y.M. Wang (1,2), Y.B. Shao (1), C. Chen (1) and U. Katwal (2)
(1) School of Civil Engineering and Architecture, Southwest Petroleum University, Chengdu, 610500, PR China
(2) Centre for Infrastructure Engineering, Western Sydney University, Penrith, NSW, 2751, Australia

ABSTRACT: Currently, finite element (FE) model is built for analyzing the shear performance of I-girder with concrete-filled tubular flanges (CFTFs) and corrugated web (CW). The accuracy of the built FE model is verified through comparison with experimental results. The failure mechanism of the composite I-girder is investigated from the FE simulations. Based on such failure mechanism, theoretical analyses are carried out to deduce equations for predicting the flexural strength of the CFTFs and the shear yielding strength of the CW. The presented equations are then evaluated, to ensure their accuracy and reliability, through comparisons with experimental results and a parametric study of 30 FE models. From the presented equations, it is found that the shear stress still distributes uniformly along the web height and the bending moment is completely sustained by the CFTFs. However, it is not suitable to assume that all of the shear force is sustained by the corrugated web because the CFTFs also sustain about 12% of the shear force.

Hamed Ahmadi (1), Gholamhossein Liaghat (1,2) and Sahand Chitsaz Charandabi (3)
(1) Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran
(2) Department of Mechanical and Automotive Engineering, Kingston University, London, United Kingdom
governing equations. Moreover, Zener mathematical model has been used for the description of the viscoelastic function through the plate thickness. The first functionally graded and viscoelastic phases. The shear moduli and complex Young’s of polymeric foam are propagation through a plate made of polymeric foam. The polymer material,”

ABSTRACT: This study presents the functionally graded viscoelastic model for calculating the wave propagation through a polymeric foam plate using the mathematical model of functionally graded viscoelastic (FGV) material”, Article 106466, Thin-Walled Structures, Vol. 148, March 2020, https://doi.org/10.1016/j.tws.2019.106466

Pedro B. Dinis (1), Dinar Camotim (1), Alexandre Landesmann (2) and André Dias Martins (1)
(1) CERIS, ICIST, DECivil, Instituto Superior Técnico, Universidade de Lisboa, Portugal
(2) Civil Engineering Program, COPPE/UF RJ, Federal University of Rio de Janeiro, Brazil


ABSTRACT: This paper reports the latest results of an ongoing investigation on the accuracy of the codified Direct Strength Method (DSM) global strength curve in predicting the ultimate strength of cold-formed steel columns failing in flexural-torsional modes. The first part of the paper is devoted exclusively to fixed-ended columns and continues recent work by the authors [1, 2] on the improvement of the flexural-torsional failure load estimation, in the moderate or high slenderness ranges - it is shown that the use of a novel set of strength curves, dependent on a cross-section normalised geometric parameter (involving the area, major and minor moments of inertia, and warping constant), leads to excellent failure load predictions, eliminating the large scatter stemming from the codified design curve and improving the DSM-based design approach proposed in [2]. The second part of the paper aims at extending the investigation to columns with other support conditions, namely three types of pinned supports, all fixed with respect to torsion and having warping prevented; end cross-sections attached to rigid plates resting on spherical or cylindrical hinges (i.e., pinned with respect to major and/or minor-axis flexure). Initially, a parametric study is performed, aimed at gathering failure loads concerning columns (i) with the cross-section shapes considered earlier (plain channels, unstiffened and stiffened lipped channels, return lipped channels, hat-sections and rack-sections), (ii) with various geometries (cross-section dimensions and lengths) and (iii) covering a wide slenderness range. These failure load data are then used to assess the quality of their estimates provided by the codified global DSM strength curve and by the strength curve set developed for fixed-ended columns. It is found that neither of them yields consistently good failure load estimates, which prompts (i) an in-depth comparative study on the elastic post-buckling strength of fixed-ended and pin-ended columns, and (ii) the proposal of modifications that lead to an efficient failure load prediction for the pin-ended columns - although the failure load set obtained in this work is necessarily limited, the fact that their predictions by the proposed DSM global design curves (i) exhibit very high quality and (ii) clearly outperform those yielded by the current design curve provides strong encouragement to search for further experimental and numerical validation.


ABSTRACT: This study presents the functionally graded viscoelastic model for calculating the wave propagation through a plate made of polymeric foam. The polymeric foam is a type of material that has both functionally graded and viscoelastic phases. The shear moduli and complex Young’s of polymeric foam are frequency dependent. Additionally, elasticity modulus and mass density vary with the change of distribution function through the plate thickness. The first-order shear deformation theory has been applied for deriving the governing equations. Moreover, Zener mathematical model has been used for the description of the viscoelastic
behavior of plate made of polymeric foam. This structure is excited by a plane wave with two elevation and azimuth incident angles. Due to the lack of researches in the vibroacoustic field of these materials, the results have been compared with those from other researchers for an isotropic material. Finally, the effects of various physical, geometrical, and environmental parameters on the wave propagation of polymeric foam plates have been analyzed. It has been demonstrated that sound transmission loss increases by enhancing material constant and decreasing the power-law index. Moreover, the obtained results show that the sound transmission loss for the functionally graded viscoelastic is enhanced in comparison with elastic, viscoelastic, and functionally graded material with lower masses.

Wenxiang Li (1), Wei Gao (2), Pan Xie (1) and Suiyin Chen (1)
(1) College of Water Conservancy and Civil Engineering, South China Agricultural University, Guangzhou, 510642, China
(2) Centre for Infrastructure Engineering and Safety (CIES), School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW, 2052, Australia
“A simplified-but-general nonlinear thin-walled beam finite element model with independent interpolated axial displacement”, Article 106467, Thin-Walled Structures, Vol. 148, March 2020,
https://doi.org/10.1016/j.tws.2019.106467
ABSTRACT: This paper presents a study performed on the simplified thin-walled beam finite element model that takes into account the effects of shear deformation and higher-order axial displacement. Without using the torsion-related warping function derived from classical theories, the axial displacement field over the cross-section is constructed by using independent Lagrange interpolation polynomials. Then, the effect of shear stress distribution can be reasonably included and the beam model is dedicated to thin-walled members with arbitrary cross-section. The expressions of the Green-Lagrange strain components are derived. The element elastic stiffness matrix and geometrical stiffness matrix are obtained to perform static and buckling analyses. Numerical examples are employed to demonstrate the effectiveness of the proposed model and discuss the probable accuracy-loss from different deformation assumptions and nonlinear strain definitions. As revealed by the results, the transverse shear deformation and higher-order axial displacement could exert significant effects on solution accuracy for static and buckling analyses under the circumstances of small slenderness and unsymmetrical cross-section. In addition, the nonlinear strain terms related to torsion and quadratic terms of the transverse shear deformation are found to be crucial to stability analysis, for which they ought to be included in a simplified strain definition.

Warlley Soares Santos (1), Alexandre Landesmann (1) and Dinar Camotim (2)
(1) PEC/COPPE/UFRJ, Programa de Engenharia Civil, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil
(2) CERIS, DECivil, Instituto Superior Técnico, Universidade de Lisboa, Portugal
“Distortional strength of end-bolted CFS lipped channel columns: Experimental investigation, numerical simulations and DSM design”, Article 106469, Thin-Walled Structures, Vol. 148, March 2020,
https://doi.org/10.1016/j.tws.2019.106469
ABSTRACT: This paper reports the results of an experimental investigation and numerical simulations concerning the influence of bolted end support conditions on the failure loads of cold-formed steel lipped channel columns buckling and failing in distortional modes, as well as on their prediction by means of the Direct Strength Method (DSM). The end supports consist of pairs of cylindrical high-strength bolts with hexagonal heads and nuts, which are inserted in standard-sized holes located at the intersections of the cross-section flanges with the minor principal centroidal axis (parallel to the web). After selecting the column geometries (cross-section dimensions and lengths) and yield stresses, the test set-up and procedure are described in detail, and the experimental results obtained are presented and discussed. Such results consist of initial imperfection measurements, equilibrium paths relating the applied load to key column displacements, deformed configurations (including the collapse mode) and failure loads. Next, those same experimental results are used to validate a previously developed shell finite model, which is subsequently employed to obtain additional numerical failure load data concerning the end-bolted columns under scrutiny. Then, attention is turned to assessing the merits of the available DSM column distortional design curves. Because it is concluded that these design curves clearly overestimate the failure load data obtained, new/modified strength curves are preliminarily proposed and shown to considerably improve the prediction quality (safety and reliability) of the
end-bolted column failure loads, thus providing motivation and encouragement to continue the search for an efficient DSM-based design approach for end-bolted columns failing in distortional modes.


ABSTRACT: Previous research has revealed shortcomings in the current Eurocode 3 (EC3) provisions for the design of semi-compact (Class 3) cross-sections. These shortcomings arise primarily from the lack of utilisation of partial plastification in bending, leading to a step in the design resistance function at the boundary between Class 2 and 3 cross-sections and an underestimation of the available capacity. This affects the accuracy of resistance predictions in bending and under combined loading, and applies at both cross-sectional and member level. To address this issue, the use of an elasto-plastic section modulus, which lies between the plastic and elastic section moduli, has been proposed and employed in the design of semi-compact I- and box sections. The aim of the present study is to develop new cross-section and member buckling design rules incorporating the elasto-plastic section modulus for semi-compact circular hollow sections (CHS), and to assess their accuracy against existing experimental and freshly generated numerical data. Firstly, an experimental database, consisting of previous cross-section and member buckling test results on steel CHS, was established. A comprehensive numerical simulation programme was subsequently carried out; in this programme, finite element (FE) models were developed, validated and used for parametric studies, where over 600 numerical structural performance data on semi-compact CHS were generated. New sets of cross-section and member buckling design expressions featuring elasto-plastic section properties were then proposed and assessed against the test and numerical data. The proposals were shown to offer improved accuracy and design efficiency over the elastic EC3 methods. The reliability of the proposed elasto-plastic design rules was then confirmed through statistical analyses in accordance with EN 1990, demonstrating their suitability for inclusion into the next revision of EN 1993-1-1.

Bo Zhang (1,2), Heng Li (1), Liulin Kong (3), Huoming Shen (2) and Xu Zhang (2)
(1) Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong, PR China
(2) Applied Mechanics and Structure Safety Key Laboratory of Sichuan Province, School of Mechanics and Engineering, Southwest Jiaotong University, Chengdu, PR China
(3) Faculty of Engineering, China University of Geosciences, Wuhan, Hubei, 430074, China

ABSTRACT: This paper proposes a strain gradient differential quadrature finite element method to analyze the size-dependent static and dynamic behaviour of Reddy-type micro-beams. This element has 6 of freedom per node and avoids the exploitation of shape functions. A sixth-order differential quadrature-based geometric mapping scheme is constructed to realize the higher-order continuity requirements of kinematic variables. And then, it is combined with the minimum total potential energy principle to derive the motion equation of a generic element. Afterwards, several numerical examples are provided to establish the validity of the developed element. Finally, we utilize this method to analyze the static bending, free vibration, and linear buckling characteristics of uniform and stepped micro-beams. Numerical results show that the current element has prominent convergence and adaptability advantages over the classical shape function-based element. Besides, the size-dependence of vibration and critical buckling mode shapes of micro-beams is demonstrated in the graphical form for the first time.

P. Phung-Van (1), Chien H. Thai (2,3), A.J.M. Ferreira (4) and T. Rabczuk (5)
(1) Faculty of Civil Engineering, Ho Chi Minh City University of Technology (HUTECH), Ho Chi Minh City, Viet Nam
(2) Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(3) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(4) Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, Portugal
(5) Institute of Structural Mechanics, Bauhaus-University Weimar, Germany

ABSTRACT: To provide reference solutions and results for structural and material design, nonlinear transient responses of porous functionally graded plate (PFGM) in hygro-thermo-mechanical environments are studied. Two different porous distributions through the thickness are considered. The material properties such as Young's modulus, Poisson's ratio and thermal conductivity are computed by a modified power law. The hygro-thermal effects are considered as nonlinear through the thickness of the plate. The geometrically nonlinear transient behaviors are expressed by adopting the von Kármán relations and solved by Newmark time integration scheme. Based on a combination between the third-order shear deformation theory (TSDT) and isogeometric analysis (IGA), discretize governing equations are approximated. These approaches achieve naturally any desired degree of continuity of basis functions, so that they are easy to fulfill the C-continuity requirement of the plate model. The formulations take into account the transverse shear deformation and account for the material properties at elevated moisture concentrations and temperature. The effects played by the moisture concentration, temperature rise, porous volume fraction, boundary conditions and thickness-to-length ratio are performed and results illustrate interesting dynamic phenomenon for PFGM in hygro-thermo-mechanical environments. With obtained results, the nonlinear characteristics of the proposed structure with porosities are based on physical parameters.

Zhanfeng Chen (1), Xuyao Li (1), Wen Wang (1), He Yang (1), Zongfu Guo (1) and Weiping Zhu (2)
(1) School of Mechanical Engineering, Hangzhou Dianzi University, Hangzhou, 310018, PR China
(2) Shanghai Key Laboratory of Mechanics in Energy Engineering, Shanghai Institute of Applied Mathematics and Mechanics, School of Mechanics and Engineering Science, Shanghai University, Shanghai, 200072, PR China


ABSTRACT: The cylindrical shell is a basic structure in transportation of dangerous goods, hydrogen storage, public safety, aerospace industries, nuclear and power engineering. The dynamic burst pressure of cylindrical shells is crucial to personal safety, environmental pollution and property damage. Based on average shear stress yield (ASSY) criterion, a novel equation is developed to predict the dynamic burst pressure of cylindrical shells. The ASSY criterion is a weighted average of the maximum shear stress and octahedral shear stress. Firstly, the non-uniform impact load is reduced to a parabolic load acting on the inner wall of cylindrical shells. The width of load is the same as the outer diameter of the cylindrical shell. And then, ASSY criterion is adopted to predict the dynamic burst pressure of cylindrical shells for the first time. In the end, the accuracy of our method is validated by comparing with the finite element method (FEM) under different pulse duration. The results indicate that our method can accurately predict the dynamic burst pressure of cylindrical shells under a non-uniform impact load. In addition, the ASSY criterion can be extended to solving dynamic problems with a high precision. Finally, our method can be used as a benchmark for approximate or numerical solutions. It is beneficial to assess the safety and integrity of cylindrical shells under a non-uniform impact load.

Lulu Zhang (1), Fangying Wang (1), Yating Liang (2) and Ou Zhao (1)
(1) School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
(2) School of Engineering, University of Glasgow, Glasgow, UK


ABSTRACT: The present paper describes an in-depth experimental and numerical investigation into the flexural responses and strengths of press-braked S690 high strength steel channel section beams bent about the minor principal axes in both the ‘u’ and ‘n’ orientations. The experimental study was performed on eight press-braked channel sections, and comprised twenty-four material flat and corner coupon tests, initial local geometric imperfection measurements, and twelve beam tests in the four-point bending configuration. This was followed by a complementary numerical modelling programme, where finite element models were firstly developed and validated against the test results and afterwards adopted for performing parametric studies to obtain an additional numerical data bank over a wide variety of cross-section geometric sizes. The acquired test and numerical data were then employed to evaluate the applicability of the Eurocode slenderness limits for welded and hot-rolled internal webs (in compression) and outstand flanges (in stress gradients) to their press-braked
counterparts, revealing that the Eurocode slenderness limits can be safely extended to cover the classifications of plate elements and cross-sections of press-braked S690 high strength steel channel section beams. Evaluation of the accuracy of the cross-section flexural strengths predicted from various design codes established in Europe, North America and Australia/New Zealand was also made, based on the test and numerical data. The results of the quantitative evaluation generally revealed that (i) all the examined design codes lead to overall conservative and scattered predicted cross-section flexural strengths for press-braked S690 high strength steel channel section beams, and (ii) the European code results in more precise design flexural strengths for beams with relatively stocky channel sections, but less accurate strength predictions for beams with relatively slender channel sections, compared to the North American and Australian/New Zealand standards.


ABSTRACT: This paper reports a study on the large amplitude nonlinear vibration of carbon nanotube-reinforced composite (CNTRC) laminated plates with negative Poisson's ratios in thermal environments. The constituent materials of CNTRCs are temperature-dependent and the plate is functionally graded (FG) in a piece-wise pattern in the thickness direction of plate. An extended Voigt (rule of mixture) model is adopted to quantify the CNTRC material properties of the laminated plate. The governing motion equations for the large amplitude vibration of FG-CNTRC laminated plates are based on the Reddy's third order shear deformation theory and the von Kármán-type kinematic nonlinearity framework, and the thermal effects and the reaction from elastic foundation are taken into account. The nonlinear solution of the motion equation can be obtained by applying a two-step perturbation approach. The effects of material property gradient, the temperature variation, stacking sequence as well as the foundation stiffness on the vibration characteristics of CNTRC laminated plates are examined and discussed in depth through a parametric study. The results show that negative Poisson's ratio has a significant effect on the linear and nonlinear vibration characteristics of CNTRC laminated plates.

Antao Deng (1), Bin Ji (2), Xiang Zhou (1) and Zhong You (1)
(1) School of Aeronautics and Astronautics, Shanghai Jiao Tong University, Shanghai, China
(2) Shanghai Key Laboratory of Spacecraft Mechanism, Shanghai, China


ABSTRACT: Foldcores have been regarded as a promising alternative to the conventional honeycomb core in lightweight sandwich structures, especially in the aerospace sector. Current research on foldcores is mainly focused on the Miura pattern. However, the Miura-based foldcores provide only edge-based bonding interfaces to the skins, which may cause a weak core-skin bonding strength. In this paper, foldcores based on the generalized Resch patterns are researched, which can provide face-based bonding interfaces. The content of the paper is threefold. First, a generic geometric design method to generate the geometries of foldcores based on the generalized Resch patterns is proposed. Second, the finite element procedures to model foldcores under quasi-static compression and shear are developed and validated through experimental results. Third, a parametric study on the quasi-static mechanical properties of foldcores of different types and with different geometries is performed. It is shown that foldcores based on the hexagonal pattern have the highest peak stress and energy absorption capacity among the three types of generalized Resch patterns, and the multi-layered foldcore in general outperforms the single-layered counterpart. When compared with the Miura-based foldcores, the generalized Resch-based foldcores assume better performance in the energy absorption capacity.

Ziqi He (1,2), Bo Zou (2), Xuhong Zhou (1,2), Zhanke Liu (3) and Zhanjie Li (4)
(1) Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education, Chongqing 400045, China
(2) School of Civil Engineering, Chongqing University, Chongqing 400045, China
(3) School of Civil Engineering and Mechanics, Lanzhou University 743000, China
(4) Department of Engineering, SUNY Polytechnic Institute, Utica, NY, 13502, USA

ABSTRACT: The objective of this paper is to develop a systematical Direct Strength Method (DSM) design formulation with a design criterion that can properly identify the occurrence of the Local and Distortional (L/D) buckling interaction for cold-formed steel compressive members and thus predict the strength. Column tests provided clear evidence of the L/D interaction and revealed the difference between the L-D and D-L interactions depending on which one buckles first. By collecting all the experimental data of cold-formed steel columns related to the L/D interaction, the current DSM predictions are first evaluated. Then, a DSM-based interaction formulation with design criterion by replacing the pure mode prediction with the interaction prediction based on the identification of the design criterion is proposed. The accuracy of the proposed method is evaluated from all the collected data experiencing the L/D interaction. Moreover, the effectiveness of the design criterion in identifying the interactive failure is also highlighted.

Faesal Alatshan (1,2), Siti Aminah Osman (1), Roszilah Hamid (1) and Fidelis Mashiri (3)
(1) Smart and Sustainable Township Research Centre, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia
(2) Civil Engineering Department, College of Engineering Technology, Houn, Libya
(3) School of Computing, Engineering and Mathematics, Western Sydney University, Sydney, Australia


ABSTRACT: The behavior of concrete filled steel tubular (CFST) elements with different types of stiffening measures has been widely investigated during the past two decades through experimental, analytical, and numerical approaches. The previous studies highlighted the importance of the presence of internal and external stiffeners to enhance the structural performance of CFST elements under different loading conditions. In this paper, a systematic methodology is proposed in order to rigorously review the current knowledge in literature about stiffened CFSTs. The reviewed studies include tests of static axial compression, pure bending and combined of static loading actions as well as the cyclic behavior and the fire resistance. A coherent taxonomy regarding the research of stiffened CFSTs is proposed based on the loading conditions besides their cross-sectional shape and type of stiffeners. The study also presents a number of practical applications of stiffened CFSTs in different engineering projects. Finally, concluding remarks, current research gap and future research directions on stiffened CFST are provided and discussed.


ABSTRACT: Understanding the mechanical response of structures such as plates and thin-walled extrusions subjected to cutting and tearing by hardened wedges (blades) is of great interest to scientists and engineers. This complex problem arises in a plethora of disciplines, including but not limited to the broad spectrums of manufacturing, construction and engineering design. Furthermore, studying this topic is a comprehensive endeavor which incorporates advanced concepts within stress analysis and materials science. Despite these challenges, a multitude of advancements were achieved through extensive physical testing, followed by the subsequent development of theoretical explanations and modeling efforts. This paper reviews the major contributions in recent decades towards understanding cutting-induced plastic deformation through experimental, analytical and numerical modeling techniques. The plate tearing problem was historically of interest to the ocean engineering community as an approximation for ship grounding incidents. More recently, the potential for cutting to serve as a means of energy dissipation for enhanced vehicular safety was identified due to the characteristic near-constant force response. Experimental studies were conducted from quasi-static to high rate blast loading conditions (V > 100 m/s). Numerical modeling with Eulerian mechanics and meshfree element formulations were identified as the most accurate techniques, although these schemes are computationally expensive. Analytical solutions are highly sought after since they provide valuable information almost instantaneously. Early modeling efforts yielded purely empirical relationships with gradual
improvement, followed by the development of fully analytical formulations which rely upon approximations of the strain fields in combination with the principle of virtual power to obtain resultant forces.


ABSTRACT: The existing literature concerning the axial performance of concrete-filled double skin tubular (CFDST) columns has been reviewed in this paper. The models in the literature for predicting the behavior of steel materials and confined concrete are summarized, and their effects of the results of finite element analysis are discussed. The applicability and accuracy of four design guidelines to predict the ultimate axial strength of CFDST columns have been assessed through this review by using an expanded database of published compression tests. Code limits in cross-sectional slenderness and material strength are reviewed. The impacts of different structural parameters on the axial behavior are reviewed and discussed. The discussion results indicate that material properties and dimensions have significant effects on the axial performance of CFDST columns. The European and Australian codes give the most reliable predictions, while American design codes give conservative predictions. Finally, recommendations for future studies are provided.

Lulu Wei, Xuan Zhao, Qiang Yu and Guohua Zhu (School of Automobile, Chang'an University, Xi'an, 710064, China), “A novel star auxetic honeycomb with enhanced in-plane crushing strength”, Article 106623, Thin-Walled Structures, Vol. 149, April 2020, https://doi.org/10.1016/j.tws.2020.106623

ABSTRACT: Auxetic honeycombs exhibit low weight, shear stiffness, and excellent energy absorption capacity and thus have great potential for achieving the requirements of crashworthiness and lightweight in automotive fields. This work presents a novel auxetic structure called the star-triangular honeycomb (STH), in which the horizontal and vertical ligaments of the star honeycombs (SH) are replaced with triangular structures. The dynamic crushing behaviors of the STH under three different crushing velocities were investigated using 1D shock theory. The results show that the STH has a more obvious negative Poisson’s ratio effect than the SH and that transverse contraction mainly occurs in the first plateau stage. Theoretical models were deduced based on the collapse mechanism of the typical unit revealed by numerical simulation for STH crushing strength prediction. The theoretical predictions agreed well with the simulation results, and two different plateau stresses appeared under low-velocity crushing. In addition, the influences of the STH geometric parameters and crushing velocity on the energy-absorbing capacity and densification strain were systematically explored. The parameter analysis indicated that the effects of the cell-wall thickness and incline angle on the dynamic response and energy absorption capacity of the STH under low-and medium-velocity crushing are more significant than those under high-velocity crushing. Moreover, the STH showed better energy absorption capacity than the SH. Thus, this design is expected to provide a novel means of improving the mechanical properties of honeycombs.

Adil Baykasoğlu (1), Cengiz Baykasoğlu (2) and Erhan Cetin (2)
(1) Dokuz Eylül University, Faculty of Engineering, Department of Industrial Engineering, Izmir, Turkey
(2) Hitit University, Faculty of Engineering, Department of Mechanical Engineering, Çorum, Turkey

ABSTRACT: Thin-walled tubes have been mostly used in passive vehicle safety systems as crash energy absorber. With the use of additive manufacturing technology, it is possible to produce novel filler materials to further enhance the crashworthiness performance of thin-walled tubes. In this study, optimal designs of novel lattice structure filled square thin-walled tubes are investigated under axial impact loading by using a compromise programming based multi-objective crashworthiness optimization procedure. Types of filler lattice structures (i.e., body-centered cubic, BCC and body-centered cubic with vertical strut, BCC-Z), diameter of lattice member, number of lattice unit cells and tube thickness are considered as design parameters, and the optimum values of these design parameters are sought for minimizing the peak crash force (PCF) and maximizing the specific energy absorption (SEA) values. The validated finite element models are utilized in order to construct the sample design space and carrying out results verification; an artificial neural network is
employed for predicting values of the objective functions; the weighted superposition attraction algorithm is used to generate design alternatives and searching for their optimal combination. The compromise programming approach is used to combine multi-objectives and to produce various optimal design alternatives. The optimization results showed that the proposed approach is able to provide good solutions with high accuracy and proper selection of design parameters can effectively enhance the crashworthiness performance of the lattice structure filled thin-walled tubes. The optimum results revealed that BCC hybrid designs have generally superior crashworthiness performance compared to that of their BCC-Z counterparts for the same compromise solutions. In particular, the PCF value of the optimized BCC-Z hybrid structures is up to 44% higher than that of BCC hybrid structures while these structures have similar energy absorption performances. The compromise solutions also show that the SEA of BCC and BCC-Z hybrid structures increases respectively by 29% and 51% depending on the selected weight factors for the design objectives.

Qing-Hua Tan (1), Leroy Gardner (2), Lin-Hai Han (3) and Tian-Yi Song (4)
(1) College of Aerospace Science and Engineering, National University of Defense Technology, China
(2) Department of Civil and Environmental Engineering, Imperial College London, UK
(3) Department of Civil Engineering, Tsinghua University, China
(4) College of Architecture and Civil Engineering, Beijing University of Technology, China
ABSTRACT: The post-fire performance of concrete-filled stainless steel tubular (CFSSST) columns subjected to an entire loading–fire history, including four characteristic phases: (i) ambient temperature loading, (ii) heating, (iii) cooling with constant external loads, and (iv) post-fire loading, is investigated in this paper. Sequentially coupled thermal-stress analyses are performed using ABAQUS to establish the temperature field and structural response of CFSSST columns. To improve the precision of the finite element analysis (FEA) models, the influence of moisture on the thermal conductivity and specific heat of the concrete in the heating and cooling phases is considered by using subroutines. Existing fire and post-fire test data on CFSSST columns are used to validate the FEA modelling. Comparisons between FEA and test results indicate that the accuracy of the model is acceptable; the FEA model is then extended to simulate CFSSST columns subjected to the four characteristic phases. The behaviour of the CFSSST columns during the four characteristic phases is explained by analysis of the temperature distribution, load versus axial deformation relations, failure modes and internal force redistribution. The excellent post-fire performance of CFSSST columns is examined in comparison with traditional concrete-filled stainless steel tubular (CFST) columns with the same total cross-sectional area. The residual strength index is studied with respect to a series of parametric analyses. It is found that the residual strength of CFSSST columns is higher than that of CFST columns after the same fire exposure, and that the diameter of the stainless steel tube, slenderness, heating time ratio and load ratio have a significant influence on the residual strength index.

Qiang Liu (1,2), Kangmin Liufu (1), Zhengliang Cui (1), Jun Li (1), Jianguang Fang (3) and Qing Li (4)
(1) School of Intelligent Systems Engineering, Sun Yat-Sen University, Shenzhen, 518000, China
(2) Lightweight Electric Vehicle and Parts Engineering Center of Guangdong Province, Dongguan City, 523000, China
(3) School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NSW, 2007, Australia
(4) School of Aerospace, Mechanical and Mechatronic Engineering, University of Sydney, Sydney, NSW, 2006, Australia
ABSTRACT: Open holes and cutouts have been widely used in composite structures for various engineering purposes. However, perforation could largely alter the structural responses and crasching behavior, thereby creating significant change in composite design. This study carried out a parametric study and design optimization on the perforation parameters for the perforated carbon fiber reinforced plastic (CFRP) square tubes to improve the structural crashworthiness. First, a finite element model was established for perforated square tube through experimental validation. Second, the support vector regression (SVR) surrogate models of the crashworthiness indices were established with respect to the perforation design variables following a
parametric study. It was found that the radius of the hole had the most significant effect on crashworthiness performance of the CFRP tube, followed by the height-to-length ratio and the offset-to-width ratio of the hole. Finally, the multiobjective optimization was performed to optimize the perforated parameters by integrating the surrogate modeling technique and multiobjective grey wolf optimizer (MOGWO). The optimal design enabled to enhance 100.47% in the specific energy absorption (SEA) (specifically from 29.61 J/g to 59.36 J/g) only with a minor sacrifice of 4.62% in the first peak load (Fmax) (from 81.22 kN to 84.97 kN).

Farhad Alinaghizadeh and Mahmoud Shariati (Department of Mechanical Engineering, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran), “Nonlinear analysis of size-dependent annular sector and rectangular microplates under transverse loading and resting on foundations based on the modified couple stress theory”, Article 106583, Thin-Walled Structures, Vol. 149, April 2020, https://doi.org/10.1016/j.tws.2019.106583

ABSTRACT: The nonlinear behavior of annular sector microplates remains poorly understood. In this study, a non-classical model for nonlinear bending analysis of annular sector microplates under transverse mechanical loading is developed based on the modified couple stress theory and the first-order shear deformation theory with von Karman nonlinearity. The model captures the size effect by a material length scale parameter. Using the principle of minimum total potential energy, the equilibrium equations and boundary conditions are obtained. The equilibrium equations are discretized according to the generalized differential quadrature method and are solved using the Newton's technique. By a proper change in the geometric parameters of annular sector plates, the results are extended to nonlinear analysis of square microplates under transverse loading. It is assumed that the microplates are resting on the nonlinear elastic foundations. The present results are verified by comparison with existing results in the literature. The effects of nonlinearity, length scale parameter, foundation parameters and geometric parameters on deflections of annular sector and square microplates subjected to distributed transverse loading are studied.

H. Debski (1), P. Rozylo (1) and A. Teter (2)
(1) Department of Machine Design and Mechatronics, Faculty of Mechanical Engineering, Lublin University of Technology, Nadybystrzycka 36, 20-618, Lublin, Poland
(2) Department of Applied Mechanics, Faculty of Mechanical Engineering, Lublin University of Technology, Nadybystrzycka 36, 20-618, Lublin, Poland

ABSTRACT: The objective of this study was to investigate the influence of eccentric compressive load on the buckling, post-buckling and load-carrying capacity of thin-walled top-hat cross-section composite columns. The CFRP columns were manufactured by the autoclave technique. The scope of the study involved performing experimental tests on real structures as well as numerical calculations by the finite element method. The experimental tests were conducted in the full range of loading, until the structure's failure. Post-buckling equilibrium paths and acoustic emission signals were measured in order to determine actual condition of the composite material. Nonlinear FEM calculations were made by the progressive damage criterion, in which the damage initiation of the composite material was estimated based on Hashin's theory, whereas damage evolution was described by the energy criterion. The numerical simulations were performed using the commercial software ABAQUS®. The numerical results were in good agreement with the experimental results obtained for real structures. The results demonstrated a significant influence of eccentric compressive load on the buckling and post-buckling characteristics of the tested structures.

Zufeng Shang (1,2), Jiayao Ma (1,2), Zhong You (2) and Shuxin Wang (1,2)
(1) Key Laboratory of Mechanism Theory and Equipment Design of Ministry of Education, Tianjin University, 135 Yaguan Road, Tianjin, 300350, China
(2) School of Mechanical Engineering, Tianjin University, 135 Yaguan Road, Tianjin, 300350, China

ABSTRACT: In this paper, the lateral indentation of a newly proposed reinforced braided tube with tunable stiffness, which takes a braided tube as skeleton and is sealed by thin membranes, has been studied experimentally and numerically. It is found out that the radial stiffness could be increased by 290% compared
with that of a stand-alone braided tube, through adjusting the negative pressure between the braided skeleton and the membranes. During deformation, the fibers in the reinforced tube are longitudinally restricted by friction, which increases the stiffness of the braided skeleton. In addition, friction dissipation due to sliding between fibers and membranes also contributes substantially to the load carrying capability of the reinforced tube, leading to a much stiffer structure than the summation of the constituents. A parametric analysis has also been conducted, from which the effects of the design parameters are obtained.

A. Harkati (1), D. Boutagouga (1), E. Harkati (1), A. Bezaï (2), F. Scarpa (3) and M. Ouisse (4)
(1) Université de Larbi Tébessi, Laboratoire des Mines, Route de Constantine, Tébessa, 12002, Algeria
(2) Laboratoire Mécanique Appliquée des Nouveaux Matériaux (LMANM), B.P 401, Université 8 Mai 1945, Guelma, Algeria
(3) Bristol Composites Institute (ACCIS) and Dynamics and Control Research Group (DCRG), University of Bristol, BS8 1TR, Bristol, UK
(4) Univ. Bourgogne Franche Comté, FEMTO-ST Institute, CNRS/UFC/ENSMM/UTBM, Department of Applied Mechanics, 24 Rue de L’épitaphe, 25000, Besançon, France


ABSTRACT: This paper is focused on the identification of the in-plane elastic constants of a new design of auxetic (negative Poisson's ratio) honeycomb configuration with curved cell walls by using analytical and numerical homogenization techniques. The sensitivity of the elastic constants is determined against the various cell geometry parameters. Good agreement between the analytical and numerical simulations is observed. We show that the specific curved wall honeycomb configuration proposed in this paper possesses a high in-plane shear compliance, tailored anisotropy and the possibility of inducing a negative Poisson's ratio behaviour in baseline honeycomb configurations that would have otherwise positive in-plane Poisson's ratios.

Shubin Wang, Weiguo Li, Yong Tao, Xin Zhang, Xuyao Zhang, Ying Li, Yong Deng, Zheng Shen, Xi Zhang, Jiasen Xu, Liming Chen and Daining Fang (All except the last author are from: College of Aerospace Engineering, Chongqing University, Chongqing, 400044, China), “Investigation on the temperature dependent out-of-plane quasi-static compressive behavior of metallic honeycombs”, Article 106625, Thin-Walled Structures, Vol. 149, April 2020, https://doi.org/10.1016/j.tws.2020.106625

ABSTRACT: This study investigates the effect of temperature on the out-of-plane quasi-static compressive behavior of metallic honeycombs by numerical and theoretical methods. Adopting a temperature dependent elastic-perfectly plastic constitutive relation, the temperature dependent out-of-plane quasi-static compressive mechanical performance of Al5052 honeycomb is studied with the finite element method. The results show that the plateau stress, peak stress and specific energy absorption (SEA) of Al5052 honeycomb decrease gradually with increasing temperature, while the crush load efficiency (CLE) and deformation pattern are temperature insensitive. Then, based on the numerical results in this study and super folding element theory, the temperature dependent theoretical models without fitting parameters for the plateau stress and SEA of metallic honeycombs are developed, respectively. These theoretical models are successfully verified against numerical simulations and experiments. Based on these theoretical models, the effects of parent material properties on the plateau stress and SEA at different temperatures are discussed. The results in this study provide useful guidelines in optimizing the choice of parent materials to fabricate metallic honeycombs with better energy absorption efficiency at different temperatures.

Yaozhong Wu (1), Jianguang Fang (2), Zhiyuan Cheng (1), Yuhang He (1) and Weijia Li (1)
(1) School of Naval Architecture & Ocean Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China
(2) School of Civil and Environmental Engineering, University of Technology Sydney, NSW, 2007, Australia


ABSTRACT: Thin-walled structures have been widely used as energy-absorbing components, which can be probably subjected to multiple loading conditions in real life, such as axial crushing and lateral bending. Most of the existing literature solely focuses on the pure axial crushing or lateral bending. In this paper, a novel tailored-property multi-cell tubular structure is proposed, where the material's ultimate strength at the corner
region is increased to accommodate both the axial crushing and lateral bending conditions. Finite element (FE) models were developed and validated through experimental results. The FE models were used to investigate the crashworthiness performances of the tailored-property multi-cell tubes under axial crushing and lateral bending. Under both axial crushing and lateral bending, it was found that the tailored-property multi-cell tubes exhibited noticeable advantages over the corresponding traditional tubes. The tailoring ratio and thickness had a significant influence on the crashworthiness performance of the tailored-property multi-cell tubes. Moreover, the well-designed tailored-property multi-cell tubes could exhibit the progressive deformation mode under axial crushing. Furthermore, a theoretical model for the tailored-property multi-cell tubes under axial crushing was developed based on the Superfolding Element (SFE) Method. The results showed that the theoretical solutions were in good agreement with the finite element analysis results. The findings of this paper have the potential for energy absorption applications under different loading conditions.

Xiang Yun (1), Nadiah Saari (2) and Leroy Gardner (1)
(1) Department of Civil and Environmental Engineering, Imperial College London, London, UK
(2) Faculty of Civil Engineering, Universiti Teknologi MARA Johor, Pasir Gudang Campus, Masai, Johor, Malaysia


ABSTRACT: The structural fire response of hot-rolled steel square and rectangular hollow sections (SHS and RHS) under combined compression and bending is investigated in this study through finite element (FE) modelling. The developed FE models were firstly validated against available test results on hot-rolled steel SHS/RHS subjected to combined compression and bending at elevated temperatures. Upon validation, an extensive parametric study was then carried out to examine the resistance of hot-rolled steel SHS/RHS under combined loading at elevated temperatures, covering a wide range of cross-section slendernesses, cross-section aspect ratios, combinations of loading and temperatures up to 800 °C. The numerical data, together with the experimental results, were compared with the strength predictions according to the current structural fire design rules in the European Standard EN 1993-1-2 (2002) and American Specification AISC 360–16 (2016) for hot-rolled steel SHS/RHS under combined loading. The comparisons generally indicated significant disparities in the prediction of resistance of hot-rolled steel SHS/RHS under combined loading at elevated temperatures, owing principally to inaccurate predictions of the end points of the design interaction curves. The deformation-based continuous strength method (CSM) has been shown to provide accurate strength predictions for these end points i.e. the resistances of hot-rolled steel SHS/RHS stub columns and beams at elevated temperatures. In this study, proposals are presented to extend the scope of the CSM to the structural fire design of hot-rolled steel SHS/RHS under combined compression and bending. The CSM proposals are shown to offer improved accuracy and reliability over current design methods and are therefore recommended for incorporation into future revisions of international structural fire design codes.

Tianxiong Zhang (1), Zongyi Wang (2,3), Yuanqing Wang (3) and Zhihua Chen (1)
were tested with no holes in the webs. Three different section thicknesses and square hole sizes were chosen for which 18 tests were conducted with central square holes of variable thicknesses and sizes, and the remaining 6 holes centrally cut from the webs. A total number of 24 tests were performed using lipped program aiming to determine the ultimate shear strengths of high strength cold formed steel channels with central square holes, Article 106647, Thin-Walled Structures, Vol. 149, April 2020, https://doi.org/10.1016/j.tws.2020.106647

ABSTRACT: Oxygen-free copper (OFC) has been increasingly used in engineering applications due to many advantageous properties. In order to investigate the flexural buckling behaviour of OFC tubular columns under axial compression, seven full-scale specimens were tested. The buckling failure modes of the specimens were analyzed, and the flexural buckling strengths were obtained. Subsequently, two finite element models were developed and verified against the test data. A parametric study was performed as well. The results showed that the OFC columns with small slenderness failed by elastic-plastic buckling, while those with high slenderness failed by elastic buckling. Eqs. (9) and (11), which are based on the Perry formula, suitably described the buckling curves of the OFC tubular columns. The value of a in Eq. (9) was 0.293; and the values of a1, a2 and a3 in Eq. (11) were 1.647, 1.041, and 0.175, respectively.

Haitao Ye (1), Xiang Zhou (1), Jiayao Ma (2), Hai Wang (1) and Zhong You (3)
(1) School of Aeronautics and Astronautics, Shanghai Jiao Tong University, China
(2) Key Laboratory of Mechanism Theory and Equipment Design of Ministry of Education, School of Mechanical Engineering, Tianjin University, China
(3) Department of Engineering Science, University of Oxford, UK


ABSTRACT: In this paper, the crushing behaviors of composite pre-folded tubes made of KFRP/CFRP hybrid laminates subjected to quasi-static axial loads are investigated both experimentally and numerically. The full-diamond origami pattern and its variation forms with curved lobes are considered for the tube design. Five pre-folded tube specimens with different ply stacking sequences consisting of CFRP and KFRP woven fabrics are manufactured and tested in quasi-static axial compression tests. The finite element models for pre-folded tubes made of KFRP/CFRP hybrid laminates are developed and validated with the experimental results. A comprehensive parametric study on the energy absorption properties of CFRP/KFRP hybrid composite tubes with various geometries is performed numerically. The results show that the energy absorption performance of the composite tubes has a strong correlation with the composition of hybrid fiber and the specimen with the stacking sequence of [theta(k), theta(c), theta(c), theta(k)] has the best overall energy absorption performance among the five specimens tested. Moreover, it is found that by converting the standard full-diamond pattern to the curved variation forms, the energy absorption performance of the pre-folded tubes can be improved.

Cao Hung Pham (1) and Gregory J. Hancock (2)
(1) Senior Lecturer in Structural Engineering, School of Civil Engineering, The Univ. of Sydney, NSW 2006, Australia
(2) Emeritus Professor and Professorial Research Fellow, School of Civil Engineering, The Univ. of Sydney, Sydney, NSW 2006, Australia

“Shear tests and design of cold-formed steel channels with central square holes”, Article 106650, Thin-Walled Structures, Vol. 149, April 2020, https://doi.org/10.1016/j.tws.2020.106650

ABSTRACT: In the latest North American Specification S100:2016 Edition and the most up-to-date Australian/New Zealand Standard AS/NZS 4600:2018, the Direct Strength Method (DSM) shear design rules for unperforated channel sections have been adopted. To date, for perforated sections, there is no DSM design rule for shear in the current Specification/Standard while the conventional reduction factor method is still in use to calculate shear strengths for these sections. This paper summarises the test results in an experimental program aiming to determine the ultimate shear strengths of high strength cold-formed C-sections with square holes centrally cut from the webs. A total number of 24 tests were performed using lipped channel sections in which 18 tests were conducted with central square holes of variable thicknesses and sizes, and the remaining 6 were tested with no holes in the webs. Three different section thicknesses and square hole sizes were chosen for...
investigation in this study. In addition, Finite Element Method (FEM) analysis was initially developed to validate against test results, and the accurate results from the FEM were then employed in a parametric study for the extension of test data by varying the section thicknesses and the hole sizes. In the DSM shear design equations, two inputs namely the shear buckling load, \( V_s \), and the shear yielding load, \( V_y \), are required. The numerical solutions for \( V_s \) for whole sections with central square holes have been proposed by first author in previous research studies. For \( V_y \) in this paper, a new and simplified model is proposed based on net web areas. Recommendations for an extension to the DSM shear design rules for channel sections with square holes up to certain hole size limit are given.

Wei Li (1), Bing Chen (1), Lin-Hai Han (1) and Dennis Lam (2)
(1) Department of Civil Engineering, Tsinghua University, Beijing, 100084, China
(2) Department of Civil & Structural Engineering, University of Bradford, Bradford, BD7 1DP, UK
ABSTRACT: The interaction between steel and concrete is important for the functionality of composite tubular construction. In this study, a series of pushout tests were carried to investigate the behaviour of steel tubes to sandwiched concrete interfaces in concrete-filled double skin steel tubes (CFDST). Parameters concerned included the diameter to thickness ratio of both outer and inner steel tubes, the hollow ratio of the cross section, the roughness of steel tube surfaces, the shrinkage of concrete, etc. The bond stress-slip relationships and the strain responses were recorded and analysed, and effects of different parameters were discussed. In general, the bond strength of the outer steel tube to concrete interface for CFDST was comparable with that of concrete-filled steel tube (CFST), and the bond strength of the inner steel tube to concrete interface was higher than that of the outer steel tube to concrete interface.

Tohid Ghanbari-Ghazijahani (1), Amin Nabati (2), Mojtaba Gorji Azandariani (3) and Nader Fanaie (4)
(1) School of Civil, Environmental & Mining Engineering, The University of Adelaide, SA, 5005, Australia
(2) Sahand University of Technology, Tabriz, Iran
(3) Structural Engineering Division, Faculty of Civil Engineering, Semnan University, Semnan, Iran
(4) Department of Civil Engineering, K. N. Toosi University of Technology, Tehran, Iran
ABSTRACT: Localised/partial loading is seen in many applications in the building and construction industry. This paper aims to study the influence of localised loading in different positions and Loading Coverage Areas (LCAs) for steel columns with concrete and timber inﬁlls, and hollow steel tubes. Fifteen tests were carried out in three categories. Structural stability of the specimens was evaluated far into their plastic response until crushing. The energy absorption of each specimen was quantiﬁed and compared with its counterparts of different materials and LCAs. Axial capacity and failure were focused on as well as the strength-to-mass ratio for each specimen. There was a noticeable capacity difference between the side-loaded and mid-loaded specimens of each group indicating the effect of material under loading on the capacity. The side-loaded specimens had a higher interface between the loading element and steel, compared to the mid-loaded specimens. Numerical analysis was also conducted, which yielded a very close consistency of results with the experiments.

Jun-ping Liu (1), Jian Yang (2), Bao-chun Chen (1) and Zong-yuan Zhou (1)
(1) College of Civil Engineering, Fuzhou University, Fuzhou, Fujian, 350116, China
(2) Dept. of Civil Engineering, The City College of New York / CUNY, New York, NY, 10031, United States
ABSTRACT: This paper describes an experimental study on the flexural and eccentric compressive behavior of concrete-filled square steel tube (CFSST) beam-columns stiffened with PBL stiffeners. Three types of CFSST beam-columns were fabricated and tested under the flexural moment and eccentric compressive load. Among the three types of columns, the two types of columns were strengthened with the PBL and steel plate stiffeners; the other type of columns was not strengthened. In addition, extensive finite element analyses (FEA) were
carried out to evaluate the stress distribution. Flexural test results show that failure modes of specimens without stiffeners were different from specimens with the PBL or steel plate stiffeners. The results also demonstrate the distribution of cracks in the concrete was affected by stiffeners and the columns with the PBL stiffeners have the most uniformed crack distributions. The capacity improved by the PBL stiffeners was insignificant. However, the flexural stiffness of the specimen stiffened with the PBL stiffeners was about 20% larger than the unstiffened specimen. Eccentric compressive load test results show the capacity of specimen with the PBL stiffeners was 6.95% larger than the unstiffened specimen. The eccentric compressive capacity decreased with the increase of the eccentricity ratio or slenderness ratio. FEA results show that stiffeners can effectively improve the mechanical behavior of CFSST specimens under bending and eccentric compressive loads.

Jingmin Xia (1), Patrick E. Farrell (1) and Saullo G.P. Castro (2)
(1) Mathematical Institute, University of Oxford, UK
(2) Faculty of Aerospace Engineering, Delft University of Technology, Netherlands


ABSTRACT: When loading experiments are repeated on different samples, qualitatively different results can occur. This is due to factors such as geometric imperfections, load asymmetries, unevenly stressed regions or uneven material distributions created by manufacturing processes. This fact makes designing robust thin-walled structures difficult. One numerical strategy for exploring these different possible responses is to impose various initial imperfections on the geometry before loading, leading to different final solutions. However, this strategy is tedious, error-prone and gives an incomplete picture of the possible buckled configurations of the system. The present study demonstrates how a deflation strategy can be applied to obtain multiple solutions for the more robust design of thin-walled structures under displacement controlled uniaxial compression. We first demonstrate that distinct initial imperfections trigger different sequences of instability events in the Saint Venant–Kirchhoff hyperelastic model. We then employ deflation to investigate multiple bifurcation paths without the use of initial imperfections. A key advantage of this approach is that it can capture disconnected branches that cannot easily be discovered by conventional arc-length continuation and branch switching algorithms. Numerical experiments are given for three types of aircraft stiffener profiles. Our proposed technique is shown to be a powerful tool for exploring multiple disconnected bifurcation paths without requiring detailed insight for designing initial imperfections. We hypothesise that this technique will be very useful in the design process of robust thin-walled structures that must consider a variety of bifurcation paths.


ABSTRACT: A circular bio-inspired in-plane gradient core is designed based on the Royal Water Lily venation structure. The dynamic responses of various clamped circular sandwich panels with the bio-inspired gradient core under blast loadings are investigated using a combined numerical and theoretical approach. Four groups of gradient cores, such as negative, hybrid, non-gradient, and positive cores, are obtained by adjusting cell wall thickness. The classical circular sandwich panel model under blast loading is modified by introducing the in-plane gradient of the core. The blast resistance of the in-plane gradient clamped circular sandwich panels are studied using the modified theoretical model. Simulation results are consistent with the theoretical predictions for clamped circular sandwich panels with various gradient cores. In comparison with other three kinds of gradient sandwich panels, the proposed sandwich panels with negative gradient cores have higher specific energy absorption and lower deflection of the back face sheet. Results show that a reasonable design of the density of the gradient core can effectively improve the mechanical behaviors of the sandwich structure without adding additional mass in the structure. Such results can provide guidance for the in-plane design of sandwich structures.

Amin Khodadadi (1), Gholamhossein Liaghat (1,2), Davoud Shahgholian-Ghahfarokhi (1), Mahmoud Chizari(3) and Bin Wang (4)
(1) Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran

ABSTRACT: This paper aims to investigate the performance of an aluminum–rubber composite plate under impact loading. The impact resistance of the plate has been evaluated using both experimental and numerical methods. The experimental tests were carried out using gas gun at velocities of 75, 101, 144 and 168 m/s. The energy absorption of composite plates has been closely examined for all samples. The effect of rubber layer positioning either on front face or on back face of the aluminum plate was also evaluated. It was found that the composite plate with rubber on front face provides higher performance to absorb the energy. In parallel to the experiment, a finite element model was created using the finite element software LS-DYNA to simulate the response of the aluminum–rubber composite plate under a high energy rate loading condition. The data obtained from finite element modeling shown a close agreement with the experimental results in terms of failure mechanism and energy absorption. In addition, a parametric study was carried out incorporating different impact velocities, rubber formulation, rubber layer thickness, interface bonding strength between rubber and aluminum layers and ballistic performance of aluminum-rubber sandwich panel. It was concluded that by increasing the rubber layer’s thickness the energy absorption of the composite plate will be increased, especially when rubber layer placed in front face of the aluminum plate. Although at high interface bonding of rubber and aluminum layer, the composite with rubber layer in front face has better performance, but low bonding of interface lead to higher energy absorption in back face configuration.


ABSTRACT: A comprehensive experimental programme was contrived with the aim of investigating the behaviour and the capacity of cold-formed steel built-up columns with particular emphasis on the effects of connector spacing and contact between individual components. A total of 24 built-up columns, including four different cross-sectional geometries, were tested between pin-ended boundary conditions, while applying the load with nominal eccentricities of L/1000 or L/1500. The columns were designed to fail by interaction of cross-sectional buckling of the components, possible global-type buckling of the components between connectors and global buckling of the whole column, and all these failure modes were successfully achieved. The built-up sections were fabricated from flat plates, plain channels and lipped channels and were assembled with either bolts or self-drilling screws. The connector spacing was varied between specimens of the same cross-sectional geometry. Tensile coupons were taken from the flat portions and the corners of the sections in order to determine their material properties, while detailed measurements of the geometric imperfections of each specimen were also carried out using a specially designed measuring rig. In addition, the isolated behaviour of both the bolts and the screws used in the specimens was investigated through single lap shear tests. It was observed that the buckling patterns in the built-up specimens were affected by contact between the various components and by the spacing between the connectors. However, in the cases where global buckling of the components in between connector points was not critical, the connector spacing had a minor influence on the ultimate capacity of the columns.

Yixin Wang (1), Mark A. Bradford (1) and Xinpei Liu (2)
(1) Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW, 2052, Australia
(2) School of Civil Engineering, The University of Sydney, NSW, 2006, Australia

Strength design of welded high-strength steel beams considering coupled local and global buckling”, Article 106391, Thin-Walled Structures, Vol. 149, April 2020, https://doi.org/10.1016/j.tws.2019.106391

ABSTRACT: High-strength steel (HSS) is gaining increasing use in modern building construction for several reasons, the most notable being that its increased strength can lead to a reduction in self-weight and correspondingly reduced emissions and waste during its manufacture. However, there is little guidance available in design standards when the steel grade exceeds 690 MPa. Such guidance is needed, because the use of thinner plate elements than would normally be encountered in mild steel members leads to an increased
importance in local plate buckling participating in the strength limit state, and its interaction with yielding and residual stresses that are germane to HSS members. This paper investigates the buckling strength of welded HSS I-beams numerically, and based on the results of the study it proposes a corresponding strength design criterion that incorporates local buckling and lateral-torsional buckling and their interaction at the ultimate limit state. The finite element model used for the analysis is based on ABAQUS software, and it incorporates the interaction of elastic buckling, yielding, residual stresses induced by welding and geometric imperfections. The numerical formulation is validated against test results reported by several investigators, and it is then used to produce a substantive set of data to investigate the buckling strength of welded HSS beams. It is shown that the buckling strength depends primarily on two parameters: the generalised (or member) slenderness and the section slenderness. It is also demonstrated that coupled modes of failure are possible for slender sections that incorporate the interaction of local and lateral-torsional modes, which traditionally are treated simplistically in current steel design standards by using effective section properties. To overcome the limitations on guidance for the strength design of HSS beams, a set of new strength design equations are proposed from the numerical data, based on the generalised and section slendernesses.

Qiang Chen (1,2), Qingguo Fei (1), Hendrik Devriendt (2), Shaoqing Wu (1), Bert Pluymers (2) and Wim Desmet(2)

(1) Institute of Aerospace Machinery and Dynamics, Southeast University, Nanjing, 211189, China
(2) KU Leuven, Department of Mechanical Engineering, Division PMA, Leuven, B-3001, Belgium


ABSTRACT: The efficient Wave-Based Method (WBM) is extended to predict the bending vibration response of thin-walled rectangular plates under thermal load. Governing equations of dynamic plate bending problems considering thermal effects are first introduced. The general solution and particular solution of governing equation are derived by the separate variable method and residue theorem, respectively. Then novel wave functions and particular solution function are selected to establish the wave-based model of dynamic plate bending problems under thermal load. The accuracy of WBM is verified by finite element method (FEM) for a simply supported plate and a clamped plate. Then the influence of thermal load on the dynamic bending responses of a clamped plate is investigated. Simulation results prove that WBM achieves higher convergence rate than FEM. The thermal load significantly changes the structural dynamic behaviors. When both the temperature-dependent material properties and thermal stresses are considered, the increase of environment temperature leads to the resonant peak of displacement response shifts toward lower frequency.

M. Bakhtiari (1), A. Tarkashvand (2) and K. Daneshjou (2)

(1) School of New Technologies, Iran University of Science and Technology, Narmak, Tehran, Iran
(2) School of Mechanical Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran


ABSTRACT: The propagation of stress waves in an impulsive load-excited fluid-filled cylindrical structure containing an internally clamped shell is investigated. The external and internal cylinders are made of functionally graded and homogeneous isotropic materials, respectively. The space between the cylindrical shells is filled with a non-viscous and compressible fluid. The equations of motion for solid media are based on the three-dimensional theory of elasticity. According to the problem definition, for establishing the relationship between the displacement and stress fields, the governing equations are extracted in the form of plane-strain. A laminate model is employed to attain the dynamic equations of the functionally graded cylinder. Next, a transfer matrix is established by considering the continuity conditions of the stress and displacement at the interfaces of the layers. Then, the Laplace transform is utilized to transfer wave equations from the time domain to the Laplace domain. Eventually, a numerical inverse Laplace transform known as the Durbin method is employed to retrieve the solutions obtained into the time domain. An excellent agreement is observed in comparing between results of the present analytical method and previous models. Next, the effects of geometrical and physical properties of the inner shell on the transient response of the functionally graded cylinder are investigated. Also, the von Mises stress as the most effective parameter in the structural design is studied. The results show that the inner shell made of a material with a lower elasticity modulus leads to a reduction in the
amount of von Mises stress in the external cylinder. As well as, an inner shell with a greater volume has a more positive effect on the transient response of the functionally graded cylinder.

Hossein Bisheh (1), Nan Wu (1) and Timon Rabczuk (2)
(1) Department of Mechanical Engineering, University of Manitoba, Winnipeg, Manitoba, R3T 5V6, Canada
(2) Institute of Research and Development, Duy Tan University, Da Nang, Viet Nam


ABSTRACT: Free vibration analysis is carried out for piezoelectric coupled carbon nanotube (CNT)-reinforced composite cylindrical shells with the influences of various boundary conditions and hygrothermal environmental conditions for the first time. A simple and effective non-iterative mathematical method is used to calculate the natural frequencies. The equilibrium equations of motion are obtained based on the first-order shear deformation shell theory with the coupling effects of piezoelectricity, temperature, and moisture, respectively based on the Maxwell equation, the Fourier heat conduction equation, and the Fickian moisture diffusion equation. The Mori-Tanaka micromechanics model is used to estimate the resulting material properties for a composite shell reinforced with CNTs. Presented methodology and attained results are validated with the existing results in the literature. The effects of the boundary conditions, lamination stacking sequence, volume fraction and orientation of CNTs, piezoelectricity, and geometry of the shell on the natural frequencies of the shell are investigated. A moderate effect of temperature/moisture variation on the natural frequencies is also observed. It is found that the influence of structural boundary conditions is more significant at higher CNT volume fractions and for thicker and shorter shells, and the piezoelectricity effect is more obvious at higher circumferential mode. The model and results presented in this study can be utilized to determine vibration characteristics of smart CNT-reinforced composites subjected to hygrothermal loading as well as mechanical loading.

Ngo Dinh Dat (1), Vu Minh Anh (2), Tran Quoc Quan (2), Pham Truong Duc (3) and Nguyen Dinh Duc (2)
(1) NTT Institute of High Technology, Nguyen Tat Thanh University, Ho Chi Minh City, Viet Nam
(2) Advanced Materials and Structures Laboratory, VNU – Hanoi – University of Engineering and Technology (UET), 144 – Xuan Thuy, Cau Giay, Hanoi, Viet Nam
(3) School of Mechanical Engineering, University of Birmingham, Birmingham B15 2TT, UK


ABSTRACT: This paper carries out the nonlinear stability of nanocomposite multilayer organic solar cell (NMOSC) subjected to axial compressive loads. The model of organic solar cell is assumed to consist five layers: Al, P3HT:PCBM, PEDOT:PSS, IOT and Glass. Based on the classical plate theory, the basic equations are established taking into account the effect of elastic foundations and initial imperfection. The approximation solutions are selected based on the boundary conditions of the four edges of NMOSC. The equation which indicates the relationship between axial compressive loads and deflection amplitude of NMOSC is obtained by using the Galerkin method. Bees Algorithm is applied to maximize the value of critical buckling load with nine variables including the thickness of five layers, the length and the width of NMOSC and two stiffness coefficients of elastic foundations. The numerical results show the effect of geometrical and material parameters, initial imperfection and elastic foundations on the nonlinear static stability and the critical buckling load of NMOSC. Optimal values of nine geometrical parameters of NMOSC are also determined.


ABSTRACT: Faced with the large annual output of construction and demolition waste, cyclic utilization of recycled coarse aggregate (RCA) is inevitable. This study uses steel-fiber-reinforced recycled aggregate concrete (RAC) in the manufacture of concrete-filled steel tube columns, to improve the utilization of RCA. A comprehensive study of the axial behavior of 54 steel-fiber-reinforced self-stressing recycled aggregate
concrete-filled steel tube (SSRCFST) columns was conducted. The variables in the experiments included the steel fiber content, self-stress, quality replacement rate of RCA, concrete strength grade, and steel tube thickness. The experimental results show that a poor concrete strength is obtained with increasing RCA content. However, under tri-axial stress in the steel tube, the negative influence of RCA is weakened. An enhancement of the ductility of SSRCFST columns can be achieved by adding a moderate amount of steel fiber. Self-stress can significantly improve the ultimate capacity and stiffness of SSRCFST columns. Moreover, design equations for the ultimate capacity of SSRCFST columns are proposed, and the predictions agree satisfactorily with the experimental results.

Chengqiang Ge, Qiang Gao, Liangmo Wang and Zhong Hong (Department of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, PR China), “Theoretical prediction and numerical analysis for axial crushing behaviour of elliptical aluminium foam-filled tube”, Article 106523, Thin-Walled Structures, Vol. 149, April 2020, https://doi.org/10.1016/j.tws.2019.106523

ABSTRACT: Dynamic crushing behavior of elliptical aluminium foam-filled tube (EFT) under axial impact was analyzed thoroughly. First, the deformation mechanism of EFT is investigated. Based on this, a theoretical model to predict the mean crushing force is established under some specific assumption. The interaction work between the foam and tube are introduced in the model to improve the accuracy. Further numerical simulations of the EFT are conducted to validate the theoretical models which indicates the theoretical model is pretty accurate. Finally, the influence of the geometric parameters of EFT on the mean crushing force is also revealed. The study aims at quantifying the energy absorption of EFT under axial impact loading, for variations in the geometry parameters of the tube. This can guide the engineers to design great energy absorber more efficiently.

Filip Ljubinković (1), João Pedro Martins (1), Helena Gervásio (1), Luís Simões da Silva (1) and Carlos Leitão(2)
(1) ISISE, Civil Engineering Department, Universidade de Coimbra, Portugal
(2) CEMMPRE, Department of Mechanical Engineering, Universidade de Coimbra, Portugal

ABSTRACT: In this paper, a comprehensive experimental study on cylindrically curved steel panels is presented, in order to characterize the structural behavior of cylindrically curved panels as individual members under uniform compression. Therefore, 32 full-scale compression tests on both stiffened and unstiffened simply supported curved panels were performed, where the radius of curvature and the number of stiffeners were varied. Based on the experimental results a numerical model is built, which was used to investigate the sensitivity to initial geometric imperfections of curved panels. One of the main conclusions is that the behaviour of a panel highly depends on the shape of the initial geometric imperfections, which also determines its ultimate resistance.

Mehdi Bohlooly (1), Mohammad Ali Kouchakzadeh (1), Babak Mirzavand (2) and Mohammad Noghabi (3)
(1) Department of Aerospace Engineering, Sharif University of Technology, P.O. Box 11155-8639, Tehran, Iran
(2) Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran
(3) Space Transportation Research Institute, Iranian Space Research Center, Tehran, Iran

ABSTRACT: A theoretical approach is presented to derive an explicit formula for buckling load and postbuckling path of advanced grid stiffened conical shells (stiffeners with laminated composite skins). Different types of fiber paths of grids including stringer, ring, and helical are considered. The simply supported truncated conical shell with imperfection is subjected to axial compression. Basic formulations are constructed using the classical theory of shells and von Karman type of nonlinear strain-displacement relationships. The equilibrium and compatibility equations are solved by Galerkin procedure, and an explicit relation is obtained to predict the equilibrium paths. Results for different conditions are verified by comparison to existing data in the literature. Novel results are revealed in the parametric study to show the effects of different fiber paths, geometrical conditions, and lay-up configurations on the buckling and postbuckling of the advanced grid
stiffened structures. As a key finding, the helical and ring fibers of grids are more effective than stringer on the buckling load and postbuckling path. Especially when high number of ribs are considered.


ABSTRACT: Special-shaped welded hollow spherical joints (WHSJ) are increasingly used in several important spatial grid structures. The corrosion of WHSJ is inevitable and can eventually threaten structural safety. There is no research or comparison on the compressive strength of corroded special-shaped WHSJ. Therefore, through the simulation and analysis of the corrosion depth, corrosion mode, corrosion size, joint size, and steel material, the compressive strength of three types of special-shaped WHSJ after corrosion was studied, and the corresponding evaluation method for compressive strength was established. Results indicated that the loss of wall thickness ($T_c/T$) and the ratio of grooving corrosion ($2W_c/D$) were the key factors affecting the compressive strength of the special-shaped WHSJ after corrosion. The effect of corrosion on the bearing capacity was related to the size ratio ($d/D$), WHSJ connected by the H-beam were most affected by corrosion; the failure mode was basically buckling failure, but punching failure might occur in the H-beam WHSJ. The results obtained could form the basis for the selection of the WHSJ shapes and the evaluation of the bearing capacity of the space grid structure with special-shaped WHSJ after corrosion.


ABSTRACT: This paper addresses lateral torsional buckling of coped beams with corrugated webs. ABAQUS is the finite element software package used to develop three-dimensional models to investigate the influence of copes on the lateral torsional buckling resistance of this type of beams. It is found that the ultimate capacity of beams is remarkably reduced by 40%–80% depending on the cope geometry. The reduction in the capacity depends on the cope length and cope depth compared to the capacity of un-coped corrugated web beams. The coped beams with corrugated webs still exhibit a greater capacity than do the corresponding coped beams with flat webs. Design equations are developed to depict the strength of coped beams with corrugated webs. In addition, due to the low stiffness in the longitudinal direction of the corrugated beams and the absence of the flange in the coped region, the web has a tendency to elongate, and the corrugations are flattened. This phenomenon affects displacements both vertically and laterally and results in large deformations that are not acceptable in engineering practice. Strengthening solutions are introduced in this study to solve this problem.

Jothiurban Dhanapal (1), Hossein Ghaednia (1), Sreekanta Das (1) and Jonathan Velocci (2)
(1) Department of Civil and Environmental Engineering, University of Windsor, ON N9B 3P4, Canada
(2) Z Modular, Harrow, ON N0R 1G0, Canada

ABSTRACT: Steel modular construction has the potential to meet the growing infrastructure needs of the big cities and hence, the demand for modular construction is on the rise. This paper introduces a unique and innovative modular construction technique which involves the use of thin-walled hollow structural steel members and a state-of-the-art cast-steel connector, namely VectorBloc connector. The performance of the beam-column connections to be used in this modular construction largely determines its performance and success. In the present study, uniaxial and biaxial bending behavior of a typical corner beam-column connection made of thin-walled hollow structural steel members and VectorBloc connector was studied through full-scale tests and nonlinear finite element method. This beam-column connection will be used for constructing an assisted living facility. This study concludes that the design loads of the proposed assisted living facility can be safely carried by the VectorBloc connection. However, the weight of the VectorBloc connector can be reduced to 80% without compromising the design requirements of the assisted living facility. This study also concludes that the VectorBloc connection can be considered as a rigid connection. However, effective bracings against horizontal displacements must be provided in the structure in which the connection is intended to be used.
coupon tests, and the models were validated. Next, a parametric study was carried out, considering the residual stresses, geometric imperfections, and stress–strain curves obtained from the tension coupon tests, and the models were validated. A parametric study was carried out to generate additional experimental and numerical data, including overpressure–time histories, strain–time histories, and permanent displacement at different locations, were recorded. The response patterns of the specimens were identified and discussed, and the critical wrinkle strains were calculated based on the tension field theory. To elucidate the effects of the length/width ratio on the wrinkling behavior, wrinkling experiments were performed on specimens with four different length/width ratios but the same thickness. In addition, the surface and internal in-plane stresses of the structures were determined by both three-dimensional DIC and the digital gradient sensing method. The results indicated that a stress-change occurs between the membrane surface and its inner structure. Finally, the critical shear displacements determined using the two methods were found to be very close.

Shaobo Qi (1), Xudong Zhi (1), Qingwu Shao (2), Feng Fan (1) and Richard G.J. Flay (3)
(1) Key Lab of Structure Dynamic Behaviour and Control of the Ministry of Education, Harbin Institute of Technology, Harbin, 150090, China
(2) China General Nuclear Power Research Institute Co., Ltd., Shenzhen, 518000, China
(3) Department of Mechanical Engineering, The University of Auckland, Private Bag 92019, Auckland, 1142, New Zealand
ABSTRACT: The dynamic performance of single-layer reticulated domes under explosions was analysed experimentally and numerically in this study. The loading was generated by a Gas Blast Shock loading system (GBS) by igniting a gaseous mixture and applying it to the reduced-scale structure to investigate the dynamic response modes. Acetylene/air mixtures with various volumes were designed in different cases. The experimental data, including overpressure–time histories, strain–time histories, and permanent displacement at representative locations, were recorded. The response patterns of the specimens were identified and discussed, and the five major failure modes are as follows: no damage mode, insignificant damage mode, moderate damage mode, heavy damage mode, and whole collapse mode. It was shown that the Gas Blast Shock loading system is feasible for studying the response modes of single-layer spherical reticulated shells under external explosion. In addition, a numerical model based on ANSYS/AUTODYN was developed to simulate the experimental tests, and an improved equivalent TNT method was used to simplify the loading system. Good agreement between the experimental and numerical results was achieved and an explosion efficiency factor was proposed.

Songzhao Qu (1), Jingyun Wang (2), Yonghua Guo (2), Jiping Hao (3) and Xiaochi Yang (2)
(1) School of Civil and Traffic Engineering, Henan University of Urban Construction, Pingdingshan, 467001, Henan, PR China
(2) Central China Electric Power Engineering Corporation Limited, Zhengzhou, 450000, Henan, PR China
(3) College of Civil Engineering, Xi’an University of Architecture and Technology, Xi’an, 710055, PR China
ABSTRACT: This study describes an experimental and numerical modelling investigation of the buckling behaviour and load-carrying capacities of pin-ended hot-rolled high-strength structural steel equal-leg angle section columns. The testing programme involved material testing, measurements of the initial geometric imperfections, and 48 pin-ended column tests. The non-linear finite element models were developed considering the residual stresses, geometric imperfections, and stress–strain curves obtained from the tension coupon tests, and the models were validated. Next, a parametric study was carried out to generate additional
numerical data. The experiment and numerical results were analysed in detail and then utilised to evaluate the accuracy of the established design rules in China, the USA, and Europe. Through an in-depth comparative study, it was proved that the prediction of the compressive load-carrying capacity of high-strength steel angle section columns, using code GB50017, is relatively accurate.

Haluk Yılmaz (1), Erdem Özyurt (2), Asım Önder (2) and Petr Tomek (3)
(1) Vocational School of Transportation, Eskisehir Technical University, 26470, Eskisehir, Turkey
(2) Department of Mechanical Engineering, Eskisehir Technical University, 26555, Eskisehir, Turkey
(3) Faculty of Transport Engineering, University of Pardubice, 53210, Pardubice, Czech Republic


ABSTRACT: This study investigates the stability loss of thin walled conical shell structures under axial loading. More specifically, conical shells with semi-vertex angle greater than 65 degrees and with different bottom edge radial stiffness were studied in order to fill the gap in existing literature. The effects of geometrical parameters of the structure on the load bearing capacity were determined. Conical shell structures with high semi-vertex angle and different boundary conditions display highly non-linear character under axial loading, hence conventional analytical approaches are not adequate to predict the limit load. Therefore, a new method was proposed in this study which can accurately predict the limit load of these structures. The deviation between the proposed method and numerical results was found to be plus or minus 13%, while it was one order higher (plus or minus 300%) in classical shell theory, based on the configuration. Furthermore, similarity parameters were suggested to increase the range of application of the proposed method. Similarity parameters enable researchers to work with scaled-down models which are capable of simulating the behaviour of real-time-scale models. In addition, the effect of geometrical initial imperfections on the load bearing capacity was investigated and a new reduction coefficient was identified which is much more accurate compared to the overly conservative standard counterpart. A numerical model was developed with COSMOS/M software. This model was validated with experiments, and then was used for the parametric study.


ABSTRACT: This paper investigates the mechanical behavior of hybrid structures under the quasi-static axial loading. The hybrid tubes with different configuration scheme, stacking sequence and foam filler are first used to perform the quasi-static axial compression tests. In addition, the tubes with aluminum, Carbon Fiber Reinforced Plastic (CFRP) and aluminum foam are also tested as a comparison of the hybrid tubes. It was found that both the empty and foam-filled aluminum/CFRP hybrid tubes showed better mechanical behavior characteristics. Based on the numerical modeling, the results have been confirmed by experiments. Furthermore, a parametric study is carried out to explore the effects of relevant parameters on the mechanical behaviors of the hybrid tubes, and some useful conclusions are achieved.


ABSTRACT: The low velocity impact performance of curved steel-concrete-steel (CSCS) sandwich shells with bolt connectors subjected to a hemi-spherical head drop hammer was investigated in this paper. Experimental results including impact force history, displacement history and permanent deformation were analyzed to reveal the influences of concrete core and steel plate thickness as well as shear connectors’ spacing on the impact performances of CSCS shells. The impact process consisted of three stages, i.e., inertial stage, loading stage and unloading stage. Meanwhile, three failure types were observed from the nine specimens subjected to impact load. They were plastic deformation of steel plate without fracture (Failure type I), fracture of steel plate (Failure type II) and penetration of steel plate (Failure type III). The presence of bolt connectors was proven to be an effective way to prevent the detachment of steel plates from concrete core. Moreover, finite element (FE)
method was used to simulate the CSCS shells subjected to impact load. The accuracy of the FE model was verified by comparing the impact load history, displacement history and failure type from FE simulations with test results. It turned out that concrete core was the main part to dissipate impact energy, followed by top steel plate and bottom steel plate.

Jumpei Yasunaga (1) and Yasushi Uematsu (2)
(1) Steel Research Laboratory, JFE Steel Corporation, Kawasaki, 210-0855, Japan
(2) National Institute of Technology (KOSEN), Akita College, Akita, 011-8511, Japan
ABSTRACT: The present paper investigates the wind-induced buckling and vibration of cylindrical storage tanks based on wind tunnel experiments and time-history response analysis. Focus is on the effect of the vibration of tank shells on the buckling behavior. The dynamic buckling loads obtained from the experiments and the time-history response analysis are compared with the results obtained from the static buckling analysis. The effect of the inertia force generated by the vibration on the dynamic buckling behavior is found to be fairly small. Finally, the dynamic buckling loads are evaluated based on the results of the analysis for static wind loading.

S.Z. Tabatabaei-Nejad (1), P. Malekzadeh (1) and M. Eghtesad (2)
(1) Department of Mechanical Engineering, School of Engineering, Persian Gulf University, Bushehr 7516913798, Iran
(2) School of Mechanical Engineering, Shiraz University, Shiraz 71348-51154, Iran
ABSTRACT: As a first endeavour, the out-of-plane vibration characteristics of laminated functionally graded graphene platelets reinforced composite (FG-GPLRC) curved beams bonded by piezoelectric layers are investigated. The displacement components are approximated through the beam thickness direction based on the first-order shear deformation theory (FSDT). Accordingly, the shear deformation and rotary inertia effects due to both the torsional and flexural deformations are considered. The effective mechanical properties of the nanocomposite layers are estimated using the modified Halpin-Tsai model. The governing equations are derived by employing Hamilton's principle, which are discretized in the spatial domain using the differential quadrature method (DQM). After validating the approach, some useful results are provided which can be used for future researches. In this regards, the effects of graphene platelets (GPLs) distribution patterns, GPLs weight fraction and dimensions, number of GPLs reinforced layers, piezoelectric layer thickness, the curved beam geometric parameters and boundary conditions on the vibrational characteristics of the laminated FG-GPLRC curved beams embedded in piezoelectric layers are studied.

ABSTRACT: In this work, an efficient four-node facet shell element is presented for analysis of doubly curved multilayered piezoelectric shells, based on an electromechanically coupled third order zigzag theory. It is motivated by the excellent performance of the shell element developed earlier by the authors for elastic laminated shells. The laminate theory not only incorporates a layerwise description of the inplane displacements but also accounts for the layerwise normal deformation due to the d33-effect of the piezoelectric layers. The number of primary displacement variables is, however, the same as for the smeared third order theory (TOT). A quadratic variation of the electric potential across the piezoelectric layers is assumed, while satisfying the equipotential condition of electroded piezoelectric surfaces using the concept of electric nodes. The performance of the element is assessed for the stress analysis under mechanical and electric potential loads, and for the free vibration response of hybrid piezolaminated deep shells in comparison with the three dimensional piezoelectricity based analytical and finite element solutions. The comparison shows excellent accuracy of the present element for the deflection, stresses, sensory potential, electric displacement and natural frequencies of hybrid shells made of composite as well as the highly inhomogenous soft-core sandwich laminates, for which
the smeared TOT is shown to produce highly erroneous results. It is also shown to yield better accuracy than the other available elements of similar computational efficiency for hybrid composite shells.

Yuwu Zhang (1,2), Shuaishuai Wang (3) and Luhui Yan (4)
(1) College of Liberal Arts and Sciences, National University of Defence Technology, Changsha, 410073, China
(2) Centre for Structural Engineering and Informatics, University of Nottingham, Nottingham, NG7 2RD, UK
(3) College of Aerospace Science and Technology, National University of Defence Technology, Changsha, 410073, China
(4) Undergraduate College, National University of Defence Technology, Changsha, 410073, China


ABSTRACT: Fibre reinforced cementitious composites (FRCC) hollow tube is a kind of promising high-toughness energy absorption structure. As this structure absorbs energy via the transverse deformation of tube, it is necessary to investigate the transverse compressive behavior and failure mode of the FRCC tubes. In this study, the transverse compressive response of cementitious composites tubes reinforced by Polyvinyl alcohol (PVA) fiber and ultra-high molecular weight polyethylene (PE) fibre, respectively, has been experimentally investigated, numerically simulated and dimensionally analyzed. According to the transverse compression tests, the FRCC tubes failed with four-hinge fracture. The FRCC tubes presented ductile fracture while the plain cement-based material (P0) tube presented brittle fracture. The numerical simulation based on extended finite element method (XFEM) has a good agreement with the experimental measurements, and both the crack development at the hinges and stress distribution on the crack section are predicted. The fibre reinforcements remarkably enhanced the mechanical properties of tubes, including the transverse force resistance and deformation capacity. The peak force and maximum energy absorption of FRCC tube is 2 times and 60 times higher than those of P0 tube, respectively. The dimensional analysis suggested that the specific energy absorption per unit volume was principally dominated by the ratio of tube thickness to average radius, whereas the stroke efficiency was governed by the ratio of tube thickness to average radius and the ratio of average radius to tube length. This work provides a guidance for developing FRCC tubes with high specific energy absorption, and is expected to widen the applicability of FRCC tubes in protection engineering.

S.J. Singh (1) and S.P. Harsha (2)
(1) Department of Mechanical Engineering, Pandit Deendayal Petroleum University Gandhinagar, India
(2) Vibration and Noise Control Lab, Mechanical and Industrial Engineering Department, Indian Institute of Technology Roorkee, India


ABSTRACT: In the present paper, an attempt has been made to obtain the solution for bending and stress under the thermal environment using Galerkin Vlasov's method. A non-polynomial based higher-order shear deformation theory with inverse tangent hyperbolic shape function is used to define the displacement field. The formulation is performed for the author's recently developed sandwich plate using a new modified sigmoid function-based functionally graded material (S-FGM) plate of different symmetric and non-symmetric configurations. Using a one-dimensional steady-state heat conduction equation, a new temperature distribution through the thickness based on modified sigmoid law is proposed. Three different types of porosity are considered viz. even, uneven but symmetric and uneven but non-symmetric. A new uneven non-symmetric porosity model is used in which micro-voids are varied in accordance with material property variation in the thickness direction in order to capture the accurate distribution of voids on the plate. The principle of virtual work is employed to derive equilibrium equations. An exact solution is obtained using the assumed solution with shape functions satisfying the edge boundary conditions. From the present study on static analysis, it is deduced that more refined and accurate results for plate in thermal environment, it is necessary to include the thermal effect on the stiffness of the plate in addition to the initial deflection of the plate. The effect of boundary conditions on stress and deflection distribution along the surface of the porous plate is studied, and it is observed that the distribution is prominently affected by the type of symmetric or asymmetric boundary conditions. The considerable increase in deflection and stress can be seen for even porosity distribution (P-1) in
comparision to uneven symmetric (P-2) or uneven non-symmetric (P-3) porosity distribution. In addition, the maximum transverse shear stresses are offset more from the center of the sandwich plate with an increase in temperature differences with a maximum offset at $\Delta T = 300 \text{ K}$ and minimum offset at $\Delta T = 0 \text{ K}$. Different examples are considered to check the accuracy and validation of the present formulation. The calculated outcomes and interpretations can be useful as a validation study for the imminent investigation of sandwich SFGM plates having porosities in the thermal environment.


ABSTRACT: This study investigates the crush response of lattice filled square tubes under quasi-static compressive loading. Auxetic lattice (auxetic strut and re-entrant) filled tubes have been compared to a non-auxetic (honeycomb) filled alternative and an empty tube. All structural lattices within this study were designed to be of equal mass. The experimental results were computationally validated using Abaqus®/Explicit. Experimental and numerical results show good agreement which highlights that the addition of lattice structures greatly improved the crashworthiness performance of the crash tube compared with an empty tube. By comparing the experimental values of energy absorption (EA), through the inclusion of a filler lattice a 62.6%, 64.0% and 79.1% increase over the empty tube were obtained for the auxetic strut, re-entrant and honeycomb structures respectively.

Mehran Safarpour (1), Aria Ghabussi (2), Farzad Ebrahimii (3), Mostafa Habibi (4) and Hamed Safarpour (3)
(1) Department of Mechanical Engineering, Faculty of Engineering, Tarbiat Modares University, Tehran, Iran
(2) Department of Civil Engineering, Central Tehran Branch, Islamic Azad University, Tehran, Iran
(3) Faculty of Engineering, Department of Mechanics, Imam Khomeini International University, Qazvin, Iran
(4) Center of Excellence in Design, Robotics, and Automation, School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

ABSTRACT: This is the first research on the free vibration analysis of functionally graded graphene platelets reinforced composite (FG-GPLRC) viscoelastic annular plate resting on the visco-Pasternak foundation and subjected to the nonlinear temperature gradient and mechanical loading within the framework of higher-order shear deformation theory (HSDT). Hamilton’s principle is employed to establish governing equations within the framework of HSDT. In this paper, viscoelastic properties are modeled according to Kelvin-Voigt viscoelasticity. The deflection as the function of time can be solved by the fourth-order Runge-Kutta numerical method. Generalized differential quadrature method (GDQM) is applied to obtain a numerical solution. Numerical results are compared with those published in the literature to examine the accuracy and validity of the applied approach. A comprehensive parametric study is accomplished to reveal the influence of the stiffness of the substrate, patterns of temperature rise, axial load, damper and viscoelasticity coefficient, weight fraction and distribution patterns of GPLs and geometric dimensions of GPLs on the frequency response of the structure. The results revealed that applying sinusoidal temperature rise and locating more square-shaped GPLs in the vicinity of the top and bottom surfaces have important effect of the highest natural frequency and buckling load of the FG-GPLRC viscoelastic structure.


ABSTRACT: This paper investigates the collapse behavior of square paper tubes and the influence of tensile-compressive yield asymmetries of paper tube materials by combining the theoretical and experimental methods. An approximate energy absorption theoretical model is developed to predict the mean crushing force of square paper tubes subjected to axial loading. Besides, combined with the remarkable linear regularity of the experimental results, the numerical curve of the effective crushing distance ratio of paper tubes is obtained to improve the applicability of the proposed model. Then the theoretical results taking account of effective
crushing distance are in excellent agreement with the experimental results. The proposed model can be used not only for the prediction of energy absorption characteristics of paper tubes in a logistics environment, but also to guide the protective packaging structure design with paper tubes.

Jian Zhang (1), Xin Wang (1), Wenxian Tang (1), Fang Wang (2) and Baoji Yin (1)
(1) School of Mechanical Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
(2) Shanghai Engineering Research Center of Hadal Science and Technology, Shanghai Ocean University, Shanghai, 201306, China


ABSTRACT: This study investigated the buckling performances of stainless steel toroidal shell segments under uniform external pressure. The toroidal shell segments used in this study exhibited a nominal section radius of 70.5 mm, nominal wall thickness of 1.346 mm, and nominal rotation radius of 138 mm. A total of 12 toroidal shell segments were manufactured using roll bending and were measured geometrically, tested hydrostatically, and evaluated numerically. Six of the shell segments had a 45° rotation angle, whereas the other six had a 90° rotation angle. Moreover, the buckling of geometrically perfect toroidal shell segments was explored under various rotation angles ranging from 30° to 360°.

Xuan Cheng (1,2), Hui Wang (3), Ali Abd El-Aty (1,4), Jie Tao (1,2), Wenbin Wei (1,2), Yao Qin (1) and Xunzhong Guo (1,2)
(1) College of Material Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 211100, PR China
(2) Nuclear Energy Equipment Materials Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 211100, PR China
(3) College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China
(4) Mechanical Engineering Department, Faculty of Engineering-Helwan, Helwan University, Cairo, Egypt


ABSTRACT: Thin–walled rectangular tube bent parts of continuous varying radii are widely used in aircraft, aerospace, aviation, radar, and several high-tech industries to save space and satisfy the internal structure compact of the specific products. In the previous years, the applications of thin-walled rectangular tubes were hindered because of the distortion in the cross-section area, which occurred during deformation. Nevertheless, due to its unique characteristic, free bending technology is highly suitable to form tubular components with a variable bending radii and bends in several planes. Thus, in this study, the deformation behavior of a thin-walled tube (with a rectangular cross-section area) of continuous varying radii during free bending technology was investigated. Besides, a stress analysis model was proposed to predict the equivalent stress and strain distribution. The proposed model was verified using simulations and experimentation. Furthermore, the influence of two key parameters (feeding speed and fillet radius) on the formability of a thin-walled rectangular tube was discussed. The remarkable results obtained from this study verify that free bending technology is a significant forming technology to manufacture rectangular thin-walled tubes with continuous varying radii.

Tong Ou (1,3), Dayang Wang (2,3), Zhiyong Xin (4), Jian Tan (1), Chengqing Wu (2,5), Qiangwen Guo (2) and Yongshan Zhang (2)
(1) Architectural Design and Research Institute of Guangdong Province, 510000, PR China
(2) School of Civil Engineering, Guangzhou University, 510006, PR China
(3) Guangdong Engineering Research Centre for Metal Cladding and Roofing System (GDERC-MCRS), 510006, PR China
(4) Zhuhai Envete Engineering Testing Co., LTD, 519000, PR China
(5) School of Civil and Environmental Engineering, University of Technology Sydney, NSW, 2007, Australia

ABSTRACT: The wind uplift performance of the continuously welded stainless steel roof (CWSSR) system adopted in the Zhaoqing New District Sports (ZNDS) Center of China is investigated in this study. To determine the optimal welding program and examine the mechanical properties of the continuously welded stainless steel joints, uniaxial tensile testing is first conducted on 27 specimens with tension-shear and tension-bending types. Two CWSSR specimens, one that is square-shaped with a horizontal layout and one that is rectangular-shaped with an inclination layout of 10.71°, are further tested under dynamic and static ultimate wind uplift loadings to explore the wind uplift capacity. All specimens are full-size, and the corresponding materials, structural details and construction technologies are kept the same as the actual building to ensure the authenticity of the testing investigations. The testing results indicate that the integrated and sealed CWSSR system has a clear force transmission mechanism and a remarkable wind resistance performance. The welded joints achieve the best performance, and the mechanical behaviours are equivalent to those of the base material under the continuously welded conditions including an electric current of 65 A and a moving velocity of 750 mm/s. An excellent dynamic wind suction performance is achieved under 5000 five-level cumulative loading cycles with a maximum pressure of 5400 Pa. The static ultimate pressure reaches 9400 Pa for the square specimen and 10,400 Pa for the rectangular specimen. Damage observations show that no tearing or rupture failures are observed for the CWSSR system. The investigation results contribute the most to the safe design of the ZNDS Center and are expected to provide guidelines for future applications of the CWSSR system.

Y. Gholami (1), R. Ansari (1) and R. Gholami (2)
(1) Faculty of Mechanical Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran
(2) Department of Mechanical Engineering, Lahijan Branch, Islamic Azad University, P.O. Box 1616, Lahijan, Iran


ABSTRACT: In this paper, a size-dependent three-dimensional (3D) nonlinear weak formulation is provided to examine the nonlinear primary resonance problem for functionally graded rectangular small-scale plates. The small-scale factors are taken into formulation by choosing the Mindlin's strain gradient theory (SGT). According to the variational differential quadrature (VDQ) method, first, the displacement field, nonlinear strain-displacement and constitutive relations as well as the potential and kinetic energies are expressed as the vector and matrix forms. Then, by applying the discretized form of differential operators obtained via the generalized differential quadrature (GDQ) method, the discretized form of aforementioned relations is achieved. Finally, Hamilton's principle is employed to access the weak form of 3D nonlinear governing equations of thick rectangular small-scale plates. The achieved formulation is solved via a multi-step numerical technique to address the size-dependent nonlinear primary resonance of considered system under the harmonic lateral force. In addition to reducing the run time, computational effort and CPU usage, the feature of proposed weak form formulation is that one can employ it in other solution approaches such as finite element method. Also, the use of this formulation provides the possibility of recovering models on the basis of other types of size-dependent theories such as modified strain gradient and modified couple stress theories (MSGT and MCST). In the numerical results, the effects of boundary conditions, small-scale parameter, material index and geometry are examined.

Man-Tai Chen (1,2), Ben Young (3), André Dias Martins (4), Dinar Camotim (4) and Pedro Borges Dinis (4)
(1) Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
(2) Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
(3) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China
(4) CERIS, DECivil, Instituto Superior Técnico, Universidade de Lisboa, 1049-001, Lisbon, Portugal

ABSTRACT: The objective of this work is to report a careful experimental investigation, planned at the University of Lisbon and carried out at The University of Hong Kong, concerning the behaviour and ultimate strength of cold-formed steel web-flange-stiffened (WFSLC) and web-stiffened (WSLC) lipped channel columns undergoing local-distortional (L-D) interaction. It involves 31 specimens (16 WFSLC+ 15 WSLC), brake-pressed from high-strength zinc-coated grades G450, G500 and G550 structural steel sheets, exhibiting critical distortional-to-local buckling load ratios ranging between 0.75 and 1.88. The column geometries were carefully selected to enable testing fixed-ended columns undergoing true L-D interaction and secondary distortional-bifurcation L-D interaction (ensuring evidence of the latter required selecting rather slender columns) – all tested specimens exhibited the expected L-D interactive failures. The specimen material properties were obtained from tensile coupon tests and their initial geometrical imperfections were measured prior to testing. The experimental results presented and discussed consist of column (i) load-displacement equilibrium paths, (ii) photos evidencing the evolution of the column deformed configurations along those paths (including the failure mode) and (iii) failure loads. Finally, the experimental failure load data obtained are compared with their estimates provided by the currently codified DSM design approaches for columns failing in L and D modes, showing their inadequacy to handle L-D interactive failures – the fresh light shed by this comparison will contribute to the timely codification, in the near future, of a DSM design procedure for columns affected by L-D interaction.


ABSTRACT: In this paper, a novel multi-cell tubal structure with randomized cell sizes is proposed to enhance the energy absorption of the conventional square tubes by utilizing the random nature of Voronoi tessellations. Experiments were conducted to develop and validate finite element models. The crashworthiness of these tubes was demonstrated by applying axial and bending loads using the finite element method. The proposed multi-cell tubal structures exhibit a progressive and stable deformation with the formation of folds in the axial loading case and a local and global deformation for the lateral bending case. The peak crushing force (PCF) and specific energy absorption (SEA) of the proposed multi-cell tubal structures were found to be better than the regular multi-cell square tubes with equal cell sizes when subjected to axial loads. When subjected to lateral bending load, the proposed multi-cell tubal structures have a better PCF while the regular multi-cell square tubes have a better SEA. An optimization problem was formulated to enhance the crashworthiness of the structures. The objective functions were derived using meta-models to speed off the search for optimal structures. The axial crushing and lateral bending cases were optimized separately and combined. Multi-objective particle swarm optimization (MOPSO) was employed to solve the optimization problems. The optimal tubal structures have a crushing efficiency of 87.1% and 85.6% for axial and bending loads, respectively.


ABSTRACT: This paper is devoted to investigate the lateral-torsional buckling (LTB) of hybrid corrugated web girders (CWGs) built up from flanges with a yield stress of 690 MPa, which has been used in bridge construction worldwide. The hybrid girders have been utilised to provide a cost-effective solution because of the high material cost of S690. This investigation has been based on the finite element (FE) modelling by using ABAQUUS program. Accordingly, material modelling of S690 has been verified by considering recent experimental tests in the literature. Then, the accuracy of the current FE models of the CWGs has additionally been checked successfully. Parametric study has been carried out on simply-supported girders, for bridge construction, considering mainly the influences of the hybrid ratio and corrugation dimensions on the behaviour of the CWGs built up from HSSs. A limiting slenderness ratio for the inelastic LTB of 2.3 has been found, where more slender girders would not benefit from using such HSS material. Additionally, the strengths of the girders have been compared with EC3 design model, which has been found to provide highly conservative predictions for the current girders. Consequently, a new design model has been suggested. This suggested bending strength is generally found to provide accurate predictions for the hybrid CWGs built up from flanges.
of S690 HSS; especially for girders failing inelastically. Finally, several comparisons have been provided that might aid the structural engineers in designing efficient hybrid cross-sections in the future.


ABSTRACT: A symplectic wave-based method is applied to the vibro-acoustic problems of submerged ring-stiffened cylindrical shells, accounting for the effects of hydrostatic pressure and acoustic-structure interaction. The symplectic wave-based method combines the symplectic state space theory with the traditional wave propagation approach, and shows the characteristics of high precision and high numerical stability. However, this method is only applied to the vibration analysis of relatively simple and geometrically regular structures before. In this paper, the method is extended to the acoustic vibration analysis of general ring-stiffened cylindrical shells, in which numerical integration strategies are adopted to deal with unknown acoustic-structure coupling terms, finally a complete coupled vibro-acoustic analysis is realized. A further quantitative investigation clearly reveals the effects of hydrostatic pressure on the vibration and acoustic responses. Compared with the existing methods, the present method shows better convergence and accuracy properties, especially when the stiffening rings are dense. It is also shown that hydrostatic pressure cannot be ignored in the acoustic radiation analysis if the low-frequency near-field acoustic pressure is concerned, otherwise, it can be ignored.


ABSTRACT: Multi-cell tubes are widely used as energy-absorption components in transportation field due to its high energy absorption capacity and good weight efficiency. However, with the increase of vehicle speed, people have high requirements for safety, and therefore, the crashworthiness performance of multi-cell tubes should be further improved. To this end, we proposed a new type of multi-cell circumferentially corrugated square tubes (CCSTs) by implementing multi-corrugation on the cross sections of the traditional multi-cell square tubes (STs). Experimental, numerical and theoretical methods were adopted to investigate the crushing mechanics of the multi-cell CCSTs. The results showed that the crashworthiness performance of the multi-cell CCSTs was significantly superior to that of the multi-cell STs. In addition, parametric study was performed to reveal the effects of geometric parameters on the crashworthiness characteristics. In conclusion, this work is of positive significance for improving the level of crashworthiness of thin-walled tubes, and this structural design method can also be used for other traditional structures.

Riming Tan (1), Jifeng Xu (2), Zhidong Guan (1), Wei Sun (3), Tian Ouyang (1) and Shoucai Wang (4)
(1) School of Aeronautic Science and Engineering, Beihang University, Beijing, 100191, China
(2) Beijing Aeronautical Science and Technology Research Institute, COMAC, Beijing, 102211, China
(3) Chinese Aeronautical Establishment, Beijing, 100012, China
(4) Shenyang Aircraft Design and Research Institute, Shenyang, 110035, China

ABSTRACT: Experiments are performed in this study to investigate the influence of impact locations on the damage and compression behavior of stiffened composite panels with a single L-shaped stiffener. After the application of low-velocity impact to the flange tip or web from the outboard side with the same energy level, significant differences among the damage types in specimens are observed. The flange tip impact induces complex damage types including ply fracture, splitting, delamination, and stiffener/skin interface debonding. The stiffness discontinuity results in the extensive propagation of delamination along the longitudinal direction. In contrast, the web impact damage is minimal because of the web's high stiffness. The results of compression after impact reveal that these two types of damage lead to considerable differences in compression behavior. The severe damage caused by the former leads to a considerable reduction in buckling load; however, the
buckling deformation drives the rapid propagation of damage without any constraint. As a result, no distinct post-buckling stage is observed, and the failure load is considerably reduced. On the other hand, the damage caused by the latter weakens the interaction between the stiffener and skin, thereby slightly reducing both buckling and failure loads. Based on these findings, several suggestions on aircraft structure design and inspection are proposed to avoid significant damage and rapid damage propagation.

Marko Lavrenčič (1), Boštjan Brank (1) and Miha Brojan (2)
(1) University of Ljubljana, Faculty of Civil and Geodetic Engineering, Jamova c. 2, Ljubljana, Slovenia
(2) University of Ljubljana, Faculty of Mechanical Engineering, Aškerčevea 6, Ljubljana, Slovenia


ABSTRACT: We propose an efficient computational model for predicting the surface wrinkling in axially compressed bi-layer cylindrical shell-substrate composites. To capture the transitions between the wrinkling modes in the far post-buckling regime, we use implicit dynamics. In this context we apply a generalized-α and an energy-decaying time stepping schemes that numerically dissipate in the high frequency range. The other components of the model are a geometrically exact, rotation-less, nonlinear shell finite element for the cylinder and an elastic foundation that represents the substrate. We show that the proposed computational model predicts the wrinkling pattern transition from axisymmetric to diamond-like mode, which is consistent with the numerical and laboratory experiments reported earlier. Furthermore, the results of our computational model show the existence of several diamond-like mode jumps in the post-buckling regime, a result that has not yet been reported for the axially compressed shell-substrate cylinders.

Nam V. Nguyen (1), H. Nguyen-Xuan (2), Dongkyu Lee (1) and Jaehong Lee (1)
(1) Department of Architectural Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul, 05006, Republic of Korea
(2) CIRTech Institute, Ho Chi Minh City University of Technology (HUTECH), Ho Chi Minh City, Viet Nam


ABSTRACT: In this study, we numerically investigate static and free vibration responses of functionally graded (FG) porous plates with graphene platelets (GPLs) reinforcement using an efficient polygonal finite element method (PFEM). While the bending strain field is approximated through quadratic serendipity shape functions, the shear strain field is calculated by employing Wachspress basis functions. In order to eliminate the shear locking phenomenon, Timoshenko’s beam theory is utilized to determine assumed strain fields on each side of polygonal domain. The present formulation possesses various outstanding features: (a) is valid for triangular, quadrilateral and polygonal elements; (b) can conveniently implement various different plate theories via choosing appropriate transverse shear function; (c) eliminates the shear locking phenomenon; (d) does not increase degrees of freedom (DOFs) per polygonal element despite employing the quadratic serendipity shape functions and (e) obtains more accurate and stable results than those of other PFEMs. Various dispersions of internal pores as well as GPLs into metal matrix through the thickness of plate are examined. The effective material properties varying across the plate's thickness can be estimated by Halpin-Tsai model for Young's modulus and the rule of a mixture for Poisson's ratio and mass density. The effect of several important parameters such as porosity coefficient, weight fraction and dimensions of GPLs, distribution of porosity and GPLs into metal matrix are thoroughly investigated via various numerical examples.

Enrico Santarpia (1) and Luciano Demasi (2)
(1) Department of Aerospace Engineering, San Diego State University and Department of Structural Engineering, University of California San Diego, USA
(2) Department of Aerospace Engineering, San Diego State University, San Diego, USA


ABSTRACT: Murakami's Zig-Zag Function in conjunction of Green-Lagrange Strain- and Second-Piola Kirchhoff Stress-tensors and Generalized Unified Formulation are introduced for the first time to present a class of Zig-Zag theories for composite structures. Transverse strain effects are retained and modeled, making the
present approach also suitable for thick structures. Each displacement variable is independently represented with user-selected order of expansion. The stress recovery is achieved with a special procedure in which combination of deformation gradient and Second-Piola Kirchhoff transverse stresses are integrated along the thickness of the undeformed geometry. Comparison with available data and commercial codes indicate the effectiveness of the proposed framework for variable kinematics Zig-Zag theories in the presence of large displacements.

ABSTRACT: This paper aims to lighten the weight of concrete-filled steel tubes using wood blocks. Different proportions of wood to concrete were used in a way that wood blocks were substituted with a fraction of concrete in small-scale columns. The behaviour of the composite members was compared with the reference specimens, i.e. fully concrete-filled tubes. Carbon Fibre Reinforced Polymer (CFRP) was also employed as a confining material for some specimens, the effect of which was investigated. The weight reduction that timber provided was evaluated against the axial capacity of each specimen. A new index is introduced to quantify the structural efficiency with a view to evaluating capacity change against the weight. A new parameter is defined in this paper to determine and quantify the transitional response of columns under compression between different peaks loads on load-displacement graphs. This parameter can further help reduce potential risks of failure/collapse at post-peak stages.
A key finding was that the number of timber blocks in specimens with the same volume of timber did not affect the axial capacity, which paves a path for designing timber blocks in multiple numbers. Despite a significant difference between the compression strength of timber and concrete, the capacity reduction provided by timber was not proportionate (was smaller) to the strength difference of the two materials, nor was proportionate to the weight reduction. This disproportion, which can be due to the interaction of all three materials, is structurally desirable especially for the seismic design where the total weight plays a key role. This can be attributed to the usage of stronger and thicker steel acting as a confining material, which is advised for similar structures based on the results of this study.

Mergen H. Ghayesh (1), Hamed Farokhi (2) and Ali Farajpour (1)
(1) School of Mechanical Engineering, University of Adelaide, South Australia, 5005, Australia
(2) Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK
ABSTRACT: A Kelvin–Voigt based constitutive equation is implemented in Hamilton's framework in order to derive the coupled in-plane/transverse equations governing the motion of a microplate with geometric imperfections, while considering geometric nonlinearities. The Kirchhoff plate theory and the modified couple stress-based theory (MCST) are utilised to obtain the strain and kinetic energies of the imperfect microsystem. Then, the Kelvin–Voigt energy dissipation scheme is employed to derive expressions for the work of the viscous components of the classical and non-classical stress tensors. Frequency-response diagrams are plotted to investigate the nonlinear resonant oscillations of the imperfect viscoelastic microsystem in the presence of geometric imperfections. Numerical simulations revealed that the concurrent presence of geometric imperfections and the nonlinear amplitude-dependent damping mechanism alters the bifurcational behaviour of the viscoelastic microsystem substantially. It is shown that at oscillations of large amplitude, the nonlinear damping contributions become significant.

S.A.M. Ghannadpour (1), F. Moradi (1) and F. Tornabene (2)
(1) New Technologies and Engineering Faculty, Shahid Beheshti University, G.C, Tehran, Iran
(2) DI2 - Department, School of Engineering, University of Salento, 73100, Lecce, Italy
ABSTRACT: The main purpose of this research is to obtain analytical formulations for exact calculation of relative post-buckling stiffness of nonlocal graphene sheets. In addition to calculating the post-buckling stiffness reduction, the buckling and initial post-buckling responses of these structures, when they are subjected to end-shortening strain, have also been studied. To investigate these phenomena, a new technique called semi-Galerkin technique is used in which the out-of-plane deflection function is firstly postulated as the only displacement field and then, exact nonlocal stress function is calculated through a complete solution of the von-Karman compatibility equation. Finally, Galerkin’s method is used to solve the unknown parameter considered in the proposed technique. The nano-sheets are modeled as an orthotropic layer with Kirchhoff assumptions and nonlocal differential elasticity theory is employed to achieve the buckling loads and exact relative stiffness values. For in-plane movements of the longitudinal edges of the nano-sheets, two essential and natural boundary conditions are adopted to be “straightly movable” or “freely movable”. The effects of aspect ratio and nonlocal parameter have been studied for each type of boundary conditions and for graphene sheets with different materials. The stress distribution along the length and the width of the nano-sheets is also investigated and discussed by the two local and nonlocal theories and for various values of nonlocal parameter.


ABSTRACT: Thin-walled tubes have been widely used in crashworthiness applications such as automotive and aerospace industries. However, inevitable structural imperfections in the tube wall impose adverse effects on the energy absorption performance of the tube. Here, we have employed a fluid-like and highly compressible material, i.e. liquid nanofoam (LN), as a filler to suppress the negative impact of structural imperfection. The mechanical performance of empty tubes and LN-filled tubes (LNFT) with different dent imperfections has been evaluated by quasi-static uniaxial compression tests. Results show that empty tube is susceptible to structural imperfection, as a v-shaped dent with 1.5 mm depth reduces the energy absorption capacity by about 20%. In contrast, the mechanical performance of LNFT is insensitive to the existence and depth of the dent. The enhanced imperfection insensitivity of LNFT is due to the intimate liquid-solid interaction at the LN filler and the tube wall interface, which effectively suppresses the curvature growth of the dent and the localized folding. The findings provide an efficient approach for designing and engineering thin-walled energy absorption devices that are resilient and of high energy absorption capacity.

Shilong Wang (1,2), Hongquan Wang (1), Yuanyuan Ding (2) and Feng Yu (1)
(1) College of Civil Engineering, Anhui University of Technology, Ma'anshan, Anhui, 243002, PR China
(2) Impact and Safety Engineering, Ningbo University, Ningbo, Zhejiang, 315211, PR China

ABSTRACT: Honeycomb structure, which presents potential ability in energy absorption and impact resistance, has advantages of simplicity, lightweight, easy manufacturing and designability. In this study, honeycomb structure panel is expanded to cylindrical shell by adopting the rolled-up algorithm and the crushing behaviors of the randomly honeycomb cylindrical shell (RHCS) structures are investigated under axial loading. The influence of geometrical and topological parameters, i.e. the thickness-to-diameter ratio, cell irregularity, relative density on the deformation evolution and energy absorption performance is systematically performed. It is found that the deformation modes of RHCS structures are significantly affected by thickness-to-diameter ratio and cell irregularity. Moreover, the rate-independent, rigid–plastic hardening (R–PH) idealisation with two parameters is adopted to characterize the crushing responses of RHCS structures and the parameters are quantified as power-law relations with respect to relative density. Further, the crushing behaviors of density-graded RHCS structures with continuously varying in density are carried out under different impact velocities. Results indicated that the introduction of density gradients can strongly affect the deformation mode, crushing force and energy absorption performance of density-graded RHCS structures. Combining with analysis of crushing front propagation, the theoretical determination of crushing responses of the density-graded RHCS under different loading rates is presented based on R–PH model. The results of predicted crushing force-time histories of density-graded RHCS structures show versatile agreement with that of finite element values at both impact and support ends. Additionally, the energy absorption capacity that is related to deformation mechanisms of density-graded RHCS structures is investigated.
Wei Xian (1,2), Wen-Da Wang (1), Rui Wang (2), Wensu Chen (3) and Hong Hao (3)
(1) School of Civil Engineering, Lanzhou University of Technology, Lanzhou, 730050, PR China
(2) School of Civil Engineering, Taiyuan University of Technology, Taiyuan, 030024, PR China
(3) Center for Infrastructural Monitoring and Protection, School of Civil and Mechanical Engineering, Curtin University, Perth, Australia


ABSTRACT: In this study, dynamic response of steel-reinforced concrete-filled circular steel tubular (SRCFST) members was experimentally studied under lateral impact loads. Eighteen SRCFST specimens were prepared and tested by the drop hammer impact test system. Various parameters, namely, cross-section of profiled steel, impact velocity and impact direction for I section profiled steel were considered to examine their influences on the failure mechanism, impact force, impact duration, displacement response and energy absorption. Since the beams may be of different constraints at boundary and the columns are axially loaded, boundary condition and axial load level were also considered. The experimental results show that the energy dissipation ratios ($E_d/E$) of all tested specimens except CIFP2-0 are more than 85% and the maximum energy dissipation ratio reaches 97.5%, indicating SRCFST members can absorb large amounts of input energy. Moreover, the inserted profiled steel can effectively enhance impact resistance while reduce energy absorption. It is also found that the peak value ($F_{\max}$) of impact force is very sensitive to the variation of impact velocity. The plateau value ($F_{\text{ave}}$) of impact force and displacement response are very sensitive to the variation of boundary conditions and axial loads, which can significantly change the lateral flexural stiffness of specimens. Given the same impact energy input, SRCFST members with cruciform section profiled steel under fixed-fixed boundary conditions exhibit the best impact resistance performance with the lowest mid-span displacement.

Seyyed Morteza Fatemi Moghaddam and Habib Ahmadi (Faculty of Mechanical Engineering, Shahrood University of Technology, Shahrood, Iran), “Active vibration control of truncated conical shell under harmonic excitation using piezoelectric actuator”, Thin-Walled Structures, Article 106642, Vol. 151, June 2020, https://doi.org/10.1016/j.tws.2020.106642

ABSTRACT: In this study, active vibration control of an FGM truncated conical shell, subjected to the harmonic excitation, is investigated via a semi-analytical method. The governing equations of truncated conical shells in conjunction with piezoelectric layers are derived using Donnell shell theory and von Karman's non-linearity. Then, the dynamic equation of the system is discretized using Galerkin method to obtain the ordinary differential equation of system. Using the semi-analytical method by means of perturbation theory, the frequency response of superharmonic and sub-harmonic analysis of the system is performed. Then, using the piezoelectric smart materials, the active vibration control for the truncated conical shell is investigated and frequency-amplitude functions are analyzed for the superharmonic and subharmonic resonances. The results present the influence of excitation amplitude and cone vertex angle on the frequency-amplitude response and in specific the effect of different control gain coefficients on the system's vibration behavior. Finally, the performance of active control strategy is investigated by means of the time response of system equipped with piezoelectric layers for different types of the FG distribution in thickness direction.

Essam Eltayeb (1,2), Xing Ma (1), Yan Zhuge (1), Osama Youssf (1,2), Julie E. Mills (1) and Jianzhuang Xiao(3)
(1) University of South Australia, School of Natural and Built Environments, Adelaide, Australia
(2) Mansoura University, Faculty of Engineering, Structural Engineering Department, Mansoura, Egypt
(3) Department of Building Engineering, Tongji University, Shanghai, 200092, PR China


ABSTRACT: This research investigates the effect of using lightweight foam rubberised concrete as an infill material for double-skinned profiled composite panels under pure shear load through experimental and analytical modelling. Three concrete mixes were used as infill materials in this study: one control foam concrete (FC), and two foam rubberised concrete (FRC) with rubber contents of 8.5% and 17% by total mix volume. The pure shear behaviours of the profiled concrete and profiled steel-concrete composite panels were investigated by
testing nine small-scale square panels. Three profiled concrete panels and three profiled steel-concrete composite panels were tested under monotonic pure shear load. In addition, three profiled steel-concrete composite panels were tested under repeated cyclic pure shear load. The monotonic test results showed comparable ultimate loads for both FRC and FC panels. Moreover, the FRC panels experienced a higher number of cracks and higher ductility. The cyclic shearing behaviour of FRC composite panels with 8.5% and 17% rubber contents outperformed the FC panels through increased capacities of about 10.3% and 8%, respectively. The increase in ductility of FRC panels with 8.5% and 17% rubber contents over that of FC panels was about 19.5% and 2.4%, respectively. The cumulative energy dissipation for FRC panels also showed a distinct increase over that of FC panels.

Zongxing Zhang, Shanhua Xu, Biao Nie, Rou Li and Zhen Xing (School of Civil Engineering, Xi’an University of Architecture and Technology, Xi’an, Shanxi, 710055, China), “Experimental and numerical investigation of corroded steel columns subjected to in-plane compression and bending”, Thin-Walled Structures, Article 106735, Vol. 151, June 2020, https://doi.org/10.1016/j.tws.2020.106735

ABSTRACT: To study the effect of corrosion on the bearing capacity of compression-bending steel members, especially the local buckling behaviors, six H-shaped Q345 steel short columns with different corrosion degrees were designed. The outdoor accelerated corrosion test for up to 2 years, monotonic tensile test of standard specimens and eccentric compression test of steel columns were carried out, respectively. The volume loss ratio was used to evaluate the corrosion degree of each specimen. The relationships between failure mode, bearing capacity and deformation behavior to corrosion degree were analyzed. In addition, based on the experimental result, the interactive modeling was carried out by the software Geomagic Studio and ABAQUS, and then the deterioration laws of the bearing capacity of corroded H-section compression-bending steel members under the real corroded surface was also studied. The results showed that the bearing capacity of H-section compression-bending steel member decreased gradually with the increase of corrosion degree, and the yield load, ultimate load and buckling load of the most seriously corroded specimen PY-6 decreased by 22.8%, 23.4% and 33.3%, respectively. Corrosion changed the failure modes of the specimens and gradually decreased the half-wavelength of local buckling, which weakened the plastic deformation capability of specimens, and leaded to the transformation of steel members from strength failure to stability failure. Finally, the novel method considering the corrosion surface morphology was verified by comparing the finite element solutions to the experimental result. It was found the rough surface of the corroded specimens caused the uneven stress distribution and stress concentration. The location of maximum stress was located in the most severely corroded area, which leaded to the failure of the specimens.

Zhanke Liu (1,2), Yu Yang (2), Xuhong Zhou (3) and Ziqi He (3)
(1) Disaster and Environment in Western China, Lanzhou University, Lanzhou, 730000, China
(2) College of Civil Engineering and Mechanics, Lanzhou University, Lanzhou, 730000, China
(3) School of Civil Engineering, Chongqing University, Chongqing, 400045, China

ABSTRACT: Unified formulae of elastic critical distortional buckling load and unified DSM expressions for columns undergoing pure distortional buckling, are proposed in this study for both pinned-end and fixed-end columns with a C/Z/hat sections. The normal stress distribution of pre-buckling and post-buckling for C-section columns undergoing distortional buckling is presented based on theoretical analysis and literature review. The basic purpose of the DSM expressions is to express the strength problem as a stability problem to determine the ultimate strength of columns experiencing pure distortional buckling. To understand the effects of both pinned-end and fixed-end conditions in the columns undergoing pure distortional buckling, the effective length factor of flexural buckling about the strong axis of a cross-section, is introduced into elastic distortional buckling load formulae and the DSM expressions. Numerical results computed by computer software (CUFSM), along with numerical and experimental results in literature reviews are used to assess the accuracy of the proposed formulae. It is shown that the proposed formulae are accurate and universal.

Lara Rodrigues (1), Frederico M.A. Silva (1) and Paulo B. Gonçalves (2)
ABSTRACT: The analysis of internal resonances in continuous structural systems is one of the main research areas in the field of nonlinear dynamics. Internal resonances enable the transfer of energy between the related vibration modes, usually leading to new phenomena that have a profound influence on nonlinear oscillations, bifurcations and dynamic instabilities. Shells of revolution usually exhibit internal resonances due to their inherent circumferential symmetry and dense frequency spectrum in the lower frequency range, which may lead not only to simple internal resonances but also to multiple internal resonances. In this work, the nonlinear response of an imperfect circular cylindrical shell, simply supported at the edges, to harmonic excitation is studied. Geometries that have two modes with n and n+1 circumferential waves, corresponding to the lowest natural frequency, are identified. These two modes are driven to resonance, with each being in one-to-one internal resonance with its companion mode, thus leading to a possible 1:1:1:1 internal resonance, a topic rarely investigated in the technical literature. The investigation of internal resonances in continuous systems is usually conducted using low-dimensional discrete models. Here, using a perturbation procedure, a consistent modal expansion is derived for an arbitrary number of interacting modes, leading to reliable low-dimensional models. Using the discrete models derived in this way, the shell nonlinear dynamics is explored by using bifurcation diagrams of the Poincaré map, continuation techniques and the Floquet stability criterion. The importance of internal resonances to the nonlinear vibrations and instabilities of the shell is clarified. It is well known that small geometric imperfections in the order of the shell thickness have a strong influence on the buckling and post buckling behavior of a thin-walled shell. However, their influence on internal resonances, dynamic instability and energy transfer is largely unknown. Thus, a detailed parametric analysis that considers different types of modal imperfection is conducted in the present work, and the influence of such imperfections on the activation of energy exchanges between the modes involved is analyzed. The results confirm that the form and magnitude of initial geometric imperfections have a profound influence on the results, enabling or preventing the transfer of energy among the resonant modes being considered.

Yan Zhou (1), Kuo Tian (1), Shengli Xu (2) and Bo Wang (1)
(1) Structural Analysis for Industrial Equipment, Department of Engineering Dalian University of Technology, Dalian, 116023, China
(2) Ocean Energy Utilization and Energy Conservation, Dalian University of Technology, Dalian, 116023, China


ABSTRACT: Stiffened shells are widely used in aerospace structures such as launch vehicles and aircraft wings. This paper presents a novel two-scale topology optimization method to design the innovative grid-stiffened pattern for maximizing the critical buckling load of thin-walled cylindrical shells. On the micro-scale, the asymptotic homogenization method is employed to calculate the general stiffness coefficients of the cell. On the macro-scale, the maximum critical buckling load is set as the objective to drive the topology optimization on the micro-scale. Besides, the repeated eigenvalues are considered both in the sensitivity analysis of buckling loads and the optimization solver with a sub-problem based on the Method of Moving Asymptotes (MMA). Through the optimization, we can obtain the optimal configuration of the grid-stiffened cell. In this paper, an illustrative example of the grid-stiffened cylindrical shell for maximizing the critical buckling load is carried out to validate the effectiveness of the proposed optimization method. In comparison to the optimal orthogrid shell, the critical buckling load with the optimal pattern obtained by the proposed optimization method have a dramatically increase of 21.7%. It can be concluded that the proposed method has huge potential to design the configuration of the grid-stiffened cell of cylindrical shells.

Xie Zhao (1), Shijie Zheng (1) and Zongjun Li (2)
ABSTRACT: In this paper, based on the strain gradient theory, a size-dependent porous axially functional gradient (AFG) flexoelectric Euler-Bernoulli nanobeam model is developed. A modified power-law formula incorporating porosity volume fraction is presented to describe material properties of porous AFG nanobeam, and two typical porosity distributions patterns are considered. The generalized differential quadrature method is employed to discretize governing equations into a series of linear algebraic equations, so that the static bending deflections and free vibration frequencies are calculated conveniently for various boundary conditions. The credibility of the present mathematical formulation and the associated numerical solution are validated by comparing the results in previous literatures. Parametric studies are performed to illustrate the effects of the flexoelectricity, material length scale parameters, functionally graded index, porosity volume fraction, porosity distribution patterns on the static bending and free vibration behaviors of porous AFG flexoelectric nanobeam. The numerical results may provide support for the application of porous AFG flexoelectric nanobeam in Nano-electro-mechanical system.

Zhi-jia Zhang (1,2), Qian-cheng Zhang (1,2), De-zhi Zhang (1), Ying Li (3), Feng Jin (2) and Dai-ning Fang (3)

(1) Intense Dynamic Loading and Effect, Northwest Institute of Nuclear Technology, Xi’an, 710024, PR China
(2) Strength and Vibration of Mechanical Structures, Xi’an Jiaotong University, Xi’an, 710049, PR China
(3) Lightweight Multi-functional Composite Materials and Structures, Institute of Advanced Structure Technology, Beijing Institute of Technology, Beijing, 100081, PR China


ABSTRACT: A novel lightweight sandwich construction with square honeycomb-corrugation hybrid core (SHCH) was fabricated by honeycomb-corrugation assembly and vacuum brazing. The out-of-plane quasi-static compression behavior of the hybrid structures was explored in detail by experimental measurement, numerical calculation and theoretical prediction. The proposed brazed structures in high density region are found still to have strength and energy absorption capacity significantly greater than the sum of those of empty corrugated sandwich and square honeycomb-cored sandwich. In addition, the compressive strengths of the proposed square honeycomb–corrugation hybrid cores exhibit obvious superiority over those of competing core topologies in the high-density region.


ABSTRACT: In this study, the dynamic characteristics (i.e. natural frequencies and associated mode shapes) of a partially filled horizontal cylindrical shell are investigated experimentally and by an isogeometric finite element-boundary element method. The proposed numerical procedure is divided into two parts. In the first part, the dynamic characteristics of the cylindrical shell under in-vacuo conditions are obtained by the isogeometric finite element method (IGAFEM) based on a linear Kirchhoff-Love shell formulation. In the second part, the fluid-structure interaction effects are calculated in terms of generalized added mass coefficients by using the isogeometric boundary element method (IGABEM), assuming that the structure vibrates in its in-vacuo principle mode shapes. By adopting the linear hydroelasticity theory, it is assumed that the fluid flow is ideal, i.e., an incompressible flow and inviscid fluid. In order to show the versatility of the numerical method, the results are compared with those obtained by the conducted experiments. Relevant numerical challenges in the hydroelastic vibration analysis are highlighted and it is shown that the numerical predictions and experimental results are in good agreement.

Gang Shi (1,2), Ziqian Zhang (1,2), Le Zhou (3), Lu Yang (4) and Wenjing Zhou (5)
ABSTRACT: A comprehensive experimental and numerical investigation of the interactive buckling behavior of welded I-section steel columns was undertaken. The experimental program employed 16 welded I-section columns made of Q235B or Q345B steel and included material tensile coupon tests, column tests, and initial geometric imperfection measurements. The specimens were selected to cover a wide range of width-to-thickness ratios and slendernesses. Comparisons between the test results and current specifications Eurocode 3 and ANSI/AISC 360–16 were presented, and the accuracy of the specifications was evaluated. In conjunction with the experimental program, a finite element (FE) model was used to replicate the tests. FE models considering initial imperfections and material nonlinearity were established and the reliability of the modeling methodology was verified by test results. On the basis of the calculation results, a design proposal for both normal and high strength steel is presented. Comparisons of the FE results with the predictions by the design provisions revealed that the new design proposal is more accurate than the current specifications.

F.R. Sarquis (1), L.R.O. de Lima (2), P.C.G. da S Vellasco (2) and M.C. Rodrigues (2)
(1) PGECIV – Civil Engineering Post-Graduate Program, UERJ – State University of Rio de Janeiro, Brazil
(2) Structural Engineering Department, UERJ – State University of Rio de Janeiro, Brazil


ABSTRACT: An experimental and numerical study was conducted aiming to understand the flexural-torsional buckling phenomenon in angle fixed end columns with equal compact legs made of hot rolled austenitic stainless steel 304. The experimental programme was divided into four steps: cross-sections and column length selection; measurement of the columns initial geometric imperfections, i.e., local (cross-section rotation) and global (major and minor-axis bending); material characterisation in terms of its response under compression and tension stresses; development of the tests aiming to determine: failure modes, equilibrium paths and the columns’ ultimate loads. A numerical investigation was also carried out, where the finite element models were validated against the performed experiments, to expand the experimental results to cover additional cross-sections and column lengths. This was followed by an assessment of two design methods for angle fixed ends columns with compact equal legs: Eurocode 3 – part 1.4, specific for the stainless steel materials, and a design procedure based on the direct strength method developed by Dinis et al. for carbon steel materials. These two methods proved not to be reliable for the column ultimate loads prediction and motivated the development of two novel design procedures based on the Eurocode 3 – part 1.4 methodology. These two novel design methods provided more consistent results when the flexural-torsional buckling ultimate limit state controls the structural design of austenitic stainless steel equal leg angle.


ABSTRACT: This paper aims to develop a practical artificial neural network tool for predicting the axial compression capacity of circular concrete-filled steel tube columns with ultra-high-strength concrete. For this purpose, a nonlinear finite element analysis of circular concrete-filled steel tube columns with ultra-high-strength concrete was conducted and verified with experiments in the literature. Accordingly, a database of 768 finite element models was generated to use for developing the artificial neural network models. In this regard,
the column length, the diameter of steel tube, the thickness of steel tube, yield and ultimate strength of steel tube, and compressive strength of concrete were considered as the input variables while the axial compression capacity was considered as an output variable. The performance of the proposed artificial neural network model was compared with the current structural design codes including AS/NZS 5100.6, Eurocode 4, AISC, and GB 50936. The comparative study indicated that the proposed artificial neural network model achieved a superior prediction compared to others. Ultimately, a graphical user interface tool was developed based on the proposed artificial neural network model to predict the axial compression capacity of circular concrete-filled steel tube columns with ultra-high-strength concrete for practical engineering design.

Hexiang Wu (1), Xinchun Zhang (2) and Ying Liu (3)
(1) School of Civil Engineering, Northeast Forestry University, Harbin, 150040, China
(2) Department of Mechanical Engineering, North China Electric Power University, Baoding, 071003, China
(3) Institute of Mechanics, Beijing Jiaotong University, Beijing, 100044, China


ABSTRACT: By combining circular cells and folded plates, this paper establishes a cross-circular honeycomb model. The model has a simple micro-topological structure. Through theoretical analysis and numerical simulation, we derive a semi-empirical equation describing the plateau stresses of cross-circular honeycombs and investigate their in-plane impact behavior. Hence, this paper primarily discusses the effect of gradient arrangement on the deformation mode, plateau stress, and energy absorption capacity of hollow-circular and cross-circular honeycombs with the same relative density at different impact velocities. The study results indicated that the deformation mode of the cross-circular honeycombs exhibited a zero Poisson's ratio, and these honeycombs exhibited a high plateau stress and high capacity for energy absorption. A density graded design could control the dynamic response characteristics of the cross-circular honeycombs within a wider range of impact velocities. Furthermore, the design of the symmetric gradient distribution provided the density graded cross-circular honeycombs with a multi-directional gradient deformation characteristic.

H.N.R. Wagner (1,2), C. Hühne (1,3) and M. Janssen (4)
(1) Technical University Braunschweig, Institute of Adaptronic and Functional Integration, Langer Kamp 6, 38106, Braunschweig, Germany
(2) Siemens Mobility GmbH, SMO RI R&D IXL PE, Ackerstr. 22, 38126, Braunschweig, Germany
(3) German Aerospace Center (DLR), Institute for Composite Structures and Adaptive Systems, Lilienthalplatz 7, 38108, Braunschweig, Germany
(4) Federal Aviation Office (LBA), Aircraft Continuing Airworthiness Monitoring, Hermann-Blenk-Straße 26, 38108, Braunschweig, Germany


ABSTRACT: Thin-walled cylindrical shells are primary structures in aerospace, marine and civil engineering. A major loading scenario for these imperfection sensitive shells is axial compression. For this load case, there is a critical disagreement between the theoretical and experimental critical load. This difference is mainly contributed due to shape deviations of the shell middle plane which are commonly described as geometric imperfections. However, some deviations between theoretical and experimental buckling loads are sometimes so severe that other imperfection types are possibly to blame.
This article describes experimental and numerical studies on the influence of loading imperfections on the buckling load of thin-walled cylinders. A global loading imperfection was applied by mistake during a buckling test of a thin-walled cylinder which led to a severe buckling load reduction and the corresponding load level was similar to the post-buckling load. Also, a series of experimental studies with localized loading imperfections is described which significantly reduced the buckling load of CFRP cylinders.
The experimental results of this article represent an example for some of the very low buckling knockdown factors from early experimental campaigns and give insights in how to avoid these critical imperfections in experimental buckling campaigns.

Shao-Feng Nie (1), Tian-Hua Zhou (1), Yang Zhang (1) and Bo Liu (2)
In this paper, a new finite element model is developed for nonlinear analysis of thin-walled beams by introducing a high-order interpolation for the warping displacement field to better simulate actual cross-section deformation. It is discovered that, due to the significant coupling between bending and membrane deformations in each wall, it is crucial for a nonlinear thin-walled beam finite element to be capable to describe complex warping displacement distribution over the cross-section. In the geometrically exact beam element model developed, the warping displacement is expressed by using a higher-order interpolation scheme, while the distortion displacements are independently described by using a number of cross-section in-plane deformation modes. Numerical results are presented to demonstrate the effectiveness of the proposed model and investigate possible impacts of interpolation schemes for the warping displacement distribution on the solution accuracy under different problem settings. The results show that with an appropriate high-order warping displacement interpolation scheme, the proposed beam model can produce very accurate results even in the case of small wall thickness, outperforming many of the existing models. It is therefore concluded that special attention is needed on the warping displacement field for a finite element model to accurately simulate the cross-section distortional deformation of thin-walled beams.

ABSTRACT: Cold-formed thin-walled steel members are commonly subjected to initial imperfection, which will greatly affect their load-carrying capacity. In this study, the load-carrying capacity and imperfection sensitivity of fixed-ended cold-formed steel web-stiffened lipped channel columns subjected to local-distortional (L-D) interactive failure (including secondary local bifurcation interaction (SLI), true L-D interaction (TI) and secondary distortional bifurcation interaction (SDI)) are investigated. A new imperfection simulation method combining finite element analysis (FEA) with the constrained finite strip method (cFSM) was firstly proposed, and then validated using experimental data from literatures. Next, 224 geometries of columns experiencing L-D interactive failure were chosen by the cFSM and their load-carrying capacity under normal state $P_{\text{norm}}$ (with unavoidable minor initial imperfection) and those under imperfect state $P_{\text{imperfect}}$ (with various imperfections) were respectively obtained using FEA. The most unfavorable imperfection patterns for L-D interactive failure were summarized by comparing the $P_{\text{norm}}$ and $P_{\text{imperfect}}$ of the members. Furthermore, the quality of the DSM-based design approaches for L-D interactive failure were evaluated by comparing $P_{\text{norm}}$ with the failure load predictions of the selected columns provided by these design approaches.


ABSTRACT: The flexural-torsional buckling response and design of stainless steel I-section beam-columns are investigated in this paper. First, a series of laboratory tests on laser-welded stainless steel I-section beam-columns susceptible to flexural-torsional buckling is presented. The results obtained are supplemented by further data generated by means of numerical parametric studies on both conventionally arc-welded and laser-welded stainless steel members covering a wide range of member slenderness and combinations of loading. Existing provisions for the design of welded stainless steel I-section elements against flexural-torsional buckling are then assessed and found to require improvement. Finally, new formulae for the design of stainless steel I-section beam-columns susceptible to flexural-torsional buckling are proposed. The new proposals yield improved accuracy and consistency over existing provisions and their suitability for inclusion in the upcoming version of the European structural stainless steel design code EN 1993-1-4 is confirmed by reliability analysis in accordance with EN 1990.

Guangyong Sun, Xiao Guo, Shunfeng Li, Dong Ruan and Qing Li, “Comparative study on aluminum/GFRP/CFRP tubes for oblique lateral crushing”, Thin-Walled Structures, Article 106420, Vol. 152, July 2020, https://doi.org/10.1016/j.tws.2019.106420

ABSTRACT: Thin-walled composite structures are increasingly used in vehicles attributed to their lightweight and high energy-absorbing capacity. However, understanding crushing behavior of tubal structures made of different materials for lateral impact loading from different directions is fairly limited, which restricts their further applications. This study aimed to investigate the oblique lateral crashworthy characteristics of thin-walled circular tubes with aluminum, glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) materials by experimental, numerical and analytical methods. Thin-walled tubes were considered to bear the combined lateral compression and shear loading radially through two parallel rigid platens from the oblique angles of 0°, 10°, 20° and 30° to the horizontal direction, respectively. The effects of loading angles on crushing process, failure modes and crashworthiness indicators were quantified. Similar deformation patterns of each type of the tubes can be observed under these different loading angles, where frictional shear was found to be of limited effect on the deformation mode. With increase in loading angle, initial crushing force decreased, also the energy absorption of GFRP tube decreased whilst those of aluminum and CFRP tubes increased as seen from a prolonged process in the energy absorption-displacement curve. The specific energy absorption (SEA) of the aluminum, GFRP and CFRP tubes ranged from 2.36 to 2.62 J/g, 1.1 to 0.88 J/g and 0.79–0.96 J/g, respectively; and their corresponding crushing force efficiencies (CFE) ranged
Further numerical investigation on the composite parts with unsymmetrical ply layups shows FEA for the curved composite parts with symmetrical ply layup cured on a wound carbon epoxy tube. The proposed analytical model is extended to investigate the cure behavior of multilayered curved composite parts. The viscoelastic effects on the residual stresses and spring-in angles of thin-walled curved composite parts during curing. The proposed model is first established to describe the viscoelastic mechanical behavior of an unidirectional curved composite layer based on the viscoelastic constitutive model with N+1 Maxwell elements. The explicit closed-form solution is obtained by a new iterative solution strategy. Then, the analytical model is extended to investigate the cure behavior of multilayered curved composite parts. The viscoelastic effects on the residual stresses and spring-in due to tangential and radial thermal-chemical expansion are separately considered to aid in understanding of their individual influence. The analytical results show good agreements with experimental data in literature and numerically predicted results by viscoelastic FEA for the curved composite parts with symmetrical ply layup cured on a wound carbon epoxy tube. Further numerical investigation on the composite parts with unsymmetrical ply layups shows that the
viscoelastic effects on the spring-in angles are closely related to the ply layups and the thickness of composite parts and have different responses for those due to tangential and radial effects.


ABSTRACT: The compressive behaviour of hot-finished circular hollow section (CHS) steel members in fire is investigated in this paper through numerical modelling. CHS members with high-strength steel grades of S690 and S460 are taken into consideration in addition to those made up of normal-strength grades S355, S275 and S235. Numerical models of CHS structural steel members able to replicate their response in fire are validated. Using the validated finite element models, extensive parametric studies are carried out for the purpose of exploring a broad range of factors influencing the cross-section and member buckling response of CHS steel members under axial compression at elevated temperatures. The accuracy and safety of the design recommendations provided in the European structural steel fire design standard EN 1993-1-2 for the determination of the axial compression resistances of CHS steel members in fire are assessed. New design methods able to provide accurate and safe estimations of the cross-section axial compression resistances and flexural buckling resistances of CHS steel members at elevated temperatures are proposed. The higher accuracy, reliability and safety of the proposed design methods relative to the existing design provisions in EN 1993-1-2 are illustrated.


ABSTRACT: In this paper, a numerical model for shear links was firstly established and carefully validated, and the cyclic web buckling behavior were also discussed with comparison to experimental results. On this basis, firstly, the influence of boundary conditions was explored. The influence of axial displacement constraint on cyclic buckling and plastic overstrength was discussed, and a theoretical plastic overstrength factor considering axial displacement constraint was proposed. In addition, the influence of axial forces on cyclic buckling and plastic overstrength was discussed, and the limited range of axial forces on shear links was recommended. Afterwards, the influence of various parameters on cyclic web buckling was analyzed and discussed, and a theoretical prediction approach for cyclic buckling angle was proposed, which was applicable to shear links with or without stiffeners. Also, the influence of parameters on plastic overstrength was analyzed and discussed, and the theoretical model of the relationship between plastic overstrength and displacement angle was proposed for shear links with or without stiffeners. Finally, based on the works above, a simplified theoretical model to predict the relationship between shear force and displacement angle was proposed, with consideration of cyclic buckling. The experimental validations confirmed it had good accuracy.


ABSTRACT: Hexagonal thin-walled structures are widely used in protective engineering and the precise prediction of their collapse behavior is very important for their crashworthiness design. In this paper, a precise theoretical model is proposed to predict the collapse behavior of hexagonal tubes under lateral compression. The rigid-linear strain hardening constitutive relation is adopted for the hexagonal tubes. A deep insight into the in-plane deformation mechanism of hexagonal tubes is presented. Comparisons of the present model with the finite element analysis, existing experiments, and conventional rigid-perfectly plastic model are conducted. It is demonstrated that the present model shows a good agreement with both the numerical simulations and the experiments. The influences of strain hardening and tube wall thicknesses on the crushing behavior are discussed. Based on the theoretical analyses, a nearly constant force-displacement plateau is obtained by selecting appropriate strain hardening modulus and wall thickness of the hexagonal tubes. The present study will pave an effective way to clearly understand the large plastic deformation of thin-walled structures with various cross sections.
Bending actions.

Accuracy of predicting the midspan load capacity of channel sections under combined web crippling and bending action was undertaken to investigate the combined web crippling and bending interaction behaviour of cold-formed steel channel sections used as bearers in floor systems with fastened supports. A numerical study was therefore undertaken to investigate the combined web crippling-bending interaction behaviour of unlifted channel sections used as bearers in floor systems with fastened supports. Web crippling finite element models developed and validated by the authors in a recent study were extended to investigate the behaviour of unlifted channels under combined action of web crippling and bending while new finite element models were developed for bending and validated using available experimental results. All three types of finite element models were used in a detailed parametric study to obtain the capacities of 12 unlifted channel sections made of G250 and G450 steels under pure and combined web crippling and bending actions. Comparison of the combined web crippling and bending capacities obtained from finite element analyses with the interaction equations in three cold-formed steel design standards, AISI S100, AS/NZS 4600 and Eurocode 3 Part 1.3, showed that the current design equations are accurate for 50 mm bearing length. However, they can also be used to predict the combined web crippling-bending capacities conservatively for bearing lengths of 100 and 150 mm. A new design equation with a suitable capacity reduction factor was then proposed to improve the accuracy of predicting the mid-span load capacity of channel sections subject to combined web crippling and bending actions.

ABSTRACT: The flexural buckling behaviour and residual strengths of stainless steel circular hollow section (CHS) columns after exposure to fire were studied, based on a thorough experimental and numerical modelling programme, and reported in this paper. The experimental programme was performed on three series of specimens, and each series contained five geometrically identical specimens, with one unheated and the other four heated to different levels of elevated temperatures (namely 300 °C, 600 °C, 800 °C and 1000 °C). The detailed heating, soaking and cooling processes, material testing and pin-ended column tests were described, with the derived key experimental results fully presented. The testing programme was supplemented by a numerical modelling programme, including a validation study where finite element models were developed and validated against the test results, and a parametric study where the validated finite element models were employed to derive further numerical results over an extended range of cross-section dimensions and member lengths. Due to the absence of existing design codes for stainless steel structures after exposure to fire, the codified design provisions for stainless steel CHS columns at ambient temperature, as established in the Europe, America and Australia/New Zealand, were assessed for their applicability to stainless steel CHS columns after exposure to fire, based on the obtained test and numerical data. The assessment results generally revealed that the design buckling curve, as adopted in the European code, and the tangent modulus method, as employed in the American specification, lead to unsafe and scattered design flexural buckling strengths for stainless steel CHS columns after exposure to fire, while the explicit approach, as used in the Australian/New Zealand standard, yields a high level of accuracy and consistency in predicting the post-fire flexural buckling strengths of stainless steel CHS columns.


ABSTRACT: While mechanical properties and material stress-strain response of different families of stainless steel (known as austenitic, duplex and ferritic) are different from each other, current cold-formed stainless steel standards do not generally take into account these differences as they provide single equations for any loading scenario to cover all groups of stainless steel. This may lead to inaccurate results, especially for austenitic steel which is a high performance material increasingly used in modern construction, due to its higher ductility and ultimate-to-yield strength ratio. This research aims to investigate the web bearing performance of cold-formed steel channels fabricated with austenitic stainless steels subject to concentrated transverse forces experimentally and numerically. The experimental programme consists of 16 thick unlipped channel specimens with different internal fillet radius and web depth to thickness ratios. For the numerical investigations, 88 detailed nonlinear quasi-static finite element models are used and validated against experimental data. Complementary parametric investigations are then conducted to ascertain the web bearing strengths in terms of various channel sizes, web thicknesses and internal fillet radius. It is found that the equations proposed by current stainless steel standards are unreliable for austenitic steel as they can lead to significantly un-conservative results (up to 43%) under both one- and two-flange loading scenarios. Other equations suggested in the literature for ferritic stainless steel are also shown to provide overestimated results (up to 34%) for austenitic steel channel sections. Based on the experimental and analytical results from this study, new equations are proposed to estimate the web bearing strength of cold-formed austenitic stainless steel channels and their reliability is demonstrated.


ABSTRACT: This work presents two finite elements for geometric nonlinear analysis of thin-walled laminated composite beams. The element cross-section properties are evaluated through a suitable thin-walled beam theory, yielding a 4x4 constitutive matrix where different couplings between generalized stresses and strains
can be considered. In the local coordinate system, one element named CRL is linearly formulated, while the other element named CRTL incorporates moderate rotations. The element independent corotational approach is used in order to deal with large rotations in 3D space. Numerical experiments, considering different cross-sections and layups, demonstrate the accuracy and effectiveness of the proposed finite elements.

ABSTRACT: Mechanical behaviors of a new foam filled 2D re-entrant hexagonal honeycomb with negative Poisson's ratio under planar compression have been investigated in this paper. Re-entrant hexagonal unit cell specimens were fabricated by aluminum alloy and polyurethane foam. The deformation modes and force-displacement curves of the unit cell specimens under compression were carried out experimentally and numerically, and a good agreement was observed between experimental results and numerical simulation results. Subsequently, mechanical behaviors of foam filled and void re-entrant hexagonal honeycomb under planar compression were observed by numerical simulation. Compared to the void honeycomb, the foam filled honeycomb has a higher specific energy absorption capability due to a higher plateau stress. According to the mechanism of auxetic effect, the re-entrant honeycomb would move inward when subjected to compression along the orthogonal direction, which cause a biaxial compression of the foam and an increasing of stiffness/strength/energy absorption capability. The present investigations provide thorough insight into the strengthened re-entrant hexagonal cellular honeycomb, and could be used in the development of novel light weight smart functional structures.

ABSTRACT: Bridges around the world have utilised individually the mono-symmetric I-section corrugated web girders and the high-strength steel materials (HSSs). However, based on open database, there has not been any investigation in the literature exploring the mono-symmetric corrugated web bridge girders (CWBGs) constructed from HSSs. The paper is, therefore, devoted to numerically explore the global buckling of such girders built up from S460, which has extensively been used in bridge construction globally. This has been made based on finite element models (FEMs) developed by ABAQUS programme. Note that this paper merely considers girders having unequal flanges, but are symmetrical with regard to their minor axis, and their wider flanges are always deemed under compression. The validity of the current FEMs has not only depended on the previous experience of the authors, but also on the comparison between the elastic critical buckling moments and the available prediction methods. Additionally, experimental test results of flat-webbed girders have been considered in the validation. Parametric study has been carried out on simply supported girders considering mainly the influences of the mono-symmetry ratio and corrugation dimensions on the flexural buckling performance of the CWBGs which utilise S460 HSS. Several conclusions have been found that might aid the structural engineers in designing efficient cross-sections in the future. Additionally, the ultimate loads of the current CWBGs have been compared with EC3 specifications, and two design failure modes have been found to take place in present parametric study; the tension flange yielding and the lateral-torsional buckling (LTB) of the compression flange. The results, generally, show that the recommended method by EC3, for equivalent welded sections, is the most suitable in predicting the strengths of the current girders. Though, two modifications have been suggested for EC3 strengths regarding the tension flange yielding design formula and the LTB curve of the girders with depth-to-width ratios ≤2.0. The modified EC3 strength is generally found to provide accurate predictions for the CWBGs which utilise S460 HSS.

ABSTRACT: Use of aluminium sections as primary load bearing members has recently expanded considerably in the building industry. Aluminium as a new constructional material has several advantages in building
structures including corrosion resistance, durability, high strength-to-weight ratio, reduced cost of transportation and ease of erection and fabrication. The popularity of aluminium structures has attracted attention regarding the efficiency and design of many sections, and roll-formed lipped channel beam (LCB) is one of these commonly used sections. However, aluminium LCBs are prone to shear buckling failures due to its increased web slenderness and low elastic modulus compared to steel. Hence an experimental study was conducted to investigate the shear behaviour of LCBs and to verify the current design rules to accurately predict the shear strengths. Shear tests have been conducted using ten different generally available roll-formed aluminium LCBs. The test sections were loaded at mid-span at the shear centre until failure. The results obtained from the tests were then compared with the predictions using the current shear design rules in the Australian/New Zealand standards and Eurocodes for both aluminium structures and cold-formed steel structures as their shear behaviour are quite similar. This paper presents the details and results of this experimental study and comparison with shear design rules based on current design rules.


ABSTRACT: Ultra high performance cementitious composites filled steel tube (UHPCC-FST) column has been widely applied as the load bearing members for long-span bridges, which are the potential bomb explosion attacking targets in terroristic activities. In the authors’ previous work, the residual axial load bearing capacity of UHPCC-FST specimens under contact explosion was investigated experimentally, and this paper further perform the corresponding numerical simulation study. By utilizing the multi-material Arbitrary Lagrange-Euler (ALE) algorithm, Fluid-Structure Interaction (FSI) method, the restart input data method and element erosion algorithm implemented in the finite element (FE) code LS-DYNA, the numerical simulations corresponding to the contact charge explosion and the following axial compression tests are carried out. The damage and failure modes of UHPCC-FST specimen are reproduced and validated by comparing with the experimental data. Furthermore, the related parametric influences, e.g., thickness and strength of steel tube, compressive strength of core concrete and column diameter, on the local blast formed crater depth, the post-blast residual axial load bearing capacity, as well as the corresponding damage index of UHPCC-FST specimen under contact detonation are discussed. The influential degree of above parameters on the residual axial capacity of UHPCC-FST specimen under contact explosion is clarified. The present work can provide helpful references for evaluating the post-blast performance as well as the design of UHPCC-FST specimen under contact explosion.


ABSTRACT: This paper describes the formulation of a thin-walled beam finite element for arbitrary open cross-sections, including doubly-, singly- and non-symmetric cross-sections. The formulation is developed within the co-rotational framework of OpenSees – an open source program available for the simulation of structural and geotechnical systems. The formulation accounts for eccentricity between the shear centre and the centroid of the cross-section, as well as warping. Both elastic and inelastic material behaviour is considered. The stiffness relation for the displacement-based beam element is established based on the Green-Lagrange strain. A local cross-section transformation matrix is derived to relate the end actions with the axial force acting at the centroid to the end actions with the axial force acting at the member axis system. The elastic and inelastic performance of the beam finite element is demonstrated through a series of stability problems comprising doubly-, singly- and non-symmetric sections subjected to compression, bending, and torsion. The buckling and post-buckling behavior predicted by the beam element is shown to be in close agreement with the results of shell finite element models, thereby demonstrating its reliability.

ABSTRACT: In this paper, the free vibration analysis of fuzzy fiber reinforced (FFRC) nanocomposite truncated conical shell is investigated. The FFRC constructional feature is that the uniformly aligned carbon nanotubes (CNTs) are radially grown on the circumferential surfaces of unidirectional carbon fibers. Using a micromechanical model based on the simplified unit cell (SUC) method, the effective material properties of the FFRC conical shells are evaluated. The thin-walled classical shell theory and Hamilton's principle are used to extract the governing equations, and the Ritz method is used to solve the problem. The model predictions are compared with other numerical results available in the literature and the correctness of the proposed theoretical method is attested. Some novel results, including the vibration results of FFRC conical shell accompanied with different combinations of boundary conditions and different material and geometrical properties are presented. The results reveal that the FFRC conical shell vibration behavior is strongly dependent on the material properties, volume fractions of two reinforcements, geometrical characteristics and boundary conditions.


ABSTRACT: The current study experimentally and numerically investigated the ultimate shear loading capacity (USLC) of sinusoidal corrugated web beams (CBWs). The aim of the study was to numerically evaluate USLC for comprehensive practical dimensions of CBWs. In order to validate the numerical simulation strategy, a series of experimental tests on nine girders is performed. A comprehensive parametric study using the nonlinear finite element method then is performed for 160 cases and the effects of various parameters are discussed. The selected dimensions for numerical cases cover the typical range of steel girders in practice. A formula based on the division of areas of the shear buckling modes of sinusoidal CBWs is suggested. The numerical parameters of the proposed relation, representing the web boundary conditions and inelastic effects on shear buckling capacity, are fitted using the parametric study results. The relation was able to predict the UPLC of the numerical cases with an average difference of 10%, which is satisfactory in practice.


ABSTRACT: In this paper, bio-based sandwich panels made of fiber-reinforced polymer (FRP) skins and two types of paper honeycomb core (namely, hollow and foam-filled) with three different thicknesses (namely, 6 mm, 12 mm, and 25 mm) were studied. Flax FRP composites made of a unidirectional plant-based flax fabric and bio-based epoxy resin (30% bio content) were used for the skins. The panels were cut into a total of 36 sandwich beam specimens with the width of 50 mm and tested under four-point bending with two span configurations to characterize the flexural and shear stiffness of the panels. The specimens with foam-filled paper honeycomb cores showed a higher load capacity than those with hollow honeycomb, however their stiffnesses were not fundamentally different. Major non-linearity was observed in the load-deflection and load-strain behavior of the specimens. An analytical model was successfully developed based on the non-linearity of the skins in tension/compression and the core in shear to predict the non-linear behavior of the specimens. A parametric study was performed on different geometrical parameters and it was shown that contribution and bending and shear changes and it can be engineered to achieve desirable strength and stiffness. Overall, the bio-based sandwich panels can be used for interior walls, doors, and furniture in building application with much less impact on the environment in comparison with their synthetic counterparts.


ABSTRACT: Many studies have focused on the topic of vehicle safety, including the study on crashworthiness. In vehicle, a crash box structure is an integral component for ensuring the safety of a car. It serves as an energy-absorbing member, together with the front bumper in case of frontal collision during car accidents. Therefore, special attention has to be given towards this structure in order to have better understanding regarding its mechanism of deformation and absorbing kinetic energy from the collision, as well as on how to obtain good
crashworthy properties from this structure. This study, primarily, is based on extensive literature survey pertaining to the topic of crash box. As the topic of energy-absorbing member in a car is extensive, this review solely focuses on crash box structure. The main motivation of this paper is to summarise the different approaches and aspects of researches performed on car crash box structure to gain comprehensive knowledge regarding the study on crash box.


ABSTRACT: As a sequel to another paper of the authors on welding-induced residual stresses [1], this paper aimed to obtain a direct measurement database of welding-induced initial deformations in a full-scale steel stiffened plate structure and also to study the applicability of computational models to predict them. A full-scale steel stiffened plate structure in association with bottom plate panels of an as-built 1,900 TEU containership was fabricated by exactly the same technology of welding as used in today's shipbuilding industry. The 3D scanner was employed to measure welding-induced initial deformations of the structure. Computational models using the three-dimensional thermo-elastic-plastic finite element method were developed to predict the plate initial deflections. A comparison between direct measurements and numerical predictions was made. Details of direct measurement databases are documented as they are useful to validate the computational models formulated by other researchers.


ABSTRACT: The delamination in curved composite laminates is one of the main defects, especially in aerospace structures. To optimize the design of the delaminated composite panels under compression loading, accurate characterization of the effects of different parameters such as features of the initial defect, the curvature of the laminate, and layup stacking sequence on the post-buckling behavior play a significant role. In this research, after a comprehensive review on the main previous researches, by implementing a Cohesive Zone Model (CZM), the nonlinear post-buckling response of different curved laminated composite panels has been investigated in the presence of various single and multiple delamination growth. To validate the present modeling procedure, the obtained results are compared with the experimental and previous numerical ones. Then, a detailed parametric study is performed on the effects of fiber angle orientation as well as number, size, location and stacking sequence of delaminations with different sizes on the post-buckling behavior of curved laminates with various curvatures. Results show that, in the panels with short length of delamination, an unstable growth occurs. In the flat panel, the amount of this phenomenon and its effects on decreasing the postbuckling load capacity are much more than the curved panel. The obtained results of this study highlight the sensitivity amount of instability behavior of curved composite panels to curvature, layup, and delamination features. The conclusions are essential and beneficial in the stability analysis and damage tolerance design of curved composite laminates, which are commonly used in the aircraft structures.


ABSTRACT: In this article, the nonlinear dynamic response and free vibration of functionally graded porous (FGP) truncated conical panel with piezoelectric actuators in thermal environments are investigated by an analytical method. The panel resting on an elastic foundation which is modeled according to the Winkler–Pasternak theory. The material properties including Young's modulus, shear modulus, and density are assumed
to smoothly through the shell thickness. Three types of porosity distribution across the thickness, namely, symmetric porosity distribution, non-symmetric porosity, and uniform porosity distribution, are considered. Theoretical formulations are presented based on the first-order shear deformation shell theory with a von Karman-Donnell type of kinematic nonlinearity. The non-linear motion equations and resulting equations are derived by using Hamilton's principle, Galerkin's method, and Runge-Kutta method. Lastly, some numerical results are presented to study the effects of shell characteristics, porosity distribution, porosity coefficient, applied actuator voltage, temperature increment and elastic foundations on the nonlinear dynamic response and the natural frequencies of the piezoelectric FGP truncated conical panel.


ABSTRACT: The novel form of hybrid columns, being fiber-reinforced polymer (FRP)-concrete-steel solid columns (FCSSCs), involves the FRP tube and the steel tube as the confining system for the concrete. The buckling of the inner steel in FCSSCs is effectively delayed by the surrounding concrete while the strength of the steel is sufficiently utilized, with it being protected by the outer FRP tube against environmental attacks. A pilot experimental program is conducted to investigate the behavior of axially loaded FCSSCs with an outer polyethylene terephthalate (PET) FRP tube. The experimental results have demonstrated that the axial load carrying capacity of an FCSSC is much larger than the total resistances of the hollow steel tube and the concrete-filled FRP tube. The test FCSSCs possess a monotonically ascending load-strain response with an excellent ductility. The comparisons between the test results and the predictions from existing models demonstrate that one existing model gives satisfactory estimations on the ultimate axial stress and strain of the confined concrete in FCSSCs, while they are incapable to accurately predict stress-strain curves of the confined concrete in FCSSCs.


ABSTRACT: The influences of different shape, size and number of lateral cutouts at various locations on the load-bearing capacity, buckling behaviour and energy absorption ($E_a$) characteristics of aluminium conical frusta under quasi-static axial loading condition were studied from both experimental and numerical procedures. In this regard, 18° semi-apical angled aluminium conical (AC18) frustas were fabricated through the metal spinning process; and circular, square, and trapezoidal shapes of cutouts with required dimensions were introduced at various lateral locations of the frustum. These conical frusta were subjected to quasi-static axial loading at a rate of 2 mm/min using a universal testing machine (UTM), and the corresponding load-deformation characteristics were recorded for axial compression of 50 mm from its original height. In addition to that, similar to experimental studies, Finite Element Analysis (FEA) was performed with conical frusta having various cutouts using ABAQUS® finite element software to study the influence of cutouts on the changes on crashworthiness performance of conical frusta. From both studies, it is observed that the energy absorption capacity of 18° semi-apical angled aluminium conical frusta was found to be decreasing in the range of 3.67%–47.60% according to the shape, size, number and location of cutouts. Further, the load resistance parameters such as first peak load ($P_1$), maximum peak load ($P_m$) and average load ($P_a$) also are found to be decreasing with an increase of cutout size. The change of cutout location from mid-height to three-fourth from the base of the frustum also resulted in a reduction of $E_a$ capacity, regardless of shape, size and number of cutouts. From these studies, it observed that the energy absorption characteristic of conical frusta having circular cutouts are found to be better than the conical frusta having square and trapezoidal cutouts at same locations. It is also observed that the $E_a$ capacity of conical frusta having cutouts was found to be non-linearly decreasing with the linear increase in the number, location, shape and size of cutouts. The specimens with a large-size of cutouts had exhibited large deformation over the cutout region that led to an unstable non-linear global buckling during axial compression. Consequently, their $E_a$ capacity was found to be decreased significantly as compared with the conical frusta with a small size of cutouts. The specimens with the small size of the cutouts exhibited progressive local buckling during axial compression, and they exhibited better energy absorption characteristics as compared with the conical frusta with large size of cutouts.

ABSTRACT: In this study, a new Kirigami corrugated structure is designed. Dash lined cuts across each row of corrugated structures are introduced and then folded inwards. The proposed Kirigami (cut and fold) modification provides extra vertical crushing resistance and constraints between the structure faces. Out-of-plane quasi-static tests are carried out for both conventional corrugated structures and Kirigami corrugated structures made of aluminium thin sheets. The numerical models with imposed imperfections are calibrated with the test data and then used for the dynamic crushing analysis of the structures under various loading rates. Key parameters such as initial peak force, average crushing resistance and energy absorption are compared among the conventional and Kirigami corrugated structures. Significant changes in deformation modes and great enhancement of energy absorption capacity under out-of-plane crushing are shown for the proposed Kirigami corrugated structures as compared to conventional corrugate structures. Furthermore, crushing resistance of the proposed Kirigami corrugated structure is less sensitive to imperfections. Great potential of the proposed Kirigami modification technique on corrugated structures is demonstrated with minimal change in its original manufacturing process but substantial enhancement in energy absorption capacities.


ABSTRACT: This paper deals with wave propagation and vibration of a porous beam embedded via nanocomposite piezoelectric layers. Various patterns of reinforcement of the face sheets by non-uniform graphene nanoplatelets (GPLs) are considered through modified Halpin-Tsai micromechanics model to approximate the Young modulus and Poisson’s ratio of graphene/piezoelectric polymer layers. The sandwich’s face sheets, due to their characteristics, are regarded as sensor and actuator with which the wave velocity and frequency of structure can be controlled and for this reason, a proportional-differential (PD) controller is handled. So as to model the structure much more realistic, the material characteristic of whole system are hypothesized as viscoelastic state according to Kelvin-Voigt model and Kerr viscoelastic foundation is developed which include two springs, two dampers and one shear elements as well. For mathematical modelling of system, refined zigzag theory (RZT) is exercised and using energy method, the motion equations are obtained. Analytical procedure is utilized for solving the governing equations as well as calculating the wave velocity and frequency of the sandwich structure. A precise parametric study is carried out focusing GPLs volume percent and distribution pattern, geometrical parameter of every layer, piezoelectric properties of GPLs, porosity dispersion of the core, exerted voltage and structural damping and their effects on the wave propagation and vibration of system. Results show that increase in the porous coefficient lead to decline in the wave velocity and frequency. In addition, considering the piezoelectric properties of GPLs enhances the wave velocity and frequency of the sandwich structure.


ABSTRACT: The radome structure is composed of the supporting skeleton inside and the stressed skin (membrane) outside. In the previous structural analysis, the stressed skin effect from the envelope is not taken into account, which results in the design of this structure being conservative. To study the effect of the stressed skin on the structure behavior, an experimental study was carried out for a full-scale radome model which has a span of 5.8 m and a height of 4.3 m. A self-designed multi-stage distribution beam loading system was applied to the structure. Therefore, simultaneous loading was realized on the multi-point of the structure. Three load cases—completely covering membranes, partially covering membranes and framework—were considered respectively. Besides, a numerical simulation method for analyzing the overall stability of the radome structure with the consideration of the stressed skin effect is established, which is verified by the test results. Different
from the previous structural analysis that the role of the envelope structure is not considered, the refined finite element model combines beam elements and shell elements to work together, which is a difficulty in the previous research. The mesh size guarantees both the accuracy of results and computational convergence. Considering geometric nonlinearity and material nonlinearity, the whole process stability analysis is carried out by the arc length method, and initial defects are introduced based on the consistent mode imperfection method. Finally, the mechanism of the stressed skin effect is revealed. Both the numerical and experimental study shows that due to the lateral bracing of the stressed skin, the prematurely elastic instability of the members around the weak axis is avoided. The global stability bearing capacity of the structure is significantly improved. As a result, in the design of such radomes, the stressed skin effect should be considered to solve the problem of structural safety and electromagnetic transparency.


ABSTRACT: This is a fundamental study on the nonlinear vibrations considering large amplitude in multi-sized hybrid Nano-composites (MHC) disk (MHCD) relying on nonlinear elastic media and located in an environment with gradually changed temperature feature. Carbon fibers (CF) or carbon nanotubes (CNTs) in the macro or nano sizes respectively are responsible for reinforcing the matrix. For prediction of the efficiency of the properties MHCD's modified Halpin-Tsai theory has been presented. The strain-displacement relation in multi-sized laminated disk's nonlinear dynamics through applying Von Karman nonlinear shell-theory and using third-order-shear-deformation-theory (TSDT) is determined. The energy methods called Hamilton's principle is applied for deriving the motion equations along with Boundary Conditions (BCs), which has ultimately been solved using the perturbation approach (PA) and generalized differential quadrature method (GDQM). At the final stage, the outcomes illustrate that patterns of FG, fibers' various directions, the \( W_{\text{CF}} \) and \( V \), factors, top surface's applied temperature and temperature gradient have considerable impact on the MHCD's nonlinear dynamics. Another important consequence is that, the influences of the \( \theta \), \( W_{\text{CF}} \) and \( V \), amounts on the disk's nonlinear vibrations may be taken into account at the larger amounts of the high deflection element and the negative axial load's impact on the structure's nonlinear dynamics is more extreme. A more general conclusion of this study is that for designing the MHCD should be more attention to the nonlinearity parameter.


ABSTRACT: The prime objective of the present investigation is to predict the shear buckling characteristics of skew nanoplates made of a functionally graded material (FGM) in the presence of surface stress effect. For this purpose, the Gurtin-Murdoch surface theory of elasticity is applied to the higher-order shear deformation plate theory within the framework of the oblique coordinate system. Different types of the homogenization scheme including Reuss model, Voigt model, Mori-Tanaka model, and Hashin-Shtrikman bounds model are taken into consideration in order to extract the effective mechanical properties of FGM skew nanoplates. The Ritz method using Gram-Schmidt shape functions is utilized to obtain the surface elastic-based shear buckling loads of FGM skew nanoplates. It is indicated that by increasing the value of the index associated with the material property gradient, the significance of the surface stress type of size effect on the shear buckling behavior of a FGM skew nanoplate improves. Moreover, by changing the boundary conditions from simply supported ones to clamped ones, the influence of the skew angle on the surface elastic-based shear buckling load of a FGM skew nanoplate increases. Also, it is illustrated that by increasing the width to thickness ratio of a skew nanoplate, the free surface area increases which results in to enhance the effect of surface residual stress on its shear buckling characteristics.

ABSTRACT: The governing differential equations of thin-walled laminated composite curved beams are derived from the principle of virtual displacement. Curvature effect is fully considered, and various displacement components of curved beams are coupled. Buckling behaviors of both the laminated composite I-section vertically (with horizontal web) and horizontally (with vertical web) curved beams are studied. The characteristic displacement function for pinned-pinned curved beams is used to describe both the in-plane buckling and out-of-plane (spatial) buckling behaviors. Closed form solution for buckling analysis of I-section curved beams under compression and bending moment is obtained. Accuracy of the present closed-form solution is verified by comparing with available solutions in the literature and the numerical results of the finite element method usingABAQUS. Then, a practical application of the closed-form solution for I-section composite laminated curved beams is demonstrated, considering the placement of I-section profile, geometry of section, layup in flanges and web, and central angle. Finally, a parametric study is conducted to evaluate the effect of central angle, arc length, radius of curvature, and fiber angle of laminates on buckling behavior of I-section curved beams with either horizontal or vertical web.


ABSTRACT: This paper presents an experimental and theoretical study on the deformation of small diameter aluminum alloy (AA6063T5) circular tubes under lateral impact loading. Seven specimens classified as three groups were investigated by the drop weight test. The patterns and extent of damage between specimens were compared and discussed. Moreover, the experimental results show that the performance of specimens subjected to the lateral impact is significantly affected by the diameter-thickness ratio and impact energy while the impact momentum has little effect. The springback of the global displacement is found to be negatively correlated with the ratio of the impact energy and the diameter-thickness ratio. Afterward, this study develops an analytic solution on the elasto-plastic global displacement of AA6063T5 tubes based on vibration theory. Compared to the experimental results, the elastic solution predicted the global displacement of the aluminum alloy specimens reasonably.


ABSTRACT: Non-linear stability plays an essential role in the design of reticulated shell structures. In order to improve the buckling strength of aluminum alloy spherical shells with gusset joints, this paper proposes a shape optimization method to maximize the non-linear buckling load using a genetic algorithm. The control points of a cubic spline are chosen as the design variables defining the height of the surface. In the non-linear buckling analysis, a linear combination of the symmetric and antisymmetric buckling modes is used as the imperfection mode, and an initial eccentricity is introduced for each member to consider the disadvantageous effect caused by the interaction between the flexural-torsional buckling and global buckling. It is verified in the numerical examples that the proposed method can increase the non-linear buckling load maintaining the smoothness of the surface, while the conventional approach of minimizing the total strain energy is not effective for improving the buckling strength. Finally, the design tables of the parameters of the optimized cubic spline curve are obtained through the parametric analysis considering various load factors and height-to-span ratios, and are verified to be practical and useful under different height of the section, number of rings and support condition.


ABSTRACT: In this paper, a new lamination parameter based method is proposed for the layup optimization of built-up composite laminates with ply drop-offs. The optimization process is divided into two stages. In the first stage, the multilevel optimization feature of the exact strip software VICONOPT MLO is extended to use the lamination parameters and laminate thicknesses of each component panel as design variables to minimize the weight of the whole structure subject to buckling and lamination parameter constraints. For the second stage,
A novel dummy layerwise branch and bound (DLBB) method is proposed to search the manufacturable stacking sequences to find those needed to achieve a blended structure. The method is based on the use of 0°, 90°, +45° and −45° plies and having lamination parameters equivalent to those determined in the first stage. The DLBB method carries out a logical search to circumvent the stochastic search feature of heuristic methods for the determination of stacking sequences. This two-stage method is an extension of a previous highly efficient two-stage method for a single laminate (Liu et al., 2019) [1]. The effectiveness of the presented method is demonstrated through the optimization of a benchmark wing box.


ABSTRACT: This paper aims to study the boundary effects on stretch-induced membrane wrinkling. Towards this end, several typical distributions of tensile loads, that are applied at the short ends of rectangular membranes, are investigated, which produce a system of forces statically equivalent to force and moment. In addition, we explore the relevance of a dimensionless parameter to the buckling loads for these loading cases. By analyzing the critical buckling loads, it is found that small differences in loading conditions lead to critical loads that can differ up to three orders of magnitudes. Besides, the dimensionless parameter is almost constant near bifurcation points independently from boundary conditions. Based on this property, a simple expression is proposed to fast predict the critical load of membrane wrinkling. This paper may provide a simple way to delay or avoid the occurrence of wrinkles by just changing the boundary conditions.


ABSTRACT: In lateral crashes, thin-walled beams may collide with impactors with multifarious shapes and sizes at any position or angle. In addition, the beams are always fixed on other structural components. However, these facts are ignored in the present studies on the bending collapse. This paper aims to investigate the influences of such factors on the transverse bending responses of thin-walled beams. Quasi-static three-point bending tests are conducted first for aluminum square beams loaded at different load angles, positions and spans. The non-linear finite element code LS-DYNA is then utilized to simulate the tests. After validated by the experiment, the finite element model is employed to perform parametric studies to investigate the influences of various factors on collapse responses of thin-walled tubes, and the ranges of the force responses with the variation of these factors are discussed. Results show that the variation of punch shape and size, load position and angle may lead to the switch of deformation modes, while the loading velocity and the height of crash boxes have very small influences on the deformation patterns. Increasing the loading velocity results in a much higher peak force, and fixing the beams on shorter crash boxes achieves a higher force level. In all cases, a sharp punch perpendicularly loaded in the middle of the span controls the lower bound of the crushing force, while the upper bound is governed by the punch approaching the support with small angles. The mean crushing force of the beams can be increased by up to 78% with the variation of the load and boundary factors in the calculations. The findings of this work would be helpful on the crashworthiness design of thin-walled beams under transverse loads.


ABSTRACT: Seismic stability of single-layer dome structures is closely related to both the external seismic ground motions and structural properties. The physical mechanism of seismic instability of single-layer reticulated dome structures is investigated from the perspective of energy, which can take into account both the external excitations and structural properties. First, the energy balance equation is established and the accuracy for calculating each energy component of structures is verified. Then, the energy-based criterion is introduced as a quantitative index for the identification of seismic stability/instability, where the first-passage of the intrinsic energy over the input energy demonstrates the seismic instability of single-layer reticulated dome structures. Besides, some qualitative indices are also employed to further confirm the judgement by the energy-
based criterion. By using the proposed criterion, the critical peak ground acceleration for seismic stability of single-layer reticulated dome structures can be identified by using the incremental dynamic analysis. The energy-based criterion is also validated by comparisons with the B-R criterion. Parametric analyses are implemented to investigate the impacts of different structural parameters on seismic stability and characteristic responses of single-layer dome structures.


ABSTRACT: The paper presents methods of analysis of built-up sections in which the discrete locations of fasteners is accounted for explicitly, rather than by smearing their effect using continuous shear flexibility as in current approaches. By considering fasteners at discrete points, it is possible to analyse the effects of placing additional fasteners at the ends (end fastener groups), to account directly for actual support conditions and to determine the optimum locations of fasteners. The paper first outlines the linear analysis of beams in flexure and introduces the notion of the effective flexural rigidity to account for partial composite actions. Closed form solutions are provided for five load and end support cases to demonstrate the application of the analysis. Next, the paper describes the linear analysis of built-up sections in torsion, considering first uniform torsion followed by non-uniform torsion. Closed form solutions are obtained for the effective torsion rigidity \((EI_\ldots)\) of built-up sections featuring closed loops. A framework is also presented for determining the effective torsion rigidity \((EI_\ldots)\) of open built-up sections in non-uniform torsion. The paper concludes with the analysis of built-up sections subject to flexural buckling. A general variational buckling equation is derived followed by an energy-type method for calculating buckling loads for common end support conditions, including columns supported on flexible end tracks. Closed form solutions are presented for up to seven rows of fasteners longitudinally. While by nature approximate, the solutions are shown to be highly accurate. Comparisons are made between the presented closed form solutions and buckling load predictions obtained using current design provisions.

References listed at the end of the paper:
1 AS/NZS4600Cold-formed Steel Structures, Standards Australia, Sydney (2018)
2 AISI-S100, North American Specification for the Design of Cold-Formed Steel Structural Members, American Iron and Steel Institute, Washington, D.C. (2016)
3 F. Bleich, Buckling Strength of Metal Structures, McGraw-Hill (1952)
7 A. Sato, C.-M. Uang, Modified slenderness ratio for built-up members, Eng. J. AISC, 44 (3) (2007), pp. 269-280
8 J. Whittle, C. Ramseyer, Buckling capacities of axially loaded, cold-formed, built-up C-channels, Thin-Walled Struct., 47 (2) (2009), pp. 190-201
10 T.A. Stone, R.A. LaBoube, Behavior of cold-formed steel built-up I-sections, Thin-Walled Struct., 43 (12) (2005), pp. 1805-1817
12 A. Gjelsvik, Buckling of built-up columns with or without stay plates, J. Eng. Mech., 116 (5) (1990), pp. 1142-1159
13 T. Kobashi, N. Shimizu, Global buckling strength of built-up cold-formed steel column under compression, F. Wald, M. Jandera (Eds.), International Colloquium on Stability and Ductility of Steel Structures (2019), Prague
19 I. Georgieva, L. Schueremans, L. Vandewalle, L. Pyl, Ultimate strength of built-up CFS columns, according to the DSM, Experimental validation on columns with varied boundary conditions, J. Loughlan, D. Nash, J. Rhodes (Eds.), 6th International Conference on Coupled Instabilities in Metal Structures (2012), pp. 319-326
Glasgow

ABSTRACT: The objective of this study is to investigate the crashworthiness performances of graded lattice structure filled tubes (GLSFTs) under multiple impact loadings. Different graded body-centered cubic

ABSTRACT: Corrosion-induced durability has become a critical issue for aging spatial structures using steel tubes as primary load-carrying structural components. Tremendous efforts have been made in predicting the ultimate strength of steel tubes under axial compression but understanding corrosion-induced buckling remains a challenge due to uncertainty of localized defects. To experimentally investigate the effect of localized corrosion on steel tubes, a modified galvanic method was developed to generate predefined corroded defects at targeted locations. A total of 24 tubes with different slenderness ratios were produced with various localized corroded defects, and then axially compressed to obtain ultimate strengths. Our experiments showed that the galvanic method could efficiently generate localized defects that could change the direction of buckling and significantly lower the ultimate strength of tubes. Further, the corrosion depth has the largest effect on the residual capacity of the tubes among three geometric characteristics of corroded patches. The influence of circumferential corrosion size is greater than that of longitudinal corrosion size due to the deviation of section centroid. From a practical perspective, our experiments indicate that the ultimate strengths of steel tubes can be lower than those estimated by both US and Chinese codes when the localized corrosion ratio exceeds 15%. Thus, the localized corrosion should be checked regularly during the maintenance routine such that buckling-induced failure can be avoided in advance.


ABSTRACT: This paper proposes a numerical and an approximate analytical method for the in-plane non-linear elastic stability of arches under the multi-pattern distributed load. There are six key parts in this paper. Firstly, the approximate analytical solution for funicular axis of arches subjected to the multi-pattern distributed load is derived from the approximations of linear elastic bending moment and horizontal reaction force in the arch end. Secondly, the numerical solution of the in-plane non-linear elastic equilibrium equation is solved by using the shooting method and the bisection method simultaneously. Thirdly, the approximate analytical solutions for the in-plane non-linear elastic equilibrium are derived according to the approximate analytical solution for funicular arch axis obtained from the first part, the simplified strain-displacement expression in Cartesian coordinate system and the virtual work principle. Fourthly, a key parameter is proposed to transform the approximate analytical solutions into the corresponding equations of catenary and parabolic arches. Fifthly, the in-plane non-linear elastic symmetric and asymmetric buckling of arches under the multi-pattern distributed load is derived analytically. Lastly, the in-plane non-linear elastic buckling behaviors of arches subjected to multi-pattern distributed load are deduced based on the obtained analytical solutions. The multi-pattern distributed load with the uniformly distributed load along the span and the uniformly distributed load along the arch is selected as example to verify the proposed method. Comparisons with numerical solutions demonstrate
that the proposed approximate analytical solutions for the funicular arch axis and linear elastic horizontal reaction force agree well with the results of Runge-Kutta method and the proposed approximate buckling predictions have sufficient accuracy compared with the results of finite element method in different rise-to-span ratios, relative slenderness and arch axis parameters.

ABSTRACT: The static stability of clamped-free columns resting on elastic foundation is investigated under a nonconservative subtangential follower force. The higher-order shear deformation beam theories are applied to treat structural instability of a clamped-free rectangular and circular beam resting on Winkler foundation. Based on Engesser's assumption, a single governing equation is derived for divergence instability of Beck cantilever under a subtangential follower force. For different warping shapes of rectangular and circular cross-sections, the critical divergence buckling loads are determined. Static buckling still occurs for a cantilever column subjected to a subtangential follower force with small nonconservativeness parameter and dynamic flutter instability occurs for large nonconservativeness parameter. In a free space, a unified relationship with the Euler buckling loads is given explicitly for the case of a dead load, and the buckling load has an apparent reduction due to shear deformation with different warping of the cross-section. The obtained results further modify the Euler buckling formula to suit for the columns with a broad range of slenderness. Elastic foundation nearly linearly increases the buckling load and a nonconservativeness parameter also raises the divergence buckling load. For shorter columns, the classical buckling loads are significantly overestimated. The effects of slenderness, warping shapes, nonconservativeness parameter, and spring stiffness coefficient are analyzed.

ABSTRACT: The present paper reports experimental and numerical studies of the minor-axis flexural buckling behaviour and resistances of welded I-section columns made of a newly developed grade EN 1.4420 high-chromium austenitic stainless steel. The structural testing programme comprised ten pin-ended column tests as well as supplementary measurements of the initial global and local geometric imperfections of the column specimens. The structural testing programme was accompanied by a numerical modelling programme, including a validation study, where column finite element models were developed and validated against the experimental results, and a parametric study, where the validated column finite element models were employed to generate an additional numerical data bank over a broad spectrum of cross-section dimensions and member effective lengths. The obtained test and numerical data, were adopted to evaluate the applicability of the design provisions for normal stainless steel welded I-section columns, as set out in the current European code and American design guide, and cold-formed doubly symmetric section columns, as given in the existing Australian/New Zealand standard and American specification, to the new high-chromium stainless steel welded I-section columns. Overall, it was found that (i) all the four considered codes can be safely extended to cover the design of high-chromium stainless steel welded I-section columns, except for the American specification, which results in unsafe flexural buckling resistance predictions, and (ii) the most accurate and consistent design flexural buckling resistances were obtained by using the European code.

ABSTRACT: The Continuous Strength Method (CSM) provides accurate resistance predictions for both stocky and slender stainless steel cross-sections; in the case of the former, allowance is made for the beneficial effects of strain hardening, while for the latter, design is simplified by the avoidance of effective width calculations. Although the CSM strain limits can be used in conjunction with advanced analysis for the stability design of members, for hand calculations, the method is currently limited to the determination of cross-sectional resistance only, i.e. member buckling resistance is not covered. To address this limitation, extension of the CSM
to the design of stainless steel tubular section columns is presented herein. The proposed approach is based on the traditional Ayrton-Perry formulation, but features enhanced CSM cross-section resistances and a generalized imperfection parameter that is a function of cross-section slenderness. The value of the imperfection parameter increases as the slenderness of the cross-section reduces to compensate for the detrimental effect of plasticity on member stability that is not directly captured in the elastic/first yield Ayrton-Perry approach. The accuracy of the proposed approach is assessed against numerical results generated in the current study and existing experimental results collected from the literature. The presented comparisons show that the CSM provides consistently more accurate member buckling resistance predictions than the current EN 1993-1-4 design rules for all stainless steel grades. The reliability of the proposed approach is demonstrated through statistical analyses performed in accordance with EN 1990. Finally, the paper presents a framework through which the proposed approach can be developed for other cross-section types and materials.


ABSTRACT: Honeycombs based composites are applied in a wide spectrum of applications. In the present study, the performance of novel foam concrete filled auxetic aluminium honeycombs subjected to quasi-static and low velocity compression is experimentally and numerically investigated. The response mode, crushing resistance and energy absorption capacity of hollow and foam concrete filled auxetic honeycombs are experimentally studied under quasi-static and low velocity loading. Numerical models, validated with the test results, are employed in parametric study to further examine the performance. If properly designed, the interaction between the auxetic honeycomb and foam concrete reinforces each other, making the two components to work in synergy. It is found that the response modes of the composites change from compression failure with low peak stress and stable plateau stress to shear failure with high peak stress and severely fluctuated plateau stress with increasing foam concrete density. The response of foam concrete filled honeycombs gradually transforms from the quasi-static mode with global deformation to dynamic mode with localized crushing near loading end, and the effective Poisson's ratio of the composites decreases, both with increasing compression speed.


ABSTRACT: Recently, a new generation of cold-formed steel (CFS) channel sections with edge-stiffened circular holes have been developed by industry in New Zealand. No previous research, however, has considered the web crippling strength of CFS channel sections with edge-stiffened circular web holes under the interior-two-flange (ITF) loading conditions. In this paper, a combination of experimental investigation and non-linear finite element analysis (FEA) are used to investigate the effect of edge-stiffened holes under ITF loading conditions; for comparison, channel sections without holes and with unstiffened holes are also considered. In total, 30 web crippling test results are reported. A non-linear finite element (FE) model is described, and the results were compared against the test results, which showed a good agreement in terms of both the web crippling strength and failure modes. The results indicate that the stiffened web holes can significantly improve the web crippling strength of CFS channel sections. Using the validated FE model, a parametric study was conducted which include 1116 FE analyses, covering the effect of different hole sizes, edge-stiffener lengths and fillet radii, length of the bearing plates and position of the holes in the web. From the results of the parametric study, design recommendations in the form of web crippling strength reduction factors are proposed, that are conservative to both the experimental and FE results.

ABSTRACT: Lightweight auxetic reentrant honeycombs (ARH) with negative Poisson's ratio (NPR) are very promising for crashworthiness applications due to high specific-strength and energy-absorption (EA). To dig up the potential of ARH, a bio-inspired self-similar “concentric auxetic reentrant honeycomb (CARH)” is proposed to reinforce the EA. Finite element model is established and verified via available reference results for quasi-static-, low-, medium- and high-velocity compression. Two types of CARHs including CARH-I and CARH-II are designed to systematically explore the crashworthiness. The quasi-static and dynamic compression behaviors and EA characteristics are compared among different structures. There is a harvest that the bio-inspired CARHs show higher plateau stress and EA than the traditional ARH, while CARH-II > CARH-I. To clearly understand strengthening mechanisms, different global and uncellular shrinkage deformation modes (e.g., “x”, “X”, “T”, “V”, etc.) are revealed under different velocities. Summarily, the enhancement is due to coupling deformation and energy-dissipation of more plastic-hinges. The horizontal strain of each layer is studied to reveal the NPR effect, which shows a significant velocity effect on the horizontal strain. From parametric studies, typical parameters (e.g. wall-thickness, distance and number of concentric walls) have considerable effects on crashworthiness of CARH. The present bio-inspired design and findings offer a reference for the development of honeycomb with special functions.


ABSTRACT: This paper presents an investigation on the performance degradation of circular thin-walled concrete-filled steel tubular stub columns in the high-latitude offshore region. 24 specimens were loaded axially after freeze-thaw cycles and salt spray corrosion. The results show that with the increase of corrosion rate and concrete grade, the strength degradation of the specimens after the peak point becomes severe. The increase of corrosion rate approximately linearly reduces the ultimate strength of the specimens after freeze-thaw cycles, regardless of concrete grade. The ductility index and the composite elastic modulus of the circular thin-walled CFST stubs are decreased by corrosion after freeze-thaw cycles. Two design methods are proposed based on the discussions of the test results. The simplified design method for predicting the ultimate strength is proposed and validated based on the test results. The design method in Eurocode 4 for the ultimate strength is improved, in terms of material property degradation. A full-range prediction of the strength degradation of circular thin-walled CFST stubs under freeze-thaw cycles and corrosion is conducted. It is concluded that the high strength of core concrete is beneficial for the duration ability of thin-walled CFST stub columns.


ABSTRACT: The shear strength, shear distortion, failure mode, and energy absorption performance of irregular circular and box-shaped tubular column panel zones (PZs) were investigated using experimental and analytical methods on the seven steel frame structures. The main parameters include the beam height ratio of left and right beams, the column cross-section, and the configuration of external diaphragm. The key variable, beam height ratio, can affect the PZ shear strength and energy absorption, but has little influence on the initial stiffness of the PZ; the PZ, PZ1, and PZ2, absorb energy together in the initial loading stages, as the load increases, most of the energy begins to be absorbed only by PZ1 which has the same height as the smaller beam, therefore, the design considering only PZ1 is incomplete; excessive PZ shear deformation can cause cracking of the weld root which adversely affects the structure; the configuration of external diaphragm should avoid stress concentration which can cause cracking of the base metal. The chosen analysis methods are capable of simulating the shear strength and failure modes of the PZ obtained in experimental results with acceptable accuracy.


ABSTRACT: The current investigation deals with the nonlinear oscillation response of conical microshells made of a composite material with functional graded (FG) in-plane heterogeneity is studied in the presence of
the size dependency. To accomplish this purpose, various types of homogenization schemes including Voigt model, Reuss model, Mori-Tanaka model, and Hashin-Shtrikman bounds model are employed. The size-dependent characteristics are taken into consideration on the basis of the modified couple stress theory of elasticity within the framework of the higher-order shear deformation shell theory. The couple stress-based differential equations of motion are constructed via the Hamilton's principle. An efficient numerical solution methodology adopting generalized differential quadrature (GDQ) method together with the pseudo-arc technique is put to use to obtain the modified couple stress-based nonlinear frequency of homogenized FG composite conical microshells. It is demonstrated that by increasing the value of the maximum shell deflection, the couple stress type of size effect plays more important role in the nonlinear vibration response of FG composite conical microshells. Additionally, it is indicated by changing the boundary conditions from simply supported one to clamped one, the influence of couple stress size dependency decreases.


ABSTRACT: It has been shown that fire disaster normally occurs following an earthquake disaster, which might cause even more serious losses than the earthquake itself. This study investigates the post-earthquake fire performance of concrete-filled steel tube (CFST) columns. The experimental programme contains two parts - quasi-static tests and fire tests. During the quasi-static tests, the square CFST columns were loaded under constant compressive force and cyclic horizontal force, until reaching different degrees of seismic damage. Afterwards, the pre-damaged columns were loaded under a constant axial compression ratio (i.e. ratio of the applied compressive load to its bearing capacity) of 0.3 at elevated temperatures. The fire resistance time and failure modes of these pre-damaged CFST columns were reported. Finite element (FE) models were developed and validated against the test results; a total of 48 numerical results were generated in the parametric study using the validated model. In the parametric study, the influence of key parameters including the thickness of steel tube, the yield strength of steel tube, the axial compression ratio and pre-damage degrees on the fire resistance of square CFST columns were analysed. The experimental and numerical results are used to propose design rules for the fire performance of square CFST columns with different degrees of seismic damage.


ABSTRACT: Modular construction has become popular for its advantages in construction efficiency and reduced manpower on site. Steel modules are typically connected using bolted connections which often suffer from inadequate allowable tolerances to accommodate imperfections due to vertical alignment of modules. To solve these problems, a shear-keyed grouted sleeve connection (SK-GSC) is proposed to connect the square hollow section (SHS) columns between the upper and lower modules. This paper investigates the axial performance of SHS SK-GSCs, specifically on their resistance and load transferring mechanism. To study the effect of shear key spacing, grout strength, and grout thickness, fifteen specimens were tested, and numerical models were calibrated against the test results to gain insight into the failure mechanism. It was found that the load-bearing resistance of SHS SK-GSCs was contributed by the frictional bond at the steel-grout interface and the diagonal compression struts developed in the grout. The proposed connections have sufficient axial resistance, stiffness and ductility to integrate the module columns vertically as compared to existing bolted connections. They were robust enough to withstand potential tension force due to accidental action in the design of modular buildings.


ABSTRACT: Columns with initial crookedness and twist are analyzed. A discrete elastic restraint resists bending and twisting as the compressive load is increased. The thin-walled columns are linearly elastic, and deformations are small. Numerical results are presented for two examples of pinned columns with half-sine
initial imperfection shapes. The first is a singly symmetric Cee section with torsional bracing. Flexural-torsional coupling occurs between the twist and bending in the strong direction. The second is a doubly symmetric I section with lateral bracing on one flange. Flexural-torsional deformation in this case involves twist and bending in the weak direction. The effects of axial load, bracing location and stiffness, and relative orientations of the imperfections are investigated. Also, the stiffness required to restrict the twist to be a certain proportion of the initial twist is determined, which is useful for designing bracing.


ABSTRACT: In the present paper, an improved procedural method for the generation of curved, arbitrarily conformed self-stiffened panels using skeleton-based integral soft objects is presented. The proposed approach extends the application of integral soft objects to curved mesh surfaces by operating an inverse anamorphic mapping of special-purpose displacement fields applied orthogonally to the patched surface representing the curved structural domain. An efficient parallel procedure, able to evaluate the vector field of normals at mesh nodes of the host domain, is preliminary illustrated. Several multi-map techniques are subsequently exploited to generate arbitrary protrusions on different curved mesh surfaces, either open or closed.


ABSTRACT: The utilization of membrane structures in space engineering has attracted considerable attention in recent decades due to ultra-light weight characteristics. The measurement and calibration of dynamic performance on ground is challenging due to air effects and equipment limitation. In this paper, a novel vacuum-level vibration-testing device is developed to realize an environment of adjustable air pressure. An improved membrane tension system is utilized to guarantee simply-supported boundary conditions and a uniform stress field, which is more consistent with theoretical and simulation requests. The modal identification method is modified based on only four measuring points because of limited space of the vacuum tank, which is a combination of FFT (Fast Fourier Transform) and SSI (Stochastic Subspace Identification) methods. The effects of non-uniform stress field and air pressure on membrane modal are investigated based on the proposed testing device and method. The effect of the non-uniform stress field on membrane frequency is analyzed by the theoretical, numerical and experimental methods, and the results show that the non-uniform stress field resulting from uneven tensions has little effect on the frequency of biaxial tensioned membranes. Meanwhile, an empirical formula is proposed to predict the first three structural frequency of a specific biaxial tensioned membrane under different air pressures.


ABSTRACT: The nonlinear parametric resonance of a cantilever under axial base excitation is examined while capturing extremely large oscillation amplitudes for the first time. A geometrically exact model is developed for the cantilever based on the Euler-Bernoulli beam theory and inextensibility condition. In order to be able to capture extremely large oscillation amplitudes accurately, the equation of motion is derived for centreline rotation while keeping trigonometric terms intact. The developed model is verified for the static case through comparison to a three-dimensional nonlinear finite element model. The internal energy dissipation model of Kelvin-Voigt is used to model the system damping in large amplitudes more accurately. The Galerkin modal decomposition scheme is utilised for discretisation procedure while keeping the trigonometric terms intact. It is shown that in parametric resonance region, the oscillation amplitudes grow extremely large even for smallest possible amplitudes of the base excitation, which highlights the significant importance of employing a geometrically exact model to examine the parametric resonance response of a cantilever.

ABSTRACT: This study presents the experimental and numerical investigation of the response of hemispherical sandwich shell structure having hexagonal honeycomb core against ogive nosed projectile impact. Aluminum AA-1100 was considered for the front and rear face sheet of 200 and 160 mm diameter whereas AA-3003H19 was used for the honeycomb core of 3.2 mm cell size, 0.05 mm cell wall thickness and 20 mm core thickness. The cylindrical ogive nosed projectile having diameter 19 mm, mass 52.5 g and length 50.8 mm was hit at the crown of the hemispherical sandwich shell structure. The experiments were carried out through a pneumatic gun whereas for numerical simulations, 3D finite element code Abaqus explicit solver was used. The ballistic resistance, failure mechanism and the energy absorption of the sandwich shell structure was investigated thoroughly through experimentation and numerical simulations and found close to each other. Moreover, the parametric study was performed through numerical simulations to study the influence of face sheet thickness (0.7, 1, 1.5 and 2 mm), cell wall thickness (0.03, 0.05, 0.07 and 0.09 mm) and cell size (3.2, 5.0, 7.0 and 9.0 mm) of the honeycomb core on the ballistic response and energy absorption. Against ogive nosed projectile, face sheets failed in radial stretching with petal formation and the core failed in crushing. Also, the face sheet thickness had a dominant effect on the ballistic limit and the energy absorption of the hemispherical sandwich shell structure. Moreover by increasing core stiffness (by using thick cell wall and small cell size) enhance energy absorption capacity of the sandwich structure.


ABSTRACT: In the present study crashworthiness performance of monolithic and co-axial multi-wall (double, triple, and four layered) frusta tube structures was investigated under the quasi-static axial loading. The developed layered frusta tubular structures having a total equivalent thickness of 2.3 mm were made of aluminium alloy AA-1080 sheet. A series of layered configurations were simulated and analysed using non-linear finite element analysis code LS-DYNA, keeping volume approximately the same as the monolithic frusta tube. For the effectiveness of the simulated results, double-tubular structure was examined through experimental results. A parametric study was performed by keeping taper angle constant as 5.71° with the variation in height (91.6 and 82 mm for double layered, 91.6, 86 and 78 mm for triple layered and 91.6, 87, 82 and 77 mm for four layered), thickness (2.3–0.4 mm) and diameter (smaller end diameter in the range of 42.8 mm–48.4 mm while larger end diameter varied from 61 mm to 64 mm) to analyse the crushing performance of layered structures. The crashworthiness performance indicator like peak force (PF), mean force (MF), energy absorbing capacity (EAC), specific energy absorption (SEA) and crush load efficiency (CLE) which is defined as the ratio of MF to the PF, were studied for the various layered frusta tubular structures. Moreover, optimization technique GRA (Grey Relational Analysis) was employed to obtain a better combination of multi-wall layered structures. With the increase in the layer, the initial peak force was reduced compared to the monolithic frusta. The optimization technique suggested the triple-layer configuration showed better crashworthiness performance.


ABSTRACT: Stiffened plate widely exists in ships, steel girders and wing of airplanes for its good bending resistance and lighter weight. The main purpose of this work is to investigate the dynamic response of stiffened plate subjected to confined blast loading through both experimental and numerical approaches. Firstly, several field blast experiments of box-shaped specimens with different dimensions and different explosive weight were conducted. The damage features of both inner-stiffened and outer-stiffened plate were obtained and investigated. Then, numerical models were built and validated by the experimental results, and the dynamic response processes were analyzed. Both the experimental and numerical results show that outward deformations
produced in both inner-stiffened and outer-stiffened plate, while the ultimate deflection of outer-stiffened plate is smaller than that of inner-stiffened. In the meantime, overall bending deformations are observed in the outer stiffeners, while in-plane bulking of the flanges and instability failure of the web are observed in the inner stiffeners. In addition, the different dynamic response of stiffened plate under confined and unconfined blast loading were analyzed and compared using the validated numerical method, and the tendency of the dimensionless deflection of inner and outer stiffened plates subjected to confined blast were discussed.


ABSTRACT: The crumpling of aluminium alloy AA6060 T4 thin-walled tubes when subjected to axial and oblique impact is often experienced in collisions. Tubes with holes (so-called windows) and multi-cell tubes are efficient in terms of the structure's energy absorption. This paper proposes a combination of rectangular windows and multi-cell square tubes to improve the structure's crashworthiness. The advantages of the introduction of windows into the structure can diminish the initial peak collapsing load. This can also improve the crashworthiness performance and the mechanism of a folding formation. However, this introduction causes cracks in the tube and thus reduces the plastic zone area of the fold. The decrease in the plastic zone area and the cracks reduce the tube's energy absorption capacity. The specific energy absorption (SEA) and mean collapsing load \( P_{c,\text{ave}} \) of WMCT-I and WMCT-III under axial impact is higher by about 20% and 16% compared to those of MCT-I and MCT-III, respectively. Relating to MCT-II having a wall-to-corner (WTC) one, the tube with holes does not improve in either case of axial and oblique impact. Extensive theoretical solutions are proposed to predict the mean collapsing loads of the windowed multi-cell tubes. The results of the theoretical predictions are compared to those of the numerical simulation. The Multi-Criteria Decision Making (MCDM) method is applied to select the better structure for the energy absorber application.


ABSTRACT: In this study, the experiments of 800 MPa high strength steel (HSS) welded I-section columns under axial compression are performed to investigate their local buckling behavior. The effects of width-to-thickness ratio and slenderness on the local buckling load are considered. Four different buckling modes of columns (i.e., web buckling, flange buckling, web and flange buckling, and global buckling) are designed. The local buckling load obtained from load-displacement curves and load-strain curves are investigated. New embedding coefficients of the web and flange in 800 MPa HSS welded I-sections are recommended. Design provisions in current specifications for predicting the ultimate bearing capacity of 800 MPa HSS welded I-section columns under axial compression are evaluated, and it is concluded that GB50017-2017, AISC360-16, and EN 1993-1-5 is a little overestimated for estimating the ultimate bearing capacity of 800 MPa HSS welded I-section columns under axial compression. A three-dimension finite element model is developed for predicting the ultimate bearing capacity of 800 MPa HSS welded I-section columns under axial compression, which is validated by test data. The effect of residual stress on the ultimate bearing capacity of 800 MPa high strength steel welded I-section columns is not obvious. A more accurate model for estimating the ultimate bearing capacity of 800 MPa HSS welded I-section columns under axial compression is recommended.


ABSTRACT: Free axisymmetric vibrations of composite annular sandwich plates with thick isotropic core and orthotropic facings have been studied using Reddy's higher-order shear deformation theory. Core is assumed to be of uniform thickness while the face sheets are treated as membranes. Equations of motion and natural boundary conditions are developed using Hamilton's principle. Chebyshev collocation technique has been applied to get the frequency equations for clamped-clamped, clamped-simply supported and clamped-free edge conditions. Obtained equations are solved numerically for the lowest three roots and reported as the frequency
parameters for the first three modes of vibration. Results obtained from the proposed approach are validated by comparing them numerically and graphically with their counterparts available in the literature. Detailed numerical results are given to analyze the effects of core thickness, thickness of faces and radii ratios on the frequency parameter. It is also shown that the published analysis based on first-order theory is not suitable for estimation of natural frequency of annular sandwich plate with thick core. Three dimensional mode shapes have been plotted for a specified plate for all the three boundary conditions.


ABSTRACT: This paper presents an investigation into the energy absorption behaviour of splitting multiple circular tubes by theoretical, experimental and numerical methods. A theoretical solution for the steady-state crushing force of splitting multiple circular tubes is derived by applying the deformation theory. To explore the energy absorption of splitting multiple circular tubes and to validate the finite element model and a theoretical solution for the crushing force, an impact experiment is performed using a test trolley to examine the splitting process and force responses of multiple circular tubes. The finite element models of splitting multiple circular tubes are then established to investigate the energy absorption behaviour of the structure. The numerical simulation results agree well with those of the impact experiment. The energy absorption of splitting multiple circular tubes with different geometrical configurations, including the wall thickness of the tubes, number of tubes, radius of the tubes and conical angle of the dies, is analysed using a validated finite element model. The results show that the geometrical configurations of the tubes and conical angle of the dies have a distinct effect on the energy absorption. An analysis is also conducted to investigate the energy absorption by the evolution of the theoretical models. It is confirmed that the theoretical solutions provide a reliable prediction of the steady-state crushing force of splitting multiple circular tubes. The effect of the velocity is investigated, and the result shows that the steady-state force increased as the impact velocity increased.


ABSTRACT: The response of non-slender flax fibre reinforced polymer (FFRP)-skinned foam filled tubes under axial compression was investigated using 39 specimens. Different cross-ply fibre arrangements and foam densities (33–65 kg/m) were tested; the responses were compared to hollow FFRP tubes and Glass-FRP (GFRP) skinned tubes. Although axial behaviour was not significantly affected by changing foam density, hollow tubes were weaker than foam filled sections. This suggests that low density foam is effective at preventing premature failure. FFRP-skinned tubes with a skin thickness of 6.4 mm behaved similarly to GFRP-skinned tubes with a skin thickness of 3.4 mm in terms of strength and stiffness but were considerably better at absorbing energy. Specific strength and stiffness were highest with the lightest foam. The best performing FFRP-skinned tubes had specific strengths about 75% that of GFRP-skinned tubes with similar dimensions and equivalent foam cores.


ABSTRACT: The important claim that the presence of the structural damping considerably lessens or even eliminates the effectiveness of the embedded shape memory elements in the dissipation of the vibration/impact energies of the structures, is stated and proven here for the first time. The finite-element-based governing equations of thick composite sandwich plates with homogeneous/FG soft viscoelastic cores and embedded SMA wires are derived based on a new hyperbolic SMA-zigzag sandwich plate theory that considers the transverse flexibility. The tension-compression asymmetry of the SMA behavior and Zener-viscoelasticity-based zigzag nonlinear corrections are implemented to guarantee the transverse stress continuity at the interfaces between layers and updating the relation between the describing parameters of the displacement field,
and the stiffness and even mass matrices of the elements within each time step. For the first time, the phase-based rather than the mixture-based stresses are considered in tracing the phase transformations. The resulting time-dependent nonlinear integro-differential equations are solved by a special algorithm. Results confirm, for the first time, that the stress-strain hysteresis loops of the SMAs may shrink or even disappear in presence of the structural damping; so that, the belief that the phase-transformation-based damping and the structural damping directly add to each other, is quite wrong.


ABSTRACT: In practice, the foundations of arch bridges or other arch structures may have non-uniform settlements leading to uneven movements or rotations of the supports of the arch. The uneven movements and rotations of the supports influence the deformations and internal forces produced by the external load as well as the in-plane non-linear instability behaviour of arches significantly. Little research is reported about effects of support movements and rotations on the nonlinear in-plane instability of shallow arches in the opening literature. This paper focuses on effects of uneven movements and rotations of the supports on the in-plane nonlinear instability of fixed shallow arches. New analytical solutions for the limit point instability load of the fixed shallow arches under a uniformly localized radial load incorporating the influences of uneven movements and rotations of the supports are derived. Comparisons against the finite element results show the analytical solutions are adequately accurate. It is found that the uneven support movements and rotations have significant effects on the nonlinear in-plane instability behaviour of fixed shallow arches. It is also found that the in-plane nonlinear instability load of a fixed shallow arch decreases with an increase of the magnitudes of uneven movements and rotations of the support.


ABSTRACT: Thin-walled shell structures such as those used for space launch vehicles are highly sensitive to various kinds of imperfections. This imperfection sensitivity makes it challenging to predict the load carrying capacity of these structures. A correlation between the manufacturing process and the load carrying capacity, called manufacturing signature, would facilitate the design of these structures. Therefore, in this paper, a step towards a manufacturing signature of flow formed unstiffened isotropic shell structures is made. For this purpose, the investigated shell structures and their manufacturing process are introduced in detail in this work. Afterwards, the geometric and thickness imperfections of these shell structures are measured using an in-house developed measurement system. The measurement results are evaluated in detail and the buckling loads of the measured shell structures are calculated numerically. The results show that all six shell structures have similar knock down factors, which indicates a correlation between the manufacturing process and the load carrying capacity. Subsequently, experimental buckling tests are carried out for three shell structures. The discrepancies between the numerically calculated and the experimentally measured buckling loads are tracked back to load imperfections. Finally, the impact of load imperfections is studied briefly.


ABSTRACT: A type of self-lock multi-cell tubes assembled by open section components is recently proposed to serve as energy absorbing devices. Due to the open feature of the section, the self-lock tubes with large width may develop global buckling mode under axial crushing and show much worse energy absorption performances. To overcome this drawback, expanded polystyrene (EPS) foam fillers are firstly employed to improve the stability of the structural deformation and to increase the energy absorption efficiency. Experiment results show that a 4% increase in mass by EPS foam leads to about 20% increase in energy absorption of the self-lock tube. Numerical analyses are also carried out to simulate the tests and analyze the structures with other enhancement methods including Al foam filling and tube enveloping. They may be employed separately or simultaneously. The combination method of Al foam filling and tube enveloping gets the highest energy
absorption capacity and efficiency. Theoretical analysis is performed to predict the mean crushing force of self-lock tubes enhanced by Al foam filling and tube enveloping, and the theoretical results compare well with numerical results. Finally, crashworthiness optimization problems are proposed and solved to explore the optimal enhancement configurations of the self-lock multi-cell tubes.


ABSTRACT: The study aims to understand the effect of stacking sequence on the impact response and residual flexure characteristics of braided composite tube by combination of low-velocity impact, fracture observation and acoustic emission monitoring. Two stacking sequence configurations of braided tube in terms of [60°/40°] and [40°/60°] were designed and their low-velocity impact response and damage behavior were examined. Uniform structures namely [40°/40°] and [60°/60°] were also employed as reference specimens. The quasi-static bending performances of intact and impacted tubes were further compared to evaluate the influence of impact damage on residual performance. The results show that failure mode of impacted tubes strongly depends on braided structure of outer ply, of which large braiding angle(60°) leads to the formation of bottom delamination and degradation of structural integrity. The comparative experiments indicate that [60°/40°] tube improves flexure after impact performance with respect to specific energy absorption by 45.98% over [40°/60°] counterpart because of absence of bottom delamination. Thus, structure design of braided composite consisting of intra-ply structure and stacking sequence would be an economically feasible method to improve the transverse mechanical performance.


ABSTRACT: In this study, the strengthening effects of carbon fiber-reinforced polymer (CFRP) on the shear strength of thin-walled steel plates (TSPs) were investigated using experiments and finite element analysis (FEA). Two types of CFRP with different fiber orientations—0°/90°, and ±45°—were used for strengthening. The experimental and FEA results indicate that CFRP could effectively increase the shear strength of TSPs under shear loading. The theoretical equations according to the lamination theory of composite materials are proposed to calculate the shear strength of CFRP-strengthened TSPs under shear load with high accuracy compared with experimental and FEA results.


ABSTRACT: This paper presents a numerical investigation on the design resistance of extruded aluminum beams subjected to concentrated loads. The study is conducted through nonlinear finite element analysis considering large displacements, initial imperfection, and taking into account the strain hardening characteristics of common aluminum alloys. The numerical model is validated against experimental works taken from the literature. Thereafter, an extensive parametric study is carried out covering a wide range of beam geometries and slenderness ratios. Resistances computed numerically are compared with those calculated using the current design provisions in the EC9 for aluminum beams subject to concentrated loads, indicating that the EC9 provisions underestimate the resistances. Then, a new resistance function is calibrated performing a statistical evaluation of experimental and numerical results. The reliability of the recalibrated resistance function is assessed according to EN 1990, the results show improvements in the predicted resistances. Finally, the use of more accurate structural design provisions enhances the possibility of higher economic benefits, and by using less material, the carbon footprint originated from aluminum production can be reduced.

ABSTRACT: Design of multi-cell sectional configuration has been considered an effective way to enhance the crashworthiness performance of metallic thin-walled structure. Nevertheless, it remains under-studied whether this approach can achieve similar effect for fiber reinforced composite structures. Therefore, this paper aims to study the crushing responses and energy absorption behaviors of multi-cell squared carbon fiber reinforced plastic (CFRP) tubes fabricated by using hot compression molding process. The effects of CFRP cell number, wall thickness and trigger mechanism on crashworthiness characteristics were investigated. The experimental results showed that under the same weight, the energy absorption of double-cell tube was lower than that of single-cell tube. This was due to the fact that there was insufficient deformation in the T-shaped region of double-cell CFRP tube. The inner fronds generated in the middle ribs caused part of tubal wall near T-shaped region to bend completely outwards rather than to crush progressively under axial compression, thus losing certain capacity of energy absorption. In addition, a double-shell finite element model was constructed to gain further insights into the crushing behavior of the double-cell CFRP tube. The numerical model effectively replicated the collapse mode; and good agreement was obtained between the experimental and numerical load-displacement curves. The study exhibits considerable potential of developing crashworthy multi-cell CFRP structures.


ABSTRACT: The effect of the number of carbon-fiber-reinforced plastic (CRFP) layers on the axial crushing capacity of aluminum–CFRP square hybrid tubes was investigated both experimentally and numerically. Increasing the number of CRFP layers led to more collapsed lobes and decreased collapsed lobe widths, resulting in an improvement of the energy absorption capacity. The simulation results revealed a distinct tube wall collapse mode in the 4-layer hybrid tubes. The higher bending stiffness of the composite layers in the 4-layer hybrid tube led to debonding of the interface between the aluminum and composite layers. After interface failure, the composite layers did not collapse following the aluminum tube wall and instead rebounded in the approximate longitudinal direction, which directly suffering the longitudinal crushing loading. This behavior led to the shortened plastic collapse width and improvement of the single-layer CFRP energy dissipation due to CFRP delamination.


ABSTRACT: This work aims to improve upon the aluminium impact attenuator currently used by the University of Lisbon Formula Student team through a composite solution. The influence of geometrical variations, particularly the use of curved walls, and the number of objectives considered for the optimization are studied. To perform the optimizations, Abaqus is coupled with the Direct Multisearch (DMS) algorithm, the overall performance of the solutions is evaluated and the influence of the introduction of curved walls on the energy absorption capabilities discussed. Off-axis impacts are studied and the effect of curved walls in that situation analysed. An overview of the best configurations achieved is provided and one final configuration is selected.


ABSTRACT: The present work is focused on the investigation of tetra-anti-chiral structures by means of experimental, numerical, and analytical methods. Specimens with different lengths of the ligaments were manufactured by laser-cutting and were tested under a compressive load to investigate the value and evolution of Poisson's ratio. Based on the experimental investigation of the material used to manufacture the samples, finite element models were developed and solved using Ls-Dyna. Subsequently, based on the strain energy approach, an analytical solution for the estimate of the Poisson's ratio was derived. The solution is capable of estimating the value for structures with various configurations, including lengths and thickness of the ligaments. A simple beam finite element model was developed and implemented for solving in MATLAB, to extend the
capabilities for evaluation and design of structures with specific parameters. An overall comparison of results is presented, showing a good agreement between datasets. The present work might set the background for future activities, allowing for a selection of individual investigation methods.


ABSTRACT: In this paper, flexural stiffness reduction factor formulations, applicable to stainless steel members with compact cold-formed square and rectangular hollow section (SHS and RHS), are extended to account for local buckling effects and initial localized imperfection (ω). Local buckling effects and the influence of ω are accounted for by means of reducing the gross section resistance using a strength reduction factor ρ, determined by the Direct Analysis Method, depending on cross-section slenderness, is adopted. For in-plane stainless steel elements with non-compact and slender sections, results determined by the extended flexural stiffness reduction factor coupled with Geometrically Nonlinear Analysis (GNA) are verified against those determined by Geometrically and Materially Nonlinear Analysis with Imperfections (GMNIA). It is found that GNA with the extended flexural stiffness reduction factor (using beam element) generally achieves the accuracy of GMNIA (using shell element). Probabilistic studies based on 3D models with random ω are carried out to evaluate the effect of uncertainty in ω on the accuracy of GNA with the extended beam-column flexural stiffness reduction factor.


ABSTRACT: A typical fiber-reinforced polymer (FRP)-concrete-steel double-skin tubular column (DSTC) consists of an FRP outer tube, a hollow steel inner tube and an annular concrete in-fill in between. The existing studies on DSTCs in the past decade have generally confirmed the good structural performance of such column form, while it is worth noting that the possible in-ward buckling of the steel tubes in DSTCs is still a problem to be addressed, especially when DSTCs are subjected to large axial deformation. Against this background, a variation form of DSTCs called R-DSTCs has been recently developed by the authors. An R-DSTC is a DSTC in which the steel inner tube is reinforced by vertical stiffeners on the outer surface and the FRP outer tube can be circular, square or rectangular. The present paper presents the first ever experimental study on the compressive behavior of circular R-DSTCs which is the most common form of DSTCs. For the circular R-DSTC specimens tested in the present study, the outer tubes are made of a type of large-rupture-strain FRP. The vertical stiffeners on the steel inner tube are expected to delay or restrain the inward buckling of the steel tube, and the large-rupture-strain FRP outer tube makes possible a relatively large axial deformation of the specimen. In total, two DSTC specimens, twelve R-DSTC specimens and three bare steel tubes with/without stiffeners were tested, with the studied parameters covering the quantity, the dimensions and the shape of the stiffeners and the thickness of the FRP outer tube. The test results showed that R-DSTC specimens had a much better performance than the corresponding DSTC specimens in terms of both axial loading capacity and ductility, due to the existence of vertical stiffeners on the steel inner tube of R-DSTCs. The effects of the vertical stiffener-related parameters on the compressive behavior of R-DSTC specimens were also carefully examined and discussed in details.


ABSTRACT: In this study, two dimensional double-U auxetic honeycombs (2D DUHs) composed of curved shell members have been proposed based on traditional double-V (concave quadrilateral or re-entrant double-arrowhead) auxetic honeycombs (2D DVHs). Theoretical analysis, numerical simulation and compression experiments are adopted to characterize the mechanical properties including equivalent Young’s modulus,
equivalent Poisson's ratio, and quasi-static collapse process of 2D DVHs and DUHs. Specimens of the 2D DUHs and DVHs made of Aluminum alloy (A6061) are fabricated through wire cut electrical discharge machining. Both numerical and experimental results illustrate that concave DUHs exhibit tunable negative Poisson's ratio and equivalent stiffness level compared to DVHs. Furthermore, DUHs have smooth geometry configurations that can reduce stress concentration at elastic region and exhibit stronger auxetic behavior during large deformation. Those mechanical properties of 2D DUHs satisfy the requirements for practical engineering applications such as energy absorption. The dynamic crushing responses of 2D DVHs and DUHs are also investigated, and it is found that the crushing collapse modes and plateau stress improvement of 2D DUHs are related to the crushing velocity. Finally, the local impact responses of 2D DVHs and DUHs are studied numerically, the influences of impact velocity and indenter size are considered. This study provides useful instructions for the design, fabrication and analysis of auxetic structures, which has a broad prospect in some advanced technical applications.


ABSTRACT: Organisms in nature can inspire human research and design. Bamboo is generally acknowledged to be the structure with the best specific energy absorption and specific stiffness in nature. Compared to trees, it is difficult to break bamboo at its root and cause it to fall under dynamic loads, which can provide a useful reference for researchers. In this paper, a tube–diaphragm coupling beam inspired by bamboo was designed. The dynamic model of the bending vibrations of was established for the first time, and the influences of the structural parameters, such as the number of diaphragms, the tube thickness, and the impact pulse width on the impact characteristics of the tube–diaphragm coupling beams under transverse impact forces were analyzed. An optimal design of the tube–diaphragm coupling beams was obtained by particle swarm optimization. Specimens of bionic, solid, and hollow beams were prepared by the SLA (stereo lithography apparatus) 3D printing technology, and impact tests were carried out. The results of impact tests showed that the base vibrations of the solid and hollow beams were greater than those of the tube–diaphragm coupling beam for different impact pulse widths. The results indicated that bamboo can change its natural frequencies by adjusting the number of diaphragms and the tube thickness to adapt to changes of the environment. This adjustment can make the tube–diaphragm coupling beam absorb more energy through deformation, and thus, the dynamic force of the tube–diaphragm coupling beam at its root was smaller than those of solid and hollow beams. The results reveal the mechanism that allows bamboo to be difficult to beak at the root and fall, which can provide a useful reference for the design of beams and rotors.


ABSTRACT: The paper proposes a carbon fiber tube reinforced polyurethane foam material (CPM). Mechanical behavior of the CPM is investigated by quasi static crushing experiment. The results show that the carbon fiber tube reinforced design can obviously improve the energy absorption and load carrying capacity of the polyurethane (PU) foam. Parameter studies show that the density of the PU foam, the number and the diameter of the thin carbon fiber tube have significant effect on mechanical performance of the CPM. Moreover, the CPM filled thin walled columns (aluminum column or carbon fiber column) are further developed and their crushing behaviors are investigated under axial crushing conditions. The results show that the CPM filled design can effectively improve the crashworthiness of the aluminum column or the carbon fiber column. The interaction behavior between the CPM and the thin-walled column presents a significant contribution to energy absorption of the CPM filled columns. Moreover, the CPM filled carbon fiber column has greater potential to improve the crashworthiness than the CPM filled aluminum column. The research findings of this paper provide a new method for designing the lightweight protective structure.

ABSTRACT: This paper presents the application of higher-order shear deformation theory and nonlocal elasticity theory to electro-mechanical vibration analysis of a doubly curved piezoelectric nano shell resting on Pasternak's foundation. The piezoelectric doubly curved nanoshell is subjected to initial electro-mechanical loads. Effect of initial electro-mechanical loads is contributed in external works. Size effects are captured by nonlocal elasticity theory and Hamilton's principle is employed to derive the equation of motion in terms of three displacements of the middle surface, two rotational components and one electric potential. The main novelty of this paper is investigating concurrent effect of initial electro-mechanical loads, higher-order shear deformation theory and size dependent theory on the free vibration responses of doubly curved piezoelectric nano shell with various boundary conditions. The electro-mechanical vibration response of the doubly curved piezoelectric nano shell is investigated using an analytical method in terms of various parameters such as two opening angles, small scale parameter, spring and shear parameters of foundation and initial electric potential. It is concluded that increasing the applied electric potential increases the natural frequencies.


ABSTRACT: Due to high sensitivity to various imperfections, buckling loads of thin-walled cylindrical shells subjected to axial load vary dramatically. In order to predict lower-bound buckling loads for axially loaded cylindrical shells rationally, a probabilistic analysis approach named Probabilistic Random Perturbation Load Approach (PRPLA) is developed in this study. Firstly, a Back-Propagation Neural Network (BPNN) based method is established to describe measured imperfection patterns. Next, Random Single Perturbation Load Approach (RSPLA) is loaded upon BPNN-based depicted traditional imperfection patterns to construct a stochastic dimple imperfection. The aforementioned scattering traditional imperfections, as well as a variety of scattering non-traditional imperfections, are then sampled using Monte-Carlo simulation to generate cylindrical shell models differentiating from a nominal one. The probabilistic distribution of lower-bound buckling loads is obtained by finite element analysis. A nominal shell's realistic lower-bound buckling load is determined by choosing a specified reliability level lastly. The results show that describing measured imperfection patterns via BPNN is very close to real ones, and PRPLA presented is an improved method to find lower-bound buckling loads efficiently compared with NASA SP-8007 and many commonly used numerical approaches.


ABSTRACT: Metallic grid stiffened cylinders are often used as tank and interstage structures in launch-vehicle systems. When subjected to axial compression, these thin-walled shells are prone to buckling. The corresponding critical buckling load heavily depends on deviations from the ideal shell shape. In general, these deviations are defined as geometric imperfections and they can significantly reduce the critical load. Considering the influence of geometric imperfections into the design process of thin-walled shells poses major challenges for structural design. This article presents an overview regarding the modelling, analysis and design of metallic grid stiffened launch-vehicle cylinders. In comparison to commonly studied unstiffened cylinders, complex shells applied in aerospace engineering can have a completely different structural response to axial compression than their unstiffened counterparts. Advanced shell buckling design concepts like perturbation approaches and energy barrier criteria are applied and validated with experimental data. Finite element models are presented and described in detail. Important aspects like skin and weld buckling as well as the influence of cutouts are analyzed and discussed.


ABSTRACT: As a lightweight and efficient energy-absorbing structure, thin-walled filled structure is widely used in various fields. This paper proposed four types of bio-inspired foam-filled thin-walled structures based
on two typical straw structures (Cornstalk and Reed): bionic foam core with a central hole, 4 square holes, 4 taper holes and 2 nodes, respectively. The energy absorption capacity and deformation mode of bionic structures were studied by dynamic drop hammer and quasi-static compression. The results showed that 9 of 12 bionic samples had higher energy absorption capacity than the corresponding fully-filled samples. Different bionic features have different effects on the deformation of thin-walled tube, and the bionic features with the best overall performance are the 4 Square Holes and 4 Taper Holes design. It is noted that the bionic method can improve energy absorption capacity and affect the deformation mode of the thin-walled tubes under certain conditions.


ABSTRACT: This paper presented the experimental and analytical results of concrete-filled fiber-reinforced polymer (FRP) tubes (CFFTs) and concrete filled GFRP-steel double skin tubular columns (DSTCs) under horizontal impact loads. The influences of the thickness of FRP tubes and impact velocity were discussed. The thickness of the FRP tubes had insignificant influence for both the peak impact force and the maximum displacement. Under the same applied impact energy, the maximum displacement of concrete filled FRP-steel DSTC specimens was ~40% smaller than that of CFFT specimens. The impact velocity had more influence on the peak impact force than the duration. Three-dimensional finite-element (FE) models were developed to simulate the impact behavior of two types of composite columns and the numerical results are compared with the test data. Then, the verified FE model was used to conduct parametric study. Moreover, analytical solutions for lateral displacement of composite columns under impact were obtained, in which the effect of impact damage was considered by introducing reduction factors into the vibration equations. The comparison between analytical results and test results showed that the maximum displacement can be accurately predicted by the proposed theoretical model.


ABSTRACT: This study addresses some key concerns on using steel tube and sandwiched concrete jackets to strengthen intact concrete-filled steel tubular (CFST) columns. The research background lies in engineering cases, in which the functional purpose changes when the structure remains intact. Within the parameters investigated, the load-bearing capacity of columns was enhanced by 114%–199% after being jacketed with steel tube and sandwiched concrete. The observable enhancement depended on section enlargement and the confinement effects of the outer steel tube, the latter of which could account for as large as 19% of the nominal load-bearing capacity. A finite element (FE) model was developed and verified, and the load distribution on components of the strengthened columns was presented. The radial stress between the inner concrete and inner steel tube was validated to increase substantially after the CFST column is jacketed with steel tube and sandwiched concrete. The decrease in the diameter-to-thickness ratio of the outer steel tube contributes to the synchronisation of the inner and sandwiched concrete in reaching peak load and benefits the load increase. A parametric study based on the FE model was conducted, and the effects of estimation error with respect to the properties of existing CFST columns were evaluated. A reasonable match between the outer steel tube grade and sandwiched concrete class was advised.


ABSTRACT: A new type of segmentally prestressed cylindrical reticulated mega-structure is proposed. The mechanism and detailed layout of the segmental cable-strut system are presented. The static properties and stability of the structure are analyzed and compared with those of the structure without cable-strut system. The reasonable ranges of key arrangement parameters for the segmental cable-strut system are obtained, including the rise-to-span ratio, length and distribution of the strut, and pretension degree and distribution of the cable. In
ABSTRACT: The purpose of this paper is to validate the General Method for the stability check of unrestrained slender I-section web-tapered columns in fire situation. The General Method (clause 6.3.4 of EN 1993-1-1) covers the introduction of the segmental cable-strut system can effectively improve the static properties and stability of the reticulated mega-structure. Member buckling has a significant adverse effect on the global structural stability, and thus their interaction should be considered in the stability analysis of the structure. Member buckling initially occurs in the lower chord members near the supports in the middle of the structure, and subsequently propagates to both ends of the structure along the longitudinal direction and toward the supports along the transverse direction at the same time. Additionally, substituting buckling-resistant members for the lower chord members within about 1/6 of the arc length of each latticed arch close to supports is an effective measure for improving global stability.

Ming Li, Liming Zhou and Changyi Liu, “The multi-physical cell-based smoothed finite element method for analyzing transient behavior of functionally grade magneto-electro-elastic thin-walled structures under thermal environment”, Thin-Walled Structures, Article 106876, Vol. 155, October 2020,  
https://doi.org/10.1016/j.tws.2020.106876
ABSTRACT: This study, the coupled multi-physical cell-based smoothed finite element method (CS-FEM) was proposed to predict the temperature environment combining mechanical load effect on the dynamic characteristics of functionally grade magneto-electro-elastic (FG-MEE) thin-walled intelligent structures. Consider the coupling effects among elastic, electric, magnetic and thermal fields, and this method possesses higher accuracy, lower mesh restriction, much less computational cost and stronger handling ability when encountering strong mesh distortion and large deformation issues compared with standard FEM. The accuracy, convergence and efficiency of CS-FEM were validated via three numerical examples. Proposed CS-FEM integrating the modified Newmark scheme explored the thermal effect on generalized displacements (x- and z-direction displacement components, electric and magnetic potential) of FG-MEE based sensors. Further, parametric studies were carried out to analyze the index factor impact on thin-walled structure performances. This study presents an effective approach to investigate the coupled multi-physical problem, and the simulation results are definitely useful for the designation of intelligence thin-walled structures in service under complex load condition.

JunYuan Zhang, Bingquan Lu, Danfeng Zheng and Zhongyu Li, “Experimental and numerical study on energy absorption performance of CFRP/aluminum hybrid square tubes under axial loading”, Thin-Walled Structures, Article 106948, Vol. 155, October 2020,  
https://doi.org/10.1016/j.tws.2020.106948
ABSTRACT: Metal/composite hybrid square tubes that combine the advantages of low-density of composite with low-cost of metal provide a potential energy absorption device for automobiles. The axial crushing performance of CFRP/aluminum hybrid square tubes wrapped with single angle-ply and antisymmetric angle-ply was studied by experimental and numerical methods. Results show that for tubes wrapped with single angle-ply [0], or [45], crack propagation occurred and the CFRP separated from aluminum, which resulted in worse energy absorption capacity than pure aluminum tube. A stable symmetric deformation was observed in hybrid square tubes wrapped with antisymmetric angle-ply. The specific energy absorption (SEA) for those tubes was improved 11% and they showed better energy absorption performance compared to pure aluminum tube. Then, the effect of thickness of tubes, including hybrid square tubes with identical aluminum and hybrid square tubes with identical mass, on the energy absorption capacity was further investigated by simulation. It was found that only when the number of CFRP layer reaches a certain value, hybrid square tubes perform better than pure aluminum tube with identical mass in energy absorption. Moreover, influence of mass of the tube, and substituting aluminum alloy with CFRP on the energy absorption of hybrid square tubes with identical aluminum and different number of CFRP layers was studied.

Élio Maia, Paulo Vila Real, Nuno Lopes and Carlos Couto, “The General Method for the fire design of slender I-section web-tapered columns”, Thin-Walled Structures, Article 106920, Vol. 155, October 2020,  
https://doi.org/10.1016/j.tws.2020.106920
ABSTRACT: The purpose of this paper is to validate the General Method for the stability check of unrestrained I-section web-tapered columns in fire situation. The General Method (clause 6.3.4 of EN 1993-1-1) covers the
A unified semi-analytical approach based on the trigonometric expansion and generalized differential quadrature (TE-GDQ) method is implemented to investigate the thermal buckling of a functionally graded graphene platelet reinforced composite (FG-GPLRC) conical shell. Graphene platelets distribution is assumed randomly oriented and uniformly dispersed for each ply. Variation of the volume fraction of plies is modeled according to a step functionally graded medium. Effective material properties of the shell are calculated using the Halpin-Tsai micromechanical rule. Equilibrium equations are derived by means of the first order shear deformation theory (FSDT), nonlinear geometrical relation based on the von Kármán theory, and the Donnell kinematics assumption. The pre-buckling of the shell under uniform thermal load is solved considering the linear membrane procedure. Afterward, the linearized stability equations are obtained utilizing the adjacent equilibrium criterion. Next, using the TE-GDQ method, stability equations convert to an eigenvalue problem. Finally, eigenvalue problem is solved and the critical temperature rise can be determined. After validation of the formulation and methods, several parametric studies are examined to research the effects of the volume fraction of GPLs, semi vertex angle, length-to-thickness ratio and other parameters on the critical temperature.


ABSTRACT: A unified semi-analytic method is developed for free vibration analysis of functionally graded material (FGM) shells of revolution subjected to arbitrary boundary conditions, and independent and coupled shells of revolution are specific cases. Material properties vary continuously in thickness direction according to the four-parameter power-low distributions in terms of volume fractions of two constituents. The shell is firstly divided to some narrow shell segments to be treated as conical shells. Differential equations of motion based on first-order shear deformation theory (FSDT) are solved by expanding displacements as power series and Fourier series in meridional and circumferential directions, so five displacements and five forces at cross-section are only expressed as 10 unknown coefficients. Continuity conditions and elastic boundary conditions are assembled to the final governing equation. Through comparing natural frequencies of present method with the ones of opened works for several typical FGM shells of revolution with uniform/stepped thicknesses and classic/elastic boundaries, rapid convergence, high accuracy and wide application of the developed method are demonstrated. Furthermore, influences of material and geometry parameters reveal that increasing the power-law exponent does not change mode shapes and circumferential mode numbers of fundamental frequencies, and mode shapes are slightly affected by the variation of thickness.


ABSTRACT: In this paper, dynamic response of multilayer functionally graded graphene platelets reinforced composite (FG-GPLRC) cylindrical shells in thermal environment under an impulse load is studied based on the first order shear deformation theory (FSDT) of shells. The cylindrical shells under consideration are made up of multiple graphene platelet reinforced composite (GPLRC) layers with uniformly distributed and randomly oriented graphene platelets (GPLs) in each layer. GPL concentration is assumed to be graded in thickness direction. A new differential quadrature method based on direct projection of the Heaviside function is utilized to spatially discretize the governing equations. To solve the resulting system of ordinary differential equations (ODE) in temporal domain, a recently developed multi-step time integration technique, introduced based on the non-uniform rational B-spline (NURBS), is employed. After validating the approach, the effects of the different GPLs distribution patterns, the weight fraction and dimension ratios of the GPLs, temperature change, time durations and types of impulse loading on the dynamic responses of the FG-GPLRC shells are investigated and discussed. It is shown that the addition of only little GPLs to polymer matrix considerably decreases the period of oscillatory portions of the center deflection.


ABSTRACT: Sandwich structures have attracted increasing attention in engineering applications due to their lightweight effect and energy absorbing capacity. In the current work, fully-thermoplastic honeycomb sandwich structures with 100% recyclability were developed, which consisted of continuous glass fiber-reinforced polypropylene (PP/GF) face sheets, polypropylene (PP) core and assembled using thermoplastic adhesive films. The experimental tests and numerical analysis were conducted to investigate the bending behavior and energy absorption of PP-based sandwich structures. Firstly, a series of three-point bending experiments were tested and the influences of structural factors on bending behaviors were investigated. The typical deformation modes were explored and the damaged microstructure of face-sheets were observed. Finite element models of the sandwich structures were developed to capture the deformation process, and the simulation results were validated with the experimental data. Afterwards, a multi-objective optimization was performed to seek for the maximum specific energy absorption together with the minimum initial peak force simultaneously. Response surface method was adopted to construct objective response functions and used for the defined optimization problem.


ABSTRACT: According to the concept of local buckling of compressed isotropic cylindrical shells, the buckling process begins with appearance of one or several dimple-like buckles. Then, depending on the load level, it leads to local or general shell buckling. The latter causes the loss of structure bearing capacity and catastrophic consequences. Therefore the stability of axially compressed cylindrical shells under different additional local perturbations was investigated intensively by many authors. Based on the performed studies, new formulae were suggested for design buckling load which improved the more conservative NASA SP-8007 (1968) recommendations. The present research is focused on analysis of post-buckling behaviour of the shell with one local dimple-like buckle. The conditions of existence and stability of such post-buckling equilibrium state were investigated. Special attention was paid to the influence of the shell material plasticity and geometrical parameter of the structure on its post-buckling behaviour. Based on this analysis the calculation methodology of design buckling load of the structure is suggested for the case of the shell with plastic material.

ABSTRACT: This research presents an experimental study to examine the flexural behavior of steel cold-formed I-beam with strengthened hollow tubular flanges. Nineteen of cold-formed steel I-beam with hollow tubular flanges were prepared and experimentally tested on four-point bending tests. One of these specimens was not strengthened, which used as a control specimen, and eighteen specimens were strengthened with filling the tubular flanges by different materials. Twelve specimens were strengthened at the compression hollow tubular flanges only, with and without shear connectors. Finally, six specimens were strengthened at the compression and tension hollow tubular flanges. The strengthened materials used are different types of wood wastes (Particleboard Wood-Sawdust with cement mortar-Sawdust with epoxy-Sawdust with polyester), light weight concrete, and polymer-mortar. All specimens were loaded by two vertical loads to failure. Specimens’ mode of failure and vertical displacements were recorded. Vertical load-deflection at mid-span relationships have been analyzed to study the effect of strengthened materials. It was observed that maximum capacity was achieved by using polymer-mortar rather than the other materials. Using shear studs and strengthened compression and tension flanges did not show an obvious effect on the ultimate load of the tested specimens compared to those that were strengthened the compression flanges only. For all the strengthened specimens, improving in the load-mid span deflection relationships were achieved compared with the control specimen. The bending moment capacities were compared with the expected values using the Egyptian Code of Practice for Steel Construction (LRFD), which indicates that the design method of this code is conservative in comparison to the experimental test results, but it is not conservative in expected the moment capacities of strengthened specimens that used the Sawdust with cement mortar and light weight concrete materials.


ABSTRACT: Supersonic flutter analysis of truncated conical shells with arbitrary classical boundary conditions is investigated in the present study. Structural equations of motion are obtained in their integral representation using the Flügge's first-order shear deformable assumptions along with the first-order piston theory for the aerodynamic model. Effects of curvature correction and airflow's yaw angle are also included in the aerodynamic model. Using a Rayleigh-Ritz based solution algorithm, the aeroelastic system of equations is solved by a standard eigenvalue solver with quadruple precision. After verification of the presented algorithm and solution procedure, a comprehensive parametric study is performed and effects of various parameters, namely the boundary conditions, semi-vertex angle, length and thickness ratios and yaw angle of the airflow on flutter boundaries of truncated conical shells are examined.


ABSTRACT: This paper studies vibration characteristics of smart laminated carbon nanotube-reinforced composite cylindrical panels resting on elastic foundations affected by hygrothermal environmental conditions. Effective material properties are estimated by the Mori-Tanaka micromechanics model. The motion equations for the vibration problem of the laminated composite panel are derived from the lamination theory and the first order shear deformation theory and take into consideration of the effects of elastic foundations, piezoelectricity, and temperature and moisture variations. Natural frequencies of panel vibration under various mechanical boundary conditions are computed using wave propagation approach. Parametric studies with the effects of boundary conditions, elastic foundations, panel geometry, carbon nanotube reinforcement, piezoelectricity, and hygrothermal conditions on frequencies are presented. Adding more ending supports, elastic foundations, and increase of nanotube volume fraction have increasing influence on the frequencies, while increase of panel length and decrease of its thickness, bonding piezoelectric materials, and increase of temperature and moisture lead to the decrease of frequencies.

ABSTRACT: This paper describes a comprehensive experimental programme in which built-up cold-formed steel stub columns with four different cross-sectional geometries were investigated. Twenty built-up sections were fabricated from individual channels and flat plates with nominal thicknesses ranging from 1.2 mm to 2.4 mm and assembled with either bolts or self-drilling screws. The connector spacing was varied among specimens of the same geometry in order to study its effect. The built-up columns were tested between fixed boundary conditions and the load was transmitted through end plates which were attached to the columns with an epoxy resin. Tensile coupons were taken from the corners and flat portions of the constituent sections in order to determine their material properties, while detailed measurements of the geometric imperfections of each specimen were also performed using a laser displacement sensor. The experiments revealed a significant amount of restraint and interaction between the individual components of the columns while buckling, with the connector spacing having a pronounced effect on the observed buckling modes. However, the ultimate cross-sectional capacity was seen to be much less dependent on the connector spacing within the considered range of spacings.


ABSTRACT: Due to the high specific strength and stiffness, thin-walled shells are widely used in aerospace engineering structures. However, along with the increase of the structure size or the structure hierarchy, the computational cost of the post-buckling analysis of thin-walled shells would increase sharply and then the imperfection sensitivity analysis would become time-consuming. In this study, an accelerated Koiter method is proposed to improve the efficiency of post-buckling analysis and imperfection sensitivity analysis of thin-walled shells under axial compression. In the framework of the accelerated Koiter method, a single mode Koiter method considering pre-buckling nonlinear behavior is used to reduce the computational time of repeated imperfection analysis, which can accurately predict the effect of the small amplitude imperfection. Furthermore, in order to obtain the expanded point of Koiter method, a Combined Approximation (CA)-based iterative eigenvalue algorithm is constructed to obtain the pre-buckling state in the neighborhood of the bifurcation point and reduce computational cost by the reasonable step length prediction. Finally, the efficiency and accuracy of the proposed method are demonstrated by means of four illustrative examples, including the composite cylindrical shell, the isotropic cylindrical shell, the isotropic conical shell and the hierarchical stiffened cylindrical shell under axial compression.


ABSTRACT: Functionally graded Ti-6Al-4V micro-lattice structures were manufactured by selective laser melting (SLM) method. By controlling the cell size along the building direction, two density distribution modes including step-wise gradient and continuous gradient were designed. The density distributions of the specimens were evaluated according to the geometric model reconstructed from the X-ray tomography images. Afterwards, the high speed impact experiments on the graded specimens were conducted by direct Hopkinson Pressure Bar (DHPB) system. Through the high speed photography and digital image correlation (DIC) method, the effects of gradient on the global deformation evolution of the graded Ti-6Al-4V micro-lattice structures under high velocity loading were revealed. Meanwhile, cell assembly based 3D mesoscopic finite element (FE) models were respectively created based on perfect beam elements and X-ray tomography. Accordingly, the dynamic response of the 3D-printed graded structures were simulated by LSDYNA. A more detail vision to the local deformation of the specimens under impact loading was provided. Finally, the protective abilities of the two graded structures under high speed collision were compared and analyzed. It was concluded that the continuously graded micro-lattice structures with negative gradient could provide better protection for the object behind, while the stepwise graded structures might lead to secondary shock which should be avoided.

ABSTRACT: This work presents an analytical approach to investigate nonlinear static and dynamic stability of toroidal shell segments resting on elastic foundation subjected to axial compression. The shells are made of functionally graded material (FGM) which created from metal and ceramic, and the volume fraction of constituents is supposed to gradually vary from one surface to another according to a power law function. Basic formulations are established based on Reddy's third-order shear deformation shell theory (TSDT) considering geometrical nonlinearity in von Kármán sense. Governing system of four-partial differential equations are converted into nonlinear differential equation using Galerkin method. Runge-Kutta method is used to solve nonlinear differential equation of motion and then nonlinear dynamic response of shell are examined. Budiansky-Roth criterion are used to obtain critical dynamic buckling load and then nonlinear dynamic stability of shells under axial compressive load linearly varying on time is analyzed. The influences of material and geometrical parameters, and elastic foundations on the static and dynamic stability of FGM toroidal sell segments are discussed in detail. The obtained results are validated by comparing with other results in the literature.


ABSTRACT: Several bamboo features are responsible for its known mechanical performance and thus were applied on bionic thin-walled structures, still the particular geometry of individual vascular bundles remains unexplored mechanically. This research investigates the mechanical influence of that region in the design of thin-walled structures, comparing it with bamboo-inspired designs from the literature. X-ray microtomography was used to explore bamboo bundle's geometry, applying it as reinforcement. The proposed new design showed improvements in strength and energy absorption in axial, lateral, and flexural explicit Finite Element Analyses. The vascular bundle's geometry was revealed as an important characteristic of bamboo performance.


ABSTRACT: In the present study, the low-energy impact response of woven carbon fibre reinforced plastic (CFRP) composite sandwich panels with thermoplastic honeycomb and reentrant cores was investigated experimentally and numerically under three different impact energies (20 J, 40 J and 70 J). The Acrylonitrile Butadiene Styrene (ABS) honeycomb and reentrant core structures were manufactured in-plane and out-of-plane oriented via 3D printer, and adhesively bonded with two CFRP face sheets. The results indicate that the in-plane reentrant core based composite sandwich panel exhibits better impact strength and energy dissipation behavior than the in-plane and out-of-plane honeycomb core based composite sandwich panels.


ABSTRACT: The study of the large-amplitude vibrations of thin-walled rotating laminated composite cylindrical shell with arbitrary boundary conditions is presented in this paper, in which the artificial spring is used to simulate the arbitrary boundary conditions. The nonlinearity is introduced by using Donnell's nonlinear shell theory, and the orthogonal polynomials are used as the admissible displacement functions. By using the Lagrange equation based on the energy method, the governing equation of motion is obtained. Then, the Incremental Harmonic Balance Method (IHBM) and the arc-length method are used in the process of solving the governing equation. The influences of rotating speed, boundary spring stiffness, and geometric parameters on the nonlinear vibration characteristics of the shell are investigated. The results show that these parameters have a significant impact on the nonlinear vibration of the rotating laminated cylindrical shell.
ABSTRACT: A thorough testing and numerical modelling programme has been conducted to investigate the flexural buckling behaviour and strengths of pin-ended hot-rolled stainless steel angle section columns. The testing programme adopted three hot-rolled stainless steel equal-leg angle sections, and included 12 pin-ended column tests about the minor principal axis as well as supplementary initial geometric imperfection measurements on the column specimens. The testing programme was accompanied by a parallel numerical modelling programme, including a validation study, where finite element models were developed and validated against the test results, and a parametric study, where the validated finite element models were employed to generate additional numerical data over a broad spectrum of cross-section dimensions and member effective lengths. The test and numerical data were then adopted to evaluate the accuracy of the relevant design rules, as given in the European code and American design guide, for pin-ended hot-rolled stainless steel angle section columns prone to flexural buckling about the minor principal axis. On the basis of the evaluation results, it can be concluded that (i) the European code results in overall accurate and consistent flexural buckling strength predictions, but many of the predictions for short and intermediate columns with member non-dimensional slendernesses less than around 1.0 are unsafe, and (ii) the American design guide leads to unduly conservative and scattered flexural buckling strength predictions. Finally, a new design approach was developed through modifications to the Eurocode design rules, and shown to offer accurate, consistent and safe-sided flexural buckling strength predictions for pin-ended hot-rolled stainless steel angle section columns over the whole considered range of member non-dimensional slendernesses up to 4.0. The reliability of the new design approach was confirmed by means of statistical analyses according to EN 1990.

ABSTRACT: The present paper reports comprehensive experimental and numerical studies of pin-ended S690 high strength steel welded I-section columns failing by flexural buckling about the minor principal axis. The testing programme was conducted on two S690 high strength steel welded I-sections, and included initial geometric imperfection measurements and ten pin-ended column tests. This was followed by a numerical modelling programme, where finite element models were firstly developed to replicate the test responses and then adopted to conduct parametric studies to generate further numerical data over a wide range of cross-section dimensions and member lengths. The obtained test and numerical data, together with the test data collected from previous literature, were analysed and employed to assess the accuracy of the relevant design rules, as given in the European code, American specification and Australian standard, for S690 high strength steel welded I-section columns failing by flexural buckling about the minor principal axis. The assessment results revealed that both the European code and Australian standard yield conservative resistance predictions for S690 high strength steel welded I-section columns failing by flexural buckling about the minor principal axis, while the American specification offers an overall satisfactory level of design accuracy, but with some over-predicted design flexural buckling resistances for those intermediate and long columns with relatively large member non-dimensional slendernesses. Finally, an improved design approach was proposed and shown to provide safe, accurate and consistent resistance predictions for S690 high strength steel welded I-section columns failing by flexural buckling about the minor principal axis.

ABSTRACT: Providing staggered slotted perforations to the Cold-Formed Steel (CFS) beams is a new approach being used in light gauge steel construction aiming to enhance both the fire and energy performances. However, slots in the web reduce the load-bearing capacity of CFS beams and existing studies do not provide a
definite evaluation of the design expressions to determine the structural performance of slotted perforated CFS flexural members. Therefore, the present study aims to establish a methodology to determine the flexural capacity of staggered slotted perforated CFS beams subject to local buckling through developing three-dimensional Finite Element (FE) models. The developed FE models were subjected to validation against the related test data. Subsequently, the validated FE model was employed to conduct further parametric studies (432 FE models). Parameters include the dimensions of the CFS beams and staggered slotted perforations, rows and row groups of slots and yield strength. The effect of these factors on the local buckling capacity of the staggered slotted perforated CFS beams under bending is discussed. The paper concludes with a proposal of Direct Strength Method (DSM) based new design equations to predict the bending capacity of the CFS beams with staggered slotted perforations subject to local buckling and to enhance their commercial aspects.


ABSTRACT: This paper investigates the nonlinear bending behaviours of multilayer functionally graded graphene nanoplatelet-reinforced composite (FG-GPLRC) beams elastically restrained at both ends and with an open edge crack. The GPLs are uniformly distributed in each individual layer but follow a layer-wise variation along the thickness direction. The effective Young's modulus is predicted by the modified Halpin-Tsai micromechanics model while both the thermal expansion coefficient and Poisson's ratio are determined by the rule of mixture. The finite element method is employed to discretize the edge cracked beam, with a particular focus on the influences of the location and depth of the open edge crack on the nonlinear bending deflections of FG-GPLRC beams. It is found that adding a higher content of GPLs into the matrix, dispersing more GPLs near the top and bottom surfaces of the beam and increasing the elastic stiffness of the end constraints can effectively strengthen the beam stiffness hence considerably reduce the deflection. An increase in the crack depth ratio (CDR) and temperature rise weaken the structure and consequently lead to bigger deflections. The nonlinear bending performance of the beam is also found to be highly sensitive to the location of the crack.


ABSTRACT: In this paper, the flexural buckling behaviour and design of duplex and ferritic stainless steel I-section columns fabricated through the welding of individual hot-rolled stainless steel plates are investigated. Finite element models able to mimic the structural response of stainless steel I-section columns are developed and validated against experimental results from the literature. Employing the validated finite element models, extensive numerical parametric studies are performed for the purpose of comprehensively assessing the behaviour of duplex and ferritic stainless steel I-section columns, considering various member slendernesses and cross-section proportions. The accuracy, safety and applicability of the existing column design provisions provided in the European, North American and Australian & New Zealandian structural stainless steel design standards and guides, some of which are only recommended for the design of cold-formed stainless steel columns, are assessed for the design of welded duplex and ferritic stainless steel I-section columns. Modifications to the column design method given in the current European structural stainless steel design standard EN 1993-1-4 are proposed. The higher accuracy of the modified column design method of EN 1993-1-4 relative to the column design methods in the existing structural stainless steel design standards and guides is illustrated in addition to its safety and high level of reliability.


ABSTRACT: This paper presents an extensive parametric study of elastic and inelastic buckling of cellular beams subjected to strong axis bending in order to investigate the effect of a variety of geometric parameters, and further generate mass data to validate and train a neural network-based formula. Python was employed to automate mass finite element (FE) analyses and reliably examine the influence of the parameters. Overall,
102,060 FE analyses were performed. The effects of the initial geometric imperfection, material nonlinearity, manufacture-introduced residual stresses, web opening diameter, web-post width, web height, flange width, web and flange thickness, end web-post width, and span of the beams and their combinations were thoroughly examined. The results are also compared with the current state-of-the-art design guidelines used in the UK. It was concluded that the critical elastic buckling load of perforated beams corresponds to the lateral movement of the compression flange while the most critical parameters are the web thickness and the geometry of the flange. However, from the inelastic analysis, the geometry and position of the web opening influence the collapse load capacity in a similar fashion to the geometry of the flange and thickness of the web. It was also concluded that the effect of the initial conditions was insignificant.

ABSTRACT: Ultra-high performance concrete filled steel tube (UHPCFST) column is an innovative and efficient structural member, especially suitable for applications requiring high load carrying capacity. This paper experimentally and numerically investigated the structural behavior of UHPCFST columns under eccentric compression, which was a continuation of the previous program regarding axially loaded members. A total of twenty specimens with circular section (CS) and square section (SS) were tested, including twelve specimens under eccentric compression and eight specimens under concentric compression as reference. The eccentric compression characteristics of UHPCFST columns were analyzed and discussed, including failure mode, load versus lateral deflection relationship, load bearing capacity and the development of bending moment and curvature. Finite element (FE) analysis was conducted to predict the behaviors of the test columns and to select a suitable numerical model for UHPC under confining pressure. Finally, the feasibility of existing design codes for predicting the load bearing capacity of UHPCFST columns under eccentric compression was evaluated.

ABSTRACT: In this paper, the effects of temperature on free vibration of carbon nanotube reinforced composite (CNTRC) joined conical-conical shells are investigated. Carbon nanotubes (CNTs) are embedded across the thickness uniformly or functionally. Material properties of the shell are assumed to be functions of temperature. To study the free vibration of shells settled in thermal environments, it requires solving the static equations. Therefore, in order to derive these equations, first order shear deformation theory (FSDT) accompanied by von Kármán types of geometrical nonlinearity are employed in Hamilton's principle. Then, initial stress resultants due to equilibrium state, are extracted via linear membrane solution. Afterward, equations of motion are derived with regard to initial deformations and stresses. With considering the equations of motion for two cones together with boundary and continuity conditions, a set of governing equations is provided. To discretize the governing equations meridionally, generalized differential quadrature (GDQ) method is proposed. The results are primarily validated via comparing them with those of relevant researches in this field. Thereafter, some studies are carried out to exhibit the significant role of temperature variations, CNT distribution patterns, CNT volume fractions, cones' angles and boundary conditions on the free vibrational behaviors of joined conical shells. For the sake of preventing buckling occurrence during the present vibration analysis, critical buckling temperature $T_c$ is obtained by the procedure that the natural frequency takes zero value for the lowest temperature.

ABSTRACT: Modular steel construction has become increasingly popular in recent years, owing to its superiority in construction speed and quality. Corrugated steel plates are commonly used as the surface enclosure and lateral force resisting component for the module unit. However, establishing precise finite
element models considering all geometric characteristics of corrugated steel plate shear walls (CSPSWs) is complex, especially for walls that include openings. Consequently, it is necessary to develop a high efficiency analysis model (HEAM) for CSPSWs to perform the dynamic structural analysis. In this paper, the skeleton curve and hysteretic regulation of CSPSWs were proposed, and universal formulas were deduced to determine the hysteretic model of CSPSWs. In addition, equivalent cross braces were proposed to simulate the seismic performance of CSPSWs, and the design parameters of the equivalent cross braces were determined according to the equivalence of the load bearing capacity and mass. The accuracy and reasonability of the HEAM were validated against available cyclic test data on CSPSWs. Furthermore, the HEAM was verified at the structural level by comparing the dynamic response of the HEAM with the precise analysis model (PAM) for a six-story and a 20-story modular container structure, respectively. The comparisons demonstrated that the HEAM was capable of providing a conservative prediction of the dynamic response of CSPSWs under earthquake compared to the PAM. The HEAM developed in this study was helpful in improving the analysis efficiency of CSPSWs and can be adopted for the nonlinear seismic analysis of modular steel construction.


ABSTRACT: Glass fibre reinforced polymer (GFRP) pipelines are widely used in civil and offshore engineering owing to their good mechanical performance and light weight. However, typical structural problems, such as low radial stiffness, are still existing in the GFRP pipelines. In this paper, a novel GFRP sandwiched pipeline structure with a stiffened core was designed and was integrally fabricated by a newly developed multistage filament winding (MFW) technique. The radial stiffness of the GFRP stiffened pipe was investigated through a combination of theoretical, numerical and experimental methods. It was found the structural layer formed by GFRP webs combined with foam blocks effectively increase the stiffness with a considerable weight reduction for the newly proposed pipe structure. In addition, the mechanical behaviour of the stiffened pipe was precisely predicted by the adopted theoretical method and the proposed numerical model. Based on the validated model, the structural stability under confined load of the GFRP stiffened pipe was numerically studied and the failure map was constructed as a function of the related geometric parameters. The results provided a new concept for the pipeline structural design and a guidance for the geometric optimization of the proposed pipeline configuration.


ABSTRACT: In this paper, the structural stability and compressive capacity of pin-ended cold-formed stainless steel angle columns with different slenderness were experimentally investigated. The experimental programme was performed on press-braked lean duplex stainless steel equal-leg angle sections with nominal dimensions of 80 × 80 × 4 mm, and involved material testing, initial imperfection measurements and 11 column tests. The test setup and procedure, together with the key experimental results, axial load vs. lateral deflections, axial load vs. torsional rotations and characterised failure modes, were fully reported and analysed. The experimental observations reveal that the failure mode type, including local/torsional, flexural-torsional and flexural effects, is highly dependent on the column's slenderness and initial imperfections. The measured compressive strengths were compared with the resistance predictions determined according to European and Australia/New Zealand codified design procedures. It was found that experimentally obtained ultimate capacities are significantly higher than those calculated according to the specifications. However, the database of test results is still quite limited, and a further research is needed to amplify the data needed to enable a more precise assessment of the codified procedures.

ABSTRACT: Plastic collapse is a critical failure mode considered in the design of ellipsoidal heads under internal pressure. It is significant to develop a formula to calculate plastic collapse pressure of ellipsoidal heads. First, we use a finite element method to calculate plastic collapse pressure, taking into account the effects of strain hardening and geometric strengthening. Second, we investigate the effects of material and geometric parameters on plastic collapse pressure. Based on parametric study, a simple formula is proposed for predicting plastic collapse pressure of ellipsoidal heads. Finally, in order to verify the accuracy of the proposed formula, a series of burst experiments are performed on full-scale ellipsoidal heads which cover various geometric parameters, various material types, and various manufacturing methods. Comparison between the predictions of the proposed formula and the experimental results of 33 full-scale ellipsoidal heads shows that the proposed formula provides a good prediction of plastic collapse pressure of steel ellipsoidal heads under internal pressure.


ABSTRACT: Due to defects in processing, there are some voids or pores inside the functionally graded material during the production progress. It has been proved that porosity has shown to have a large influence on the mechanical response of the structure, but the effect of porosity on the acoustic performance is still worth studying. To reveal these effects, the thermoacoustic response of porous functionally graded material (PFGM) cylindrical shell on elastic foundation under nonlinear thermal environment are investigated analytically. In the analysis, three common types of PFGM cylindrical shell, namely, uniform, symmetric and asymmetric distribution are considered. Assuming that material properites are related to temperature, and the thermomechanical stresses are obtained according to the nonlinear heat conduction equation. The Pasternak model is used to describe elastic foundation, and the cylindrical shell dynamic equation based on the first-order shear deformation shell theory is established by Hamilton's principle. By using the velocity continuity condition at fluid-structure interfaces to consider the fluid-structure coupling. By comparing the numerical results with the existing solutions in open literature, the validity of the proposed theoretical model is verified. Finally, the influences of porosity distribution type, gradient index, porosity volume fraction, material properties, elastic foundations and nonlinear temperature fields on the acoustic characteristics of PFGM cylindrical shell have been investigated.


ABSTRACT: Perforated core plate buckling-restrained brace (PBRB) is a new type of energy dissipation device proposed recently. Several perforated zones are evenly distributed along the brace length of PBRB to dissipate seismic energy and separated by transition zones to improve their strong-axis stability. Previous studies showed that improper perforated core plate (PCP) configurations may lead to premature strong-axis buckling and rupture failure in the perforated zones. However, effect of the PCP configurations on the performance of PBRB still remains unclear. This study aims to investigate numerically and experimentally the influence of PCP configurations on the strong-axis stability and seismic performance of PBRB. Key parameters include the type of perforated zone, the length of transition zone, and the ratio between the length of a perforated zone and the width of a yielding segment. Numerical analysis shows that (1) the perforated zone with the semi-circle type is more beneficial in improving the stability and seismic performance of PBRB than the rectangle type; (2) The length of transition zone has significant impact on the stability performance of PBRB, and it is recommended to be no less than half the width of a yielding segment. Cyclic tests of three PBRB specimens with the semi-circle type were conducted, and the experimental and numerical results show that increase in the length of perforated zone is beneficial in improving the seismic performance of PBRB but may trigger strong-axis buckling in the perforated zone. A practical criterion to prevent the strong-axis buckling of PBRB is quantified by parametric analysis.

ABSTRACT: Based on the first-order shear deformation theory (FSDT) as well as isogeometric analysis (IGA), the static bending, free vibration and buckling analysis of porous bi-directional functionally graded (BDFG) plates are investigated in this paper. The bi-directional gradients vary along the thickness (z-) and x-axis directions according to the power law, and porosity distributions are divided into even and uneven types. With the help of Hamilton principle, the governing equations of porous BDFG plates are derived. Compared with other reported literatures, several examples reveal that the accuracy and convergence of the present IGA model utilizing cubic non-uniform rational B-splines (NURBS). The effects of aspect ratios, boundary conditions, porosity distributions and coefficients on static bending, free vibration and buckling analysis of porous BDFG plates are studied in detail. These results show that increasing the volume fraction of porosity makes considerable effects on the mechanical behaviors of porous BDFG plates. Moreover, the deflections, frequencies and buckling loads of BDFG plates with even porosity are quite sensitive to the variation of porosity coefficients.


ABSTRACT: An efficient design optimization method assisted by multi-fidelity surrogate models is presented for the buckling design of thin-walled variable stiffness composite cylinders made by fiber steering. To reduce the computational burden, a multi-fidelity surrogate model called hierarchical kriging model is constructed through a few expensive high-fidelity samples and many cheap low-fidelity samples. Fine and coarse finite element (FE) analysis is performed respectively to calculate the structural responses for corresponding datasets. The Efficient Global Optimization based on a modified Expected Improvement criterion is introduced to adaptively select new sampling points of variable fidelity. Two case studies, a circular composite cylinder under pure bending and an elliptical composite cylinder under torsion, are considered. The effects of different number of design variables on the optimum configuration are studied to demonstrate the validity and robustness of the method. The effects of the structural parameters of the elliptical cylinder on the buckling load improvement are also investigated. The results indicate that the optimization efficiency is remarkably improved by the present method when compared with standard Efficient Global Optimization as well as available methods in the literature. Additionally, the investigation in the mechanism of load carrying capacity improvement shows that the increase is mainly due to the load redistribution.


ABSTRACT: Concrete-filled double skin steel tubular (CFDST) columns have been increasingly applied in the fields of bridge and building construction due to their superior structural performance. This paper experimentally studied the compressive behavior of square CFDST short columns with double internal steel tubes (2 × SHS or 2 × CHS). The influence of concrete strength, eccentricity ratio, and section hollow ratio on the strength, deformation, and ductility of specimens was systematically investigated. Experimental research showed that the concrete strength had the most remarkable impacts on the ultimate strength of the column, followed by the section hollow ratio. However, the effect of eccentricity ratio on the ultimate strength of the column could be nearly neglected. The ductility of the column was positively correlated with the section hollow ratio, which was completely contrary to the effect of concrete strength. Nevertheless, the eccentricity ratio negligibly affected the ductility of the column. Furthermore, comparisons of the experimental ultimate strength of CFDST columns were made with three different design methods (AISC-360, Eurocode 4, and Han's formulae). The design formulae suggested by Han et al. (2009) could better predict the ultimate strength of CFDST short columns with double internal square steel tubes, but the prediction result was unconservative to some extent. Finally, the simplified formulae were proposed to estimate the ultimate strength of CFDST short
columns, which could authentically reflect the combined impacts of the eccentricity ratio and section hollow ratio.


ABSTRACT: This paper investigates the nonlinear free and forced vibration of axially moving simply-supported thin circular cylindrical shells in the sub-harmonic region, considering the effect of viscous structure damping. Motion equations of axially moving circular cylindrical shells in cylindrical coordinates are derived with the aid of the Hamilton principle and employing the Donnell–Mushtari nonlinear shells’ theory. Three nonhomogeneous nonlinear partial differential equilibrium equations concerning displacements across the three directions of cylindrical coordinate are reduced to two equations as a result of using the definition of the airy function. The particular and private solution of airy stress function is obtained utilizing the assumption of the form of the displacement in the radial direction based on the simply-supported boundary conditions and combination of axisymmetric and asymmetric driven and companion modes. By gaining the airy function, the third motion equation is discretized using the Galerkin method into the set of coupled nonlinear nonhomogeneous ordinary differential equations. The perturbation method and Runge–Kutta 4th order are employed as a semi-analytical and a numerical solution method, which in practice leads to the prediction of the nonlinear frequencies and amplitudes of various modes of vibration at different velocities and external excitation fluctuation domain and frequency. The bifurcation analysis of the velocity and external excitation parameters in sub-harmonic regions shows the changes in the instability condition of the system. It causes the appearance of the pitchfork bifurcation and the Neimark–Sacker bifurcation points. The accuracy of both, the direct normal form and numerical method results are compared against each other and validated in the particular case in the absence of the velocity with available data. The system would be more stable at a higher speed near 1:1 external resonance due to the activation of more asymmetric vibration modes and the growth of the nonlinear softening characteristic in the absence of companion vibration modes.


ABSTRACT: A comprehensive experimental and numerical study into the cross-sectional behaviour of structural steel circular hollow sections (CHS), with an emphasis on high strength steel, is presented in this paper. Six cold-formed high strength steel S700 CHS profiles – 168.3×4, 139.7×4, 139.7×5, 139.7×6, 139.7×8 and 139.7×10 (diameter × thickness, in mm), spanning from Class 1 to Class 4 in compression according to EN 1993-1-1, were experimentally examined. The test programme consisted of twelve tensile coupon tests, local geometric imperfection measurements, six stub column tests, six four-point bending tests, six three-point bending tests and fifteen short beam-column tests. In parallel with the experimental study, finite element (FE) models of CHS were established and validated against the obtained experimental results, and parametric studies were subsequently carried out using the developed models to expand the cross-sectional resistance data pool. Finally, the cross-section design provisions specified in the European code prEN 1993-1-1:2018 and the American Specification ANSI/AISC 360-16 were assessed using the freshly generated experimental and numerical results as well as the existing test data on hot-rolled and cold-formed CHS from the literature. The present study provides the basis for the development of improved cross-section design rules for normal and high strength steel CHS in future research.


ABSTRACT: In this study, the linear and nonlinear buckling problems of circumferentially corrugated cylindrical shells under uniform external pressure were investigated, as was the effect of corrugation amplitude on buckling. Five sets of shells with different amplitudes were fabricated; each group had two identical cylindrical shells made of photosensitive resin, and their wall thickness and geometric appearance were
measured and tested to collapse under hydrostatic pressure. A comparison between finite element results and experimental data was also made for an externally pressurised cylindrical shell. According to the experimental results, as the amplitude of the corrugation increased, the buckling capacity of the cylindrical shell first increased and then decreased, which may have been related to the performance of the material. The location of the model failure was basically the same as the location of maximum stress, and the experimental results agreed well with the numerical calculation.

H. Zakhimi (1), H. Hofmeyer (2), H.H. Snijder (2) and M. Mahendran (3)
(1) SWECO, De Bilt, The Netherlands Formerly Student at Eindhoven University of Technology, the Netherlands
(2) Eindhoven University of Technology, Department of the Built Environment, Eindhoven, the Netherlands
(3) Queensland University of Technology, Science and Engineering Faculty, Brisbane, Australia


ABSTRACT: For trapezoidal steel sheeting, design codes so far calculate the web crippling strength via curve fitted rules; bending moment failure is predicted by the effective width method or the Direct Strength Method (DSM); and their combination is handled by a curve fitted interaction rule. As the DSM is easy to use, potentially more accurate, and closer to a mechanical description than curve fitted rules, this paper investigates whether it can be used for trapezoidal sheeting, limited here to the first-generation, i.e. without stiffeners. First, an existing set of experiments is presented, in which first-generation sheeting has been subjected to combined web crippling and bending moment via three-point bending tests. In these experiments, web-crippling deformation, beam deflection, and support rotations have been recorded, and failure behaviour has been studied well beyond the ultimate load. These experiments are simulated by the finite element method, and after verification, the simulations are used to record the first Eigenvalue, first yield, and the ultimate load of the experiments. Additionally, each experiment is also modelled as an Interior One Flange (IOF) web crippling test and a pure bending moment test. Finally, the DSM is developed based on the simulation data (not the experimental data), using two approaches. (i) For the interaction approach, only the web crippling strength and the bending moment capacity are predicted by the DSM, using the simulation data from the IOF web crippling tests and pure bending moment tests. Interaction is described by an interaction rule, calibrated to the simulations of the three-point bending tests. (ii) For the explicit approach, the DSM is used to predict the combined load capacity, based on the simulation data from the three-point bending tests. It is concluded that both approaches work, but the interaction approach performs better than the explicit approach. Using Interior Two Flange (ITF) Eigenvalues in combination with IOF yield loads and IOF ultimate loads increased the performance of the IOF web crippling DSM equations, however, it not leads to a further improvement of the interaction approach.

References listed at the end of the paper:
4 AISI S100-16, The North American Specification for the Design of Cold-Formed Steel Structural Members, American Iron and Steel Institute, Washington (2016)
7 M.C.M. Bakker, M. Rosmanit, H. Hofmeyer, Prediction of the elasto-plastic post-buckling strength of uniformly compressed plates from the fictitious elastic strain at failure, Thin-Walled Struct., 47 (2009), pp. 1-13
8 H. Hofmeyer, M. Rosmanit, M.C.M. Bakker, Prediction of sheeting failure by an ultimate failure model using the fictitious strain method, Thin-Walled Struct., 47 (2009), pp. 151-162
11 J.M.S. Franco, E. Batista, Buckling behavior and strength of thin-walled stiffened trapezoidal CFS under flexural bending, Thin-Walled Struct., 117 (2017), pp. 268-281
12 M. Bock, E. Real, Strength curves for web crippling design of cold-formed stainless steel hat sections, Thin-Walled Struct., 85 (2014), pp. 93-105
14 B.W. Schafer, T. Peköz, Direct strength prediction of cold-formed steel members using numerical elastic buckling solutions, Proceedings of the 14th International Specialty Conference on Cold-Formed Steel Structures, October 15-16, St. Louis, MO, USA (1998)
17 AS/NZS 4600, Australian/New Zealand Standard, Cold-Formed Steel, SAI Global Limited, Sydney (2018)
18 Z. Li, B.W. Schafer, Buckling analysis of cold-formed steel members with general boundary conditions using CUFSM: conventional and constrained finite strip methods, Proceedings of the 20th Specialty Conference on Cold-Formed Steel Structures, November 3-4, St. Louis, MO, USA (2010)
19 V.V. Nguyen, G.J. Hancock, C.H. Pham, Development of the THIN-WALL-2 program for buckling analysis of thin-walled sections under generalised loading, Eight International Conference on Advances in Steel Structures, July 22-24, Lisbon, Portugal (2015)
20 G.J. Hancock, C.H. Pham, Buckling analysis of thin-walled sections under localised loading using the semi-analytical finite strip method, Thin-Walled Struct., 86 (2015), pp. 35-46
21 Z. Li, J.C. Batista Abreu, J. Leng, S. Adány, B.W. Schafer, Review: constrained finite strip method developments and applications in cold-formed steel design, Thin-Walled Struct., 81 (2014), pp. 2-18
26 P. Keerthan, M. Mahendran, E. Steau, Experimental study of web crippling behaviour of hollow flange channel beams under two flange load cases, Thin-Walled Struct., 85 (2014), pp. 207-219
29 P. Natário, N. Silvestre, D. Camotim, Direct strength prediction of web crippling failure of beams under ETF loading, Thin-Walled Structures 98 (2016), pp. 360-374
31 B.W. Schafer, Advances in the direct strength method of thin-walled steel design, Proceedings of the 8th International Conference on Thin-Walled Structures ICTWS, July 24-27, Lisbon, Portugal (2018)
32 D. Camotim, P.B. Dinis, A.D. Martins, Direct strength method a general approach to the design of cold-formed steel members, C. Yu (Ed.), Recent Trends in Cold-Formed Construction, Woodhead Publishing, Sawston, UK (2016)
33 S. Torabian, B. Zheng, Y. Shifferaw, B.W. Schafer, Direct Strength Prediction of Cold-Formed Steel Beam Columns, American Iron and Steel Institute, Washington, USA, (2016), Report RP16-3
34 M.C.M. Bakker, J.W.B. Stark, Theoretical and experimental research on web crippling of cold-formed flexural steel members, Thin-Walled Struct., 18 (1994), pp. 261-290
35 Dassault Systemes, Abaqus 6.12, Dassault Systemes, Vélizy-Villacoublay, France (2019)

www.3ds.com/products-services/simulia/products/abacus
38 W. Rust, K. Schweizerhof, Finite element limit load analysis of thin-walled structures by ANSYS (implicit), LSDYNA (explicit) and in combination, Thin-Walled Struct., 41 (2003), pp. 227-244
40 M. Mahendran, Local plastic mechanisms in thin steel plates under in-plane compression, Thin-Walled Struct., 27 (1997), pp. 245-261
ABSTRACT: In this study, the compression behaviours of Miura-ori metamaterials were experimentally and numerically investigated under quasi-static loading and impact loading. The Miura-ori sheets had four acute angles, 50, 55, 60, and 65 degrees, which produced four uniform specimens and nine graded specimens with different stacking orders. All specimens were manufactured by polymer 3D printing. The results showed that for the uniform structures, the specific energy absorption first increased with the acute angle alpha and then decreased when the angle alpha continued to increase. All the investigated graded structures considerably enhanced the energy absorption capacity and avoided the force drop after the initial peak force due to their different deformation modes compared with that of the uniform structures. For the impact loading tests, the initial peak force increased as the acute angle increased for the uniform specimens. Comparison experiments were carried out for specimens 50-55-60-65 with positive and negative gradients, and the results showed that the specimen with a negative gradient had a better energy absorption capacity.
ABSTRACT: It is challenging to maintain the lightweight performance of sandwich structure while at the same time to obtain high bending stiffness and strength. In this study, sandwich beams with hierarchical honeycomb cores were proposed. Corresponding mechanical responses subjected to three-point bending load were explored and compared with that of the sandwich equipped with conventional honeycomb core by means of numerical simulation. Theoretical solutions of equivalent bending stiffness coincide well with numerical results. Scaling effect of vertex cell and cell size on the hierarchical honeycomb sandwich was investigated. Two tailored hierarchical patterns were proposed by replacing the hexagonal vertex cells with circular and square cells. Compared with the conventional counterpart, the hierarchical sandwich beams offer higher load-bearing capacity. Distinctions of bending strength of each configuration demonstrate different influences of tailored hierarchical cores on enhancing bending resistance ability. There are more local interactions of cells for hierarchical structures. The local improvement promotes more cells to withstand load and the whole sandwich beam can be globally strengthened.

ABSTRACT: Longitudinally profiled (LP) steel plates are plates rolled to variable thickness along the rolling direction in order to suit practical loading distributions in construction applications. The elastic buckling load of LP steel plates is different to normal flat plates due to the change in thickness and it is hard to find analytical solutions to the governing equation. In this paper, the elastic buckling coefficients of rectangular LP plates were calculated using the Galerkin and Rayleigh-Ritz method (GRM). The plates were under uniform compression and four typical boundary conditions were considered. The element expression of the feature matrix was obtained by theoretical derivation and the elastic buckling coefficients were obtained by calculating the eigenvalues of the feature matrix numerically with MATLAB. Numerical models of LP plates were developed to validate the derivation. Upon validation it was further found that the elastic buckling coefficients of LP plates can be approximately expressed by those of constant thickness steel plates together with variable thickness coefficients. A series of approximation formulae of elastic buckling coefficients of LP rectangular steel plates were proposed. Simplified design formulae of elastic buckling coefficients of LP plates were proposed for the first time to promote the application of LP plates in engineering practice.

ABSTRACT: Thin-walled tubes are widely used as energy absorption devices in transport vehicles. In this paper, with the goal of improving the energy absorption performance of tubes under quasi-static axial loading, origami tubes with polygonal cross-sections are designed. The geometric characteristics of polygonal origami tubes are controlled by three parameters: the number of sides, the number of modules and the dihedral angle. To investigate the effect of the origami pattern and polygonal structure on the crashworthiness of tubes, a full factorial experiment is adopted, and then parametric analysis is conducted based on eighty-five simulations. The numerical results validate that origami tubes collapsing in the complete diamond mode perform better than conventional tubes. However, this special mode can only be triggered in the crushing process of square and hexagonal origami tubes with smaller dihedral angles. The optimal design leads to a maximum reduction in the initial peak crushing force of 56.96% and a maximum increase in the mean crushing force of 45.49%. The parametric study shows that the initial peak crushing force of tubes with an identical number of modules and edges increases with an increasing dihedral angle, while it decreases with an increasing number of modules when the angle remains the same. Additionally, the influence of geometric parameters on the mean crushing force varies with different collapse modes. Furthermore, a deep insight into the in-extensible deformation mechanism of origami tubes deformed in the complete diamond mode is presented. The theoretical model is subsequently proposed to predict the mean crushing force.

ABSTRACT: This study investigates the problems of non-linear stability and load-carrying capacity of thin-walled composite Z-profiles under compression. The primary objective of the study was to determine the effect of eccentric load and ply-stacking sequence on the post-critical behaviour and load-carrying capacity of the analysed structures. Experimental and numerical methods were employed, which made it possible to describe structural performance of the analysed composite structures over the full range of loading, including the description of composite material damage. Experimental tests were performed on the physical models of CFRP profiles made by autoclaving. The real structures were subjected to compression until a complete loss of their load-carrying capacity. Simultaneously, numerical calculations were performed by the finite element method. The progressive damage model was used to evaluate the degree of damage in the composite material. The developed numerical models were validated with the results of experimental tests.


ABSTRACT: Learning from natural materials, such as nacre, bone and spider silk, is an effective way to develop future high-performance composite materials and structures. In this work, a conceptual composite panel inspired by nacre from mollusc shells is proposed and simulated with different types of interlocked wavy laminates. The deformation and failure mechanisms of individual fibre and matrix (Vinylester resin) laminas in the proposed composite panel under dynamic loading are modelled and compared with their flat and traditional interlocked dog-bone-like counterparts. An effective polyurea backing layer, which was demonstrated to significantly reduce damage to the flat composite laminate in the author’s previous work, is also added to the back of the current composite panels to activate mix-mode damages in the panel. The numerical results highlight the essential role of the wavy laminate in enhancing the panel's performance by mitigating the transmitted dynamic load and reducing either inter-lamina delamination or fibre degradation. Parametric studies were carried out on different sectional shapes to demonstrate the significant improvement of the wavy composite Fibre/Vinylester layers under blast and impact loads.


ABSTRACT: A series of 112 experiments were conducted to investigate the response of monolithic and multi-layered metallic plates under repeated uniform impulsive loading up to five times. 15 various testing groups were considered to study the effects of different charge masses, layering configurations, layering arrangements, layer thicknesses, and stand-off distances on the central deflection of single-, double-, triple-layered and triple-layered mixed plates made of aluminum alloy and mild steel materials. The results showed that the triple-layered mixed configuration made of thick aluminum middle and front plates and thin mild steel plate has the best performance compared to other tested configurations from the 1st to 5th loading cycle while the triple-layered steel plate has the poorest performance at the 1st and 2nd loading cycle. Also, the triple-layered mixed configuration with thin mild steel back and front layers showed the poorest blast performance after the 2nd cycle. Additionally, empirical design formulae were proposed to predict the central deflection of monolithic and multi-layered plates under repeated impulsive loading based on new dimensionless numbers.


ABSTRACT: This study presents an analysis of the static bending of a sandwich plate composed of a functionally graded (FG) core and face sheets manufactured of piezoelectric material. The sandwich plate is resting on Pasternak's elastic foundations and subjected to sinusoidal thermo-electro-mechanical loads. Four-unknown shear deformation theory is utilized to define the displacement components. The equilibrium equations are established using the virtual work principle and solved by following Navier's solution method.
The influences of applied voltage, thermal expansion coefficients, volume fraction exponent, elastic foundations parameters, side to-thickness ratio, and aspect ratio have been discussed. The current formulation is supported by comparisons with the published results.


ABSTRACT: This paper presents an in-depth experimental and numerical investigation into the behaviour of laser-welded stainless steel channel sections under combined compression and bending moment about the major axis. Two laser-welded austenitic stainless steel plain channel sections were considered in the experimental investigation, and for each channel section, four eccentrically loaded stub column tests were conducted under various initial loading eccentricities. The experimental results were then adopted in a numerical investigation for the validation of finite element models, by means of which parametric studies were conducted to generate further structural performance data over a wider range of cross-section sizes and initial loading eccentricities. Both the obtained experimental and numerical results were carefully analysed and then used to evaluate the accuracy of the current codified design rules for welded stainless steel channel sections under combined compression and major axis bending. The evaluation results generally revealed that the codified design rules yield excessively conservative and scattered resistance predictions, owing to the neglect of the favourable material strain hardening of stainless steel and the beneficial stress redistribution within channel sections under combined loading. An improved design approach has been proposed through extension of the deformation-based continuous strength method (CSM) to the case of laser-welded stainless steel channel sections under combined compression and major axis bending. Quantitative evaluation of the new design approach was made through comparing the predicted resistances against the experimental and numerical failure loads, with the results revealing that the new design approach yields a much higher level of design accuracy and consistency than the current codified design rules. Finally, statistical analyses have been conducted to confirm the reliability of the new design approach according to EN 1990.


ABSTRACT: In-plane collapse behaviors of second-order wood-inspired hierarchical honeycombs (replace each solid side of a conventional honeycomb with a wall comprising smaller hexagons) under quasi-static and dynamic in-plane compression were examined via experiments and finite element (FE) simulation. Analytical formula for the initial crushing strength and plateau crushing force were also developed. Compared to the conventional honeycomb, a hierarchical honeycomb displays a higher mean post-yield crushing stress, although its specific energy absorption is slightly lower. Their initial phase of energy dissipation is linked to the rotation and shortening/compression of the inclined hierarchical walls. Due to less catastrophic collapse of the smaller first-order cells, the plateau stress phase is more stable and gradual overall hardening is evident in the stress-strain curve. Under dynamic loading, the initial peak force and subsequent plateau force are elevated. There are three types of responses – quasi-static, transition/progressive and dynamic – depending on the magnitude of the impact velocity.


ABSTRACT: This research proposes a novel analytical model capable of accurately predicting the strain-dependent characteristics of fiber reinforced composite shells (FRCSs) with partial constrained layer damping (CLD) treatment by considering the nonlinearities of fiber reinforced composite and viscoelastic materials simultaneously. The nonlinear material properties are represented based on Jones-Nelson nonlinear theory, energy-based strain energy method, and complex modulus method. Then, the governing equations of motion for FRCSs are developed via Ritz method, and the identification procedure of nonlinear fitting parameters is also presented. By taking a T300 carbon fiber/epoxy resin cylindrical shell with partial CLD patches as an example, a series of experiments are carried out to validate the proposed modeling approach. Finally, the effects of
material properties on nonlinear vibration behaviors of FRCSs covered with partial CLD patches are evaluated. Comparisons show that the proposed nonlinear model is more accuracy than that without considering strain dependence, where the maximum errors between the proposed model and measured data for natural frequencies, damping ratios and resonant response are 6.9%, 11.3%, and 11.2%, respectively.


ABSTRACT: Towers, trusses and bracings diaphragms generally utilise angles cross-sections. Although the angles represent one of the simplest steel cross-sections, their design and structural response are usually not simple. This paper addresses the behaviour of carbon steel hot-rolled equal-leg angle cross-section under compression subjected to the flexural-torsional buckling failure mode. The adopted methodology encompassed an experimental campaign consisting of eighteen full-scale tests on ASTM A36 carbon steel equal-leg angle columns. Three different cross-sections were utilised, L64x64x4.8, L76x76x6.4 and L102x102x6.4 corresponding to b/t (leg width to thickness) ratios of 13.33, 11.88 and 15.94, respectively. All investigated columns presented flexural-torsional buckling failure modes characterised by major axis bending accompanied by a cross-section rotation. This experimental programme was followed by finite element simulations, validated against the experimental results, taking into account the geometrical and material nonlinearities. These models were used to expand the database involving the flexural-torsional buckling response in fixed-ends hot-rolled angle columns made of carbon steel. Afterwards, the results were compared with Eurocode 3 (EC3) and modified DSM (mDSM) predictions. The EC3 presented more significant discrepancies when compared to experiments and numerical results, confirming the conservatism of this code. On the other hand, the performance of the mDSM method was significantly better.


ABSTRACT: This paper proposes N-sided polygonal tubes with hierarchical triangular cells (PHTNs) for use as energy-absorbing devices. Different cross sections of the PHTNs are obtained by changing the number of sides and cells of the sandwich wall. Quasi-static compression experiments and finite element (FE) simulations are used to analyse the axial crushing behaviour and energy absorption performance of the PHTNs. The results show that the PHTNs has two deformation modes: when N ≤ 24, the deformation mode is progressive folding, whereas when N > 24, the deformation mode is sandwich folding. The 24-sided PHTN (PHT24) exhibits the best energy absorption performance, and the specific energy absorption (SEA) of PHT24 is 110.37% greater than the minimum SEA, which is exhibit by PHT06. The results also reveal that the energy absorption is improved mainly by shortening the wavelength or increasing the plastic bending moment of the sandwich wall. Finally, theoretical models are established for predicting the mean crushing force in the PHTNs under both deformation modes. The predictions from these models are in good agreement with the FE simulation results, thereby indicating that the predictions are highly accurate.


ABSTRACT: Silos in the form of the thin-walled cylindrical steel shells are commonly supported on a ring girder, which rests on a limited number of columns to discharge the content by gravity flow into transportation systems. Local supports in the elevated steel silos produce a significant circumferential non-uniformity in the axial membrane stresses in the silo shell. One way of reducing the non-uniformity of these stresses is to use a very stiff ring girder which partially or fully redistributes the stresses from the local support into uniform stresses in the shell. Previous works that attempt to produce design expressions only address isolated ring girders and ignore the key role of the interaction between the cylindrical shell and the supporting ring girder. The aim of this study is to achieve a more efficient and realistic design of ring girders resting either on four supports, or on four supports with secondary beams, or on eight supports. Pursuant to this goal, variations of the stress resultants and displacements in the ring girder which rests on different support conditions are derived for the first time using Vlasov’s curved beam theory. These expressions have been evaluated with finite element analyses for an isolated ring girder. Subsequently, a complementary finite element parametric study was
conducted to investigate the variation of the stress resultants and displacements caused by the connection of the shell and ring girder resting on different supporting conditions. These variations were plotted as a function of the shell-ring girder stiffness ratio ($\psi$) for each support condition. Finally, considering lower bound limits for the stress resultants and displacements, design equations were proposed for ring girders which rest on different support conditions. These expressions may easily be placed in a practical spreadsheet, which could be used with different data to give realistic predictions.


**ABSTRACT**: Thin-walled tubular components are featured in transport structures for increased occupant protection in the event of a crash. However, when the limits of their design are sought through deterministic procedures, components often become unreliable due to uncertainties which may cause them to underperform or even fail. Seeking a deeper understanding of the effect of incertitudes on the thin-walled tubes' performance, this research focuses on the crashworthiness quantification of diverse sources of uncertainties in the progressive collapse of these components under axial loads. For a broader insight on the tubes’ behavior, diversity is considered and scrutinized on all the main fields involved in the research: studying two cross-sections, three sources of uncertainties, and the two epitomical crashworthiness metrics, namely the average and peak crushing loads. The process is undertaken via three different methods, combining analytical formulas, numerical simulations, and surrogate modeling. Results show that the best approximation is offered by the multivariate adaptive regression splines metamodel, yielding similar mean values as with the statistical propagation of the analytical formulas, while the standard deviation is overestimated by 1%–3%. The numerical noise quantified for the simulations results shows oscillation frequencies below 40% and a breadth of three-sigma under 9% for both metrics. The uncertainty quantification of both tubes offers a similar response when studying geometric uncertainties, with the plate thickness having a more relevant effect on the results than diameter or edge length. However, material uncertainties affect the absorbers in an opposite manner, as variations in the elastic modulus contribute the most to the square section metrics, while the circular tube is more affected by variations in the equivalent flow stress. Incertitudes in the operational conditions lead to reduced peak load values when the impact angle varies from a perfect axial collision, consequently delivering reduced mean values and high standard deviations.


**ABSTRACT**: It is widely known that the demand for lightweight structures with excellent energy absorption capacity is paramount in numerous engineering applications. Many publications have revealed that corrugated structures can collapse in a relatively controlled manner with a uniform force-displacement response and have remarkable energy absorption efficiency when compared with traditional structures without corrugations. The present work provides a comprehensive overview of recent advances in the development of corrugated structures for energy absorption applications, also considering the effects of corrugation characteristics on their crashworthiness. Such advanced energy absorbers include corrugated tubes, corrugated tapered tubes, corrugated beam and plates, corrugated honeycombs, corrugated core sandwich panels and other hybrid structures with complex corrugations. This review demonstrates that thin-walled structures with introduced corrugations can achieve more efficient and effective energy absorption. Finally, contemporary challenges of design and manufacture are discussed, as well as future directions for corrugated structures. This synopsis provides a useful platform for researchers and engineers designing corrugated structures for energy absorption applications.


**ABSTRACT**: The corrugated steel web girder (CSWG) has been widely used since its light self-weight and high shear stability. Previous studies on the shear response focus on the shear buckling behavior of corrugated
steel webs that dominates shear strength of the girder. However, there is a lack of theoretical explanation for this phenomenon. Besides, research on the post-buckling performance of CSGBs is quite limited though that has been observed by several researchers. In this paper, a theoretical approach adopting the rotated stress field method was proposed to analyze stress states in girders with corrugated steel webs under shear and was verified by experimental data. The results could explain the shear strength determined by shear buckling behaviour theoretically. Then, nonlinear finite element analyses were performed on 24 I-beam specimens to investigate the post-buckling performance and ultimate failure mechanisms of the CSWG. The post-buckling performance is provided by a frame system composing the tension zone in the web, the flanges and the stiffeners. When plastic hinges form in the flanges, the girder collapses and the possible collapse mechanisms include the quasi mid-section mechanism, the mid-section mechanism and the girder mechanism. Level of the residual shear strength after buckling and the collapse mechanism are significantly affected by the flange bending stiffness and the web width/height ratio.


ABSTRACT: A novel Layerwise theory (LT) along with the higher-order shear deformation theory (HSDT) is investigated to determine the stress distribution in a three-layer sector of the spherical sandwich shell with piezoelectric face sheets and functionally graded carbon nanotube (FG-CNT) core. The simply-supported sandwich shell is subjected to the internal blast pressure so that the positive and the negative phases of the pressure are considered. The blast pressure is generated by a 1 Kg TNT hemispherical surface burst detonated. The out-of-shell displacement of the sandwich spherical shell at each layer is assumed to be a quadratic polynomial function of the radial component in addition to a function of the coordinate components within the shell. The nineteen equations of motion are derived by Hamilton's principle and Maxwell's static equations. By solving these nineteen equations, the stress distribution is calculated in the spherical sandwich shell in terms of time.


ABSTRACT: The buckling capacity of plates can be enhanced by appropriately placing discrete point-support(s) at optimal locations. However, determining the optimal locations of point-supports to achieve maximum buckling coefficients is a challenging problem, as it couples the analysis procedures for buckling and optimisation. This paper investigates the optimal positioning of point support(s) in Levy-type plates subjected to in-plane loads for maximum buckling coefficients and presents a novel and efficient solution framework for this problem. The framework is based on the application of the one-dimensional impulse function approach (1D IFA) in combination with the particle swarm optimisation (PSO) method. As shown previously [1], the 1D IFA is a suitable method for the secure handling of multiple point-supports and changing their locations in rational plate buckling analyses. Using the presented framework, a set of demanding analytical solutions for the buckling of Levy-type plates with arbitrarily positioned single or multiple point-supports subjected to linearly varying in-plane loads are first verified against convergence and comparison studies. Subsequently, buckling results are presented for a wide range of rectangular plates with various numbers of point-supports and various combinations of mixed edge support conditions. The results for the optimal locations of point-supports include surprising findings, including (a) some of the optimum solutions can be achieved when the point-supports are positioned over a line of finite length, rather than at discrete points; (b) there can be multiple solutions for one specific aspect ratio and edge condition; (c) some of the optimum solutions for the location of point-supports are not symmetric with respect to symmetry axes of geometry and/or loading.


ABSTRACT: An expression for cross-sectional bending capacity prediction curve is proposed in this study based on the Direct-Strength-Method (DSM) approach using a comprehensive data from the literature on
structural carbon steel Circular-Hollow-Sections (CHSs). Later, according to the Equivalent-Resistance-Capacity-Method (ERCM), improved empirical expressions for the equivalent CHS diameter of Elliptical-Hollow-Section (EHS) are derived using the proposed CHS bending capacity prediction curve and the data of EHSs from the literature. A unified set of cross-section slenderness limits for assessing the CHS and EHS members under bending is proposed. Also, the proposed expression for the bending resistance curve based on DSM is transformed into the generalized form of the traditional cylindrical shell buckling capacity curve as a practical solution in harmony with the newly introduced Reference-Resistance-Design (RRD) guidelines. Finally, the behaviour of EHS cantilever members under cyclic bending is assessed in terms of cyclic moment resistance and rotation capacities based on the authors’ previous study.


ABSTRACT: In this study, the investigation on the overall-local interactive buckling performance of high strength steel welded I-section columns was carried out. Finite element models of steel columns of different yield strength (235 MPa, 460 MPa, 500MPa, 690 MPa, 800MPa, 960 MPa) were constructed considering geometric imperfection and residual stresses, and verified against the existing test results. Effect of geometric imperfection including global imperfection and local imperfection was found to be largely dependent on the nominal slenderness ratio of columns (\(\lambda\)). Local imperfection present prominent influence for the case of \(\lambda\) lower than 0.4, while global imperfection for the case of \(\lambda\) exceeding 0.95. Effect of four types of residual stress patterns on ultimate capacity were compared, the disparity of which was around 10%. Comprehensive effect of imperfections on local buckling load was found to be smaller resulted from higher steel grade; whilst that on stiffness became more pronounced. Based on the test data of stub columns, new predict formulas were proposed for the local post-buckling strength using effective width method and direct strength method respectively. Continuing the investigation of stub columns, the formulas for interactive buckling resistance of high strength steel welded I-section around the weak axis were studied, where column curve b in Eurocode3 was suggested to be adopted.


ABSTRACT: In hygrothermal environment, vibration study of a simply supported smart sandwich plate embedded in an elastic substrate medium is presented in the present article. The sandwich plate contains layers of fiber-reinforced and magnetostRICTive materials and core of viscoelastic material. The kinematic equations system is derived via employing Hamilton's principle with considering the transverse shear strains with and without the normal strains effect. Various numerical examples are carried out to study the effects of temperature rise, degree of moisture concentration, elastic foundations parameters, thickness ratio, aspect ratio, thickness ratio of magnetostrictive layer to viscoelastic layer, modes, lamination schemes, magnitude of the feedback coefficient, position of the magnetostrictive layers and viscoelastic structural damping coefficient on controlled motion and vibration characteristics of plate. Some observation about influences of the temperature and humidity concentrations on vibration characteristics of studied plate are presented in detail. The outcomes indicate that the hygrothermal environments have negative effects on vibration suppression of advanced composite structures especially the uniform hygrothermal distribution. The frequencies increase with increasing the viscoelastic structural damping coefficient and the foundation constants.


ABSTRACT: The pier of a bridge crossing the road is susceptible to vehicle impact, and thus it would be useful to design an energy absorption structure to reduce the damage or even avoid the collapse of bridge under the collision of aberrant cars. To provide good crashworthiness and performance, an energy absorption structure consisted of thin-wall ‘U’ shape steel and filled composite honeycomb tubes was adopted. The present paper
aims to assess the dynamical performance and energy absorption capacity of the designed protection structure under various vehicles collision for its application, in which the Ford Taurus, Chevrolet pickup and truck provided by NACA (National Crash Analysis Centre) are adopted in the numerical simulations. For obtaining reliable results, the FE (finite element) model of energy absorption structure and actual vehicles are separately calibrated by experimental results. Based on the validated FE modelling technology, the dynamical response and performance of the designed protection structure are investigated considering various influential parameters, including impact velocities, angles, and types of vehicle.


ABSTRACT: This work presents tests and finite element analyses of a two-story, buckling-restrained braced frame (BRBF) with BRBs arranged in an X configuration along the building height, called an X-BRBF. The BRB in this work is composed of a core plate sandwiched by a pair of restraining members, called a sandwiched buckling restrained brace (SBRB). The weak axis of the SBRB core is transverse to the dual-gusset-plate connection and the in-plane movement of the frame to eliminate its weak-axis buckling. The objectives of two phase tests were to evaluate: (1) the seismic performance of SBRBs with a small width-to-thickness ratio of the core plate (=3), (2) the effects of free-edge stiffeners on the gusset and SBRB stability, and (3) the SBRB stability associated with beam buckling. All gusset connections had free-edge stiffeners in Phase 1 test, and free-edge stiffeners were removed from half of gusset connections in Phase 2 test. The X-BRBF in Phase 1 test exhibited good performance up to a second-floor drift of 1.6%, but in Phase 2 test the second-floor SBRB, caused by the lateral-torsional buckling (LTB) of the beam, experienced asymmetric buckling about the strong axis of the core at 1.6% second-floor drift. The other SBRB with no beam LTB showed one-side buckling about the strong axis at 2% drift (near an inter-story drift of 2.5%). However, the strength degradation of the specimen was not observed during the strong-axis instability of SBRBs, indicating acceptable orientation for excluding the weak-axis buckling of SBRBs. The strong-axis instability of SBRBs in Phase 2 test could be evaluated by using the stability concept with measured out-of-plane deformation of gusset plates. A nonlinear finite element analysis was conducted on the specimen for further investigation of SBRB instability.


ABSTRACT: High-strength steels (HSSs) are now used globally in different structural applications. Nevertheless, investigations on HSS elements are still rare. Herein, the shear buckling response of S690 steel plate girders with corrugated webs (CWGs) is explored. This is based on virtual tests, generated by finite element (FE) modelling, that well simulate their actual behaviour. Accordingly, S690 material model is firstly checked from a recent test campaign by Sun et al. (2019). Then, the FE models are verified through comparisons with the available tests on HSS CWGs conducted by Driver et al. (2006). Based on the successful validation, virtual testing, by using the software Abaqus, is currently generated to examine the effects of the geometrical characteristics of the cross-section (in terms of the thickness (t) and the height (h) of the web). The results show that by increasing the value of t, the strength of the girders increase efficiently. Conversely, increasing h is found to increase the girder's strength, but with slightly less increase in the strength compared with the increase of the web's weight. Furthermore, the shear strengths are compared with different design models available in the literature. The design model by Leblouba et al. (2017) is found to be the best predictor for the current girders with equal fold widths. The paper extends to explore the effect of varying the design parameters of the corrugated webs on the shear response of CWGs with unequal fold widths. Accordingly, multiple virtual tests are simulated and compared to help in designing efficient corrugated webs in the future. At the end, the design model by Leblouba et al. (2017) is slightly modified by considering the effect of the fixed juncture between the rigid flanges and the web. Through this modification, the most suitable predictor for S690 CWGs is obtained with an accuracy that is not depending on the slenderness of the girder. So, it is currently recommended for design purpose of S690 CWGs with unequal fold widths.
ABSTRACT: To investigate the collapse behavior of steel frames under the random earthquake, it is essential to grasp the hysteretic behavior of beam members. However, in the large-deformation region, the behavior of beams is difficult to be captured precisely because of the local buckling of the flange plate and the web plate. This paper presents a method to obtain the monotonic curve and the hysteretic curve efficiently for H-shaped beams subjected to bending moment. 96 models for H-shaped beams were designed and analyzed under the monotonic and cyclic loading using finite element analysis. Parameter study was implemented to grasp the influence of width-to-thickness ratio, shear span, and the beam depth. Depending on the numerical analysis, a monotonic model was proposed which can obtain the monotonic curve precisely and efficiently. Consequently, through combining with the modified Ibarra-Medina-Krawinkler hysteretic model, the accuracy for predicting the hysteretic behavior of beams was verified through comparing with the numerical results.


ABSTRACT: Optimal design of a structural member is a design process of selecting alternative forms to obtain its maximum strength while maintaining the same weight, leading to the most economical and efficient structure. Amongst steel structures, cold rolled steel ones can effectively gain this requirement as they are thin-walled structures that offer the high ratio of strength over weight. However, the design is very challenging as these members are prone to buckling and failure at low loads. In this paper, the buckling and ultimate strength of cold rolled channel sections was studied using numerical modelling. In order to improve the section strength, the development of various alternative cold rolled formed sections included additional bends such as intermediate stiffeners. The section strength was optimised through a practical approach which altered the stiffener's position and shape and searched for maximum buckling and ultimate strength under bending. In this approach, a nonlinear Finite Element model was first developed for an industrial channel beam subjected to four-point bending tests and this model was validated against experimental test data. The verified model was then used to conduct a parametric study in which the effects of a stiffener's properties on the section strength including its position, shape, size and material properties by the cold work at bends were investigated in detail. Several different cold rolled channel sections having intermediate stiffeners at web and flanges with and without the cold work effect on material properties at the stiffener's bends were considered for this investigation. In addition, a design method, the Direct Strength Method (DSM), was utilised to take into account the effects of a stiffener's properties on the section strength and results were compared with the Finite Element modelling results. It was found that some significant improvements were obtained for the section strength of the optimised sections in comparison to the original sections. An optimal shape for the channel section with maximum ultimate strength in distortional buckling could be obtained with both the stiffeners' position, shape, size and quantity, and the cold work effect. The cold work effect was found most significant in the cases of changing the width of the web stiffeners and the position of the flange stiffeners. It also revealed that, the currently available DSM beam design curve for distortional buckling provided good agreement in predicting buckling load and ultimate strength capacity for most of the considered sections with and without the cold work effect included; however, the DSM provided overestimate results compared to the Finite Element model results in the sections with web intermediate stiffeners, in particular, when the tip of web intermediate stiffener moved away from the web-flange junction in the horizontal direction.


ABSTRACT: This paper presents a finite-element (FE) investigation on the axial compressive capacity of aluminium alloy circular hollow sections (CHSSs) with circular holes. The geometrical and material non-linearities were considered in the finite-element analysis (FEA). Two consecutive steps including an eigenvalue analysis and a load-displacement non-linear analysis were performed in the FEA. The FE models were validated against the test results reported by the first author in a previous study. The validated FE models were used to
conduct an extensive parametric study comprising 300 FE models, to investigate the effects of five geometrical parameters on axial compressive capacity: the wall thickness, overall length, the diameter, and the quantity and location of the circular through-holes. In addition, a comparison was performed between the FEA strengths and design strengths calculated using the design formulae of American Design Manual (AA), European Code (EC9), Australian/New Zealand Standard (AS/NZS), Chinese Code for imperforated members, and North American Specification (NAS). Moreover, the FEA strengths were compared against the design strengths calculated from the proposed design guidelines of Dhanalakshmi and Shanmugam, Shanmugam et al., Shanmugam and Dhanalakshmi, and Moen and Schafer for cold-formed steel (CFS) sections with holes. The comparison of design strengths against FEA results showed that the current design formulae for CFS perforated sections are not suitable for aluminium alloy CHSs with circular holes. Therefore, new design equations were proposed based on the current design formulae that use effective area method (EAM) by considering the influences of key geometrical parameters.


ABSTRACT: This study presents the first ever investigation aimed at accurate numerical modelling of the behavior of hybrid fibre reinforced polymer (FRP)-timber laminated (HFT) Cee section columns under axial compression. Existing numerical modelling approaches for modelling thin-walled structural members, such as modelling using composite laminate shell elements, orthotropic laminate shell elements with experimentally obtained properties, were found to either over-predict or under-predict the stiffness and capacity depending on the approach used. Existing modelling approaches fail to accurately capture the effects of possible interlaminar slips under combined flexural and axial loading. A new modelling approach using ABAQUS subroutine UGENS was proposed incorporating both in-plane stiffness matrix and bending stiffness matrix simultaneously, forming the general section stiffness matrix. Failure initiation criteria and a damage evolution law were incorporated in the subroutine to derive the damaged section stiffness matrix. The predictions from the proposed numerical model showed much improved agreement with the test results.


ABSTRACT: The free flexural vibration of thin-walled honeycomb sandwich cylindrical shell was investigated by experiments and Flügge's shell theory simulations. The natural frequencies were measured and compared with simulations three-dimensional model. In the simulation analysis, the porous honeycomb core is simplified as a homogeneous orthotropic material, and its equivalent material properties are determined by the corrected Gibson's formula. Flügge's shell theory is compared with experimental results and finite element method calculation results, and the maximum relative error is only 4.749%. The comparison results show that Flügge's shell theory can accurately calculate the natural frequency of the thin honeycomb sandwich cylindrical shell.


ABSTRACT: Herein, several approaches with the aim of improving the crashworthiness performance of expanded metal tubes were assessed experimentally and numerically. In this regard, various expanded metal tubes were produced out of expanded metal sheets including expanded metal tubes, stiffened expanded metal tubes, foam-filled expanded metal tubes and multi-layered expanded metal tubes. Their crashworthiness performance was evaluated under quasi-static axial compressive loading. The effect of cross-sectional type (square and circular) and cell size (large and small) were also evaluated. Results showed the significant effect of cell size on the crashworthiness performance of expanded metal tubes, while the cross-sectional type had negligible effect. Moreover, the energy absorption properties of expanded metal tubes improved through welding expanded metal sheets in the core (stiffened expanded metal tubes), embedding expanded metal tube in foam, and placing several expanded metal tubes concentrically. Among the studied approaches, the foam-filled expanded metal tubes exhibited the most stable compressive load-displacement response, which is desirable for energy dissipation. Furthermore, the load-displacement responses of prepared expanded metal tubes were also
predicted acceptably by the proposed finite element modeling. Finally, the effects of expanded metal tube parameters on the crashworthiness performance of tubes were investigated numerically.


**ABSTRACT**: The buckling and collapse behaviors of a cracked thin steel panel subjected to sequential tensile and compressive loading were investigated. An experimental apparatus was developed. Three different test specimens were employed, i.e., an intact panel and cracked panels with different crack lengths. The load-displacement curve and crack opening displacement (COD) were measured during the loading. The experimental results were examined via finite element (FE) computation. The results revealed that the developed experimental apparatus is quite suitable for investigating the buckling and collapse behaviors. Furthermore, the maximum tensile load, ultimate strength and local deformation around the crack were well simulated by the FE computation. The presence of the crack and length of the crack were strongly affected to the buckling and collapse behaviors.


**ABSTRACT**: In order to study the wind-induced performance of super-large steel structure cooling towers, a super-large hyperbolic 216.3m-high cooling tower comprising a double-layer steel-truss structure with steel-sheet cladding was taken as a case study. The dynamic characteristics of this cooling tower were analyzed and compared with those of a similar-scale reinforced concrete cooling tower. Then, fluctuating wind loads measured in wind tunnel tests were applied directly to a structural finite-element model based on proper orthogonal decomposition and reconstruction of the wind pressures. The displacement response of the cooling tower was subsequently obtained by full transient dynamic analysis, and then the distribution characteristics of mean response, the mode participation contribution of the fluctuating displacement responses, the wind-induced vibration factors and the influence of structural damping ratio were investigated and compared with those of a concrete cooling tower. The comparison results mainly show that the steel-structure cooling tower has higher natural vibration frequencies, a lower-order number of lateral overturning mode (indicating a higher risk of overturning collapse), simpler resonant modes, smaller variance ratio of resonant component and weaker sensitivity of dynamic response to structural damping. The study results could assist in wind resistance design of similar super-large steel-structure cooling towers.


**ABSTRACT**: Dual-angle cross combined section columns (starred angles) have been extensively utilised as transmission tower legs because of their large bearing capacity. However, combined members may fail in different modes, and the provisions on bearing capacity in the regulations of different countries are diverse. To overcome the limitations of existing research and design approaches, a three-dimensional finite element (FE) model is developed in this study and is validated against all column test data available in the literature. Using this model, parametric analyses are performed on varying grades of steel, patterns of filler plates, and the number of filler plates, and the effect of the number and pattern of filler plates is determined. The shortcomings of the current design methods are highlighted along with the necessary solutions, based on a comparison of the results of experiments and those of numerical analysis using values calculated as per various regulatory codes. It is demonstrated that the type and the number of filler plates only affect the starred angles with flexural buckling about the imagine axis, and that torsional buckling and local buckling in the combined section columns do not occur simultaneously. When considering the influence of local buckling on the reduction in the bearing capacity of members, repeatedly factoring in torsional buckling is unnecessary. Furthermore, through modification of the slenderness ratio of the sub-members in the calculation of the equivalent slenderness ratio of starred angles, the calculation results obtained using the code agree well with the results of the numerical analysis.

Abstract: Bidirectional self-locked structure has important significance in energy absorption protection, especially complex loading absorbing energy. This paper reports on the lateral crushing behavior of novel carbon fiber/epoxy composite bidirectional self-locked thin-walled tubular structure (BST) and system (BSTS), as well as some improved bidirectional self-locked thin-walled tubular structures and systems. The lateral crushing behaviors of BST and BSTS were investigated by experiment and finite element analysis. It was found that the specific energy absorption (SEA) of BSTS was inferior to BST, which indicated the assembly system weakened energy absorption. The simulated results indicated that changing stacking sequence of carbon fiber/epoxy prepreg had not significantly effect on crushing performance of BST. Finally, the improved bidirectional self-locked thin-walled tubular structures and systems were designed and tested. The improved design enabled to enhance 139.9% in the crushing force efficiency (CFE) (specifically from 33.3% to 79.9%) and 27.5% in the SEA (from 4.0 J/g to 5.1 J/g). It was worth mentioning that the bidirectional self-locked system with PMI foam-filled enhanced 20.8% than bidirectional self-locked thin-walled tubular structure with PMI foam-filled in the SEA (from 5.3 J/g to 6.4 J/g).


Abstract: The minor-axis flexural buckling behaviour and strengths of pin-ended press-braked stainless steel channel section columns have been investigated in the present paper through laboratory testing and numerical modelling. An experimental programme was firstly conducted, and included initial global and local geometric imperfection measurements and twelve pin-ended column tests about the minor principal axis. The key obtained test results, including the failure loads, the mid-height lateral deflections at the failure loads, the load–mid-height lateral deflection curves and the failure modes, were reported and discussed in detail. The experimental programme was followed by a numerical modelling programme; finite element models were developed to simulate the test responses and then adopted to perform parametric studies to generate further numerical data on press-braked stainless steel channel section columns over a wide range of cross-section dimensions and member effective lengths. The obtained experimental and numerical data were employed to assess the accuracy of the relevant design rules for press-braked stainless steel channel section columns failing by flexural buckling about the minor principal axis, as given in the European code, American specification, Australian/New Zealand standard and SCI design manual. The results of the assessment indicated that (i) the European code yields unsafe flexural buckling strength predictions for those relatively short and intermediate press-braked stainless steel channel section columns with member non-dimensional slendernesses less than around 1.0, (ii) the American specification leads to unsafe predictions of flexural buckling strength for press-braked stainless steel channel section columns over the whole considered range of member non-dimensional slendernesses up to 3.0, and (iii) the Australian/New Zealand standard and the SCI design manual result in lower levels of design accuracy than the European code and American specification, but with significantly reduced number of unsafe flexural buckling strength predictions.


Abstract: Cold-formed steel (CFS) channel beams are an increasingly popular choice as load-carrying members in building structures. Such channel beams often include web holes for installation of services. Traditional web holes are normally punched and are un-stiffened. This can restrict the size and spacing of web holes. Recently, a new generation of CFS channel beams with edge-stiffened web holes has been developed and used widely in New Zealand. However, no experimental investigation has been reported in the literature for such channel beams under bending. In this paper, a total of 215 results comprising 16 four-point bending tests and 199 finite element analysis (FEA) are reported on the moment capacity of CFS channel beams with both edge-stiffened and un-stiffened web holes. For comparison, channel beams without web holes were also tested.
For all specimens, initial imperfections were measured using a laser scanner. A nonlinear elasto-plastic finite element (FE) model was also developed, and the results showed good agreement with the test results. A parametric study was conducted using the validated FE model to investigate the effects of beam length, hole diameter, stiffener length and fillet radius on the moment capacity of CFS channel beams. It is shown that for the case of a channel beam with five edge-stiffened web holes, the moment capacity increased by as much as 14.5%, compared to that of a plain channel beam. For comparison, the same section with un-stiffened web holes had a 13.6% reduction in moment capacity, compared to that of a plain channel beam. Furthermore, the accuracy of current design guidelines in accordance with the American Iron and Steel Institute (AISI) and Australia/New Zealand (AS/NZ) standards were verified by comparing the tests and FEA results against the design strengths for moment capacity of CFS channel beams without web holes. On the other hand, for CFS channel beams with web holes, the moment capacity obtained from tests and FEA were compared against the moment capacity calculated from the design equations of Moen and Schafer. Upon comparison, it was found that the AISI and AS/NZS can closely predict the moment capacity of CFS channel beams without web holes. The Moen and Schafer design equations were found to be over-conservative by around 11% and 28% for moment capacity of CFS channel beams with un-stiffened and edge-stiffened web holes, respectively.


ABSTRACT: The concept of green environmental protection is becoming increasingly important. This study used green high-performance basalt-fiber filament tows as raw materials to prepare tubular three-dimensional (3D)-woven preforms on a semi-automatic loom. Then, using the prepared preforms for reinforcement and resin as the matrix, a vacuum-assisted resin-transfer method was used to prepare tubular 3D-woven composites with three different internal diameters and layers. Axial-compression experiments were conducted to obtain the tubular 3D-woven composites’ load-displacement curves and the energy-absorption capacities. The results reveal that both the inner diameter and the number of layers have significant effects on the composites’ axial-compression properties. As the inner diameter and layers increase, the peak load and energy absorption of tubular 3D-woven composites both have clearly increasing trends. Finally, a finite element analysis from a mesoscale approach was conducted to simulate the axial compression of the tubular 3D-woven composites in comparison with the experimental results. The analysis shows the initial damage, stress evolution, and final failure; it also reveals the stress concentration and failure mechanisms of the composites following the axial compression. Additionally, the preforms used as reinforcements withstand the main loads in the compression process. Finally, the stress-distribution analysis confirms a secondary role for the resin.


ABSTRACT: We revisit some existing time-stepping schemes for structural dynamics with the algorithmic dissipation that fall either into the class of generalized- methods or into the class of energy-decaying (and momentum-conserving) methods. Some of the considered schemes are designed for the second-order and some for the first-order form of the differential equations of motion. We perform a comparison (for linear dynamics) of their accuracy, dissipation, dispersion, as well as of the overshoot. In order to study how these features extend to nonlinear dynamics, we choose numerical tests on shell-like examples. Shell models are a difficult check for dynamic schemes because numerically stiff equations need to be solved as an effect of a large difference between the bending (and shear) and the membrane deformation modes. For the considered schemes we illustrate their ability to decay/dissipate energy, their ability to fully/approximately conserve the angular momentum, and nonlinear order of accuracy by error indicators.

Paweł Czapski, Patryk Jakubczak, Piotr Zgórecki, Tomasz Kubiak and Jarosław Bieniawski, “Influence of manufacturing technique and autoclaving curing rate on the non-linear behaviour of thin-walled, GFRP channel...

ABSTRACT: The target of this research is to investigate the influence of manufacturing technique and autoclaving process parameters on the buckling and post-buckling behaviour of thin-walled, GFRP laminates. We investigated the compression of channel cross-section profiles with the following dimensions of the inner perimeter: (web × flange × length of the profile): 80 mm × 38 mm × 240 mm. The nominal wall thickness of the columns was equal to 1.2 mm. The inner radius at the web-flange junction was equal to 2 mm. The material used to produce the samples was eight-layered pre-preg tape with an angle-ply, symmetric layer arrangement: [45/−45/45/−45]. The columns were manufactured using two different techniques. The first technique was to form the channel cross-section profile by draping over an aluminium mandrel, while the second was to form square cross-section profiles, by winding around an aluminium mandrel, which are then cut into two channel-cross sections. Moreover, two curing process types were applied. The first is a nominal (suggested by the pre-preg producer) curing cycle on a hollow section aluminium mandrel, while the second is a modified curing cycle on a solid aluminium mandrel. In total, four different sets of specimens were produced and subjected to static compression. Higher buckling strength (denoting critical loads and post-buckling behaviour) is shown to be a result of internal, after curing stresses in the composite – the highest buckling resistance is achieved for the columns manufactured as square hollow sections and machined into channel sections. This solution is the most economically efficient. Additionally, the samples were 3D scanned in order to assess post-manufacturing distortions and the deviations from the nominal geometry.


ABSTRACT: This paper investigates the effect of carbon nanotubes (CNTs) agglomeration on the free vibration characteristics of three-phase CNT/polymer/fiber laminated truncated conical shells surrounded by an elastic foundation. The shell material is considered to be composed of a CNT-reinforced polymer enriched by the oriented reinforcing fibers. The material density and the effective elastic properties are calculated based on the rule of the mixture, and the Eshelby–Mori–Tanaka scheme along with Hahn's homogenization technique, respectively. The third-order shear deformation theory (TSDT) is used for the analysis of the shear flexible shell and the foundation is modeled based upon the Winkler-Pasternak theory. A set of governing equations are derived using Hamilton's principle, and solved numerically by the generalized differential quadrature method (GDQM). After confirming the convergence and accuracy of the results, a parametric study is carried out to examine the influences of various parameters on the natural frequencies of the three-phase CNT/polymer/fiber laminated truncated conical shells such as boundary conditions, circumferential mode number, the geometrical parameters including the ratios of thickness/length to radius, and the semi-vertex angle, the material parameters contain the mass fractions of CNTs and fibers, chiral numbers as well as the agglomeration characteristics of CNTs, and finally the foundation parameters including the Winkler stiffness and shearing layer stiffness.


ABSTRACT: This paper presents the experimental and numerical investigations of concrete-filled cold-formed high strength steel (CFHSS) circular stub columns. Firstly, a series of tests was conducted on CFHSS circular tubular sections infilled with three different concrete grades, i.e., C40, C80 and C120. The CFHSS circular tubular sections had the nominal 0.2% proof stress (yield stress) up to 1100 MPa. The test specimens were subjected to uniform axial compression The ultimate loads and failure modes of the specimens were obtained and reported in this paper. Secondly, an extensive numerical study accounting for the confinement effect, as well as the non-linearities of materials, geometry and contacts was performed. Upon validation against the test results, a parametric investigation was conducted. A wide range of the cross-section dimensions and section slenderness of CFHSS circular tubular sections infilled with different grades of concrete were considered. The structural behaviour of concrete-filled CFHSS stub columns was investigated, including the ultimate load, end shortening, strength enhancement index and ductility index. Finally, the experimental and numerical results were used to assess the suitability of the design equations specified in the existing American Specifications (AISC and ACI), European Code (EC4) and Japanese Code (AIJ) for the compressive strength of the concrete-
filled CFHSS circular stub columns. It was found that the predictions from the existing international design specifications were generally conservative, except for EC4. The predictions by the AIJ are the least conservative and least scattered. However, by using the effective section area of steel tubes for slender cross sections, EC4 provided the most accurate and consistent predictions than the other design specifications.


ABSTRACT: The ballistic limit velocity, energy absorption and the effects of facesheets thickness ratios for three types of sandwich panels consist of titanium facesheet and aluminum honeycomb core were studied experimentally and numerically. The tests are carried out by a nitrogen gas gun and 24 g hemispherical steel projectiles with velocity ranges from 100 m/s to 190 m/s. A proper ABAQUS/Explicit model was developed using the experimental data. Results shown the impact energy mainly absorbed by the rear facesheet in symmetrical sandwich panels. The ballistic limit enhanced almost linearly with increasing rear or front facesheet thickness in specimens with the same weight.


ABSTRACT: This paper presents experimental and numerical investigations of cold-formed circular stainless steel tubular (HSST) stub columns strengthened externally using carbon fiber reinforced polymer (CFRP) wraps. For the experimental investigation, eleven stub columns were tested under axial compression loading. The experimental variables were the CFRP thickness (t), the CFRP arrangement (fully or partial wrapping), and the diameter-to-thickness ratio of stainless steel tubes (D/t). The ratio of the compressive strength of wrapped specimens to that of unwrapped specimens (strengthening ratio) was employed to assess the compressive behavior of CFRP-wrapped HSST columns. Three-dimensional finite element (FE) simulation was implemented using ABAQUS software and validated against the experimental results. A parametric study was performed on the validated FE models for further investigation. The experimental results indicated that the full CFRP wrapping reasonably enhanced the ultimate compressive strength of the columns. In contrast, the partial wrapping showed no improvement in the ultimate compressive strength. The FE parametric study results showed that the strengthening ratio (i) decreases with increasing the diameter of the tubes, (ii) decreases when the failure mode changes from outward to inward local buckling (iii) is affected by the strength of the CFRP and tube materials. Based on the parametric study results, a design model was proposed to predict the ultimate strength of axially loaded CFRP-wrapped HSST stub columns.


ABSTRACT: Recently, bionic thin-walled structures have attracted widespread attention in automotive safety design because of their excellent crashworthiness behavior and weight efficiency. In this paper, inspired by the evolution laws and microstructure of plant stems, a group of bionic tubes with “m” parts and “n” layers (PmLnBTs) are proposed and investigated by theoretical prediction and numerical analysis. Theoretical models of PmLnBTs are developed to predict the specific energy absorption. Finite element model is conducted with LS-DYNA and validated by a quasi-static axial crushing experiment. The accuracy of the theoretical model is verified by numerical analysis, and the maximum relative error is less than 7%. Furthermore, parametric studies are conducted to investigate the effects of geometric parameters on the energy absorption capability of PmLnBTs. The results indicate that the PmLnBTs exhibit superior crashworthiness performance compared to traditional bi-tubular circle tubes. Moreover, when designing such a bionic energy absorber, it can effectively improve the crashworthiness performance by appropriately increasing the number of layers, reducing the outermost circle diameter or avoiding innermost circle diameter value too large or too small. The findings of this paper provide a guidance for the design of energy absorber with excellent energy absorption performance.

ABSTRACT: Combined aluminium honeycomb has been considered a promising structure in the protection field due to its excellent energy absorption capacity. To improve its application, it is crucial to understand the mechanical behaviour of combined honeycomb under explosion. Here, we examined the compression characteristics of combined honeycomb structure under explosion experimentally and through simulations. The effect of parameters, i.e. explosive scaled distance and slider thickness on compression depth and normalized compression stress were examined. Results showed that the energy absorption and compression strain decreased with the slider thickness and scaled distance. The normalized compression stress of the cutting stage remained unchanged and not sensitive to the slider thickness and scaled distance. Compared with other conventional honeycomb structures, the combined honeycomb structure exhibited promising application prospects in linear energy absorption structures. In addition, a semi-empirical formula was proposed to calculate the compression depth of two stack-up combined honeycomb, in which structural parameters and mechanics properties of the base material were considered. The predicted results were in good agreement with the experimental results.


ABSTRACT: In this study, the material and stability of 10 axial compression aluminum alloy columns are systematically tested at five temperatures. The material grade of the aluminum alloy used in the tests is 6082-T6. The experimental results demonstrate that flexural buckling occurs in all the column specimens under different temperature environments. A finite element (FE) model of the experiment is established, and the obtained results are compared with the experimental results to verify the accuracy of the FE model. To study the stability at different temperatures, 765 FE models considering geometry and material nonlinearity are created in five different temperature environments. Three section types (H-type, rectangular, and circular tube sections), three sectional dimensions for each section type, and 17 slenderness ratios are considered in the models. Based on the FE results and the statistical regression method, the formula for calculating the stability coefficient for the columns with different slenderness ratios at different temperatures is fitted. The fitting formula is compared with the test results, Chinese Code (GB), and European Code (EC9). The comparison results demonstrate that the fitting formula can provide a more accurate stability coefficient for the columns at different temperatures.


ABSTRACT: Hybrid cold-formed steel (CFS) wall panel, composed of square hollow sections (SHS) and CFS open sections, can offer some great advantages with respect to the lateral performance of light steel frames, in particular for applications in mid-rise construction. This paper presents non-linear finite element modelling of hybrid wall panels, calibrated through experimental tests, and their applications to different designs. The study involves the lateral behaviour of the proposed hybrid walls in terms of load-displacement curve, failure mode, stiffness, ductility ratio, energy absorption, and strength to weight ratio. First, a numerical model, verified and calibrated based on the experimental tests on the hybrid wall panels, is presented. Thereafter, using the validated numerical model, twenty new hybrid wall panel designs are proposed in order to investigate the effect of different SHS brace configurations on the hybrid panels’ performance. The comparison of the experimental and numerical results indicates that superior seismic performance can be achieved from the proposed hybrid CFS wall designs.


ABSTRACT: This paper presents the study on crushing response of functionally stepwise graded foam under quasi-static and dynamic compression using three-dimensional (3D) Voronoi model. A series of simulations is conducted to acquire proper computing parameters and to validate the predictability of numerical model by comparing with experiment results. Two different strategies are proposed to achieve the gradient change in
relative density by changing equivalent radius and cell-wall thickness. The main focus of present paper is placed on the effect of gradation configuration on the stress-strain response, deformation propagation and energy absorption. The results show that the gradation configuration has little effect on the crushing behavior of graded foams under quasi-static compression. However, the performance of graded foam under dynamic compression could be promoted by tailoring its gradation configuration. Adopting a negative gradation is beneficial for reducing the stress at the stationary side and maximizing the energy absorption under low strain level. A positive gradation would be preferred as an energy absorber under high strain level.


ABSTRACT: In this paper, the extended higher-order sandwich plate's theory (EHSAPT) is used to analyze the free vibration of the sandwich plate with compressible core and different boundary conditions in contact with fluid. First-order shear deformation theory is adopted for the top and bottom face sheets, while the in-plane and transverse displacements of the core are considered to be cubic and quadratic functions of the transverse coordinate, respectively. A single series is considered with two-variable orthogonal polynomials as a set of admissible functions satisfying the boundary conditions. Besides, the fluid is considered to be irrotational, inviscid and incompressible. By taking into account the boundary conditions and compatibility conditions, the fluid velocity potential is acquired. The natural frequencies of the system are calculated by the Rayleigh-Ritz method. An excellent accuracy is obtained between the results in the available literature and the present method. Finally, the effects of various parameters including boundary conditions, side-to-thickness ratio, thickness of the core to thickness of the face sheets ratio, face sheet to core flexural modulus ratio, dimensions of the container, and aspect ratios on the natural frequencies of the sandwich plate are presented and discussed in detail.


ABSTRACT: Auxetic materials are one of the metamaterials that have potential applications in many scientific and engineering fields. In this paper, an investigation is presented on the postbuckling responses of axially loaded graphenereinforced metal matrix composite (GRMMC) laminated cylindrical panels with in-plane negative Poisson's ratio (NPR). The panels are made of GRMMC laminates and rest on an elastic foundation in thermal environments. The graphene volume fraction in GRMMC layer may vary across the panel thickness in order to achieve a piece-wise functionally graded (FG) pattern. The GRMMC layers have in-plane NPR and temperature dependent material properties. The governing differential equations for the GRMMC laminated cylindrical panels are formulated based on the Reddy’s third order shear deformation shell theory and are solved by using a singular perturbation technique along with a two-step perturbation approach. Numerical investigation is carried out to study the influence of the in-plane NPR, the FG patterns, the thermal environmental conditions and the foundation stiffness on the postbuckling responses of the GRMMC laminated cylindrical panels under axial compressive load. The results reveal that the in-plane NPR can lead to a substantial change of the postbuckling behaviors of the GRMMC laminated cylindrical panels.


ABSTRACT: To investigate the effect of corrosion on the local and post-buckling behavior of axially-compressed steel members, H-shaped Q345B steel columns with different corrosion degrees were obtained by accelerated corrosion test. Then, an axial compression test was performed to analyze the relationships between the failure mode, local buckling load, and ultimate load and the corrosion degree. Finally, more than 80 finite element models of steel columns with different corrosion parameters were established in the software ABAQUS, and a modified direct strength method for corroded axially-compressed steel stub columns considering local buckling was proposed. The results showed that the axial-load capacity of the axially-compressed steel column decreased gradually with the increased degree of corrosion. The yield load, ultimate load and local buckling load of the most seriously corroded specimen decreased by 15.0%, 18.9% and 21.4%, respectively. The corrosion changed the failure modes of specimens and gradually decreased the half-
wavelength, which weakened the plastic deformation capability of specimens and led to the failure mode of the steel columns transforming from strength failure to stability failure. In addition, the corrosion pits had less of an effect on the axial-load capacity of specimens than the thickness loss. Under the same corrosion type, the location and size of the corrosion would not affect the ultimate load of the axially-compressed members, which only depended on the damage degree of weakest section. Finally, the proposed formula can accurately predict the post-buckling behavior and ultimate load of corroded H-shaped axially-compressed steel columns by comparing the experimental data with the finite element results and the results in the existing literature.

ABSTRACT: This paper is concerned with the effect of variation in temperature and moisture concentration on free vibration response of skew laminated hybrid composite and sandwich plates. The coupled thermo-elastic and hygro-elastic finite element model is formulated using the first-order shear deformation theory (FSDT). Uniform temperature and moisture concentration rise is considered for the analysis. Soft-core viscoelastic materials are considered for the sandwich plates and are modeled using the complex modulus approach. Linear strain-displacement relations are used to develop a mechanical stiffness matrix, and the initial stress stiffness matrix is generated using non-linear strain-displacement relations to represent the non-mechanical stiffness matrix. Numerical examples for the generated finite element model are presented and discussed comprehensively to understand the effect of temperature, moisture concentration, skew angle, length to width ratio, length to thickness ratio, and boundary conditions on the vibration response of the laminated hybrid composite and sandwich plates. Further investigation is devoted to studying the influence of temperature and moisture concentration-dependent material properties, stacking sequence, core to face sheet thickness ratio, and fiber orientation on vibration behavioral response of sandwich and hybrid composite plates.

ABSTRACT: The design and multiobjective optimization of graded foam-cored sandwich cylinders (GFSCs) composed of tubular face sheets and layered gradient foam core under internal air-blast loading were examined. The response surface method and nondominated sorting genetic algorithm were used in the defined optimization problem to determine the optimal face-sheet thickness and core gradient as well as achieve the minimum specific deflection of outer face sheet (SDF) and maximum specific energy absorption (SEA). Multiobjective optimization was subsequently conducted to obtain the Pareto front and improve the blast-resistant performance of the optimum GFSC configuration. Results obtained via these optimizations further indicated that the optimal GFSCs demonstrated better energy absorption characteristics than ordinary sandwich cylinders. Under the same SDF, SEA increased by 75.4% and 45.0% compared with that of the initial baseline design when the core gradient and face-sheet thickness were individually optimized, respectively. The joint optimization of face-sheet thicknesses and core gradient could significantly improve the blast-resistant performance by 171.1%. The optimization of GFSCs should primarily optimize the design variables with high-price performance ratio while reasonably arranging the design variable quantity, ensuring the controllable cost of calculation, and significantly improving the blast-resistant performance. The results also showed that the strength of CFSCs and the interaction between the face sheets and the core improved the blast-resistant capacity. The design optimization results could provide appropriate guidance in the crushworthiness design of GFSCs.

ABSTRACT: Wrinkling of QSTE700 high strength steel thin-walled rectangular welded tube is easy to occur in rotary draw bending (RDB) process due to the existence of non-homogeneous weld zone and corner with cold bending effect. So the FE model of RDB of QSTE700 rectangular welded tube considering weld zone and corner with cold bending effect was established. Based on this FE model, the effect of weld zone and corner with cold bending effect on wrinkling of inner flange and side wall of rectangular welded tube in RDB was researched. The results showed that: when weld zone and corner with cold bending effect were studied
ABSTRACT: The stability of functionally graded porous plates with graphene platelets reinforcement (FGP-GPLs) is investigated in this paper. Combining with a new metamodeling approach, namely the Kriging enhanced Neural Network, a stochastic isogeometric analysis (SIGA) framework is proposed for assessing the structural stability. The uncertainties of material properties of both FGP matrix and graphene platelets are considered in the form of random fields and variables. Karhunen-Loève expansion based Nyström method is applied to random field discretization. The Dagum function is adopted as a new kernel function to further improve the performance of the proposed approach. Statistical information including but not limited to statistical moments, probability density function (PDF), and cumulative distribution function (CDF) of the critical buckling load of the plate structure can be effectively estimated through a non-intrusive fashion. In order to illustrate the effectiveness and applicability of the proposed stochastic computational analysis, both theoretical and real-life engineering examples have been investigated in this study.


ABSTRACT: Any research and development of the analysis methods, theoretical or numerical ones, for evaluating hull girder's ultimate torsional strength must be based on a thorough understanding of the torsional collapse behaviors of the hull girder, especially for the warping and shear characteristics involved in hull girder's torsional collapse process. In this paper, firstly, the torsional collapse behaviors of a single-compartment hull girder that could represent a scale model of the mid-ship compartment of a container ship are illustrated based on both experimental and numerical observations. Then, torsional collapse mechanisms of the global hull girder (i.e., the full-length model) are parametrically studied to figure out the major factors and the critical point that make the hull girder collapse in different failure mechanisms (i.e., warping or shear failure). Also, a formula is developed to quantitatively characterize the effect of hull girder's longitudinal dimension and transverse frameworks' rigidity on the ultimate torsional strength of the hull girder. Results show that the torsional collapse mechanisms between the single-segment hull girder and the global hull girder are very different due to warping effect. The longitudinal dimension and transverse frameworks of the global hull girder can have a considerable effect on hull girder's torsional collapse behaviors and ultimate torsional strength. The objective of this research is to make a detailed and comprehensive understanding of hull girder's torsional collapse process and behaviors, figuring out the major factors and the critical point that govern warping or shear failure mechanisms of the hull girder under torsion.


ABSTRACT: The dynamic response of polyurethane (PU) foam core sandwich panels subjected to contact underwater explosions (UNDEXs) was experimentally investigated in this paper. The investigation focused on the effect of face-sheet configurations on the deformation/failure modes and protective performance of the target sandwich panels. Special attention was paid to discussing the relative performance and intrinsic mechanisms amongst PU foam core sandwich panels and other two groups of sandwich panels with polyvinyl chloride (PVC) and aluminum (AL) foam cores. Multiple failure modes were exhibited by the post-tested specimens including petalling of the front face, fragment generation, petalling and Mode Itc of the back face, core perforation and global bending, as well as core-face debonding. Regardless of stand-off distances and core
materials, a more efficient way to minimize the damage level of the target panels and the permanent deformation of witness plates is allocating more mass to the back face rather than the front one. The promising core material to resist the contact UNDEX is the PVC foam with a higher crushing strength when the impulse is relatively low. If the impulse possesses a high-level intensity enough to induce petalling failure of back faces, the AL foam with a higher perforation resistance would become the best option to avoid the generation of a back cap.

ABSTRACT: This paper presents solutions for the buckling load of rectangular shear-deformable orthotropic laminated plates under uniaxial compression within the framework of Reddy's third-order shear deformation theory (TSDT). The supporting effect of the surrounding structure is represented by laterally attached rotational restraints. First, an analysis approach is presented that uses a simple energy-based formulation in the form of a Rayleigh-quotient for which specific and rather straightforward shape functions for the out-of-plane buckling deformations as well as for the rotational degrees of freedom are employed. Second, a Lévy-type solution is derived for the plate buckling problem in the framework of the TSDT. A comparison of the results with the Lévy-type solution and reference results shows that the analysis approach works with satisfying accuracy, thus making it suitable for engineering analysis of plates with arbitrary thickness especially when computational time and effort are essential factors.

ABSTRACT: Beams are structural components that are mainly utilized to resist flexure. However, beam sections are also commonly used to resist axial tension and compression in certain situations such as when they are used as truss members or braces. Pretwisting compression members strengthens their weak flexural plane and weakens their strong flexural plane, leading to an overall improvement in the buckling capacity. In this paper, pretwisting is applied to structural steel UB100 × 50 × 9.3 beam sections, both experimentally and numerically using finite element (FE) analysis, in an attempt to improve their critical buckling capacity. The experimental study consists of fourteen specimens of three different lengths and a variety of pretwist angles, while the linear-perturbation FE analysis considers ninety-one specimens of eight length groups and a pretwist angle range between 0° and 180°. In both studies, it was found that pretwisting improves the critical buckling capacity of UB100 × 50 × 9.3 beams. The linear-perturbation analysis also showed that the length of the members has no effect on the buckling capacity improvement, and that this improvement is highly significant under fixed-fixed end conditions but not under pinned-pinned conditions.

ABSTRACT: A novel method for the spatial discretization of two-dimensional domains is derived and applied to the problem of free vibrations of singly curved shells. This new method utilizes a tensor product of two independent families of lines to discretize the geometry and kinematics of a surface. The first family consists of NURBS functions which are implemented in agreement with the isogeometric approach. The second family of lines is a carefully selected series which satisfies boundary conditions a priori. The present hybrid formulation unifies spatial discretization schemes of the semi-analytical Finite strip method and the Isogeometric analysis. The obtained method inherits many features of both of the underlying techniques, e.g., high continuity in both directions, decoupling of the governing equations, and exact initial geometry. Thorough numerical analysis shows that this novel method is well-suited for the efficient and accurate free vibration analysis of singly curved thin shells.

ABSTRACT: For the first time, an investigation on the shape and material optimization for buckling behavior of functionally graded (FG) toroidal shells using differential evolution (DE) algorithm is presented in this paper. For buckling analysis, an analytical approach is used to derive governing equations, then combining with the Galerkin procedure to obtain the critical buckling load. In the optimization problem, the material distribution of functionally graded material is described by interpolated points whose coordinates of these interpolated points are located along the thickness direction of the toroidal shell using Hermite cubic functions. The design variables are volume fraction at the interpolated points. The DE algorithm is employed to find maximum critical buckling loads with ceramic volume fraction constraints. In the section of numerical results, the reliability of the current formulation is validated by several examples. Furthermore, a comprehensive examination of the influences of geometric and material parameters, etc., on the buckling behavior of the FG toroidal shells are performed. Besides, the study sets out to explore current optimal results to its effectiveness and robustness, in particular distributions, in order to examine its impact on critical buckling loads.


ABSTRACT: In this paper, the buckling performance of curvilinearly grid-stiffened variable-stiffness composite cylindrically curved panels subjected to in-plane compressive loads under different boundary conditions is addressed. A Python-Abaqus script is developed to perform the buckling analysis of the panels. A novel planar mesh wrapping based approach is proposed to ease modelling of such curved panels with complex geometry. This approach offers numerous advantages including but not limited to separately modelling the skin and stiffeners using conventional shell elements as well as studying the mesh convergence of each component independently leading to more efficient and robust finite element models appropriate for optimization implementation. Using the proposed approach various parametric studies are conducted to investigate the influence of the panel curvature and the stiffness variation created by the fibers and stiffeners on the buckling response. Subsequently, an optimization routine is implemented to simultaneously determine the optimal fiber and stiffener paths for maximum buckling capacity. It is shown that by replacing the straight stiffeners by curvilinear ones the buckling resistance of the grid-stiffened quasi-isotropic skins can be enhanced. It is also shown that the panel curvature has a significant effect on the optimal layout of the grid-stiffeners. Optimization results demonstrate that for shallow curved panels up to 100% improvement in the buckling performance can be achieved by concurrently optimizing the curvilinear fiber trajectories of both the skin and stiffeners compared to their straight fiber and stiffener design counterparts.


ABSTRACT: Graded core sandwich structures have great potential for designing and optimization under special requirement. In the present work, the dynamic response of clamped square sandwich panel (SP) with layered-gradient metal foam core subjected to blast loading was investigated. A new yield criterion of SP with three-layer metal foam core was proposed, and the analytical solutions for maximum deflection over the center point of the panels were obtained. Furthermore, the corresponding results of finite element simulations and experiments were compared to validate the theoretical model. The numerical simulation and experimental results both show good agreements with theoretical predictions. It is shown that the uniform core SP is better than that of the gradient core one and the negative gradient SP is superior to that with positive gradient core in blast resistance for the same equivalent mass. Finally, the minimum mass designs of three-layer SP are stated by constructing geometry optimization diagram according to analytical formula. The theoretical analysis established is of great important in guiding engineering application of sandwich structure with multi-layer core under air-blast loading.

ABSTRACT: The shear response of the cold-formed stainless steel lipped channel sections with longitudinal stiffeners has not been investigated adequately in the past. Therefore, this paper presents the details of numerical investigations conducted to study the shear behaviour of longitudinally stiffened cold-formed stainless steel lipped channel sections. Following a validation study of the finite element models of lipped channel sections, the effect of return lips and web stiffeners on the shear response of lipped channel sections was examined through comprehensive numerical parametric studies. In addition, numerical investigations were conducted to study the elastic shear buckling response of the sections and the shear buckling coefficients were back-calculated. It was found that the longitudinal web stiffeners enhance the shear buckling resistance of lipped channel sections considerably with increased stiffener depth. However, the shear capacity increment is not significant compared to plain lipped channel sections. The presence of the web stiffeners is found to be not preventing the out-of-plane buckling of the sections. The evaluation of Eurocode 3 and the direct strength method shear provisions for stainless steel channel sections with longitudinal stiffeners illustrates inaccurate capacity predictions. Therefore, modifications were proposed and comparisons reveal that the proposed provisions enhance the shear resistance predictions with good accuracy over the codified provisions.


ABSTRACT: In this paper, a comprehensive examination is presented to study the free vibration treatment of pre- and post-buckled rotating functionally graded beams. The framework of the Euler-Bernoulli beam model alongside the von-Kármán strain-displacement relationship is employed to access the weak form of the nonlinear governing equations. The thermo-mechanical properties of the constituent materials are considered to be temperature-dependent. The nonlinear finite element method is accompanied by some proposed algorithms to release the pre/post-buckling natural frequencies. The outcomes for the pre/post-buckling fundamental natural frequencies reveal that rotating simply-clamped beams treat qualitatively different in comparison with the other boundary condition types including the clamped-simply one although stationary simply-clamped and clamped-simply beams treat similarly.


ABSTRACT: The coupled effect of geometric and material nonlinearity existing in the buckling process of the stiffened plates sometimes makes it difficult to evaluate their ultimate load capacity numerically. Therefore, so far, experimental tests are still indispensable in the design process of a complicated structure. However, the experimental methods for predicting the whole buckling process of a stiffened plate subjected to in-plane compressive load are still not well developed. In this paper, the fundamental element in the complicated bearing structures, stiffened plate, was set as the object, and its buckling process was deeply analysed. Then, a set of similarity criteria for the stiffened plate subjected to compressive load were proposed based on the Buckingham's Pi theorem, by which the designed scale models for experimental tests could keep similar to the real structures in the whole loading process. Then, the similarity criteria were verified by numerical simulations and experimental tests with different scale models. The work presenting in this paper may potentially contribute to improving the precision of the experimental prediction of the structural ultimate load capacity and the corresponding optimization works.

References listed at the end of the paper:
1 O.F. Hughes, B. Ghosh, Y. Chen, Improved prediction of simultaneous local and overall buckling of stiffened panels, Thin-Walled Struct., 42 (2004), pp. 827-856
2 J.K. Paik, B.J. Kim, Ultimate strength formulations for stiffened panels under combined axial load, in-plane bending and lateral pressure: a benchmark study, Thin-Walled Struct., 40 (2002), pp. 45-83
5 M.C. Xu, C. Guedes Soares, Comparison of calculations with experiments on ultimate strength of wide stiffened panels, Mar. Struct., 31 (2013), pp. 82-101
7 N.E. Shanmugam, D.Q. Zhu, Y.S. Choo, M. Arockiaswamy, Experimental studies on stiffened plates under in-plane load and lateral pressure, Thin-Walled Struct., 80 (2014), pp. 22-31
12 S. Zhang, I. Khan, Buckling and ultimate capability of plates and stiffened panels in axial compression, Mar. Struct., 22 (4) (2009), pp. 791-808
30 T. Yao, M. Fujikubo, Buckling and Ultimate Strength of Ship and Ship-like Floating Structures (2016)
34 J. Berthier, P. Silberzan, Microfluidics Biotechnol., 1 (2006)

ABSTRACT: By proposing the unifier factors, a unified formulation for the generalized coupled thermo-viscoelasticity response of hollow spheres based on the Lord–Shulman, Green–Lindsay, and Green–Naghdi models is developed. Kelvin–Voigt model is used in the current research to consider the viscoelastic response of the sphere. This formulation is used to capture the thermoviscoelastic response of finite isotropic hollow sphere under thermal shock. After transforming the one-dimensional radial equations into the non-dimensional form, finite element method (FEM) based on the Galerkin weak formulation is implemented. The governing equations are discretized through the radial domain utilizing FEM. The determined system of ordinary differential equations is traced using the average acceleration method as a type of Newmark time marching scheme. After validation, novel numerical results are demonstrated to analyze the influences of viscoelastic damping on the response of hollow sphere under rapid surface heating based on various types of generalized theories.


ABSTRACT: Metal cylindrical shells subjected to axial compressions are prone to buckling. The buckling strength is highly sensitive to geometric imperfections. Experimentally tested cylinders with intended imperfection have already, in most cases, inevitable (unintended) forms of imperfections, such as weld depressions at the weld joints, irregularity in the shape of the cylinder and imperfections due to loading/supporting conditions. The interaction between the effects of the intended and the unintended imperfections in the experimental investigations makes the determination of the sole effect of either one hard to be identified. To evaluate the buckling strength reduction due a certain intended form of imperfection such as a localized dent, the effect of the other hidden (unintended) imperfections should be accounted for, otherwise a misleading strength reduction value will be obtained. In this study, a simple approximate procedure accounting for the effect of the unintended imperfections is proposed and explained though a finite element (FE) analysis of experimentally tested specimens with intended dent imperfections. Geometric imperfections equivalent in their strength reduction to that of the unintended imperfections are introduced to the FE analysis and referred to as “equivalent imperfection”. The experimental value of the buckling strength for the intact specimen (without a dent but having unintended imperfections) along with the FE model are used to calibrate the equivalent imperfection that represents all possible forms of unintended imperfections. On the light of this study, general recommendations for conducting combined experimental-numerical parametric studies are proposed.

References listed at the end of the paper:
1 J.G.A. Croll, Towards simple estimates of shell buckling loads, Stahlbau, 44 (1975), pp. 243-248
2 J.G. Croll, Towards a rationally based elastic-plastic shell buckling design methodology, Thin-Walled Struct., 23 (1-4) (1995), pp. 67-84
4 R.C. Batista, A Design Approach for Unstiffened Cylindrical Shells under External Pressure, Thin-Walled Structures, Granada (1979)
C. Hühne, R. Rolfs, E. Breitbach, J. Teßmer, Robust design of composite cylindrical shells under axial compression - simulation and validation, Thin-Walled Struct., 46 (7-9) (2008), pp. 947-962


S.G.P. Castro, R. Zimmermann, M.A. Arbelo, R. Degenhardt, Exploring the constancy of the global buckling load after a critical geometric imperfection level in thin-walled cylindrical shells for less conservative knock-down factors, Thin-Walled Struct., 72 (2013), pp. 76-87


B.C. Cerik, Ultimate strength of locally damaged steel stiffened cylinders under axial compression, Thin-Walled Struct., 95 (2015), pp. 138-151


ABSTRACT: This article describes an experimental study of the impact behaviour of a novel composite corrugated core sandwich structure under low-velocity impact. Influences of geometric parameters of the novel sandwich core, such as thickness, height, and short span length were studied. Four different configurations of composite corrugated core sandwich structures were prepared and tested. The impact events were monitored using a high-speed camera and measured by an impact force transducer and accelerometer attached to the impactor. The results revealed that the increase of core thickness improved impact capacity while the increase of core height decreased sandwich strength by increasing elastic deformation. The damage status of the novel composite core sandwich was simulated and insight into the damage mechanism was gained with finite element analysis. This study proposes an improved numerical model by incorporating the effect of the impactor head which was able to predict the impact capacity to within 10% variation of the experimental results. The results also identified that the multi-cell composite corrugated core increased the impact capacity due to the continuity of the fibres between adjacent cells. Moreover, the trapezoidal composite corrugated sandwich core showed higher specific strength compared to traditional honeycomb, truss and foam cores.

References listed at the end of the paper:

2 A. McCracken, P. Sadeghian, Partial-composite behavior of sandwich beams composed of fiberglass facesheets and woven fabric core, Thin-Walled Struct., 131 (2018), pp. 805-815
ABSTRACT: This paper presents the experimental investigation of aluminum alloy built-up sections subjected to low-velocity impact event. Aluminum alloy built-up sections were manufactured with different lengths and hole diameters. The capacity of web would reduce due to loss of material. The influence of web holes on the flexural behavior and strength was studied experimentally. The predicted strengths were also compared with the experimental results. It was found that the current DSM can be used to predict the flexural and shear strengths of aluminum alloy perforated built-up beams, and the predicted results are generally conservative.

References listed at the end of the paper:

3 Y. Kim, T. Pekoz, Flexural strength of aluminum members with tapered thickness component elements, Thin-Walled Struct., 135 (2019), pp. 507-520
ABSTRACT: This paper investigates graphene nanoplatelets (GPLs) reinforced composite (GPLRC) with matrix cracks by using element-free IMLS–Ritz method. The effective Young's modulus of each GPLRC layer is determined by the modified Halpin-Tsai micromechanics model while its Poisson's ratio and mass density are predicted according to the rule of mixtures. The degraded stiffness of cracked layers is modeled via the self-consistent micromechanical model. The first-order shear deformation theory and first-order piston theory are
employed to formulate aeroelastic model. Element-free IMLS-Ritz method is applied to discretize the equation of motion. The accuracy of the IMLS-Ritz results is examined by comparing the natural frequency and critical aerodynamic pressure with those obtained from published values. A comprehensive parametric study is carried out, with a particular focus on the effects of matrix crack density, distribution pattern, weight fraction, total number of layers, geometry of GPLs, and aspect ratio of plates on the flutter bound of matrix cracked GPLRC plates.

Konstantinos Bakalis (1) and Spyros A. Karamanos (2)
(1) Resilient Steel Structures Laboratory (RESSLab), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland
(2) Department of Mechanical Engineering, University of Thessaly, Volos, Greece


ABSTRACT: Motivated by the seismic response of unanchored liquid storage tanks, their uplift mechanism under strong lateral loading is examined. Using three-dimensional finite element models, nonlinear static analysis is conducted to define the moment-rotation relationship of uplifting tanks resting on rigid foundation and describe the evolution of critical response parameters with increasing level of lateral loading. Meridional and hoop stress, as well as their distribution and evolution with increased uplift are computed. Comparing the numerical results with the corresponding results from anchored tanks, striking differences are observed on the values of compressive meridional stresses and their distribution around the tank circumference. Cyclic analysis, associated with repeated uplift at both sides of the tank, is also performed, to obtain the corresponding hysteretic response and verify the assumption of nonlinear-elastic tank behaviour, used in several previous works. Finally, an analytical solution is developed, capable of describing tank uplift in an efficient manner. The analytical solution accounts for the special features of uplift, obtained from the finite element solution, and can be used for simple and reliable assessment of seismic performance in unanchored liquid storage tanks.

References listed at the end of the paper:
1 K. Hatayama, Damage to oil storage tanks from the 2011 Mw 9.0 Tohoku-Oki tsunami, Earthq. Spectra, 31 (2015), pp. 1103-1124, 10.1193/07013EQS120M
7 American Petroleum Institute, Seismic Design of Storage Tanks - Appendix E, Welded Steel Tanks for Oil Storage, (2007), p. 552
9 NZSEE, Seismic Design of Storage Tanks, New Zealand, National Society for Earthquake Engineering Wellington, New Zealand (2009)
13 INDUSE-2 SAFETY, Component fragility evaluation and seismic safety assessment of ‘special risk’ petrochemical plants under design basis and beyond design basis accidents, http://www.induse2safety.unimn.it/ (2014)
16 J.M. Rotter, Elephant's foot buckling in pressurised cylindrical shells, Stahlbau, 75 (2006), pp. 742-747, 10.1002/stab.200610079
22 M. Vathi, S.A. Karamanos, I.A. Kapogiannis, K.V. Spiliopoulos, Performance criteria for liquid storage tanks and piping systems subjected to seismic loading, J. Pressure Vessel Technol., 139 (2017), Article 051801, 10.1115/1.4036916
46 CEN, Hot Rolled Steel Channels, I and H Sections - Dimensions and Masses, (2017), EN 10365:2017
47 CEN, Structural Steel Equal and Unequal Leg Angles, (2017), (EN 10056-1:2017)
48 ABAQUS Documentation (6.13), Dassault Systèmes, Providence, RI, USA (2013)
Aileen G. Bowen (1), Giovanni Zucco (1) and Paul M. Weaver (2)

(1) University of Limerick and Bernal Institute, Ireland
(2) Bernal Chair in Composite Materials and Structures, University of Limerick, Ireland


ABSTRACT: Aerospace and industries where both localised compliance and weight savings play a central role in design can benefit from using flexible hinges. These morphing structures use no mechanical hinges for folding. They fold by exploiting the limit point, i.e. the Brazier moment, of a geometrically nonlinear structural response characteristic of thin-walled beams under bending. Therefore, a smaller Brazier moment induces smaller non-classical stresses in the hinge during folding. Two aspects make cross-ply laminates attractive for designing flexible hinges. Firstly, the difference between the Brazier moment of an optimal symmetric generic laminate and that of an optimal symmetric cross-ply is relatively small. Secondly, cross-ply laminates do not exhibit extension-shear or bend-twist couplings which can induce complex deformations which can present challenges during design, especially considering that available analytical solutions of the Brazier moment neglect their effects. Driven by these premises, this work contributes to the preliminary design of flexible hinges by offering an analytical solution of the optimum symmetric cross-ply laminate for minimising the Brazier moment, which is subsequently validated through geometrically nonlinear finite element analysis. Moreover, this work provides insights into the prediction of the folding load considering the effects of local buckling instabilities.

References listed at the end of the paper:

10 T. Von Kärmán, Ueber die forderung dummwanndiger rohre, insbesondere federrnder ausgleichrohre, Z. VDI, 55 (1911), pp. 1889-1895
12 A. G. Bowen P, G. Zucco, P. M. Weaver, Orthotropic cylindrical flexible hinges by exploiting nonlinear brazier phenomena, Submitted to AIAA J.

ABSTRACT: To improve the load carrying capacity, structural stiffness, and impact resistance of a honeycomb sandwich structure, the honeycomb holes are filled with metallic tubes. Experimentally and numerically studies were carried out on the drop weight impact response of the tube-reinforced honeycomb sandwich structure. The results show that the stiffness and peak load of the honeycomb sandwich structure were increased by the metallic tube filler. The addition of tube filler made the Mises stress and deformation distribution of the front and back face-sheets more uniform. In addition, the tube-reinforced structure absorbed the impact energy more quickly than the empty honeycomb sandwich structure and the front face-sheet deformation was markedly reduced by tube reinforcement. The peak load and contact energy (the energy absorbed by the local deformation of sandwich structures) were predicted theoretically for both empty honeycomb sandwich structure and tube-reinforced honeycomb sandwich structure. The finite element parametric study shown that, compared with the empty honeycomb sandwich structure, the maximum deflections of the front and back face-sheets of the globally filled tube-reinforced honeycomb sandwich structure were reduced by 18.6% and 36.4% respectively. The tube-reinforced honeycomb sandwich structure is a promising structure for weight sensitive applications owing to its improved load carrying capacity and impact resistance.

References listed at the end of the paper:


2 Z.G. Wang, Recent advances in novel metallic honeycomb structure, Compos. B Eng., 166 (2019), pp. 731-741


7 C.C. Foo, L.K. Seah, G.B. Chai, Low-velocity impact failure of aluminium honeycomb sandwich panels, Compos. Struct., 85 (1) (2008), pp. 20-28

22 X.Y. Zhang, F. Xu, Y.Y. Zhang, F. Wei, Experimental and numerical investigation on damage behavior of honeycomb sandwich panel subjected to low-velocity impact, Compos. Struct., 201 (2020), p. 111882
References listed at the end of the paper:

51 M.N. Su, B. Young, Material properties of normal and high strength aluminium alloys at elevated temperatures, Thin-Wall Struct., 137 (2019), pp. 463-471
53 M.M. Xu, G.Y. Huang, Y.X. Dong, S.S. Feng, An experimental investigation into the high velocity penetration resistance of CFRP and CFRP/aluminium laminates, Compos. Struct., 188 (2018), pp. 450-460


ABSTRACT: Angle sections have been extensively used in bridge bracings, communication and power towers, trusses and bracings diaphragms. Within these cases, a commonly adopted configuration is the starred section, usually achieved with the association of two equal-leg angles connected by welds or bolted plates. On the other hand, stainless steel has been increasingly being adopted in structural engineering due to its high versatility, high corrosion and excellent mechanical properties. This paper focus on the torsional buckling behaviour of A304 austenitic stainless steel starred angle rolled sections behaviour under compression. The adopted methodology involved an experimental campaign totalling eight tests. These tests were performed on L63.5 × 63.5 × 4.76 rolled sections in starred angle section assembled in three configurations: angles without internal connections; angles connected by welding; and angles connected by bolted plates. The experimental campaign was followed by comprehensive finite element simulations, considering geometrical and material nonlinearities, made to enlarge the database involving a torsional buckling failure mode. Subsequently, the results were also compared with Eurocode 3 (EC3) and two alternatives (Alpha and Lambda) design methods. The EC3 prediction presented more significant discrepancies compared to experimental and numerical results, confirming this code's natural conservatism. These discrepancies were not observed when the alternative (Alpha and Lambda) design methods were utilised to forecast the torsional buckling ultimate loads indicating a significant performance improvement.

References listed at the end of the paper:
1 P.B. Dinis, D. Camotim, N. Silvestre, On the local and global buckling behaviour of angle, T-section and cruciform thin-walled members, Thin-Walled Struct., 48 (2010), pp. 786-798
12 D. Popovic, G.J. Hancock, K.J.R. Rasmussen, Compression tests on cold-formed angles loaded parallel with a leg, J. Struct. Eng., 127 (2001), pp. 600-607
13 AS 4600, Cold-formed Steel Structures, Standards Australia/Standards New Zealand, Sydney, Australia (1996)
14 AISC, Specification for the Design of Cold-Formed Steel Structural Members, American Iron and Steel Institute, Washington, D.C (1996)
17 B. Young, Tests and design of fixed-ended cold-formed steel plain angle columns, J. Struct. Eng., 130 (2004), pp. 1931-1940
18 B. Young, Experimental investigation of cold-formed steel lipped angle concentrically loaded compression members, J. Struct. Eng., 131 (2005), pp. 1390-1396
23 P.B. Dinis, D. Camotim, N. Silvestre, On the mechanics of thin-walled angle column instability, Thin-Walled Struct., 52 (2012), pp. 80-89
24 E. Mesacasa Jr., P.B. Dinis, D. Camotim, M. Malite, Mode interaction in thin-walled equal-leg angle columns, Thin-Walled Struct., 81 (2014), pp. 138-149
33 Y. Sun, L. Zhanke, L. Yating, O. Zhao, Experimental and numerical investigations of hot-rolled austenitic stainless steel equal-leg angle sections, Thin-Walled Struct., 144 (2019), pp. 1-12

ABSTRACT: The present study develops a theory for the static analysis of thin-walled members with general asymmetric cross-sections. The theory captures global and through-thickness warping, in addition to shear deformation effects. Starting with the principle of stationary potential energy, the governing equilibrium equations are developed along with the possible boundary conditions. The theory leads to seven field equations in the axial displacement, lateral and transverse displacements, bending rotation angles, angle of twist, and warping deformation. Unlike conventional non-shear deformable thin-walled beams which predict a torsional response that is uncoupled from the flexural responses, the differential equations obtained herein are fully coupled when applied to beams with asymmetric cross-sections. Closed-form solutions are formulated for beams with asymmetric, monosymmetric, point symmetric, and doubly symmetric cross-sections. Comparisons with the predictions of previous thin-walled beam theories/finite elements and shell finite element solutions verify the validity of the present theory and quantify the effects of shear deformation, through-thickness warping, and the coupling arising from to shear deformation. Numerical examples illustrate the partial coupling effects arising in the special cases of monosymmetric, point symmetric, and doubly symmetric sections.

References listed at the end of the paper:

17 M. Mohareb, F. Nowzartash, R.E. Erkmen, Torsional analysis of wide flange beams including shear deformation effects, Proceedings of the Eighth International Conference on Computational Structures Technology, Las Palmas de Gran Canaria, Spain (2006)
18 R. Emre Erkmen, M. Mohareb, Torsion analysis of thin-walled beams including shear deformation effects, Thin-Walled Struct., 44 (2006), pp. 1096-1108
24 F. Laiuero, M. Savoia, Shear strain effects in flexure and torsion of thin-walled beams with open or closed cross-section, Thin-Walled Struct., 10 (1990), pp. 87-119
26 J. Jönsson, Distortional theory of thin-walled beams, Thin-Walled Struct., 33 (1999), pp. 269-303
27 N.-I. Kim, M.-Y. Kim, Exact dynamic/static stiffness matrices of non-symmetric thin-walled beams considering coupled shear deformation effects, Thin-Walled Struct., 43 (2005), pp. 701-734
38 N.M.F. Silva, N. Silvestre, D. Camotim, GBT formulation to analyse the buckling behaviour of FRP composite open-section thin-walled columns, Compos. Struct., 93 (2010), pp. 79-92
39 S. de Miranda, A. Gutierrez, R. Miletta, F. Ubertini, A generalized beam theory with shear deformation, Thin-Walled Struct., 67 (2013), pp. 88-100
42 N. Silvestre, D. Camotim, Generalized beam theory to analyze the vibration of open-section thin-walled composite members, J. Eng. Mech., 139 (2013), pp. 992-1009
ABSTRACT: The conical shell structure is prone to dynamic instability when subjected to time dependent periodic axial loads and it can cause structural damage. Based on that this paper presents an accurate and semi-analytical method for investigation the dynamic instability of porous functionally graded material (PFGM) conical shell in thermal environment. In the analysis, three common types of PFGM conical shells, namely, uniform, symmetric and asymmetric distribution are considered assuming that material properties are related to temperature. The governing equations of conical shell subjected to parametric excitation are established by the Hamilton's principle considering first order shear deformation theory. Then the Mathieu-Hill equations describing the parametric stability of conical shell are obtained by generalized differential quadrature (GDQ) method, and the Bolotin's method is utilized to obtain the first-order approximations of principal instability regions of shell structure. By comparing the numerical results with the existing solutions in open literature, the validity of the proposed theoretical model is verified. Finally, the influences of porosity distribution type, gradient index, radius-to-thickness ratio, porosity volume fraction and temperature fields on the dynamic stability of PFGM conical shell have been investigated, wherein for different porosity distribution types, the UPD type is more sensitive to gradient index as compared to other three types, while the SPD has the minimum relative width.

References listed at the end of the paper:
8 J. Tani, Influence of deformations before instability on the parametric instability of conical shells under periodic pressure, J. Sound Vib., 42 (2) (1976), pp. 253-258
9 J. Tani, Influence of deformations prior to instability on the dynamic instability of conical shells under periodic axial load, J. Appl. Mech., 43 (1) (1976), pp. 87-91
13 K.Y. Lam, T.Y. Ng, Dynamic stability of cylindrical shells subjected to conservative periodic axial loads using different shell theories, J. Sound Vib., 207 (4) (1997), pp. 497-520
15 Q. Han, F. Chu, Effects of rotation upon parametric instability of a cylindrical shell subjected to periodic axial loads, J. Sound Vib., 332 (22) (2013), pp. 5653-5661
17 Q. Han, F. Chu, Parametric resonance of truncated conical shells rotating at periodically varying angular speed, J. Sound Vib., 333 (13) (2014), 2866-2844
30 A.H. Sofiyev, Influences of shear deformations and material gradient on the linear parametric instability of laminated orthotropic conical shells, Compos. Struct., 225 (2019), p. 111156
32 A.H. Sofiyev, N. Kuruoglu, Domains of dynamic instability of FGM conical shells under time dependent periodic loads, Compos. Struct., 136 (2016), pp. 139-148
35 X. Li, C.C. Du, Y.H. Li, Parametric instability of a functionally graded cylindrical thin shell subjected to both axial disturbance and thermal environment, Thin-Walled Struct., 123 (2018), pp. 25-35
42 X.L. Huang, L. Dong, G.Z. Wei, et al., Nonlinear free and forced vibrations of porous sigmoid functionally graded plates on nonlinear elastic foundations, Compos. Struct., 228 (2019), p. 111326

ABSTRACT: An initially curved beam is considered and its motion is constrained using two elastic constraints; the corresponding non-smooth nonlinear transverse dynamics is investigated for the first time. A clamped-clamped beam with one axially movable end is modelled via Bernoulli-Euler beam theory together with the inextensibility condition, giving rise to nonlinear inertial terms along with nonlinear geometric terms. Furthermore, the damping is modelled via Kelvin-Voigt internal damping model. The proposed model is verified for linear and nonlinear behaviours via comparison to a finite element model. The impact between beam and constraints is incorporated via calculating its work contribution. The nonlinear equation of motion is derived while incorporating geometric, damping, inertial, and constraints nonlinearitys. A series of spatial basis functions together with corresponding vibration modes are used as the proposed solution of the transverse displacement. A modal discretisation is performed via the weighted-residual method of Galerkin and the corresponding non-smooth terms are kept intact while conducting numerical integration. A numerical continuation technique is utilised to solve the resultant equations. The non-smooth response is obtained for various cases and the effects of several parameters are studied thoroughly.

References listed at the end of the paper:
5 W. Zhang, J. Yang, Y. Hao, Chaotic vibrations of an orthotropic FGM rectangular plate based on third-order shear deformation theory, Nonlinear Dyn., 59 (2010), pp. 619-660
9 W. Zhang, Chaotic motion and its control for nonlinear nonplanar oscillations of a parametrically excited cantilever beam, Chaos, Solitons & Fractals, 26 (2005), pp. 731-745
10 W. Zhang, F. Wang, M. Yao, Global bifurcations and chaotic dynamics in nonlinear nonplanar oscillations of a parametrically excited cantilever beam, Nonlinear Dyn., 40 (2005), pp. 251-279
13 C.C. Hong, GDQ computation for thermal vibration of thick FGM plates by using fully homogeneous equation and TSDT, Thin-Walled Struct., 135 (2019), pp. 78-88
15 X. Li, C.C. Du, Y.H. Li, Parametric instability of a functionally graded cylindrical thin shell subjected to both axial disturbance and thermal environment, Thin-Walled Struct., 123 (2018), pp. 25-35
18 N.-I. Kim, J. Lee, Coupled vibration characteristics of shear flexible thin-walled functionally graded sandwich I-beams, Compos. B Eng., 110 (2017), pp. 229-247

ABSTRACT: Automotive crash boxes require a material selection with strength and ductility in a balanced combination. In this work, the behaviour of double-chamber AA6063 and AA6082 aluminium profiles subjected to quasi-static and dynamic axial crushing was studied experimentally. The profiles were stretched to two different levels between extrusion and artificial ageing to temper T6. The higher pre-stretch resulted in a more ductile material with a slightly lower ultimate tensile strength. By visual inspection and by studying X-ray Computed Tomography scans of the tested profiles, dynamic loading was found to cause a larger amount of fracture than static loading.

References listed at the end of the paper:
ABSTRACT: The design of cold-formed steel flexural members using the Direct Strength Method (DSM), use signature curves of cross-sections with the assumption of equal end moments and uniform stresses in the longitudinal direction. However, for beams subjected to general transverse loads, the assumption of longitudinal uniform stress is conservative. In calculating elastic critical loads of thin-walled flexural members, to incorporate a non-uniform variation of longitudinal stresses, this paper presents a spline finite strip computational procedure, which can also be used for beams with intermediate restraints. To the authors’ knowledge, such a procedure using spline finite strip is presented for the first time in the literature. The present formulation is comprehensive in its generality compared with similar works published. The membrane and shear stresses due to transverse loads on the beam are determined in the local direction of the plate at section knots of the spline strip. These stresses are incorporated in the geometric stiffness matrix, and buckling analysis is performed for calculating the elastic buckling load. Restraint matrices are incorporated in buckling analysis for the decomposition of buckling modes and for calculating mode participation. The proposed formulation is compared with generalized beam theory (GBT) for lipped channel cross-section with variation in span, general loading, and intermediate restraints. This method is demonstrated to be good for calculating elastic buckling stresses for the practical design of thin-walled flexural members.

References listed at the end of the paper:
3 H.C. Bui, Buckling analysis of thin-walled sections under general loading conditions, Thin-Walled Struct., 47 (2009), pp. 730-739, 10.1016/j.tws.2008.12.003
4 G.J. Hancock, C.H. Pham, Buckling analysis of thin-walled sections under localised loading using the semi-analytical finite strip method, Thin-Walled Struct., 86 (2015), pp. 35-46, 10.1016/j.tws.2014.09.017
6 V.V. Nguyen, G.J. Hancock, C.H. Pham, Analyses of thin-walled sections under localised loading for general end boundary conditions – Part 2: Buckling, Thin-Walled Struct., 119 (2017), pp. 973-987, 10.1016/j.tws.2017.01.008
10 S.C.W. Lau, G.J. Hancock, Buckling of thin flat-walled structures by a spline finite strip method, Thin-Walled Struct., 4 (1986), pp. 269-294, 10.1016/0263-8231(86)90034-0

S.S. Ajeesh (1) and S. Arul Jayachandran (2)
(1) School of Civil Engineering, Vellore Institute of Technology, Vellore, India
(2) Department of Civil Engineering, Indian Institute of Technology, Madras, India


ABSTRACT: To predict the low-velocity impact (LVI) and compression-after-impact (CAI) behaviour of woven carbon fibre reinforced polymer (CFRP) composites, a finite element (FE) model was developed addressing the inter-laminar and intra-laminar failure of the CFRP composites. First, LVI and CAI experiments were performed to obtain the force-displacement relations, failure modes, microscopic damage and CAI strength of the CFRP laminates, and the experimental results were utilised to validate the present FE model. The LVI and CAI responses of the composites obtained from the FE results agreed well with the experimental ones. Microscopic damage analysis of the CFRP composites after LVI and CAI tests was then conducted by scanning electron microscopy (SEM), indicating the occurrence of three failure modes, i.e. fibre breakage, matrix cracking and delamination, which were addressed in the FE model. Finally, the effects of impactor diameter and impact energy on the impact damage and CAI behaviours were determined using the present FE model, and the damage mechanism was correspondingly discussed.

References listed at the end of the paper:

3 S. Abate, Modeling of impacts on composite structures, Compos. Struct., 51 (2) (2001), pp. 129-138
8 Z. Cheng, J. Xiong, Progressive damage behaviors of woven composite laminates subjected to LVI, TAI and CAI, Chin. J. Aeronaut. (2020)
15 B. Ostre, C. Bouvet, C. Minot, et al., Experimental analysis of CFRP laminates subjected to compression after edge impact, Compos. Struct., 152 (2016), pp. 767-778

(Ref. [27] is missing)

33 S.W. Tsai, Strength Theories of Filamentary Structure. Fundamental Aspects of Fiber Reinforced Plastic Composites (1968)
38 VUMAT for Fabric Reinforced Composites, Dassault Systemes (2008)

Reference 40 is missing here. Perhaps the last reference (labeled No. 50 below) is actually the missing Ref. [40].

50 (Note: Maybe this is the missing Ref. [40]; see above.)


ABSTRACT: This paper presents an analytical approach on the nonlinear vibration of nanocomposite multilayer organic solar cell (NMOSC) subjected to the combination of wind load and uniform temperature change. The NMOSC comprises of five layers, which are made of Al, P3HT:PCBM, PEDOT:PSS, Graphene and Glass. Compared to common models of the NMOSC, ITO is replaced by graphene to control the output colors of NMOSC. The nonlinear motion equations and the compatibility equation are deriving by taking into account the effect of viscous damping, von Karman nonlinearity terms, elastic foundations and initial imperfection. The formula of the wind load is improved for consideration in the general case that the direction
of the wind load is not just perpendicular to the structure. Four edges of the NMOSC are assumed to be simply supported and immovable in the transverse plane. The Galerkin and Runge–Kutta methods are applied to obtain the dynamic response and the natural frequency of the NMOSC. Four optimization algorithms (Bees Algorithm, Basic differential evolution algorithm, enhanced colliding bodies optimization algorithm, social group optimization algorithm) are used to determine the maximum value of natural frequency of the NMOSCs, which depends on nine variables including the geometrical parameters, elastic foundations stiffness and temperature increment. In the numerical results, the effects of elastic foundations, initial imperfection, viscous damping ratio, temperature increment, wind load and the length to width ratio on the dynamic response and natural frequency are considered in details. The maximum values of the natural frequency of the NMOSC with four algorithms are obtained and compared. The results show that the optimal value obtained by four algorithms is close to and with Bees Algorithm is the longest of all.

References listed at the end of the paper:

ABSTRACT: Due to their thin-walled nature and complex geometry, cold-formed steel purlins are prone to a variety of instabilities. Sigma purlins are a family of cold-formed steel members with folding-lines along their webs. The non-straight geometry of their web is beneficial in terms of reducing the susceptibility of the web to local buckling, however, it increases their susceptibility to web crippling when the purlins are subjected to concentrated transverse loads and hence it may reduce their overall moment resistance. This paper reports a series of experiments on sigma purlins under the interior-one-flange (IOF) loading condition. Two different section geometries and three different bearing plate widths were examined. To investigate further the effect of web geometry on the IOF web crippling strength of sigma sections, an FE model was developed and validated against the reported test results. Following successful replication of the experimental observations, a comprehensive parametric study was performed, and several sigma sections covering a wide range of cross-sectional geometries and slenderness were numerically modelled. Finally, a slenderness-based (or direct strength) design approach previously developed for the web crippling design of channel and hat sections is extended to sigma sections.

References listed at the end of the paper:
8 N. Hetrakul, W.W. Yu, Structural behaviour of beam webs subjected to web crippling and a combination of web crippling and bending, Civil Engineering Study 78-4, Final Rep., Univ. Of Missouri-Rolla, Rolla, Missouri, USA (1978)
10 R.R. Gerges, Web Crippling of Single Web Cold-Formed Steel Members Subjected to End One-Flange Loading [MSc Project], University of Waterloo, Canada (1997)
11 B. Young, G.J. Hancock, Design of cold-formed channels subjected to web crippling, J. Struct. Eng., 127 (2001), pp. 1137-1144

ABSTRACT: The present paper studies buckling and free vibration analyses of sandwich beam. The sandwich beam is composed of a soft core integrated with functionally graded graphene nanoplatelets reinforced composite face sheets. Kinematic relations are developed based on Extended Higher-Order Sandwich Beam Theory (EHSP). The governing equations are derived using Ritz-Lagrange formulation. The effective mechanical properties of epoxy/GPLs composites are obtained from the Halpin-Tsai micro-mechanical model and rule of mixture. The numerical results are obtained using the Ritz Method. The natural frequencies and buckling loads are obtained in terms of weight fraction and distribution of graphene nanoplatelets, length to thickness ratio, core to surface ratio, and different boundary conditions. Before presentation of complete numerical results, a comparative study is presented to check trueness and correctness of the results. It is concluded that maximum and minimum natural frequencies and critical buckling loads of sandwich nanobeam are obtained for FG-X and FG-O distributions, respectively.

References listed at the end of the paper:

6 Y. Frostig, Hypothermal (environmental) effects in high-order bending analysis of sandwich beams with a flexible core and a discontinuous skin, Compos. Struct., 37 (2) (1997), pp. 205-221, 10.1016/S0263-8223(97)80013-X
7 H. Schwarts-Givili, Y. Frostig, High-order behavior of sandwich panels with a bilinear transversely flexible core, Compos. Struct., 53 (1) (2001), pp. 87-106, 10.1016/S0263-8223(00)00181-1
16 R. Li, G.A. Kardomeas, Nonlinear high-order core theory for sandwich plates with orthotropic phases, AIAA J., 46 (11) (2008), pp. 2926-2934, 10.2514/1.37430


Refs. 34 and 35 are missing.


Ref. 40 is missing.


Ref. 42 is missing.


ABSTRACT: Profiled steel sheets are widely used in composite wall systems to form profiled double skin composite walls (PDSCWs), serving as structural components in low- and medium-rise building structures. By using the profiled faceplates with re-entrant corrugations, the trough regions not only form vertical ribs to enhance the stability performance of the faceplates, but can also hook to the infilled concrete to eliminate the need for additional connecting elements. The sectional strength of the PDSCWs under combined axial and out-of-plane bending loads is investigated in this paper. A nonlinear finite element (FE) model is presented for simulating the combined axial and bending resistant behaviour, which is validated by comparing with independent series of tests. A numerical parametric study is conducted, which involves the parameters including faceplate thickness, wall depth, faceplate steel strength, infilled concrete strength and faceplate type, and the interaction curves between ultimate axial and bending resistance (N-M curves) are obtained based on extensive models with different eccentricities. By introducing a sectional analysis model which considers the local buckling effect of faceplates, the sectional axial and bending strength of PDSCWs is theoretically evaluated. By comparing the derived N-M interaction curve against FE results, it is found that the proposed design formulas are capable of conservatively predicting the ultimate resistance of the PDSCWs under combined axial and bending effects. Hence, these formulas can provide valuable references for designing the PDSCWs in practise.

References listed at the end of the paper:
5 Tata, Composite Floor Decking Design and Technical Information: Tata Steel in Europe (2017)
11 X. Ma, J.W. Butterworth, G.C. Clifton, Unilateral contact buckling of lightly profiled skin sheets under compressive or shearing loads, Int. J. Solid Struct., 45 (2008), pp. 840-849


ABSTRACT: A 3D UOE manufacturing process is established by ABAQUS software in this study with the consideration of detailed boundary conditions. From two aspects of geometric profile and material distribution, the effects of each forming step are determined from three directions: circumferential direction, radial direction and longitudinal direction. As for the geometric profile of the 3D UOE model, the radius distribution of X70 is more concentrate around the nominal value than X80 pipe. As the longitudinal deformation in O forming and expansion step is not uniform, greater compression ratio and expansion ratio are needed for reducing section ovality. Under the effect of twice expansion steps, the ovality in the overlapping area is smaller than that in the region subjected to one-step calibration. As for the structural behavior of UOE pipe, the weakest position of the pipe after UOE manufacturing process is determined according to the principle of Bauschinger effect. Different with 2D model, 3D UOE pipe has a stronger collapse resistance under the effect of low ovality and the supporting of neighboring sections. Comparing with the offshore standard DNV-OS-F101, the accuracy of 3D UOE model is verified whose resistance to the external pressure is more sensitive with the expansion ratio than the internal pressure.

References listed at the end of the paper:

ABSTRACT: The subject of the study were thin plate elements with a central cut-out of regular shapes, made of carbon-epoxy composite, subjected to uniform compression. The purpose of the analysis was the possibility of using such elements as elastic elements, which stiffness can be designed by changing the geometric parameters of the cut-out and by the appropriate configuration of the composite layers layout. To ensure the stable work of the structure in the postcritical range, in the plate construction an unsymmetrical composite layer layout was used, having selected B matrix couplings, described in i.a. by York and Altenbach. For the adopted solution, a
numerical analysis of the structure using the finite element method was carried out. The scope of numerical simulations included linear analysis of eigen problem and calculations using geometrically non-linear procedures. The numerical tool used in research was the ABAQUS® program. Experimental studies were carried out on an universal testing machine using the optical ARAMIS system. The purpose of the calculations was to select the laminate layer layout ensuring the lowest flexural-torsional buckling form, ensuring stable work of the structure in the postcritical range.

References listed at the end of the paper:
3 T. Kopeci, P. Mazurek, T. Lis, Experimental and numerical analysis of a composite thin-walled cylindrical structures with different variants of stiffeners, subjected to torsion, Materials, 12 (19) (2019), p. 3230, 10.3390/ma12193230
4 P. Rozyno, H. Debiki, J. Kral, Buckling and limit states of composite profiles with top-hat channel section subjected to axial compression, AIP Conf. Proc., 1922 (2018), Article 080001
8 T. Kubik T, S. Samborski, A. Teter, Experimental investigation of failure process in compressed channel-section GFRP laminate columns assisted with the acoustic emission method, Compos. Struct., 133 (2015), pp. 921-929
13 S. Samborski, Analysis of the end-notched flexure test configuration applicability for mechanically coupled fiber reinforced composite laminates, Compos. Struct., 163 (2017), pp. 342-349
22 W. Pennington Vann, Compressive buckling of perforated plate elements, Proceedings of the First Specialty Conference on Cold-Formed Structures, University of Missouri-Rolla (1971), pp. 51-57
Ying Xu (1,2), Xiaoning Zhang (2) and Qinghua Han (1,2)
(1) Key Laboratory of Coast Civil Structure Safety of China Ministry of Education, Tianjin University, Tianjin, 300350, China
(2) School of Civil Engineering, Tianjin University, Tianjin, 300350, China


ABSTRACT: Progressive collapse accidents of single-layer latticed shells introduce a serious threat to public safety. The progressive collapse-resisting capacity (PCRC) has gradually become an essential requirement in the design of spatial structures. In this study, the progressive collapse test and numerical simulation of a single-layer cylindrical latticed shell were conducted to evaluate the effect of the joint stiffness on the PCRC of fabricated single-layer latticed shells. A combined spring model was established to simulate the semi-rigid performance of fabricated joints in the FEA. The failure mechanism of single-layer cylindrical latticed shells with different joint systems was thoroughly discussed from multiple perspectives. The results show that the combined spring model can accurately simulate the progressive collapse of a single-layer latticed shell with semi-rigid joints. The progressive collapse of the cylindrical latticed shell with type-II AH joints showed brittle features during the test. Most joints experienced connection failure. Although the rigid jointed shell and latticed shell with type-II AH joints have much higher PCRC, the semi-rigid jointed shell with type-I AH joints has better ductility during progressive collapse. This paper offers a reference for the progressive collapse-resisting design of latticed shells with fabricated joints.

References listed at the end of the paper:
1 C. Downey, Investigation of Charles de Gaulle collapse is highly critical, Architect. Rec., 193 (4) (2005), p. 40

References listed at the end of the paper:

ABSTRACT: A hot-press molding technique is developed to design and manufacture carbon fiber reinforced polymer (CFRP) X-core sandwich panels that allowed both the composite face sheets and its X-core to be simultaneously molded together. Compression tests were performed on the sandwich panels to assess the effects of relative density on its compressive properties and the failure mode that it develops. Analytical models were developed to predict the panel stiffness and strength; and a failure map of its deformation modes is generated based on the geometric parameters of the unit cell. Linear and nonlinear finite element analyses were performed to further investigate the effects of initial geometric imperfection and progressive damage on the response of the sandwich panels with different cell wall slenderness. Predictions from analytical and numerical models will be shown to be in good agreement with the experiments. The CFRP X-core sandwich panels will be shown to attain good compressive properties that are comparable to typical high-strength structural materials, which will be potentially useful for lightweighting applications.

References listed at the end of the paper:


30 M. Wolf, Full Scale Collision Experiment, X-type Sandwich Side Hull. EU Sandwich Project Report Deliverable TRD448, EU Sandwich project (2003), p. 21
38 PAMG-XR1 5056 Aluminium Honeycomb, MI 49464-0170.
ABSTRACT: In a recent work [1], the authors proposed a versatile and computationally efficient method to model thin-walled members with complex geometries, which combines standard shell and GBT-based (beam) finite elements. In the present paper, the approach is extended to the physically non-linear case (in particular, J2 plasticity), by using an adaptive mesh refinement strategy that updates the finite element model such that the plastic zones are handled by the shell elements, whereas the elastic prismatic beam parts are dealt with using standard GBT-based elements with a minimum number of deformation modes (hence a minimum number of DOFs). This proposed approach offers two advantages: (i) versatility, in the sense that non-prismatic zones can be easily modelled, using shell elements, and (ii) computational efficiency, since the adaptive plastic zones are confined to the shell substructures, which require a much lower computational cost than GBT elements in handling physically non-linearity, whereas the elastic zones are most efficiently dealt with by GBT elements. For illustrative purposes, three examples are presented to demonstrate the capabilities of the proposed approach. These examples concern (i) a simply supported hat section beam, (ii) a lipped channel cantilever with two long holes in the web and (iii) a plane frame with I-section members. For comparison and validation purposes, full shell finite element model solutions are provided. It is concluded that, in all cases, the proposed approach leads to excellent results throughout the load-displacement range considered.

References listed at the end of the paper:


References listed at the end of the paper:

2 R. Schardt, Verallgemeinerte Technische Biegetheorie, Springer Verlag, Berlin, Germany (1989) (in German)
5 L. Duan, J. Zhao, GBT deformation modes for thin-walled cross-sections with circular rounded corners, Thin-Walled Struct., 136 (2019), pp. 64-89
6 M. Nedelec, GBT formulation to analyse the behaviour of thin-walled members with variable cross-section, Thin-Walled Struct., 48 (8) (2010), pp. 629-638
10 R. Gonçalves, D. Camotim, Geometrically non-linear generalised beam theory for elastoplastic thin-walled metal members, Thin-Walled Struct., 51 (2012), pp. 121-129
14 R. Gonçalves, D. Camotim, Improving the efficiency of GBT displacement-based finite elements, Thin-Walled Struct., 111 (2017), pp. 165-175
15 C. Basaglia, D. Camotim, Buckling, postbuckling, strength, and DSM design of cold-formed steel continuous lipped channel beams, J. Struct. Eng., 139 (5) (2013), pp. 657-668
16 D. Camotim, C. Basaglia, On the behaviour, failure and direct strength design of thin-walled steel structural systems, Thin-Walled Struct., 81 (2014), pp. 50-66

ABSTRACT: This paper aims to investigate the ultimate strength of steel-concrete composite cellular beams, considering the web post buckling. The numerical model is calibrated via experimental tests consolidated in the literature by geometrical non-linear analyses. Asymmetric and symmetric sections are investigated. For each section, the ratio of the web-post width to opening diameter, and opening diameter to the depth of the parent section are varied. The results are compared with analytical procedures. In the models, web post buckling and the Vierendeel mechanism were observed. The end post width affected the ultimate behavior of the concrete slab. The calculation procedures proved to be conservative.

References listed at the end of the paper:

1 ArcelorMittalACB® and Angelina® Beams - A New Generation of Cellular Beams (2018)
4 W.C. Clawson, D. Darwin, Composite Beams with Web Openings, University of Kansas, Lawrence (1980)
26 R.M. Lawson, S.J. Hicks, Design of Beams with Large Web Openings, The Steel Construction Institute (2011)
47 O. Hechler, C. Müller, G. Sedlacek, Investigations on Beams with Multiple Regular Web Openings (2006)
48 A. Nadjai, Performance of Cellular Composite Floor Beams at Ambient Temperature (2005)
50 Dassault Systèmes Simulia, Abaqus (2016)
reliability analysis of stainless steel compression members. The suitability of the proposals was confirmed by means of buckling behaviour carried out to investigate the effect of production routines. An extensive study, data from different products, values for the yield stress and ultimate tensile strength, were used to derive a series of buckling curves for the design of stainless steel compression members. The suitability of the proposals was confirmed by means of reliability analysis.
References listed at the end of the paper:
2 SEI/ASCE-8, Specification for the Design of Cold-formed Stainless Steel Structural Members, American Society of Civil Engineers, Reston (2002)
3 AS/NZS 4673, Cold-formed Stainless Steel Structures, Australian/New Zealand Standard, Sydney (2001)
16 ABAQUS Version 6.14-1, Dassault Systmes Simulia Corp. USA (2014)
18 O. Zhao, L. Gardner, Young, Buckling of ferritic stainless steel members under combined axial compression and bending, J. Constr. Steel Res., 117 (2016), pp. 35-48
19 J.K. Sonu, K.J. Singh, Shear characteristics of Lean Duplex Stainless Steel (LDSS) rectangular hollow beams, Structure, 10 (2017), pp. 13-29
20 H.T. Li, B. Young, Cold-formed ferritic stainless steel tubular structural members subjected to concentrated bearing loads, Eng. Struct., 145 (2017), pp. 392-405

ABSTRACT: In this paper, a combination of tests and non-linear finite element analyses is used to investigate the web crippling strength of cold-formed ferritic stainless steel unlippered channels with fastened flanges under the end-two-flange (ETF) loading condition; the cases of both unlippered channels with and without web holes are considered. The results of 27 web crippling tests are presented, with 9 tests conducted on unlippered channels without web holes and 18 tests conducted on unlippered channels with web holes. In the case of tests with web holes, the holes are located either centred or offset to the load and reaction plates. An extensive parametric study is undertaken, using quasi-static finite element analysis, to investigate the effects of web holes. The strengths obtained from reduction factor equations are first compared to strengths calculated from equations recently proposed for cold-formed stainless steel lipped channels. It is demonstrated that the strength reduction factor equations previously proposed for cold-formed stainless steel lipped channels can be unconservative for cold-formed ferritic stainless steel unlippered channels by up to 10%. The laboratory investigation also shows that, for the case of unlippered channels without web holes, the European Standard (EN 1993-1-4) and the American Society of Civil Engineers Specification (SEI/ASCE-8) are too conservative by 43% and 28%, respectively. From both laboratory and finite element results, web crippling design equations are proposed for both sections, with and without web holes.

References listed at the end of the paper:
4 American Society of Civil Engineers (ASCE), Specification for the design of cold-formed stainless steel structural members, SEI/ASCE 8-02, Reston, VA (2002)
7 Eurocode 3: design of steel structures—part 1.3 (EN 1993-1-3), General Rules—Supplementary Rules for Cold-formed Members and Sheeting, European Committee for Standardization (CEN), Brussels (2006)
8 NAS, North American specification for the design of cold-formed steel structural members, American Iron and Steel Institute, AISI S100-2016, AISI Standard (2016)
9 A.M. Yousefi, J.B.P. Lim, A. Uzzaman, Y. Lian, G.C. Clifton, B. Young, Web crippling strength of cold-formed stainless steel lipped channel-sections with web openings subjected to Interior-One-Flange loading condition, Steel Compos. Struct., 21 (2016), pp. 629-659
10 A.M. Yousefi, J.B.P. Lim, A. Uzzaman, Y. Lian, G.C. Clifton, B. Young, Web crippling strength of cold-formed duplex stainless steel lipped channel-sections with web openings subjected to interior-one-flange loading condition, Proceeding of the Wei-Wen Yu International Specialty Conference on Cold-formed Steel Structures, Missouri University of Science and Technology-Rolla, Missouri (2016), pp. 313-324
14 S.A. Korvink, G.J. van den Berg, Web crippling of stainless steel cold-formed beams, Proceeding of the 12th International Specialty Conference on Cold-formed Steel Structures, University of Missouri-Rolla, St. Louis (1994), pp. 551-569
16 F. Zhou, B. Young, Yield line mechanism analysis on web crippling of cold-formed stainless steel tubular sections under two-flange loading, Eng. Struct., 28 (2006), pp. 880-892
17 F. Zhou, B. Young, Cold-formed high-strength stainless steel tubular sections subjected to web crippling, J. Struct. Eng., 133 (2007), pp. 368-377
20 A.M. Yousefi, J.B.P. Lim, G.C. Clifton, Cold-formed ferritic stainless steel unlipled channels with web openings subjected to web crippling under interior-two-flange loading condition - part I: tests and finite element model validation, Thin-Walled Struct., 116 (2017), pp. 333-341
21 A.M. Yousefi, J.B.P. Lim, G.C. Clifton, Cold-formed ferritic stainless steel unlipled channels with web openings subjected to web crippling under interior-two-flange loading condition - part II: parametric study and design equations, Thin-Walled Struct., 116 (2017), pp. 342-356
24 A. Uzzaman, J.B.P. Lim, D. Nash, J. Rhodes, B. Young, Web crippling behaviour of cold-formed steel channel sections with offset web holes subjected to interior-two-flange loading condition, Thin-Walled Struct., 50 (2012), pp. 76-86
25 A. Uzzaman, J.B.P. Lim, D. Nash, J. Rhodes, B. Young, Effect of offset web holes on web crippling strength of cold-formed steel channel sections under end-two-flange loading condition, Thin-Walled Struct., 65 (2013), pp. 34-48
26 A. Uzzaman, J.B.P. Lim, D. Nash, J. Rhodes, B. Young, Cold-formed steel sections with web openings subjected to web crippling under two-flange loading conditions—part I: tests and finite element analysis, Thin-Walled Struct., 56 (2012), pp. 38-48
27 A. Uzzaman, J.B.P. Lim, D. Nash, J. Rhodes, B. Young, Cold-formed steel sections with web openings subjected to web crippling under two-flange loading conditions—part II: parametric study and proposed design equations, Thin-Walled Struct., 56 (2012), pp. 79-87
28 K. Poologanathan, M. Mahendran, E. Steau, Experimental study of web crippling behaviour of hollow flange channel beams under two flange load cases, Thin-Walled Struct., 85 (2014), pp. 207-219
30 S. Lavan, M. Mahendran, K. Poologanathan, Experimental studies of lipped channel beams subject to web crippling under two-flange load cases, J. Struct. Eng., 142 (2016), Article 04016058

ABSTRACT: Experimental results and finite element (FE) analysis results on stainless steel lipped C-section beams are scarce. Therefore, a series of tests were performed on S30408 stainless steel, including 6 major-axis bending and 6 weak-axis bending specimens. Two numerical modelling programmes, major-axis bending and weak-axis bending, have been carried out to investigate the behavior of stainless steel lipped C-section beams. The numerical models, which were developed using the FE package ABAQUS, were verified by experimental results. The models were used to conduct parametric studies of the impact of key parameters on the moment capacity of stainless steel lipped C-section beams subject to failure by local buckling. Finally, based on FE analysis of 238 specimens under major-axis bending and 229 members under weak-axis bending, direct strength equations for lipped C-section stainless steel beams under major-axis bending and weak-axis bending are proposed. A comparison of test results with equation predictions indicates that the formulas have high accuracy and reliability and can accurately calculate the moment capacity of stainless steel lipped C-section beams.

References listed at the end of the paper:
1 Z. Feng, B. Young, Experimental investigation of cold-formed high-strength stainless steel tubular members subjected to combined bending and web crippling [J], J. Struct. Eng., 133 (7) (2007), pp. 1027-1034
2 Z. Feng, B. Young, Cold-formed high-strength stainless steel tubular sections subjected to web crippling [J], J. Struct. Eng., 133 (3) (2007), pp. 368-377
3 Z. Feng, B. Young, Cold-formed stainless steel sections subjected to web crippling [J], J. Struct. Eng., 132 (1) (2006), pp. 134-144
6 Liu Fang, Theoretical and Experimental Investigations on the Method of Effective Section of Stainless Steel Lipped C Stub Columns [D], Thesis (Master) School of Civil Engineering, Southeast University, Nanjing (2015)
8 Yuan Huanxin, Local and Local-Overall Buckling Behavior of Welded Stainless Steel Members under Axial Compression [D], Tsinghua University (2014)
11 Ding Zhixia, Research on the Moment Capacity of Stainless Steel Lipped C-Section Members Considering Local Buckling [D], Thesis (Master), School of Civil Engineering, Southeast University, Nanjing (2017)
12 ASCE, Specification for the Design of Cold-Formed Stainless Steel Structural Members, American Society of Civil Engineers, Reston, Virginia (2002), SEI/ASCE-8-02
13 Eurocode 3, EN 1993-1-3, Design of Steel Structures—Supplementary Rules for Cold Formed Thin Gauge Members and Sheeting, Brussels (2006)
15 North American S, Design of Cold-Formed Steel Structural Members, American Iron and Steel Institute, Washington, DC (2007)
16 AS/NZS 4600, Cold-Formed Steel Structures, Structures, Sydney, Australia (2005)

ABSTRACT: Flexural and flexural-torsional buckling are stability phenomena and the controlling limit state for carbon steel angle columns. When these columns are made of austenitic stainless steel, some structural response differences are expected and motivated the present investigation. In fact, the stainless steel grade has been investigated in last few years due to unique proprieties in comparison with the carbon steel grades. Therefore, this paper aimed to enlarge the available experimental data for austenitic angles under compression. To fulfil these objectives, thirteen specimens were tested on $64 \times 64 \times 6.4$ hot rolled equal-legs angles with lengths varying from 250 mm to 1500 mm. A numerical study has been developed comparing the results with experimental tests. In addition, a parametric analysis was performed where the slenderness and cross sections ranges were expanded to investigate their influence on the structural behaviour. These results were compared to Eurocode 3 part 1–4 and enabled the suggestion of better-suited values for the adopted Eurocode column curve parameters $\lambda$, and $\alpha$, respectively.

References listed at the end of the paper:

5 B. Young, Experimental and numerical investigation of high strength stainless steel structures, J. Constr. Steel Res., 64 (2008), pp. 1225-1230
24 H. Kuwamura, Local buckling of thin-walled stainless steel members, Steel Struct., 3 (2003), pp. 191-201
33 SEI/ASCE 8-02, Specification for the Design of Stainless Steel Cold-Formed Structural Members, (2002)
38 A.D. Martins, A. Landesmann, D. Camotim, P.B. Dinis, Distortional failure of cold-formed steel beams under uniform bending: behaviour, strength and DSM design, Thin-Walled Struct., 118 (2017), pp. 196-213
42 Shapes Database, Version 14.0, American Institute of Steel Construction (2012)

https://doi.org/10.1016/j.jcsr.2018.03.026

ABSTRACT: Stainless steel is widely used in construction due to its combination of excellent mechanical properties, durability and aesthetics. Towards more sustainable infrastructure, stainless steel is expected be more commonly specified and to feature in more substantial structural applications in the future; this will require larger and typically welded cross-sections. While the structural response of cold-formed stainless steel sections has been extensively studied in the literature, welded sections have received less attention to date. The stability and design of conventionally welded and laser-welded austenitic stainless steel compression members are therefore the focus of the present research. Finite element (FE) models were developed and validated against a total of 59 experiments, covering both conventionally welded and laser-welded columns, for which different residual stress patterns were applied. A subsequent parametric study was carried out, considering a range of cross-section and member geometries. The existing experimental results, together with the numerical data generated herein, were then used to assess the buckling curves given in European, North American and Chinese design standards. Following examination of the data and reliability analysis, new buckling curves were proposed, providing, for the first time, design guidance for laser-welded stainless steel members.

References listed at the end of the paper:

ABSTRACT: Concrete filled stainless steel tubular (CFSST) columns have attracted increasing research interests in the last decade. This paper briefly introduces the material properties of stainless steel and reviews recent research on behaviour of CFSST columns and joints at both ambient and elevated temperatures. The reviewed studies include tests of bond behaviour between the stainless steel tube and core concrete, and the static behaviour of CFSST stub columns, slender columns, beams, stainless steel-concrete-carbon steel double-skin tubular columns, and concrete filled bimetallic tubular columns. The cyclic behaviour of CFSST beam-columns under combined axial and lateral cyclic loading as well as the impact behaviour of CFSST columns is also introduced. Fire test results of full-scale CFSST columns are presented along with finite element analysis results. The behaviour of composite joints with CFSST columns is also briefly reviewed in this paper. Based on the previous research, future research directions on CFSST are summarised and discussed.

References listed at the end of the paper:
12. F. Wang, B. Young, L. Gardner, Experimental investigation of concrete-filled double skin tubular stub columns with stainless steel outer tubes, Proceedings of the 8th International Conference on Steel and Aluminium Structures. Hong Kong, China (2016)
27 R. Feng, B. Young, Behaviour of concrete-filled stainless steel tubular X-joints subjected to compression, Thin-Walled Struct., 47 (4) (2009), pp. 365-374
31 AS/NZS 4673, Cold-formed Stainless Steel Structures. Sydney, Standards Australia, Australia (2001)
32 BS EN 10088-1, List of Stainless Steels, British Standard Institution, British (2014)
35 BS EN 10088-2, Technical Delivery Conditions for Sheet/Plate and Strip of Corrosion Resisting Steels for General Purposes, British Standard Institution, British (2014)
41 SEI/ASCE 8-02, Specification for the Design of Cold-formed Stainless Steel Structural Members, American Society of Civil Engineers, Reston, Virginia, USA (2002)
53 K.T. Ng, L. Gardner, Buckling of stainless steel columns and beams in fire, Steel, Construction, 29 (5) (2008), pp. 717-730
60 Y. Ye, L.H. Han, Z.X. Guo, Concrete-filled bimetallic tubes (CFBT) under axial compression: analytical behaviour, Thin-Walled Struct., 119 (2017), pp. 839-850

ABSTRACT: A finite element analysis and design of austenitic and duplex stainless steel tubular section beam-columns is presented in this paper. The nonlinear finite element model was verified against experimental results of stainless steel tubular section beam-columns and beams. In this study, square and rectangular hollow sections were investigated. It was shown that the finite element model closely predicted the ultimate loads and failure modes of the tested beam-columns and beams. Hence, the finite element model was used for an extensive parametric study. The axial compressive strengths of the beam-column specimens predicted by the finite element analysis are compared with the design strengths calculated using the linear interaction equation and direct strength method. Reliability analysis was performed to assess the reliability of these design rules. It is shown that these design rules generally provide accurate and reliable predictions for stainless steel tubular section beam-columns. Design recommendations for linear interaction equation and the direct strength methods are proposed for stainless steel SHS and RHS beam-columns.

References listed at the end of the paper:
7 B. Young, W.M. Lui, Tests of cold-formed high strength stainless steel compression members, Thin-Walled Struct., 44 (2) (2006), pp. 224-234
11 Y. Huang, B. Young, Structural performance of cold-formed lean duplex stainless steel columns, Thin-Walled Struct., 83 (2014), pp. 59-69
12 F. Zhou, B. Young, Tests of cold-formed stainless steel tubular flexural members, Thin-Walled Struct., 43 (9) (2005), pp. 1325-1337
13 G. Kiymaz, Strength and stability criteria for thin-walled stainless steel circular hollow section members under bending, Thin-Walled Struct., 43 (10) (2005), pp. 1534-1549
17 Y. Huang, B. Young, Experimental and Numerical Investigation of Cold-Formed Lean Duplex Stainless Steel Flexural Members, Thin-Walled Struct., 73 (2014), pp. 216-228
18 A. Talja, P. Salmi, Design of Stainless Steel RHS Beams, Columns and Beam-Columns, VTT Building Technology, Finland (1995)
23 Y. Huang, B. Young, Experimental investigation of cold-formed lean duplex stainless steel beam-columns, Thin-Walled Struct., 76 (2014), pp. 105-117
28 I. Arrayago, E. Real, E. Mirambell, Experimental study on ferritic stainless steel RHS and SHS beam-columns, Thin-Walled Struct., 100 (2016), pp. 93-104
31 O. Zhao, B. Rossi, L. Gardner, B. Young, Experimental and numerical studies of ferritic stainless steel tubular cross-sections under combined compression and bending, J. Struct. Eng., ASCE, 142 (2) (2016), Article 04015110
34 O. Zhao, L. Gardner, B. Young, Buckling of ferritic stainless steel members under combined axial compression and bending, J. Constr. Steel Res., 117 (2016), pp. 35-48
35 O. Zhao, L. Gardner, B. Young, Experimental study of ferritic stainless steel tubular beam-column members subjected to unequal end moments, J. Struct. Eng., ASCE, 142 (11) (2016), Article 04016091
40 Commentary on North American Specification for the Design of Cold-Formed Steel Structural Members. AISI S100–16, American Iron and Steel Institute, Washington, D.C. (2016)
41 Australian/New Zealand StandardCold-Formed Steel Structures. AS/NZS 4600:2005, Standards Australia, Sydney, Australia (2005)
42 B.W. Schafer, T. Peköz, Direct strength prediction of cold-formed steel members using numerical elastic buckling solutions, Proceedings of the 14th International Specialty Conference on Cold-Formed Steel Structures, University of Missouri-Rolla (1998), pp. 69-76
46 H.M. Duong, G.J. Hancock, Recent developments in the direct strength design of thin-walled members, Proceedings of the International workshop on recent advances and future trends in Thin-Walled Structures. technology, J. Loughlan, Loughborough, Canopus (2004), pp. 43-62

ABSTRACT: Following the experimental study and finite element (FE) model validation described in the companion paper, numerical parametric studies and the evaluation of design provisions for stainless steel channel sections under combined axial compressive load and minor axis bending moment are presented herein. The parametric studies were carried out to generate additional structural performance data over a wider range of cross-section aspect ratios and slendernesses, loading combinations and bending orientations. The test data and numerical results have been carefully analysed to develop a comprehensive understanding of the structural performance of stainless steel channel sections under combined compression and minor axis bending moment, and to assess the accuracy of the existing design provisions in Europe and North America. Comparisons of ultimate loads from the tests and FE simulations with the codified resistance predictions revealed that the current design standards typically under-estimate the capacity of stainless steel channel sections under combined compression and minor axis bending moment; this is attributed primarily to the neglect of material strain hardening and the employment of conservative interaction formulae. Improved design rules featuring more efficient interaction curves, anchored to more precise end points (i.e. cross-section resistances under pure compression and bending moment), are then proposed and presented. The new design proposals are shown to yield both more accurate and more consistent resistance predictions over the existing design provisions. Finally, statistical analyses are presented to confirm the reliability of the new design proposals according to EN 1990.

References listed at the end of the paper:

1 O. Zhao, L. Gardner, B. Young, Behaviour and design of stainless steel SHS and RHS beam-column, Thin-Walled Struct., 106 (2016), pp. 330-345
4 A. Liew, L. Gardner, Ultimate capacity of structural steel cross-sections under compression, bending and combined loading, Structure, 1 (2015), pp. 2-11
8 Y. Huang, B. Young, Experimental and numerical investigation of cold-formed lean duplex stainless steel flexural members, Thin-Walled Struct., 73 (2013), pp. 216-228
15 O. Zhao, B. Rossi, L. Gardner, B. Young, Experimental and numerical studies of ferritic stainless steel tubular cross-sections under combined compression and bending, J. Struct. Eng. ASCE, 142 (2) (2016), Article 04015110
17 O. Zhao, L. Gardner, B. Young, Experimental study of ferritic stainless steel tubular beam-column members subjected to unequal end moments, J. Struct. Eng. ASCE, 142 (11) (2016), Article 04016091
ABSTRACT: In structural frames, second order effects refer to the internal forces and moments that arise as a result of deformations under load (i.e. geometrical nonlinearity). EN 1993-1-1 states that global second order effects may be neglected if the critical load factor of the frame $\alpha_c$ is greater than or equal to 10 for an elastic analysis, or greater than or equal to 15 when a plastic global analysis is used. No specific guidance is provided in EN 1993-1-4 for the design of stainless steel frames, for which the nonlinear stress-strain behaviour of the material will result in greater deformations as the material loses its stiffness. A study of the effects of material nonlinearity on the stability of stainless steel frames is presented herein. A series of different frame geometries and loading conditions are considered. Based on the findings, proposals for the treatment of the influence of material nonlinearity on the global analysis and design of stainless steel frames are presented.

References listed at the end of the paper:


ABSTRACT: This research work presents a parametric numerical study on the resistance at elevated temperatures of stainless steel members, subjected to combined bending and axial compression. Previous studies have shown the need for the development of further research works aiming at better predicting the fire behaviour of stainless steel beam-columns. However they have only considered beam-columns composed of stocky I sections. Hence, this paper focuses on austenitic stainless steel (European grade 1.4301 also known as 304) beam-columns composed of square hollow sections (SHS) and circular hollow sections (CHS), considering different cross-sections classes (1 to 4), according to Eurocode 3 (EC3) classification.

The numerical analyses were performed using the finite element program SAFIR®, with material and geometric non-linear analysis considering imperfections. The influence of the following parameters was evaluated: bending moment diagram shape, cross-section slenderness considering the local buckling occurrence on the thin-walled sections, and member slenderness for the global instability due to flexural buckling.

Comparisons between the obtained numerical results and the interaction curves of Eurocode 3 are presented. The results show that specific design approach should be developed for these stainless steel members under fire situation, taking into account the above mentioned parameters.

References listed at the end of the paper:
8 CTICM/CSM, Stainless Steel Column Buckling Behaviour at Elevated Temperatures - Comparison of Euro Inox and Cticm Methods, (2005)
11 A. Scifo, Fire Resistance of Stainless Steel Hollow Section Columns, Université de Liège, Faculté des Sciences Appliquées (2013)
15 N. Lopes, P.M.M. Vila Real, Fire resistance of stainless steel structural elements with class 4 square hollow sections subject to combined bending and axial compression, 8th International Conference on Structures in Fire, SiF, Shangai, China (2014)
16 J.-M. Franssen, Real P. Vila, Fire Design of Steel Structures, (2nd edition), ECCS; Ernst & Sohn, a Wiley Company (2015)

ABSTRACT: Reactive powder concrete (RPC) is a type of ultra-high strength concrete that has a relatively high brittleness. However, its ductility can be enhanced by enclosure in a steel tube. This paper presents an experimental study of the axial compressive behavior of RPC-filled circular steel tube stub columns. Twenty short composite columns under axial compression are tested and information on their load-deformation behavior, axial load capacity, failure modes and confinement mechanism are presented. The effects of tube thickness, mix design, loading and curing conditions on the compressive strength of these columns are discussed. The experimental results show that: (1) confinement increases the load capacity of the test specimens by 3% to 38%, (2) the increase in load capacity is more pronounced when the confinement coefficient (defined as the ratio of axial load capacity of the steel tube to the RPC core) is high, (3) the load capacity also increases when the steel tube is not subjected to any direct axial stress, when a larger amount of steel fibers is added, or when a higher curing temperature is used, (4) the transverse to axial strain ratio can be used as an indicator to determine when the effect of confinement develops. Using the measured strains and theories of elasticity and plasticity, the stresses in the steel tube and the PRC core are calculated, from which expressions for the peak stress of confined RPC are proposed. Equations for stress-strain curves that can be used to describe the behavior of confined RPC are derived.

References listed at the end of the paper:
The purpose of this paper is to verify whether the factor $\alpha$ can correctly include the influence of combinations of flexural and torsional boundary conditions which GoDvenjezer did not investigate, and to verify if the simplified formula (6.35) may be used for any boundary conditions. The authors used GoDvenjezer's method for 8 different shapes of monosymmetric cross-sections for all 100 theoretical possible combinations of boundary conditions, and for two different fundamental functions: a) eigenfunctions of flexural vibration modes.
(which were also used by Goľdenvejzer) and b) eigenfunctions of buckling modes (which is a more natural choice). All results are verified by the finite element method with 1D member elements.

References listed at the end of the paper:

1 R. Kappus, Drehnicken zentrisch gedruckten Stabe mit offenem Profil in elastisch Bereich, Luftfahrtforschung, 14 (9) (1937)
2 V.Z. Vlasov, Thin-Walled Elastic Beams. Strojizdat Narkomstroja, GISL, Moscow-Leningrad (1940), pp. 1-276 (In Russian)
5 A.L. Goľdenvejzer, Stability of thin-walled members under axial force depending on boundary conditions. Trudy laboratorii strojiteľnej mechaniki, ČNIPS (1941), pp. 53-68 (In Russian)
6 V.Z. Vlasov, Thin-Walled Beams. 2nd rewritten and complemented edition, GIF-ML, Moscow (1959), pp. 1-568 (In Russian)
18 CUTWP software developed by Andrew Sarawit and prof. Teoman Pekoz, Cornell University


ABSTRACT: Researchers have not yet reached a consensus on which buckling curve to use for the calculation of the lateral torsional buckling (LTB) resistance of cellular steel beams in the current version of EC3. In addition, there is a new proposal for the future update of EC3, in which the imperfection factor is a function of the elastic section modulus, as well as material imperfections. The aim of this study is to investigate the LTB resistance of cellular steel beams by modifying the distribution of residual stresses after the manufacturing process. Geometrical and material nonlinear analysis are performed using the software ABAQUS 6.12. The cellular steel beams are simply supported, with fork-supports at the end, and subjected to uniform bending, mid-span concentrated load and uniformly distributed loads. In the latter two cases, neutral and destabilizing effects of loading are considered. The results are compared to analytical procedures, international standards, and also, with the possible EC3 updating. It was concluded that the calculation prescription of the new proposal, considering the imperfection factor that meets the magnitude of the residual stresses after the manufacturing process of cellular steel beams, is effective, accurate and conservative for LTB resistance in inelastic and elastic behavior. However, for the case of stocky cellular steel beams, whose shear stress is preponderant, ultimate limit states, such as Vierendeel mechanism and web post buckling, must be verified first.

References listed at the end of the paper:

1 ArcelorMittal. Cellular Beams. (ACB (R) 2015-1).
11 D. Sonck, Global Buckling of Castellated and Cellular Steel Beams and Columns, Phd dissertation, Ghent University (2014)

ABSTRACT: In this study, a theoretical model called the improved softened membrane model for torsion (ISMMT) is proposed for evaluating prestressed composite box girders with corrugated steel webs (PCBGCSWs) under pure torsion. First, considering the mechanical properties of PCBGCSWs, a series of equations are derived from equilibrium and compatibility conditions and constitutive relationships of the materials. In the equations, the criteria of shear flow equivalence and shear strain equivalence are adopted to determine the relationships between the concrete flanges and the corrugated steel webs (CSWs) before and after the yielding of the CSWs, respectively. Then, the solution algorithms, including a general algorithm for the entire torsional process and a simplified algorithm for the stage when both steel bars, the prestressing steel and the CSWs are in the elastic state, of the ISMMT are presented to solve all the equations. To validate the feasibility of the proposed theoretical model, the experimental results of a prismatic PCBGCSW under pure torsion available in the literature are selected for comparison. Additionally, a three-dimensional (3D) finite element (FE) model of the specimen is established using ABAQUS software. The results from the theoretical model, including the overall torque-twist curve, shear strain in the CSWs and strains in the prestressing steel and steel bars, are compared with those from the FE model and the experiment. The theoretical, numerical and experimental results are in good agreement, demonstrating that the proposed analytical model accurately predicts the torsional behaviour of the PCBGCSWs under pure torsion, including the torsional behaviour during the pre- and post-cracking stages.

References listed at the end of the paper:
17 R. Dabrowski, Curved Thin-Walled Girders Theory and Analysis, Cement and Concrete Association (1968)
Specifically, the profile steel yielded before the square steel tube, and the internal RAC was crushed. The failure process and modes, load-RCA replacement percentage, width-aggregate concrete composition of RAC, and postcracking behavior of specimens were considered: recycled coarse aggregate (RCA) replacement percentage, width-thickness ratio of square steel tube, profile steel ratio and RAC strength. The failure process and modes, load-displacement and load-strain curves and axial stiffness of specimens were obtained and analysed in detail. Results showed the similar failure process and modes of each specimen. Specifically, the profile steel yielded before the square steel tube, and the internal RAC was crushed.
subsequently. Bulging deformation was evident on square steel tube, thus indicating that the column lost its bearing capacity. With the increase in RCA replacement percentage and width-thickness ratio of the square steel tube, the axial bearing capacity of specimens decreased remarkably. However, the axial bearing capacity of columns increased with the increase in profile steel ratio and RAC strength. These design parameters remarkably influenced the initial stiffness of the short columns, but exerted minimal effect on stiffness degradation at the latter stage of loading. Overall, the composite short columns exhibited high bearing capacity and good deformability in the tests. On this basis, a calculation formula for the axial bearing capacity of the columns was established through theoretical analysis and by considering the adverse effects of RCA replacement percentage. The calculated results showed good agreement with the experimental findings, thus verifying the validity of the established formula. The research conclusions can provide references for engineering applications on this type of columns.

References listed at the end of the paper:


ABSTRACT: Multiple cross-arm Pre-tensioned Cable Stayed Buckling-Restrained Braces (MPCS-BRBs) can significantly enhance the elastic buckling performance and load resistance over common double-tube BRBs
because of the additional cable stayed system. Previous studies conducted by the authors intended to investigate the lower limits of restraining ratios of MPCS-BRBs with pin-ended stays subjected to either monotonic or cyclic axial loads, where the initial geometric imperfection was taken to be consistent with the first order buckling mode. This study is a continuation of the previous paper, and it aims to explore interactive buckling of MPCS-BRBs with pin-ended stays in order to obtain a safe estimate of their load-carrying capacities through nonlinear Finite Element Analysis (FEA). In addition, interactive buckling of MPCS-BRBs is considered by introducing a series of asymmetric imperfections that are the mixtures of symmetric and antisymmetric imperfections during buckling analysis. The effects of different imperfections (symmetric, antisymmetric, and asymmetric) and initial pre-tensioning force of cables on the load-carrying capacities of the MPCS-BRBs with and without minor diagonal cables are explored and compared. Furthermore, a conservative design approach for those MPCS-BRBs can be established by fulfilling the corresponding lower limits of restraining ratios and optimal initial pre-tensioning force of cables based on the findings considering different types of initial geometric imperfections. Finally, such a conservative design approach is validated through nonlinear FEA for MPCS-BRBs subjected to either monotonic or cyclic axial loads. The findings in this study could provide guidance for a preliminary conservative design of the MPCS-BRBs in actual engineering applications.


ABSTRACT: Although structural fire performance of hot-rolled carbon steel columns is already well known, limited design specifications are available for stainless steel columns. European fire design guidelines allow for a different material strength and stiffness degradation at high temperatures for stainless steel and, yet, the same buckling curve is recommended for stainless steel and carbon steel columns. This paper reports an experimental investigation on the structural behaviour of hollow steel columns under fire conditions for assessing mainly their fire resistance, critical temperatures and failure modes. The main variables tested included the: (a) cross-section type (circular, square); (b) axial load ratio (0.30 and 0.70); and (c) steel type (carbon and austenitic stainless steel). The structural fire behaviour of stainless steel columns was hence compared with similar carbon steel columns. Furthermore, European fire design methods both for the prediction of the temperature evolution on stainless steel members and for the estimation of the critical temperature of this type of column were also used to compare with experimental data. As well as that, the experimental results were still compared with predictions from other available analytical models, taking into account changes in the buckling curve established in the European design rules. Finally, such design rules were found to be over-conservative for high load ratios and so the development of a different design buckling curve might be useful for an accurate prediction of the fire resistance of stainless steel columns.


ABSTRACT: An oval (unequal-height periphery) hybrid cable dome structural system is put forward, and is firstly adopted in the roof of an indoor stadium with hectometer-level in China. In this study, a 1:15 scale model of the roof structure was made and taken as a research object. Then a static load test was performed on the model, considering 1/8, 1/4, and 1/2 regional distribution of snow loads. By comparing the experimental results with ANSYS numerical simulation results, the influences of different snow distribution forms on the mechanical properties of the hybrid cable dome structure were obtained. Several relatively adverse snow distribution forms were selected to conduct a whole load process analysis of the structure, considering geometric nonlinearity. Results indicated that, under the action of snow loads with half-span distribution along 45° axis and diagonal half-span distribution along long axis, much lower structural bearing capacity would be obtained. Accordingly, a parametric analysis was implemented, considering the effect of initial prestress and cable cross section, and the influence laws of the two factors on the mechanical properties of the hybrid cable dome structure were acquired. Consequently, a theoretical basis was provided for the analysis and design of this new-type cable dome structure and its engineering application.
ABSTRACT: This study investigates the axial strength of circular steel tube confined concrete (STCC) columns with the employment of plain ultra high performance concrete (UHPC) and ultra high performance fiber reinforced concrete (UHPFRC) having compressive strengths of cylinders varying from 178.9 MPa and 198 MPa. UHPFRC used in this study had 1% and 2% volume fraction of steel fibers in the mixture. Eighteen specimens including both short and intermediate columns were cast and tested under concentric loading on the concrete core to generate the maximal confinement effect. Experimental results showed that the effect of steel fibers on the axial load versus axial strain responses, and on the enhancement of strength and ductility was insignificant, while the parameters of the steel tube and the concrete core length were found to play a major role. The ultimate loads of the tests presented herein were compared with those obtained from the predictions by seven analytical models and five existing design codes. The design expressions from these analytical models and codes were assessed. For the prediction of the ultimate loads of both short and intermediate column, the model by De Oliveira et al. [13] was the most suitable approach among seven selected models, whereas the ACI provision [1] was the best among five existing design codes. Furthermore, the experimental ultimate loads obtained from this study were combined with those from previous studies to examine the influence of different concrete strength ranges on the strength enhancement. Finally, unified formulae to predict the ultimate strength with a wide range of concrete strength up to 200 MPa were also proposed for both short and intermediate columns.

ABSTRACT: Nowadays, cold-formed thin-walled steel tube truss (CTSTT) shear walls are popularly used in engineering practice because of their superiority in light weight, convenient construction and good ductility. However, little attention to the seismic response of the CTSTT shear walls has been paid. This paper aims to investigate the effect of wall openings on seismic behavior of cold-formed thin-walled steel tube truss (CTSTT) shear walls. Five full-scale specimens of CTSTT shear walls sheathed with double-sided oriented strand board (OSB) panels and one full-scale specimen of CTSTT skeleton were tested under vertical axial compression combining lateral low-cyclic load. The parameters, including the type and layout of openings, stressed skin diaphragm as well as opening rate, were estimated in the quasi-static tests. The seismic performance of CTSTT shear wall was evaluated in terms of shear capacity, rigidity, ductility and energy dissipation, etc. Moreover, a simplified empirical formula for predicting the shear capacity of CTSTT shear wall with opening was proposed and verified by the experimental data. The test results indicated that the CTSTT shear wall with double-sided OSB panels exhibited admirable rigidity, good ductility and excellent energy dissipation properties. The shear capacity of CTSTT shear wall decreased by wall opening setting, while seismic behavior of the type of wall could be improved by using four-limb studs within the vicinity of opening. These experimental and analytical studies would improve the application of the CTSTT shear walls in engineering practice.

ABSTRACT: This paper presents equations to determine the ultimate shear strength reduction factor of web plate in steel plate girders due to initial imperfection. The proposed equations are based on a parametric study of shear behavior of steel plate girders considering variation in geometrical properties of the section. 112 models with various initial imperfections, flange-to-web stiffness ratios, and web slenderness were analyzed using finite element software ABAQUS. Both geometric and material nonlinearity have been considered. According to the results, the ultimate shear strength proposed by AISC code is conservatively less than the obtained results by FEM, especially for slender plates; the difference between these two values could reach up to 60% in some cases. That is while, for compact and non-compact web plates, maximum difference is about 10%. Furthermore, it is observed that AISC elastic shear buckling strength is conservatively less than the results derived from FEM. This difference in slender and compact web plates reaches to almost 40% and 20%, respectively. This
study reveals that the initial geometrical imperfection is an effective parameter on the shear strength of web plates. According to the results, the sensitivity of girders to initial imperfection is greater in non-compact-web girders than the slender or compact ones, and the maximum shear strength reduction is observed about 23% for maximum allowable imperfection as recommended in part 1–5 of EC3. Based on the obtained results, a maximum permissible construction tolerance is proposed as well.


ABSTRACT: The shear behaviour of stainless steel plate girders investigated in this study is related to the introduction of diagonal stiffeners. Four plate girders with or without diagonal stiffeners were fabricated by welding hot-rolled stainless steel plates of different thicknesses. All the plate girders were tested to failure subject to shear loading. The critical shear buckling stress, ultimate resistance and post-peak response were recorded and carefully analysed. Elaborate finite element (FE) models were developed by means of the FE software package ABAQUS and were validated against the test results. A comprehensive parametric analysis of key parameters including the web aspect ratio and slenderness, the flexural stiffness of diagonal stiffeners and the material properties was further conducted, reflecting the influence of these parameters on structural responses. The critical shear buckling stresses obtained from eigenvalue buckling analysis were compared with theoretical predictions of the elastic buckling stress, and a new calculation approach for the shear buckling coefficient of diagonally stiffened web panel that can account for the flexural stiffness of diagonal stiffeners and the effective restraint from flanges was proposed. Based on the obtained ultimate shear resistances, the existing design methods were assessed; and a new design proposal within the framework of EN 1993-1-4 + A1 for predicting the shear resistance of diagonally stiffened stainless steel plate girders was developed. In this novel method, the shear contributions from diagonal stiffeners and the shear buckling coefficients for diagonally stiffened web panels were revised. The reliability of the new proposal was also confirmed by further statistical analysis.


ABSTRACT: A general forming method for super-long span mega-latticed structures has been developed, based on the key parameters for five types of structure, together with a finite element model. The method combines the molding idea for universal spherical mega-latticed structures and the geometric topological relations of the improved traditional single-layer reticulated shell. The static and economic indexes of six kinds of 800 m span mega-latticed structures, with the same geometry, control parameters and loads, were calculated, and the force law for these structures under static load identified. Then structures suitable for spans of 1000 m and 1200 m were considered. The static performance and economic indexes showed that the mechanical and economic performance of the Geodesic type mega-latticed structure and the Three-dimensional grid type mega-latticed structure were excellent. In order to promote the engineering application of these structures, the influence of four key parameters on the performance of 1000 m structures was studied, and a reasonable range of indicative parameters obtained.


ABSTRACT: This paper provides an insight into the buckling behavior of high strength concrete encased steel (CES) columns through a comprehensive investigation including experimental, numerical and analytical analyses. Three long CES column specimens made of high strength concrete C100 and S355 H-section were tested under axial compression. The maximum test loads obtained from these tests were compared with the buckling resistance predicted by EN 1994-1-1, AISC 360-10 and ACI 318-08. Nonlinear finite element analyses were performed to predict the buckling resistance and trace the load displacement behaviour of these columns. In the finite element model, the column initial imperfections were carefully chosen to predict the maximum resistance and the load-displacement response, and compared with the equivalent imperfection values stipulated.
in the modern design codes. In order to examine the validity and limitation of the current design approaches in predicting the buckling resistance of CES columns made of high strength concrete, a statistical study was undertaken based on the established database covering a wider range of material strength and geometric configurations. In the statistical study, the buckling resistance and effective flexural stiffness obtained from the tests were compared with the codes’ predictions from EN 1994-1-1, AISC 360-10 and ACI 318-08. Finally, the reliability of the current design methods is assessed by correlating their accuracy with respect to the variation of material strength, column slenderness ratio, load eccentricity and steel contribution ratio.


ABSTRACT: The present paper shows an experimental and numerical modelling investigation of the flexural-torsional buckling behaviour and load-carrying capacities of fixed-ended hot-rolled austenitic stainless steel equal-leg angle section columns. The testing programme was conducted on four austenitic stainless steel angle sections and involved material testing, initial global and torsional imperfection measurements and sixteen fixed-ended column tests. This was followed by a numerical simulation study, where the numerical models were firstly developed to validate against the experimental data and then utilised to perform numerical parametric studies to generate additional results over a broader range of member lengths and cross-section geometric dimensions. The derived test and finite element results were carefully analysed and then utilised to evaluate the accuracy of the established design rules in Europe, America and Australia/New Zealand. Comparisons of the failure loads derived from the experimental and numerical studies with the corresponding codified flexural-torsional buckling strength predictions revealed an unduly high level of conservatism and scatter. Extension of the direct strength method to carbon steel equal-leg angle section columns has been recently made, and the applicability of the approach to fixed-ended hot-rolled austenitic stainless equal-leg steel angle section columns was also assessed. The new approach was generally shown to yield more precise flexural-torsional buckling resistance predictions than the existing design standards, but a large portion of the predictions were unsafe, indicating that further improvements are required.


ABSTRACT: Spiral welded stainless steel tubes are produced by helical welding of a continuous stainless steel strip. Recently, spiral welded stainless steel tubes have found increasing application in the construction industry due to their ease of fabrication and aesthetic appeal. However, an in-depth understanding of the behaviour of these types of structural elements is still needed due to the insufficient experimental evidence and lack of rational design guidance. In the present paper, an extensive experimental program was carried out to investigate the behaviour of axially loaded hollow and concrete-filled spiral welded stainless steel tubes. The effects of various design parameters were investigated throughout the test program. In addition to the experiments, this paper presents a finite element model for the prediction of these columns. Specifically, the proposed finite element models take into account the effects of material and geometric nonlinearity. The helical welding is modelled as an independent part that is further tied to the stainless steel tube. Moreover, the initial imperfections of the stainless steel tube and the residual stresses resulting from helical welding are included. Enhancement of the understanding of the experimental results can be achieved by extending the parametric studies based on the developed finite element model. Furthermore, a comparison of the ultimate strength between the experimental results and those obtained from existing codes of practice is conducted.


ABSTRACT: The use of beams with isolated openings in the webs is common in steel structures. However, the presence of large openings in the web generates specific mechanical behavior in comparison with that of solid web beams and leads quite often to the reinforcement of the opening by welding stiffeners. An experimental program based on thirteen steel beams with a single rectangular web opening is performed. It aims to evaluate the influence of the openings reinforced or not by stiffeners on the behavior of the beam loaded in shear and
bending. The stiffeners are used to increase the resistance of the openings. Different solutions are compared using various positions and lengths of stiffeners in the longitudinal and vertical directions. The comparisons are based on the failure load, the stiffness and the strain distribution. The experimental results and observations show the efficiency and the limits of the different studied solutions of stiffening. It has been observed that long horizontal stiffeners were the best stiffening solution. Furthermore, the use of double or single sided stiffeners showed that in both cases, they improve significantly the ultimate carrying capacity of the beam as long as the anchorage length is sufficient. The results can be used as a basis to develop numerical and analytical models.


ABSTRACT: Structural engineers often face the challenge of assessing the residual structural performance of fire-damaged structures, especially the performance under seismic loading. This study presents investigations on concrete-filled double-skin steel tubes (CFDSTs) after exposure to fire. Physical tests are performed on 12 concrete-filled double-skin steel tubular (CFDST) specimens. The fire tests are conducted first with specimens heated for a specific heating period. After cooling down to ambient temperature, the cyclic tests are carried out with the constant axial load and reverse lateral cyclic load applied on the specimens. Parameters varied include the heating period, the nominal steel ratio, the hollow ratio and the axial load level on the column. Various indexes are used to evaluate the post-fire seismic performance of the CFDST columns, such as the stiffness degradation, the strength degradation and the energy dissipation. Finally, a simplified method is proposed to predict the residual initial flexural stiffness of the CFDST columns exposed to fire. The experimental results provide a basis for the assessment of fire-damaged CFDST structures, and the proposed method provides predictions with reasonable accuracy.


ABSTRACT: The local buckling behaviors of welded π-shaped stub columns were investigated experimentally and numerically in this study. Nine welded π-shaped columns made from Q345 steel with different width-to-thickness ratios were tested under axial compression. The material properties, initial geometric imperfections and welding residual stress distribution of specimens were measured. Results from the tests, including the strengths, the load-deformation responses, and the failure modes were presented. The strengths determined by tests were compared with the design strengths predicted by the current steel design specifications. The experimental studies were complemented by the numerical investigations, in which the finite element models were initially verified against the test results and subsequently used for parametric studies covering a wide range of cross-sections. The modifications on the Bleich formulas were derived to calculate the buckling coefficient of π-shaped section. Based on the experimental and parametric analyses, formula for direct strength method (DSM) was proposed to predict the compressive strengths of welded π-shaped stub columns, which offered reasonable predictions.


ABSTRACT: High-strength structural steel plates are being increasingly used as composite columns in tall buildings, bridges and large infrastructure. The presence of concrete infill in these composite sections enhances their local buckling strength, and thus very slender steel plates can be used in their fabrication. This paper presents the results of an experimental study and numerical investigation of the local buckling slenderness limits for high-strength steel plates. A set of sixteen tests were conducted on both hollow steel and steel-concrete composite sections to explore their local and post-local buckling behaviour under axial compression. A numerical model which accounts for the effects of residual stresses and initial geometric imperfections was developed to predict the local buckling and post-local buckling response of box and I-section columns. This model was verified against the test results. Yield slenderness limits obtained from numerical results were compared with existing codes of practice for both hollow steel and composite sections incorporating high-strength steel plates.
ABSTRACT: The present study investigates the flexural-torsional struts buckling and beam lateral buckling analyses. In the highlight of braced structures, analytical solutions are derived for higher 3D buckling modes of simply supported struts with arbitrary cross-sections. Closed-form solutions are also investigated for lateral buckling strength of beams with doubly symmetric cross-sections. For more general cases, the finite element approach is adopted. In presence of torsion, warping is of primary importance. For this aim, 3D beams with 7 degrees of freedom (DOFs) per node are adopted in the analysis. The model is able to carry out higher buckling modes of bars under compression or lateral buckling modes of beams initially in bending. The analytical and the numerical results of the present model are compared to some available benchmark solutions of the literature and to finite element simulations of some commercial codes (Abaqus, Adina). The efficiency of the closed form solutions and the numerical approach is successfully verified. Applications of higher buckling modes in design of braced structures are considered according to Eurocode 3 code. A particular attention is pointed out to torsion and flexural-torsional buckling modes not considered in bar strength. At the end, some solutions are proposed in order to cover the full strength of columns and beams in presence of instabilities. This proposal makes steel structures more performant and attractive when effects of instabilities are limited at a minimum.


ABSTRACT: A comprehensive experimental and numerical study is presented into the behaviour of stainless steel welded I-section beams-columns. Twenty test specimens were fabricated from grade 304 (EN 1.4301) austenitic and grade 2205 (EN 1.4406) duplex stainless steel plates – ten were tested under major axis bending plus compression and ten under minor axis bending plus compression. Material tensile coupon tests and geometric imperfection measurements were also conducted. Numerical models were developed, calibrated against the test results and subsequently employed in parametric studies considering a wider range of specimen geometries. Based on the obtained test and numerical results, the accuracy and reliability of existing design rules given in EN 1993-1-4 and AISC DG 27, as well as recent proposals, were assessed.


ABSTRACT: This paper studies the behaviour of sea sand concrete-filled stainless steel tube (CFSST) stub columns under axial compression through experimental investigations. A total of 48 specimens were tested, including circular and square stainless steel tubes filled with three types of core concrete, including natural river sand concrete, desalted sea sand concrete and natural sea sand concrete. The effects of key parameters such as the tubular thickness of stainless steel, the cross-sectional configuration and the types of concrete infill on the behaviour of these innovative composite columns were investigated. The confinement effects of CFSST with sea sand concrete were evaluated and compared with that of CFSST with conventional river sand concrete. Testing results showed that the tested CFSST columns showed generally high strength and excellent ductility, while the confinement effect of stainless steel on the sea sand concrete is as reliable as that on the river sand concrete counterpart. Comparisons were made between the test results and the predicted ultimate sectional capacity using the existing specifications AISC360–10 (2010), EC4 (2004) and DBJ/T13-51-2010 (2010). These codes are proved reasonably conservative for predicting the sectional strength of sea sand concrete-filled stainless steel tubular stub columns.

Qihan Shen, Jingfeng Wang, Jiaxin Wang and Zhaodong Ding (School of Civil Engineering, Hefei University of Technology, Anhui Province 230009, China), “Axial compressive performance of circular CFST columns

ABSTRACT: To explore the axial compression property and failure mechanism of concrete-filled steel tubular (CFST) columns partially wrapped by carbon-fibre-reinforced polymer (FRP), a series of tests using carbon-FRP-strengthened circular CFST stubs and slender columns imposed with axial loads were conducted. The effects of various parameters including steel yield stress, number of carbon-FRP layer, slenderness ratio of the composite column, and spacing of carbon-FRP strip on the axial load bearing capacities of the tested specimens were studied. Moreover, the axial compression behaviour of the circular CFST columns with carbon-FRP composites was evaluated in terms of axial compression force (N)–longitudinal shortening displacement (δ) curves, axial stiffness, strain response, strength enhancement indexes, and ductility indexes. Subsequently, a nonlinear finite element (FE) analysis modelling concerning the surface contact action of carbon-FRP-strengthened circular CFST columns was established and validated experimentally. The experimental and analytical results indicate that strengthening the circular CFST stub columns using carbon-FRP wraps could improve their axial load bearing capacities and prevent outward local bulges for the thin-walled steel tubes. Only a slight effect was observed when laterally confined carbon-FRP strips were used for the type of slender composite columns. Finally, several simplified empirical formulas for predicting the axial load bearing capacity of the circular CFST column partially wrapped by carbon-FRP are proposed.


ABSTRACT: A buckling-restrained steel plate shear wall with inclined slots (simply referred as “slotted SPSW”) consisting of an inner steel plate sandwiched between two precast concrete panels, has been developed as an energy dissipation device of structures. The steel strips between inclined slots behave like a series of buckling-restrained braces to dissipate the energy through inelastic axial deformation when subjected to cyclic loading. This paper experimentally investigated the seismic behavior of slotted SPSWs. Three half-scale specimens were fabricated and tested under quasi-static cyclic loading. Details for proper fabrication of slotted SPSWs were firstly configured. The results illustrated that the slotted SPSW could sustain the target lateral drift ratio (2%) without a reduction of shear force and energy dissipation capacity. Moreover, the tested specimens exhibited stable fatigue hysteresis loops when the cyclic loadings were repeated 30 times at 1.5% peak lateral drift ratio. The maximum drift ratio of tested specimens reached 3.5%, and the cumulative plastic ductility factor was larger than 200. The experimental results indicate that the slotted SPSW is capable of providing high lateral force-resisting and energy dissipation, which can be widely used in engineering structures.


ABSTRACT: With the continuing developments in composite design technology, such as classical Concrete Filled Steel Tubes (CFST), concrete filled double skin tubes and concrete filled double section tubes, understanding the performances of such columns in a comparative way is timely. Although significant amount of literature has been gathered around the themes of concrete filled classical and double skin columns, the number of studies on double section columns is very limited. Nevertheless, in existing research, double section column concept has been proven to be very efficient in providing very high strength, ductility and stiffness. The challenge here is to find a route from concept to design which requires significant amount of comparative experiments on classical, double skin and double section columns. This paper, for the first time, examines the performances of concrete filled classical, double skin and double section stub columns which have practical range of material and geometrical properties. Experimental procedures were undertaken for composite columns with normal and high strength self-compacted concrete. To be able to address the effect of tube configurations, two types of outer and two types of inner steel tubes with different mechanical and geometrical properties were utilized. The experimental program revealed the robust characteristics of double section columns. Furthermore, the modified versions of EC4 and AISC 360–16 formulations were assessed against the test results for design
ABSTRACT: The paper presents the detailed test setup and results of a test series on bolted single steel angles in compression with varying end support conditions and slenderness ratios. For all tests FEM-calculations were done, which are also presented. In total 27 specimens with one-bolt and two-bolt connections with and without preload are tested. Three different boundary conditions on both ends are investigated: Boundary condition 1 (BC1) is a clamped support. BC2 is a knife edge support that allows only for rotations about the axis parallel to the connected leg. BC3 is a fully hinged support. In addition to the results of the member tests, imperfection measurements and results of material tests are presented in order to carry out the FEM-calculations and to allow for comparison with current design standards.


ABSTRACT: This paper presents experimental and analytical studies on the structural behavior of circular tubed steel-reinforced-concrete columns subjected to eccentric compression. The specimens were tested to investigate the effects of load eccentricity, diameter-to-thickness ratio of steel tube, and use of shear connector studs on steel sections. The test results indicated that all specimens showed flexurally dominated failure, and the tube confinement decreased with the increasing slenderness of the columns. A nonlinear finite element model was developed using ABAQUS, in which the initial geometric imperfections and the slenderness effects on tube confinement were taken into account. A modified plastic stress distribution method was proposed to predict the resistance of the critical section of the column. Finally, an equation to estimate the effective stiffness of the column was proposed.


ABSTRACT: Cold-formed steel haunched portal frames are popular structures in industrial and residential sectors. They are commonly used in rural areas for sheds, garages, and shelters, and are now being constructed with spans of up to 30 m in Australia. As these large structures are relatively new to the market, there is limited data on their behavior and design recommendations, including connection stiffness and design. Numerical and experimental parametric studies were conducted on a haunched portal frame composed of back-to-back lipped channel sections bolted through the webs for the main frame members, and back-to-back L-brackets bolted though the webs at the connections. An advanced shell finite element model was created and validated with experimental results to confirm the suitability of the modeling technique. The validated finite element model was then used for parametric studies to determine the effects of various components of the frame, including column base connection stiffness and modifications to the knee brace-to-column connection design, on the frame capacity and behavior. An experimental program was conducted to quantify column base connection stiffness where the connection was comprised of L-brackets bolted through the column flanges at the base. Stiffness was quantified for bending about the column major and minor axes for various thickness L-brackets and for a U-bracket. Apex in-plane connection stiffness was quantified experimentally for several rafter channel thicknesses and depths. Discussions of the results of the parametric studies are presented in addition to the resulting design recommendations for constructing effective long-span cold-formed steel portal frames.

ABSTRACT: In the safety assessment of existing spatial structures, sampling measurements are widely used to investigate structural geometries. The information from sampling measurements is limited and leads to the positional uncertainty of unmeasured nodes. Uncertain nodal positions have a significant influence on the stability assessment of the spatial structures with high geometric-imperfection sensitivity. To deal with the uncertainty of nodal positions, a probabilistic framework based on the randomness of nodal positional deviations was proposed. In the framework, uncertain nodal positions are modeled by random field, whose relevant parameters were inferred with the data from sampling measurements; based on the random field model, a full-probability analysis is adopted to determine the load-bearing capacity and further perform the stability assessment. According to the analysis of the correlation between nodal positions, correlated and uncorrelated random fields were respectively introduced to model the correlated and uncorrelated nodal deviations. And the detailed modeling methods were discussed, including the inference of distribution types, parameters and correlations. Finally, an existing single-layer reticulated shell was used to validate the reliability of the proposed probabilistic framework.


ABSTRACT: The accuracy of the interaction methods for combined flexural and lateral torsional buckling are investigated using statistical data, which has become available after the introduction of Eurocode EN1993-1-1:2005. The freely available statistical data for geometric and material parameters for standard profiles are quite limited and as background documents are based on IPE 160 profile, our investigations are also based on this profile. A semi-probabilistic first order reliability approach is used and the resistance of the member is treated as a stochastic variable. Latin Hypercube Sampling is used for population sampling. This simulation approach for determination of the buckling interaction surface has not previously been reported. The Eurocode handles buckling interaction through two interaction equations. These equations include a number of interaction factors. The calculation of the interaction factors may be performed by one of two methods, referred to as Method 1 and Method 2. Both interaction methods make use of the buckling curves for determination of reduction factors for both flexural and lateral torsional buckling. The flexural buckling curve is well calibrated; however, this is not the case for lateral torsional buckling. It turns out that the methods may lead to unsafe designs when a lateral torsionally slender column is loaded predominantly in bending. The present paper investigates how the Eurocode emulate the complex behavior also for very slender beam-columns. The 0.1% quantile interaction curves are compared to those resulting from the use of Method 1 and Method 2.


ABSTRACT: Cold-drawing is one of typical cold-forming techniques in producing stainless steel tubes. Compared with cold-rolling, cold-drawing can be used to manufacture large scale stainless steel tubes. In this study, material properties tests of 14 coupons taken from cold-drawn duplex stainless steel square tubes were reported, along with six stub and seven long column tests under axial compression. Stress-strain curves, ultimate loads and failure characteristics of stub and long columns were obtained. Test results indicate that cold-drawn duplex stainless steel tubes have pronounced cold-forming effect, the yield strength of the flat region reaches up to 750 MPa and the elongation at the fracture decreases significantly. And, all the stub columns show local buckling mode, while most of the long columns undergo overall flexural buckling mode. Finite element models were developed, validated using test data, and then used to generate more results over a wider range of cross-sectional and member slenderness. Both the results of test and numerical modeling were compared with the design strengths of the European, American, Australian/New Zealand and Chinese codes, the design method
proposed by Afshan, and the deformation based continuous strength method (CSM). Comparisons show that:
for stub columns, design strengths according to all the design codes are underestimated, while the continuous
strength method provides reasonable predictions especially for both the stocky and slender cross-sections; for
long columns, design strengths calculated using the European, Australian/New Zealand, Chinese codes and the
method proposed by Afshan are conservative, while those calculated using the American code are unsafe.

Yancheng Cai, Wai-Meng Quach, Man-Tai Chen and Ben Young (First author is from: Department of Civil
Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, China), “Behavior and design of
cold-formed and hot-finished steel elliptical tubular stub columns”, Journal of Constructional Steel Research,
ABSTRACT: Significant progress has been made on structural behavior of hot-finished (HF) steel members
with elliptical hollow sections (EHS) in the past few years. However, there is very limited research on cold-
formed (CF) steel members with EHS. In this study, both CF and HF steel elliptical tubular stub columns are
investigated. The investigation includes laboratory testing, numerical analysis and design evaluations. The
geometric imperfection measurements, full load-end shortening relationships and load-strain curves of the stub
columns are detailed in this paper. A non-linear finite element model was developed and validated against test
results obtained from the present study as well as from the literature. The validated numerical model was
employed to perform an extensive parametric study, where the CF and HF stub columns with EHS were
carefully designed to include a broad range of the cross-section slenderness and aspect ratio. The cold-forming
effect on the CF sections was taken into account in a conservative manner. The ultimate strengths obtained from
the tests and numerical analysis were compared with the predictions in the design strengths predicted by the
design methods proposed in the existing literature and the Direct Strength Method (DSM). The comparisons
showed that the strengths predicted by the equivalent diameter method, the DSM and the modified DSM are
generally conservative and reliable. The modified DSM provides the most accurate and the least scattered
predictions among these design methods. Therefore, the modified DSM is recommended for the design of CF
and HF steel elliptical tubular stub columns.

Myung-Sung Kim, Sun-Beom Kwon, Seul-Kee Kim, Jeong-Hyeon Kim and Jae-Myung Lee (Department of
Naval Architecture and Ocean Engineering, Pusan National University, Busan 46241, Republic of Korea),
“Impact failure analysis of corrugated steel plate in LNG containment cargo system”, Journal of Constructional
ABSTRACT: In the present study, the failure characteristics of the primary barrier of a GTT Mark-III type
liquefied natural gas (LNG) cargo containment system (CCS) under cyclic impact loads were analyzed using a
comprehensive failure model. The three types of failure modes that mainly occur in a thin-walled structure,
namely, localized necking, ductile failure, and shear failure, were considered to evaluate the different failure
phenomena for large and small corrugations of the primary barrier consisting of 304 L stainless steel. To
validate the numerical analysis approach, a series of impact tests were conducted, and the reaction force history
along with the permanently deformed configuration of the thin-walled structure was compared to the simulation
results of structural impact failure. Through the comparative study, it was confirmed that the simulation
outcomes were in good agreement with the experimental results. The proposed failure analysis model was used
to quantitatively predict the structural impact failure of the primary barrier under severe impact (or sloshing)
loads, and the estimated structural life was proposed based on the failure index concept.

J.H. Wang, J. He and Y. Xiao (Primarily from: College of Civil Engineering, Nanjing Tech University, Nanjing,
Jiangsu Province, China), “Fire behavior and performance of concrete-filled steel tubular columns: Review and
discussion”, Journal of Constructional Steel Research, Vol. 157, pp 19-31, June 2019,
https://doi.org/10.1016/j.jcsr.2019.02.012
ABSTRACT: This paper presents a review of the fire behavior and performance of concrete-filled steel tubular
(CFST) columns. The motivation for the studies on the fire behavior of CFST columns is provided. The effects
of many structural parameters on this fire behavior are reviewed and discussed. The equations in the current
design codes for predicting the fire resistance capacity and residual axial load carrying capacity are
summarized, and comparisons between the experimental results and the predicted results are performed. The
discussion results indicate that the fire resistance capacity decreases with the increase in the slenderness ratio,
axial load applied, and normal concrete strength, and with the decrease in the cross-sectional dimension and the ratio of reinforcing steel rebar to thickness of fire protection. The Chinese and North American codes provide reasonable prediction of the fire resistance of a CFST column, whereas the Japanese and the modified European codes overestimate the experimental results. Besides, the Chinese code and the Han model predict the residual axial load carrying capacity with better accuracy than the European and Japanese codes. Finally, recommendations for future studies are provided.

Yiran Wu, Yonglei Xu, Yongjiu Shi and Huiyong Ban (Key Laboratory of Civil Engineering Safety and Durability of China Education Ministry, Department of Civil Engineering, Tsinghua University, Beijing 100084, China), “Overall buckling behavior of fire-resistant steel welded I-section columns under ambient temperature”, Journal of Constructional Steel Research, Vol. 157, pp 32-45, June 2019, https://doi.org/10.1016/j.jcsr.2019.02.019

ABSTRACT: The fire-resistant steel as a type of high performance steel has significant application potential in building structures. The overall buckling behavior of fire-resistant steel columns at elevated temperatures is remarkably different from those of mild steel and high strength steel. However, structural behavior at ambient temperature had to be understood first before the investigation at elevated temperatures. This paper presents compressive tests on WGJ high performance fire-resistant steel welded I-section columns. The experimental results are compared with suggested values of Chinese, European and American specifications. Finite element models are established and the parameter analysis are carried out, showing current Chinese specification, Eurocode and American specification cannot be directly applied to determine the buckling resistance of high performance fire-resistant steel welded I-section columns. In addition, the modification on the design methods specified in current Chinese specification is also proposed.


ABSTRACT: Shear behaviour of cold-formed steel beams with an aspect ratio (shear-span/web-depth) of 1.0 has been studied thoroughly, mainly using central point load tests. However, for beams with higher aspect ratios, the effect of bending causes a reduction of shear capacity and alters the failure modes. This paper introduces a new test setup, the dual actuator test rig, which is equipped with two actuators moving independently at customizable displacement rates to control and minimize applied bending moments in the shear spans of interest. Shear strength close to pure shear capacity can be therefore reached even at an aspect ratio of 2.0. Experimental series recently performed at the University of Sydney on channel section members using the new test configuration is presented. The experimental results together with other available experimental data are combined and used to validate and re-calibrate the Direct Strength Method design formulae incorporated in the AISI S100:2016 Specification and the AS/NZS 4600:2018 Standard.


ABSTRACT: Concrete-filled steel tubular (CFST) columns are adopted in many structural applications, especially for tall buildings, bridges and large infrastructure due to their substantial structural and economic benefits. However, the design guidelines for CFST columns with high strength materials and slender sections are still limited. In acknowledging these limitations, a large number of tests on high strength CFST columns have been conducted. In this paper, the most recent experimental data on CFST columns with high strength materials and slender sections are collected and merged with existing databases to establish a comprehensive database with over 3100 tests. The test results are then compared with those predicted from existing design codes, including Eurocode 4, Australian/New Zealand code AS/NZS 2327 and American code AISC 360-16 to calibrate their accuracy in strength prediction of CFST columns. In general, all codes give conservative predictions for CFST columns. Eurocode 4 and AS/NZS 2327 give the best predictions, whilst AISC 360-16 gives conservative predictions. The effects of material strengths and section slenderness on the code predictions
are also investigated to evaluate the applicability of the codes beyond their material strength and section slenderness limits.


ABSTRACT: This paper presents a numerical investigation on concrete-filled steel tubular (CFST) beam-columns with square sections subjected to combined sustained load and corrosion. A general numerical method is used for the simulation of the time dependent behaviour of the core concrete, while the wall-thickness loss of the outer steel tube induced by corrosion is considered in this model simultaneously. The established finite element analysis (FEA) 1261odeling is verified with test data and used for further investigations of the load-deformation relationship, load-transfer mechanism, stress and strain development, failure modes and ultimate states on CFST beam-columns when suffering combined sustained load and corrosion. Parametric studies are conducted to reveal the effects of key parameters, based on which simplified design method is suggested for square CFST beam-columns under combined sustained load and corrosion.


ABSTRACT: Previous researches on cold-formed steel members are mainly focused on non-annealed sections while research on annealed sections is quite limited. This research is focused on the material properties and overall stability behavior of annealed cold-formed thick-walled SHS and RHS steel tubes. An experimental study including the material property tests on axially compressed annealed cold-formed thick-walled SHS and RHS steel tubes was presented in this paper. The material properties were compared with that of non-annealed sections and it was shown that annealing process can improve the ductility of coupons. The test results were used to validate the finite element analysis which provided the basis for proposing the column curves. Then the curves were compared with the column curves in the Chinese codes and North American specifications. It was found that most of the test and FEA points were above the curves of GB 50018-2002 and AISI which indicated that the column curves in these codes were not suitable for annealed thick-walled steel members. Finally, the column curves of annealed and non-annealed sections were compared and the effect of residual stress was studied.

Ying Qin, Gan-Ping Shu, Guan-Gen Zhou and Jian-Hong Han (Primarily from: Key Laboratory of Concrete and Prestressed Concrete Structures of Ministry of Education, National Prestress Engineering Research Center, School of Civil Engineering, Southeast University, Nanjing, PR China), “Compressive behavior of double skin composite wall with different plate thicknesses”, Journal of Constructional Steel Research, Vol. 157, pp 297-313, June 2019, https://doi.org/10.1016/j.jcsr.2019.02.023

ABSTRACT: Double skin steel-concrete composite walls could offer high capacity and stiffness while affiliating the construction. The structural behavior of double skin steel-concrete composite walls under axial compression is largely dependent on the interface bonding between the steel plate and the concrete core. Weak restraint between these two different materials may lead to early local buckling of the steel plate and thus the separation between the steel and concrete surfaces under large compression. Furthermore, the plate thickness is essential to the axial behavior of composite walls. Thin plate may cause early local buckling and thus reduce the axial load capacity. This paper investigates a new type of double skin composite wall. The steel truss constructed by two angles and kinked rebar is acting as the interface connector. Full-scaled tests were conducted on three specimens with different plate thicknesses. The structural behavior of the walls was comprehensively evaluated in terms of load-displacement curve, buckling stress, axial stiffness, ductility ratio, strength index, load-lateral deflection response, and strain distribution. The influences of plate thickness on the structural performance were discussed in details. The test data was compared with the calculated results based on three modern codes. It was found that Eurocode 4 provides the most conservative results while CECS: 2018 offers the most suitable predictions.

ABSTRACT: Buckling resistance predictions resulting from flexural and flexural–torsional buckling of double tee section members subjected to compression and bending are considered. A novel analytical model is developed for establishing design criteria based on decomposition of the member buckling behaviour into in-plane and out-of-plane resistance. The former is based on second-order bending relationships of load effects of structural members with in-plane equivalent imperfections, while the latter is based on the stability theory of thin-walled open sections. First part of this study presents an analytical formulation of the in-plane buckling resistance of beam–columns. In this regard, further decomposition is postulated for the in-plane first-order bending moment diagram that results in the loading state to be the superposition of two components. The first component is related to symmetrical loading and the second to antisymmetric loading. To consider the second-order effects, prebuckling displacements generated by the abovementioned loading components are amplified with regard to the inversion of the residuum of the buckling force 1262odeling1262on ratio in order to obtain approximate values of second-order displacements and internal moments. As a result, the in-plane interaction curve, expressed in dimensionless coordinates, that describes the beam–column in-plane flexural buckling resistance without considering lateral–torsional buckling effects, is obtained. The results of nonlinear finite element simulations are used for the verification of the developed analytical formulation. It is concluded that this proposal yields less conservative predictions than those based on the interaction relationships of clause 6.3.3 of Eurocode 3, Part 1–1.


ABSTRACT: The steel structures of conveyance guiding systems, particularly steel guides used in mine shafts, are commonly made of box-section beams welded from hot-rolled channel sections. Hot-rolled profiles are generally resistant to local buckling; however, long-term exposure to the aggressive environment of a mine shaft leads to high corrosive loss of the material and reduction of the wall thickness. Some industrial regulations on shaft steelwork design and maintenance allow more than 50% corrosion loss for guides; however, they do not require local buckling calculations. This study investigated the buckling resistance of box-section beams welded from hot-rolled channel sections under bending, in terms of uniform corrosion loss. Laboratory bending tests were conducted on five beams for three levels of web thickness reduction achieved by etching and the results were compared with those obtained from finite element (FE) simulations. Linear modal analyses and nonlinear Riks simulations with imperfections were performed. The hot-rolled box-sections, which are generally resistant to local buckling, were found to be susceptible to local buckling at 46 and 60% corrosion losses in the plastic state and at 71% corrosion loss in the elastic state. This study highlights the need to consider local buckling when using hot-rolled closed profile beams at high corrosion loss.


ABSTRACT: One of the greatest challenges in the design of shell structures made of stainless steel compared to those made of carbon steel is the meaningful consideration of the nonlinear stress-strain behaviour of stainless steels which has a significant influence on the buckling behaviour of axially compressed shells in the medium slenderness range and lead to lower buckling strengths. A detailed description of the actual material behaviour of stainless steels is given by the material model developed by Arrayago, Real and Gardner on the basis of the by Rasmussen modified two stage Ramberg-Osgood material model. One of the parameters of which the model consists is the exponent n, which describes the nonlinear behaviour just before the 0.2% proof stress. This exponent is of great importance for the buckling behaviour of axially loaded shell structures of medium slenderness. For this reason, a thorough numerical parametric study has been conducted in order to evaluate the effect of the nonlinear material behaviour described by the exponent n on the buckling resistance of austenitic,
duplex, and ferritic stainless steel shells. The numerical model has been validated by experimental results of axially compressed cylindrical shells conducted in the frame of the European RFCS-research project BiogaSS.


ABSTRACT: This paper presents a new buckling-restrained steel plate shear wall system with assembled multi reinforced concrete (Multi-RC) panels (MBRSPSW). The finite element model of MBRSPSW system with hinged frame, validated by existing experimental results, is developed to investigate the general mechanical behaviors, such as hysteretic property, horizontal shear force, internal force demands of boundary columns and damage of RC panels. Three key parameters, including steel plate slenderness ratio, gap width between RC panels and number of RC panels, are established. To investigate the general behavior of MBRSPSW system and conventional buckling-restrained steel plate shear wall (BRSPSW) system, two test specimens with rigid frame corresponding to actual moment-resisting frame are further conducted. The results show that MBRSPSW system provide stable bearing capacity and good energy dissipation capacity by dividing single RC panel into multi-RC panels. The internal force demands of the boundary column of MBRSPSW system, especially for the bending moment, decrease significantly compared to that of BRSPSW system. Damage of RC panels of MBRSPSW system is greatly decreased compared with that of BRSPSW system. Number of RC panels and the gap width of MBRSPSW system have significant effect on the tension damage of RC panels, especially for the number of RC panels. BRSPSW system is found to fail prior to MBRSPSW system with a plastic hinge at the bottom of boundary column in test investigation and damage of RC panels of the latter is much lower than that of the former. The experimental observations agree well with the numerical results.


ABSTRACT: When it is subjected to a fire, creep strain developed in a steel column can significantly influence the behaviour of the column. As the result, the column deformation will be increased and the strength will be decreased. However, the effect of creep in steel structures has not been fully considered in current fire resistance design codes. Presented in this paper is a study on creep buckling of Q460 steel columns subjected to elevated temperatures via experimental and numerical investigations. Six high-strength Q460 steel columns with welded H shape were tested for the determination of creep buckling strength at elevated temperatures. The effects of the slenderness ratio, load ratio, and elevated temperature on failure time corresponding to creep buckling (also called as creep buckling time) were taken into consideration in the investigations. The evolutions of furnace and column temperatures, column lateral and axial displacements associated with fire duration were measured. The creep buckling time of the columns were obtained based on the magnitudes of axial and lateral displacement of the columns subjected to constant elevated temperature and compressive load. The test results showed that the creep deformation of high strength Q460 steel columns became significant at temperature 800 °C even the applied load level was as low as 10%. The creep buckling time of Q460 steel columns are sensitive to load ratio, slenderness and temperature. Finite element analysis program ANSYS was employed to establish a structural model of Q460 steel column subjected to the constant elevated temperature and compressive load, with mechanical properties at elevated temperature, creep strains and residual stresses induced by welding being taken into account. The finite element model was validated by the test results. Parametric studies were carried out to quantitatively determine the effects of the slenderness ratio, load ratio, temperature and geometric imperfections on the creep buckling time of Q460 steel columns.


ABSTRACT: Experimental studies on concrete-filled stainless steel (SS) circular stub columns (in the form of fully filled and double-skin) have been reported in the last 10 years, but there is still a lack of theoretical model
to predict the complete load-axial strain curve of such stub columns under axial compression. This study presents a load-axial strain model for concrete-filled SS tubes, which takes account of the interaction between the encasing tube and concrete core. A dilation model is first proposed in which the dilation rate is expressed as a function of axial strain and outer tube diameter-to-thickness ratio. The theory of metal plasticity in the form of deformation type is adopted to calculate the bi-axial stresses in the SS outer tube. The SS inner tube is assumed to be under uni-axial compression and continuous strength method (CSM), which is suitable for strain hardening material such as SS, is adopted. The effect of SS tube buckling on reducing the axial stress and confining stress is considered in the model. Numerical procedures are proposed to generate the complete load-axial strain curve which involve an incremental process. Finally, the predicted load-axial strain curves are compared with the experimental results obtained by the authors and other researchers, and a good agreement is achieved.

ABSTRACT: In this paper, a large database of 491 test results of circular concrete-filled steel tube (CFT) columns under axial compression was collected from the available literature. The collected results were employed to investigate the effects of loading conditions, diameter-to-thickness ratio, concrete type and compressive strength on the load-carrying capacity of CFT columns, from which models for the hoop stress of steel tubes are obtained through nonlinear regression analyses. Based on the von Mises yield criterion together with the proposed hoop stress models, a model for predicting the load-carrying capacity of CFT columns was developed. The performances of the proposed model and the existing models were evaluated using the database. Due to the rationality of the model development process, the proposed model offers a more reasonable and accurate prediction of load-carrying capacity for CFT columns under various loading conditions.

ABSTRACT: This paper presents an investigation of the optimum locations of multiple longitudinal web stiffeners (up to six) for steel plates under pure bending by using the gradient-based interior point optimization algorithm. Performing eigenvalue buckling analyses, buckling coefficients are calculated accounting for the lowest eigenvalues. The optimization algorithm is then employed to maximize the buckling coefficients until the optimum stiffener locations of the plates are attained. Based on this research, the optimum locations of multiple longitudinal stiffeners are suggested for plates under pure bending. Moreover, equations to determine minimum flexural rigidities of multiple longitudinal stiffeners for steel plates are also proposed. The results obtained from this study are compared with the AASHTO requirement and previous works. It is proved that the minimum flexural rigidities of stiffeners recommended by AASHTO and the previous work are conservative.

ABSTRACT: This paper presents a comprehensive investigation of the numerical modelling of cold-formed steel single C-section portal frames using shell elements. The model accounts for the semi-rigid behaviour of connections using mesh-independent point-based fasteners at the location of physical bolts. The behaviour of deformable fasteners is ascribed though the use of connector sections. Nonlinear analysis is carried out to obtain the load-displacement response leading to the prediction of frame strength. The predicted strengths of frames are compared with experimental results. The main cause of the observed flexural-torsional buckling behaviour of frames is highlighted and the importance of using an accurate fastener model is emphasized.

ABSTRACT: The vibration of lightweight floors under service loads may cause annoyance to the occupants of buildings, particularly when the fundamental natural frequency of the floor is close to the range of frequencies
4–8 Hz to which the human body is sensitive. Accordingly, the vibration response of the floors is a governing factor in the structural design of steel-timber composite (STC) flooring systems, which have been proposed as an innovative alternative to conventional steel-concrete floors. The current study is part-2 of a comprehensive experimental and numerical study on serviceability performance of the STC floors under human-induced excitations. Natural frequencies are often used as measure of the acceptable vibration performance of the floors. Accordingly, the finite-element (FE) models calibrated and validated against the experimental results in part-1 are used to predict the natural frequencies of the typical STC floors with medium to long spans, and the effect of the geometry of the floor, the mechanical properties of the connections and the magnitude of superimposed loads on the natural frequencies of the STC floors are investigated through a parametric study. In addition, dynamic analyses are carried out to predict the vibration response (i.e. displacements, velocities and accelerations) of the STC floors, developed in the parametric study, subject to human activities and the vibration performance of the floors with respect to acceptability criteria derived from various building codes is assessed. Lastly, some floor design recommendations are made to ensure satisfactory performance of the STC floors under human-induced vibrations according to the existing building codes.


ABSTRACT: The companion paper Part I [1] deals with the experimental campaign of longitudinally stiffened plate girders subjected exclusively to patch loading. The current paper focuses on the numerical research and parametric study of the influence of patch load length and initial geometrical imperfections on the ultimate strength of longitudinally stiffened plate girders. In order to assess the patch load resistance, a geometrically and materially nonlinear finite element analysis has been performed. For a better verification with the experimental results, the finite element model includes the experimentally measured initial geometrical imperfections and material properties based on laboratory tests. The verification of the numerical model has been obtained through the comparison of the numerically and experimentally attained results for the ultimate loads and elastoplastic behavior of the girders. It has been shown that the numerical and experimental results are in perfect agreement, which enabled a fruitful background for parametric analysis, in which different initial geometrical imperfections have been used to ameliorate understandings about their influence on the ultimate strength under different patch load lengths. Conclusively, it may be stated that initial geometrical imperfections can play a decisive role, especially for longitudinally stiffened girders. Initial geometrical imperfections of stiffened girders that correspond to deformed shape at the collapse (collapse-affine imperfections), especially in the zone where the load is applied, will give the most unfavorable ultimate strengths. For the considered geometry in the present paper, the third buckling mode of longitudinally stiffened girders corresponds to the deformed shape and the lowest ultimate strengths are obtained.


ABSTRACT: The axial performance of a type of concrete-encased CFST box stub column, which consists of the outer reinforced concrete (RC) box column and six embedded CFST components, is investigated in this study. A total of eight axial compression tests on the concrete-encased CSFT box specimens under axial compression were carried out. A finite element analysis (FEA) model was developed to analyze the structural behavior of the composite columns. The effects of material nonlinearity and interaction properties between the concrete and the steel tubes on the simulation were considered. The verified FEA model was then used to conduct a full-range analysis on the load-deformation responses. The results of typical failure modes, internal load and stress distributions and the contact stresses between the concrete and the steel tubes were also discussed. Parametric studies were conducted to investigate the effects of geometric and material properties on the compressive behavior of the concrete-encased CSFT box members. Finally, a simplified model was proposed to predict the ultimate strength and the initial stiffness of the concrete-encased CFST box stub columns under axial compression.

ABSTRACT: This paper presents the experimental and numerical investigation on the behavior of cold-formed steel elliptical hollow section beams. In the test program, a total of 20 beam tests was conducted. Four elliptical section series with the nominal cross-section aspect ratio ranging from 1.65 to 3 were bent about the major and minor axes in both three-point and four-point bending configurations. Finite element models were established to replicate the beam tests numerically. Based upon the validated model, extensive parametric study was conducted on 235 beam specimens to study the behavior of cold-formed steel elliptical hollow sections subjected to bending. The results obtained from experimental and numerical investigation were used to assess the existing design methods and to propose modified design methods for cold-formed steel elliptical hollow section beams. It should be noted that the current design codes do not cover the design of elliptical hollow section beams. The flexural strengths of beams were compared with the design strengths predicted by the equivalent diameter and equivalent rectangular section methods proposed by previous researchers, the traditional design methods using equivalent diameter as well as the Direct Strength Method and the Continuous Strength Method. The applicability and reliability of these design methods were assessed. The results indicate that the existing design methods are not capable to predict the flexural strengths of cold-formed steel elliptical hollow section beams in accurate and reliable manner. In this study, the modified Direct Strength Method and Continuous Strength Method are proposed, which provide accurate and reliable flexural strength predictions.


ABSTRACT: This paper presents a thorough experimental and numerical investigation into the structural performance and load-carrying capacities of circular concrete-filled stainless steel tube (CFSST) stub columns under axial partial compression. The experimental programme was carried out on 3 fully loaded (reference) circular CFSST stub column specimens and 15 partially loaded circular CFSST stub column specimens, with a series of material and geometric parameters (including the concrete grade, the stainless steel tube size and the area and shape of the partial compression region) varied. Analysis of the obtained test results revealed that the partial compression area ratio, defined as the ratio of the concrete gross area to the partially loaded area, and the confinement factor, given as the steel tube to concrete plastic compression resistance ratio, are the two key factors influencing the structural behaviour and load-carrying capacities of circular CFSST stub columns subjected to partial compression. The testing investigation was supplemented by a systematic finite element (FE) modelling study, where the numerical models were firstly developed and validated against the experimentally derived results and then employed to conduct parametric studies for the purpose of expanding the experimental data pool over a broader range of partial compression area ratios and confinement factors. In the absence of the established codified design provisions for CFSST stub columns subjected to partial compression, the corresponding design rules for partially loaded concrete-filled carbon steel tube stub columns, as given in the European code and American specification, were evaluated for CFSST stub columns under partial compression load, and shown to result in both conservative and scattered resistance predictions. Other recently developed proposals for partially loaded concrete-filled carbon steel tube stub columns were also assessed for CFSST stub columns, indicating a high level of design accuracy on average but with many unsafe resistance predictions. Finally, a new design approach was developed specifically for CFSST stub columns under partial compression, and shown to yield precise, consistent and safe-sided resistance predictions through comparing against the test and FE results.


ABSTRACT: This paper presents an experimental investigation on the axial behavior of square ultra-high performance concrete (UHPC) filled steel tube columns (SUHPCFSTs). To this end, 32 short specimens are fabricated and tested in the presence of uniaxial compression. The confinement index is considered as a variable by changing the steel tube thickness and the UHPC strength. The roles of failure modes, load-deformation curves, ultimate load bearing capacity, and post-peak ductility of specimens are examined in some detail. The
results indicate that the axial load-deformation curves can be classified into three distinct types with three stages based on the confinement index. Good ductility is observed for all specimens with the confinement index in the range of 1.41 to 5.27. The ductility and strength indexes grow by increasing of the confinement index, in spite that the increase of the strength index is insensitive. Additionally, the interaction between the UHPC and the steel tube is mainly treated in the ductility, not the load bearing capacity of columns. Finally, a revised calculation method for predicting the ultimate bearing capacity of SUHPCFSTs is proposed, and then, it is validated by the experimental results.

ABSTRACT: The existing literature concerning the flexural strength of circular concrete-filled steel tubes (CFSTs) has been reviewed in this paper. Using a much-expanded database of published flexural tests than considered in previous review studies, the applicability and conservativeness of four commonly used design standards to assess the flexural capacity of circular CFSTs have been substantiated through this review. This was verified to be the case irrespective of the type of concrete used for infilling the steel tubes of the circular CFST. Reliability analyses performed based on 219 circular CFST flexural tests obtained from the literature provided confirmation that the capacity factors stated for steel and concrete in AS/NZS 2327 provide an adequate reliability level for structural design. The calibrated capacity factors for the target reliability index exceeded the values given in the standard thereby confirming the conservatism of the code. In addition, it was ascertained that the slenderness limits specified for compact behaviour in the design standards were significantly conservative. Further bending tests on larger diameter tubes with thinner walls and higher steel strengths are needed to establish the actual limits. Further testing is also needed to ascertain the effect of the steel tube fabrication method on the flexural capacity of circular CFSTs.

ABSTRACT: The structural responses of cold-formed high strength steel (HSS) square and rectangular hollow section (SHS and RHS) beams at elevated temperatures were examined in this study. Stress-strain relationships of cold-formed HSS at elevated temperatures were proposed and verified against material test results. The proposed stress-strain relationships were then employed in a finite element (FE) analysis to study the behaviour of cold-formed HSS SHS/RHS beams at elevated temperatures up to 1000 °C. The developed FE model was verified with available test results of cold-formed HSS SHS/RHS beams; upon verification, a total of 252 numerical flexural capacities were gained from FE analyses. The numerical results were used to investigate the suitability of existing cross-section slenderness limits to the HSS tubular sections at elevated temperatures. The applicability of current flexural design provisions in the Eurocode 3, AISC and AISI specifications to the investigated HSS tubular beams at elevated temperatures was also examined. Overall, it is shown that the codified provisions can provide quite conservative predictions; an improved design rule is proposed by modifying the direct strength method (DSM) in the AISI specification. Furthermore, reliability analyses were carried out to assess reliability levels of codified and modified provisions. It has been demonstrated that the modified DSM can produce accurate and reliable design and therefore is recommended to be used for cold-formed HSS SHS/RHS beams at elevated temperatures.

ABSTRACT: This paper presents a finite element analysis based study of web crippling failures in cold-formed steel unlipped channel sections with their flanges fastened to supports under one-flange load cases (EOF and IOF). Currently no design equations are available in the current cold-formed steel specifications to determine the web crippling capacities of unlipped channel sections with restrained flanges under one flange load cases. Hence the web crippling behaviour of unlipped channel sections was first investigated experimentally using 28 tests and suitable coefficients were proposed for the current web crippling design equation. However, the applicability of the proposed coefficients was limited to the tested channel sections. In this study advanced
finite element models were developed in ABAQUS/CAE and validated in terms of ultimate failure loads, load versus deflection curves and failure modes. The developed models were analysed using nonlinear static and quasi-static analysis based on implicit and explicit integration schemes. This study addressed the effects of mesh size, element type, mechanical property model and inertia of support and loading plates. Also, the effects of two enhancement techniques of explicit analysis such as mass scaling and artificial loading rates with different thicknesses were investigated and the results are presented. A detailed parametric study was then conducted using the validated finite element models. New and improved design equations were proposed to determine the web crippling capacities of unipped channel sections using the results from both finite element analysis based parametric study and experiments.


ABSTRACT: Concrete-filled stainless-steel tube (CFSST) columns, which would be more durable than their mild-steel counterparts, are potentially a more economical method of using stainless-steel for structures. Spiral-welded stainless-steel tubes (SWSSTs) could further increase the cost-effectiveness of CFSST columns. SWSSTs are an alternate and advantageous form of welded tube fabricated by welding a helically bent steel plate. The behaviour of concrete-filled SWSST (CF-SWSST) columns can potentially be different to CFSSTs using other tube types, especially due to larger residual stresses present in SWSSTs. Given this background, twelve self-compacting CF-SWSST short columns with nominal diameter-to-thickness ratios (D/t) equal to 51, 76, 101.5 and 114.5 were tested under axial compression considering eccentricities of 0, 0.15D and 0.4D. The observed failure mode, consisting of flexural local buckling, was equivalent to that reported for non-SWT CFSST columns. The spiral weld did not act detrimentally to the strength. Concrete-filled mild-steel tube design standards provided satisfactory predictions of the experimental capacities for CF-SWSSTs under eccentric loading though they were less conservative when the loading was concentric. The need for separate calibration of design guidelines for CF-SWSST short columns was established since, on average, the actual to predicted capacity ratios were noticeably less than those of non-SWT CFSSTs. Fibre-based section analyses using a confined concrete material model gave better predictions of the eccentric axial capacities than codified methods suggesting greater confinement benefit than considered in the standards are applicable to eccentrically loaded CF-SWSST short columns. The study also confirmed equivalent strength behaviour of CF-SWSST short columns to their mild-steel counterparts though with greater ductility.


ABSTRACT: The study is aimed at clarifying the elastic and inelastic behaviour of irregular panel zones (PZs) in a steel moment-resisting frame with circular hollow section (CHS) steel columns and H-shape steel beams connected with external diaphragm under cyclic loading, where the elevations of the beams on left- and right-hand sides of the column are different. To this end, experiments were carried out on the beam-to-column steel sub-assemblage frame connected with an external diaphragm. A parametric study was conducted by considering different values of a parameter β (the ratio of the elevation difference of the beams on both sides of the column to the beam height), and different configurations of the external diaphragm in the connection. The experimental results revealed that the parameter β has a significant influence on the stiffness of the PZs, but no significant effect on the shear strength of the PZs, and the stiffness of the PZs decrease as β increases. In addition, the shape of the external diaphragm has significant influences on the energy dissipation capacity and load bearing capacity of the frame. A qualitative evaluation of the mechanical performance of the PZs is given, and a reasonable connection configuration for the structure design with the PZs is provided. The non-linear finite element analysis (FEA) method was also used to analyze the test specimens. By comparing with the experimental results, the FEA method can give a reference for quantitative analysis of the mechanical properties of the irregular PZs.
ABSTRACT: The behaviour of prestressed stayed steel columns under axial compression has been intensively investigated; however, research on their behaviour under eccentric loading has not been conducted. This current work investigates the stability behaviour of prestressed stayed steel box section columns under eccentric loading by using finite element analysis. It was demonstrated that the load carrying capacity could be decreased by the load eccentricity. A reduction factor that quantitatively denotes the effect of load eccentricity on the load carrying capacities was defined, and approximate formulae calculating the reduction factor have also been proposed. Further, it has been found that the effect of eccentricity on the load carrying capacity is significantly affected by the critical buckling modes of prestressed stayed steel columns. In addition, the effects of slenderness ratio, crossarm length, and stay diameter have also been presented in this work. The results will be of great assistance when designing this type of column under eccentric loading.

Yong Chen, Ji-yang Wang, Yong Guo, Shi-jie Guan, ... Bing-nan Sun, “Mechanical behavior of welded hollow spherical joints with diameter exceeding 1.0m”, Journal of Constructional Steel Research, Vol. 159, pp 21-33, August 2019, https://doi.org/10.1016/j.jcsr.2019.04.023
ABSTRACT: The welded hollow spherical joint (WHSJ) with diameter greater than 1.0 m is commonly employed in long-span tubular transmission towers. It has a relatively higher ratio of diameter to thickness compared to traditional spherical joints, since the larger thickness leads to difficulties in fabricating a spherical joint with a diameter of more than 1.0 meter, and will also lead to deterioration of mechanical properties of materials. Therefore, longitudinal and transverse stiffeners are usually set inside to avoid local buckling and improve bearing capacity. In this study, experimental tests and finite element (FE) analyses of full-scale WHSJs with a diameter of 1400 mm under the multi-axial load are conducted. The results indicate that all specimens have similar failure modes, namely the indentation of the hollow sphere near the main tube, and the failure of the longitudinal stiffeners at the same position. In addition, the setup of longitudinal stiffeners would obviously improve the ultimate bearing capacity (UBC) of WHSJ. After the validity of the FE model is verified, the parametric study is carried out. The results indicate that the UBC of stiffened WHSJ can be approximated by the sum of the resistances of the corresponding unstiffened WHSJ and the stiffeners. Accordingly, design equations are proposed for stiffened WHSJs with diameter greater than 1.0 m. The results obtained by proposed equations are compared with that obtained by tests and FE analyses. They are basically in good agreement, which shows the validity of the equations.

ABSTRACT: Curved steel panels are increasingly used in several engineering fields yet, design provisions to predict their strength are mostly empirical and with a limited range of application. Consequently, the aim of this paper is to propose expressions for the prediction of the ultimate load of curved panels under uniaxial compression based on a physically robust approach, using semi-analytical methods (SAM). The formulation is based on large deflection theory incorporating initial imperfections and geometric nonlinearity and a first yield criterion applied to the von Mises' stresses is employed. The ultimate load is calculated for a wide parametric variation of geometries considering different amplitudes and patterns of imperfections and boundary conditions. In order to assess the influence of the geometry on the resistance of the curved panels, the curvature parameter, Z, the aspect ratio, α, and the width over thickness, al/h, are varied with the objective to cover most cases of unstiffened curved panels with practical applicability. The influence of these parameters is calculated and validated with the results of the FEM showing good agreement.

ABSTRACT: Ultra-high-strength steel (UHSS) has been gaining increasing attention globally due to its significant structural and economic benefits. Specifically, the use of UHSS in steel and composite column sections can reduce the dimensions and self-weight of the structural components. However, the utilisation of
UHSS slender sections also renders the structural members more susceptible to local buckling. The reduced ductility as well as less strain hardening of UHSS can also affect the post-buckling load. In order to clarify the local buckling and post-buckling load of compressive members using UHSS plates, the authors herein present an extensive experimental program. A total of sixteen steel and composite specimens are tested with the slenderness limits ($\lambda_\text{p}$) and effective widths ($b/b$) being identified. Finite element models which account for the effects of residual stress and initial geometric imperfection are developed to capture the buckling behaviour of the box and I-section columns. The enhancement of local buckling and post-local buckling load of UHSS composite sections due to the presence of infilled concrete is demonstrated. In addition, the slenderness limits and effective widths of both bare steel sections and composite sections incorporating UHSS plates are further compared with existing codes of practice. Corresponding design recommendations are consequently provided.


ABSTRACT: Buckling-restrained braces (BRB) have been widely used as cost-effective energy dissipators in seismic designs of steel buildings. However, several issues of out-of-plane (OOP) instability have been observed in previous research. The stability evaluation method commonly used in seismic design practice applies three limit states to check the stability of the steel casing, connections, and gussets separately. Nevertheless, they appear to be over-simplified, by adopting unreasonable end conditions and neglecting coupling effects among them. Therefore, this study adapts an advanced stability assessment procedure and proposes a new stability model that considers the flexural deformation of the restrainer, gusset rotations, and the aforementioned coupling effects. In addition, an evaluation method is developed for finite-element model analysis to compute the gussets' rotational stiffness and strength. To verify the effectiveness of the proposed model, four full-scale BRB specimens each 5.8 m long with a 988-kN nominal yielding strength, varying restrainer stiffness, gusset thickness, and with/without edge stiffeners or OOP end drift are tested. The proposed model satisfactorily predicts specimens' failure modes and buckling strengths with errors less than 6%. Test results show a 9% drop in buckling strength due to a 57-mm OOP end drift, highlighting the significant impact from the OOP end drift. The proposed model exhibits an improvement in the buckling strength of over 80% with a 24% enlargement in the restrainer diameter, indicating the critical effects of the restrainer's flexural stiffness. The research results can be adopted to improve the practice of BRB frame design.


ABSTRACT: When selective pallet racks are allowed to rock in the cross-aisle direction during an earthquake, the uprights are subjected to short duration high axial forces at stomping. In this paper, the amplitude of the stomping force needed to compromise the upright's residual capacity is assessed for 59 configurations using nonlinear inelastic static and dynamic analyses. Parametric studies are performed to investigate the effects of upright length, bracing pitch, section slenderness, torsional restraints and multiple impulses on the residual capacity of an upright due to rocking. Uprights that fail in the flexural-torsional buckling mode perform better than those that fail by local-distortional buckling as the stomping causes permanent local-distortional deformations rather than sweep (torsional deformation). A rack upright that has a greater length, greater thickness and lower torsional restraint tends to have a higher residual capacity (relative to the undamaged capacity). A typical cold-formed steel rack upright can sustain a 0.1 s stomping force that is at least 15% greater than its static ultimate capacity without significant reduction in residual capacity. An implication is that an unanchored upright that survives an earthquake through rocking may double its storage load during the post-earthquake emergency period. The present shell element analysis results can be used to plan an experimental program for optimising the resilience of storage rack uprights against stomping.


ABSTRACT: This paper presents a finite element analysis (FEA) model for the behaviour of square concrete filled double skin steel tube (CFDST) under local bearing force. Feasibility of the developed FEA model was
validated extensively against available experimental results. The predicted results obtained from the FEA modelling were found to match well with those observed from the tests in terms of failure patterns, load versus deformation curves and bearing capacities. The full-range load-transferring mechanism of square CFDST under local bearing force was then analyzed using the FEA model. Comprehensive parametric studies were also carried out to investigate the effect of various parameters on the bearing capacity of square CFDST subjected to local bearing force. The evaluated parameters mainly included the hollow ratio of CFDST, geometric configuration of the bearing member (BM) and the CFDST, the width to thickness ratio of steel tubes, and the strengths of steel and concrete materials. Based on the parametric analysis results, simplified design formulae were proposed for calculating the bearing capacity of square CFDST under local bearing force. Validated through the reported experimental data, the proposed formulae were featured with a reasonable accuracy and could be adopted in the practical design of square CFDST members subjected to local bearing force.


ABSTRACT: This paper investigates the behavior of multi-cell composite T-shaped concrete-filled steel tubular (MT-CFST) columns subjected to compression under biaxial eccentricity. Nineteen specimens were tested and presented. The main variables were the position and angle of eccentric loading. The experiment showed that the main failure modes of the specimens were overall bending and local buckling. The position and angle of eccentric loading were two important factors that affected the ultimate load of MT-CFST columns. Finite element software was used to analyze MT-CFST columns subjected to compression under biaxial eccentricity. The simulated results were in good agreement with the experimental data. By modifying the relevant parameters, the effect of the strength of concrete, the thickness of steel tubes, and the section dimension on the ultimate load of specimens were investigated. Based on fiber element analysis, the N–M curves and failure surface of the specimens were obtained. According to the fiber element analysis results, a simplified formula was proposed to predict $M/M_0$ curves for specimens subjected to compression under biaxial eccentricity. It can be used to check the bearing capability of MT-CFST columns subjected to compression under biaxial eccentricity. The results predicted by the simplified formula coincide with both the results of experimental testing and finite element analysis.


ABSTRACT: A series of fire tests on eight circular tubed steel reinforced concrete (CTSRC) stub columns subjected to axial loading are presented in this paper. The influences of load level and steel tube thickness on the fire resistance of the CTSRC stub columns were investigated. Two similar specimens were tested with the same test scenario to obtain more reasonable data. The temperatures in steel and concrete, axial displacement, fire resistance, and failure mode were recorded and discussed. The test results show that the load level has a great influence on the fire resistance of CTSRC stub columns. The steel tube thickness has a significant influence on the fire resistance of CTSRC stub columns when subjected to a higher load level. Thermal and structural finite element (FE) models were developed to analyze the temperature distributions and fire responses of CTSRC stub columns by employing the program ABAQUS. These developed models were validated by the test data. Extensive parametric studies were carried out by using the FE method to investigate the influences of key factors on the temperature distributions and fire resistances of CTSRC stub columns. The factors considered for thermal analysis include cross-sectional dimension, steel tube thickness, and concrete type, while the factors considered for structural analysis include load ratio, cross-sectional dimension, steel tube thickness, concrete strength, and steel strength. The parametric studies indicate that the cross-sectional dimension has a more significant influence than the steel tube thickness on the temperature magnitudes of CTSRC stub columns. The load ratio, cross-sectional dimension, and steel tube thickness have more significant influence than concrete strength on the fire resistance of CTSRC stub columns. Based on the results of the parametric studies, a simplified method to predict the steel temperatures and the compressive load bearing capacities of CTSRC stub columns exposed to fire is proposed.

ABSTRACT: The particularity of the non-linear creep behavior of the circular concrete-filled steel tubes (CFST) is 1) the concrete core will not exchange moisture with the surrounding environment as sealed inside the steel tube, and 2) confinement effects will restrain the development of microcracking and prevent creep failure. In this context, the available creep model and analysis method will not be applicable in the prediction of the non-linear creep responses of circular CFST columns. In this paper, a non-linear creep model was proposed for circular CFST columns. This model was benchmarked against available experimental data. Extensive parametric study was performed to investigate the non-linear creep effects on the static responses of circular CFST columns. Finally, the applicability of different algebraic methods in calculating the non-linear creep responses of circular CFST columns was evaluated against the results obtained from refined analysis procedure. Investigation results have shown that non-linear creep could lead up to a 90% increase in the creep coefficient and, if not well accounted, would make the steel tube yield in the service life. The long-term responses of the circular CFST columns can be well depicted by introducing an ‘amplification factor’ into the Eurocode 2. The Age-Adjusted Effective Modulus method was recommended for simple design calculations.


ABSTRACT: To achieve a well-balanced structural design, a customized performance assessment approach based on the structural capacity reserve (SCR) is proposed for commonly used long-span single-layer lattice shells. The SCR is calculated by integrating the normalized residual seismic capacity (RSC) over the entire range of possible earthquake-induced damage levels. Six typical RSC ratio curves and the corresponding ranges of the SCR index are discussed and verified for several spherical single-layer lattice shells. The impact of the arrangement of the components on the structural deformability, failure mode, plasticity and damage development as well as the RSC and SCR is clarified for two Schwedler shells. Based on observations from vulnerability and sensitivity analyses, several alternative strengthening schemes are generated for an S12 Schwedler single-layer lattice shell, and the optimal one is determined by means of a multiple-objective evaluation system that includes the SCR. The investigation indicates that normalized RSC ratio curves can reflect the design rationality of structural layouts and that they can clearly capture the dynamic instability of lattice shells. The ability of lattice shells to retain their post-earthquake resistance reserves is found to depend primarily on the locations where damage develops. The localization of fully yielded components has the potential to create several weak regions, leading to a high possibility of substantial loss of resistance reserves. The case study of the S12 Schwedler shell demonstrates the necessity of considering the SCR in a comprehensive structural performance evaluation system.


ABSTRACT: Spiral-welded tubes (SWTs) are fabricated by helically bending a steel plate and welding the resulting abutting edges. SWT is a more cost-effective form of tube that can be used for concrete-filled steel tube (CFST) columns. SWTs contain larger residual stresses and distinct imperfection patterns compared to other tube types and hence warrant separate consideration. Previous research into concrete-filled spiral-welded steel tube (CF-SWST) columns has been mainly limited to considering short column behaviour. In contrast, most practical columns are ‘long columns’ where length dependant effects limit the column capacity. To address this research gap, 12 mild-steel self-compacting CF-SWST columns with diameter to thickness (D/t) and effective length to diameter (L/D) ratios in the ranges 56–118 and 10.5–11.9 were tested under axial compression. Load-eccentricities of 0, 0.15D and 0.4D were considered for the tests. A stable global flexural buckling type failure mode was observed consistent with those previously reported for CFST long columns of other tube types. Local buckling also occurred in the post-peak region. The spiral weld seam was observed not to be a preferential location for failure. On average, the experimental capacities were well predicted by the guidelines of six internationally used design standards. The scatter of the actual to predicted capacity ratios obtained was either equivalent to or more conservative than that reported for comparable CFST long columns of
other tube types. The results suggest that greater strength enhancement than considered in the codes may be effective for sections with $D/t<87$ in the tested $L/D$ range. For eccentric loading, fibre-element based analyses using confined concrete material models gave closer predictions of experimental capacities than codified methods. The study provided evidence of equivalent behaviour of CF-SWST long columns to comparable CFSTs of other tube types and the applicability of existing guidelines for evaluating their strength.

Jin-Guang Yu, Li-Ming Liu, Bo Li, Ji-Ping Hao, Xi Gao and Xiao-Tian Feng, “Comparative study of steel plate shear walls with different types of unbonded stiffeners”, Journal of Constructional Steel Research, Vol. 159, pp 384-396 August 2019, https://doi.org/10.1016/j.jcsr.2019.05.007

ABSTRACT: This paper presents a comparative study of the steel plate shear walls (SPSWs) with different types of unbonded stiffeners. Multiple ribs and precast concrete panels are installed for restraining the out-of-plane deformation of steel plates. The effect of spacing of unbonded ribs on the behaviour of SPSWs is first investigated through a finite element analysis. Subsequently, three 1/3-scale one-bay, two-storey SPSW specimens, namely unstiffened SPSW (US-SPSW), partially restrained SPSW (PR-SPSW) and completely restrained SPSW (CR-SPSW), are tested under cyclic loading. Test results indicate that specimens PR-SPSW and CR-SPSW exhibit similar load-carrying capacity, energy dissipation capacity, and stiffness degradation. Out-of-plane deformations of infilled steel plates, inward deformation of columns, and rotation of beam-column connections in both specimens PR-SPSW and CR-SPSW are effectively restrained, which alleviates the pinching phenomenon of hysteretic curves and stiffness degradation. As compared to the complete restraints for steel plates, partial restraints can increase the buckling area of the infilled steel plates and subsequently enhance the ductility of SPSW structure. They can also convert the deformation mode of infilled steel panels from the high-wave-low order to the low-wave-high order. In general, specimen PR-SPSW stiffened by unbonded multiple ribs with an appropriate spacing shows the excellent structural behaviour and constructability.


ABSTRACT: The behaviour of square stainless steel tubular (SSST) stub columns after elevated temperatures under axial compression is presented in this paper. A total of sixty specimens were tested, including forty-eight SSST stub columns at elevated temperatures cooled in air, nine SSST stub columns at elevated temperatures cooled in water and three SSST stub columns at ambient temperature. A total of twelve square CFSST stub columns were carried out load-strain tests. The main parameters explored in the test include thickness (1.0mm, 1.2mm, 1.5mm), high temperature duration (30min, 60min, 90min, 120min), temperature ranging from 400°C to 1000°C and cooling methods. This paper presents the failure modes, ultimate load-bearing capacity, load-strain curves, load versus displacement curves, initial stiffness at the elastic stage and ductility of the specimens. It was found that high temperature has the greatest influence on the ultimate load-bearing capacity of the columns, and the cooling methods also have some effect on it. As the elevated temperature specimens subjected increased, the percentage decrease in load-bearing capacity had an obvious increase, the ductility became worse and the initial compressive stiffness slightly decreased. The crack resistance of the specimens improved after elevated temperature. The axial deformation versus load curves had an obvious elastic-plastic stage as the elevated temperature duration increased to 120min. Based on the experimental results, a formula was proposed to calculate the ultimate load-bearing capacity of SSST stub columns after elevated temperatures.


ABSTRACT: The objective of this work is to develop design guidance for existing hollow steel columns that are retrofitted by infilling concrete into the tubes. The primary challenge is the unknown effect of the existing preload on the steel columns prior to the concrete infill. Composite performance and buckling behaviour of circular hollow section (CHS) steel columns strengthened by infilling concrete under preload was experimentally and numerically investigated in this study. A total of 34 CHS steel columns were tested under pin-ended boundary conditions, and the overall buckling failure modes and corresponding ultimate buckling resistances were recorded. Prior to the member testing, material properties of the steel columns and the infilled concrete were attained. By means of the finite element (FE) software package ABAQUS, elaborate FE models
for the CHS columns strengthened by infilling concrete were developed and validated against the obtained test results, which were further verified with other available test data. Using the validated FEA models, systematic parametric studies were conducted to examine the influences of the major factors affecting the ultimate capacities of the CHS columns strengthened by infilling concrete, including preload ratios, steel and concrete strengths, steel ratios, initial global imperfections, eccentricity ratios and column slenderness ratios. The obtained test and numerical results were therefore utilised to develop design criteria for predicting the overall buckling resistance of CHS steel columns strengthened by infilling concrete. In view of the difficulty of determining the key parameters in practice and the uncertainty of the strengthening process, a new simplified design coefficient was proposed, taking into account the influence of the preload. It has been demonstrated that accurate and reasonable strength predictions can be provided by the proposed design method.


ABSTRACT: This paper presents a nonlinear finite element analysis and also depicts the design of stainless steel hollow square and rectangular sections strengthened by CFRP under web crippling loading configurations. Current design rules do not provide sufficient information for predicting the performance of CFRP-strengthened stainless steel hollow sections against web crippling. To develop a new comprehensive design rule, this research provided a nonlinear finite element analysis (FEA) based on a series of laboratory tests. The tests were conducted subjected to four different loading conditions, end-two-flange (ETF), end-one-flange (EOF) interior-two-flange (ITF) and interior-one-flange (IOF). Geometric and material nonlinear finite element models were developed, substantiated by the experimental results. The traction separation law was used to simulate the debonding mechanism between the CFRP plate and stainless steel tubes in the nonlinear analysis process for the cohesive zone modeling. The finite-element models explicated well the behavior of CFRP strengthening and closely predicted the ultimate load-carrying capacity, web-crippling failure modes, as well as web-deformation curves of the tested sections. A parametric investigation was conducted using the verified finite element models for tubular sections with different dimensions. For CFRP enhancement of stainless steel members, the validated finite element models have been demonstrated as a constructive and time-saving method to determine the strengths of web crippling. The proposed design equation predictions also agreed well with the tests and numerical results. The web crippling strengths can be predicted effectively by the proposed design equation for CFRP enrichment stainless steel hollow sections against web crippling loading configurations.


ABSTRACT: Formulae for determining elastic local buckling half-wavelengths of structural steel I-sections and box sections under compression, bending and combined loading are presented. Knowledge of local buckling half-wavelengths is useful for the direct definition of geometric imperfections in analytical and numerical models, as well as in a recently developed strain-based advanced analysis and design approach (Gardner et al., 2019a, 2019b). The underlying concept is that the cross-section local buckling response is bound by the theoretical behaviour of the isolated cross-section plates with simply-supported and fixed boundary conditions along their adjoined edges. At the isolated plate level, expressions for the half-wavelength buckling coefficient \( k_u \), which defines the local buckling half-wavelength of a plate as a multiple of its width \( b \), taking into account the effects of the boundary conditions and applied loading, have been developed based on the results of finite strip analysis. At the cross-sectional level, element interaction is accounted for through an interaction coefficient \( \xi \) that ranges between 0 and 1, corresponding to the upper (simply-supported) and lower (fixed) bound half-wavelength envelopes of the isolated cross-section plates. The predicted half-wavelengths have been compared against numerical values obtained from finite strip analyses performed on a range of standard European and American hot-rolled I-sections and square/rectangular hollow sections (SHS/RHS), as well as additional welded profiles. The proposed approach is shown to predict the cross-section local buckling half-wavelengths consistently to within 10% of the numerical results.

ABSTRACT: An experimental study was performed on thin-walled concrete-filled steel tubular (CFT) columns. In practical applications of CFT columns, the use of high-strength steel non-compact or slender section is expected to grow because thin plates are advantageous in steel production and economy. Thus, the present study focused on evaluation of the axial load-carrying capacity of rectangular CFT columns with high-strength steel (grade 800) slender section. The test parameters were the yield strength of steel, the width-to-thickness ratio of steel plates, and the use of stiffeners. Five specimens were tested under monotonic axial-compression loading. Although elastic local buckling occurred in the high-strength steel slender sections, unlike the expectation, the specimens exhibited significant post-buckling reserve strength, exceeding design code predictions. The specimens strengthened with vertical stiffeners showed enhanced performance, attaining the plastic capacity of the composite section. To investigate the characteristic behaviors such as steel local buckling and concrete confinement, nonlinear finite element analysis was performed on the specimens. The experimental and numerical results showed that the steel peak stress is affected by the lateral expansion of the crushed concrete, and the peak stress of the high-strength concrete is generally lower than the cylinder strength. On the basis of the results, a modified fiber analysis model and a simplified strength equation were proposed.


ABSTRACT: This paper describes a comprehensive testing and numerical simulation investigation into the material properties, membrane residual stresses and compression capacities of S690 high strength steel welded I-section stub columns. The testing programme was performed on eight welded I-sections fabricated from 5mm thick S700MC high strength steel hot-rolled plates by means of gas metal arc welding, and included material tensile coupon tests, membrane residual stress measurements, initial local geometric imperfection measurements, and sixteen concentrically loaded stub column tests. A membrane residual stress distribution model for S690 high strength steel welded I-sections was firstly proposed, based on the experimentally measured results. In conjunction with the structural testing, a numerical modelling study was carried out, in which finite element models were initially developed and validated against the experimental results, and afterwards employed to conduct parametric studies, aiming at generating further structural performance data over a broader range of cross-section sizes. The obtained experimental and numerical data were used to evaluate the accuracy of the slenderness limits (for classifications of plate elements and cross-sections) and design rules for S690 high strength steel welded I-section stub columns, as set out in the European, American and Australian standards. The results of the evaluation revealed that the codified slenderness limits are accurate for the plate element and cross-section classifications of S690 welded I-sections in compression, and the established local buckling design provisions in the considered three codes result in precise and consistent cross-section compression resistance predictions for both non-slender and slender S690 welded I-section stub columns.


ABSTRACT: Experimental researches on the behaviors of large-diameter concrete-filled steel tube (CFT) columns are quite limited because of expenses and capacity of testing equipment. Finite element (FE) technique is an alternative and efficient method if suitable models of materials are available. Many FE models have been proposed to simulate the behaviors of CFT columns. Results predicted by the existing models are generally found to agree well with the experimental results of CFT columns, the diameters of which, however, are generally <300 mm. It is uncertain whether these models are still suitable for the columns with diameters larger than 300 mm. In this paper, a unified FE model applicable to both small- and large-diameter CFT stub columns is proposed. The proposed FE model is then used to study the influence of column parameters and size on the behaviors of steel tube and confined concrete in CFT columns, based on which an ultimate strength considering size effect is proposed. It was found that the existing FE model predicts conservative results for large-diameter columns, whereas the proposed model performs well for both small- and large-diameter columns. Parametric studies suggest size effect on the behavior of confined concrete in a CFT column is more significant than that of
steel tube, which, however, is mitigated due to the confinement effect resulting from steel tube when compared with that of plain concrete. Finally, the proposed ultimate strength model is found to perform well and more accurate than the existing model.


ABSTRACT: It is commonly known that compression resistance of longitudinally stiffened orthotropic plates depends on both the column and plate-like behavior. Large number of previous investigations studied the structural behavior of stiffened plates subjected to compression. However, a comprehensive investigation and a parametric study is not available in the international literature about applicable interpolation function for plates having closed section stiffeners. It is known from previous research results that the interpolation function can be different depending on the calculation method of the critical stresses (analytical or numerical). It is also known, that the application of the numerically computed critical stresses in the Eurocode based design method can lead to overestimation of the compression resistance through the increased critical stress resulting in smaller slenderness ratio. However, there is no recommendation for applicable interpolation formula when computed critical stresses are used by the designers. Therefore, the current research program focuses on the investigation of longitudinally stiffened orthotropic plates, studying the application of interpolation curve between plate and column-like buckling behavior. The applicability of the EN 1993-1-5 based interpolation curve is discussed and evaluated. The reason of the differences by using analytical and numerical critical stresses are explained and applicable interpolation function is proposed for both cases.


ABSTRACT: To examine the seismic performance of steel plate shear walls (SPSWs) and the corresponding steel plate reinforced concrete composite shear walls (SPCSWs), six 1:2 scale shear wall specimens (flat, vertical and horizontal corrugated SPSWs and the corresponding SPCSWs) are tested. The deformation capacity and failure modes of the specimens under cyclic loading are studied. The force–displacement hysteretic curves, envelope curves, bearing capacity and displacement values at various stages are obtained. The failure characteristics, deformation and energy dissipation capacity and the stiffness and the characteristics of degradation of the bearing capacity are analysed, and the design formulas of the shearing capacity of corrugated SPSWs and the corrugated SPCSWs are also proposed. The test results indicate that the lateral stiffness, ductility and energy dissipation capacity of composite shear walls are all better than those of the SPSWs. The lateral force bearing capacity of flat steel plate, vertical corrugated and horizontal corrugated SPCSW are 176%, 92%, 41% higher than that of the corresponding SPSWs, respectively. The displacement ductility coefficient of flat steel plate, vertical corrugated steel plate and horizontal corrugated steel plate composite wall is 1.86, 1.6 and 1.83 times higher than that of corresponding SPSWs, respectively. Due to the mechanical constraints that concrete applies to steel, the initial stiffness of composite shear walls is considerably higher than that of SPSWs.


ABSTRACT: A novel analytical model is proposed for establishing design criteria based on the decomposition of the in-plane deformation and out-of-plane stability states. First part of this study considered the in-plane buckling resistance of beam–columns. This study uses the results from Gizejowski et al. [42] to develop an analytical model for the inelastic out-of-plane buckling resistance of beam–columns subjected to a moment gradient. The elastic flexural–torsional buckling solution is combined with the in-plane solution via the generalised Ayrton–Perry model. In order to unify the recommendations for the resistance evaluation of beams, columns, and beam–columns, the model is customised to conform to the standard Eurocode technique of modelling buckling resistance of steel elements in compression or bending about the cross-sectional axis with the greater moment of inertia. As a result, the out-of-plane resistance interaction curves, expressed in
dimensionless coordinates, which describe the beam–column flexural–torsional buckling resistance and consider lateral–torsional buckling effects, are obtained. The results of finite element simulations are used for the verification of the developed analytical formulation. Two numerical techniques of imperfection modelling are used: an equivalent geometric imperfection approach with the Maquoi–Rondal generalised initial imperfection and an approach that individually considers geometric and material imperfections. The results obtained from the proposed analytical model and those obtained using the Eurocode design criteria and other recent analytical proposals are compared. Finally, concluding remarks and directions of future studies are also presented.


ABSTRACT: The response of I-shaped, or wide-flange, sections subjected to close-in detonations has been evaluated through numerical simulations. A simulation approach for close-in detonation, which includes two stages, is suggested. The first stage includes the modelling of the detonation process through computational fluid dynamics (CFD) and the second stage includes only the free vibrations of the structural member. The suggested approach is validated by a comparison with two experimental results for close-in detonations. Then, a parametric study for I-sections with their weak axis subjected to close-in detonations has been performed. Various spherical charges and standoff distances have been studied, with scaled distances in the range of 0.15–0.29m/kg . Bare members and members strengthened with stiffeners have been simulated. The influence of charge and standoff distance, and the addition of stiffeners on several parameters affecting deformation and folding angles, has been studied. The effect of localized pressure confined between the flanges and the stiffeners at the midspan, which can lead to increased total and local deformations, is illustrated. Finally, an alternative strengthening method, in which the flanges are connected with bars, is presented as an optional stiffening technique.


ABSTRACT: Based on two quasi-static experiments of steel tube confined reinforced concrete columns (STRC) under pure torsion load, detailed finite element (FE) simulation and theoretical derivation of the corresponding calculation methods were conducted in this paper. FE models of STRC specimens under pure torsion were established using the finite element software ABAQUS, the feasibility of which was then validated against the testing results in terms of both ultimate torsional capacity and failure modes. Comprehensive parametric analysis was presented, including the yield strength of steel tube, the thickness of steel tube, the dimension of cross-section, the strength of concrete, the yield strength of longitudinal reinforcement, the ratio of longitudinal reinforcement, the yield strength and the ratio of stirrup, to investigate the influence on the torsional capacity of STRC columns with important structural factors. It can be found from the parametric analysis results that, the thickness of steel tube, the dimension of cross-section and the ratio of longitudinal reinforcement are the most important parameters for the torsional capacity of STRC. Based on the results parametric analysis, an accurate and simplified calculation method for the ultimate torsional capacity of STRC columns under pure torsion was proposed.


ABSTRACT: To meet the requirements of good seismic behavior, rapid assembly, and economic feasibility for a high-rise steel residential apartment, the authors developed two innovative double-skin composite walls (DSCWs) with L-shaped and C-shaped connectors. DSCWs are composed of concrete-filled double steel faceplates, which are divided into several compartments by connectors and two boundary columns filled with concrete at the ends of the composite wall. In this paper, eight DSCWs were tested under cyclic loads to investigate the seismic behavior of these new composite walls considering the effect of low axial compression ratio and spacing-to-thickness ratio. Results show that no significant buckling of steel faceplates was observed before the peak load was reached. No obvious pinching effect was observed on the hysteresis curves for all
specimens. Ultimate drift ratio ranged from 1/59 to 1/45, and the ductility coefficients varied from 2.45 to 3.80. The equivalent viscous damping coefficient versus drift ratio curves were close to an exponential distribution, and all specimens exhibited great energy dissipation capacity. The strain on connectors was below the yield strain throughout the experimental process, indicating the connectors have a good working performance. Finally, formulas were established for calculating the load-carrying capacity.


ABSTRACT: Based on field investigation of a damaged transmission line following Typhoon Mujigae in 2015, a failure analysis is performed to estimate the load-bearing capacity of a transmission tower. Static nonlinear buckling analysis and dynamic analysis are employed to assess the ultimate load capacity and the most vulnerable parts of the tower. In the dynamic analysis, a tower-line (TL) coupled model is established which accounts for members buckling capacity. The two methodologies predicted close wind load capacity (34.8m/s in static analysis and 34m/s in dynamic analysis), while the failure modes and buckled members are different. While static analysis shows that the leg members buckled, dynamic analysis reveals that it is the diagonal members that buckle. Reasons are explained in this paper and suggestions are given that the dynamic analysis should be adopted in integrally evaluating a transmission tower, especially when locating the buckled member. More, emphasis should be given to the design of diagonal members.


ABSTRACT: Although the stochastic nature of several parameters, the application of the methodology given in EN1993-1-5:2006 for the determination of the resistance of class 4 cross-sections under direct stresses leads to the use of the effective area where each plate is individually assessed by a semi-empirical approach proposed by Winter in 1947. Once the level of reliability of this approach is not adequate in light of the rules given in EN1990, this paper aims at finding the actual safety level of the methodology given in EN1993-1-5. In order to achieve this, Monte Carlo simulations with a Latin Hypercube sampling strategy is performed in selected cross-sections under pure compression and pure bending with varying slenderness and aspect ratio of the web plate. All parameters are stochastically modelled, and each generated element (I- and H-section stubs) is numerically computed using a general-purpose finite element software. The final results are actual partial factors values and width reduction factors for each cross-section.


ABSTRACT: A stiffness reduction method (SRM) for the design of hot-finished tubular steel members is presented in this paper. Stiffness reduction functions that fully capture the adverse influence of imperfections and plasticity on member stability are developed. The proposed SRM is implemented by (i) reducing the flexural stiffness (EI) of the member using the developed stiffness reduction functions, (ii) performing elastic Linear Buckling Analysis (LBA) and Geometrically Nonlinear Analysis (GNA) of the member with reduced flexural stiffness and (iii) making cross-section strength checks and ensuring that the lowest buckling load amplifier from LBA is greater than or equal to 1.0. Owing to the full allowance for the spread of plasticity, residual stresses and geometrical imperfections through stiffness reduction and instability effects through LBA and GNA, the proposed approach offers an enhanced and more direct assessment of structural behaviour relative to traditional design where structural analysis is accompanied by member design equations, effective lengths and the notional load concept. The proposed method is verified against nonlinear finite element modelling for a large number of tubular steel members. Comparisons of the proposed approach against the methods recommended in the European structural steel design code EN 1993-1-1 for the design of tubular members are also provided.

ABSTRACT: In this study, a discontinuous cover plate connection (DCPC) was proposed for a prefabricated steel plate shear wall with a beam-only-connected infill plate. This design is suitable for prefabricated high-rise steel structures and assumes that bolt slippage does not precede the yielding of the steel plate tension field. Three 1/3-scale specimens were designed, and the hysteretic behaviour, skeleton curves, energy dissipation capacity, ductility, and failure modes were investigated using quasi-static tests and finite element analyses. Then, the hysteretic behaviour, ductility, and energy dissipation capacity of the prefabricated steel plate shear wall were compared to those of a traditional welded steel plate shear wall through finite element analyses. The results showed that the prefabricated steel plate shear wall with a DCPC had good hysteretic behaviour, energy dissipation capacity, and ductility. Further, the bolt pre-tightening force in the connection was directly proportional to the thickness of the infill plate. The ultimate lateral bearing capacity of the prefabricated steel plate shear wall was slightly less than that of the welded steel plate shear wall. In addition, the prefabricated steel plate shear wall can be assembled rapidly and simply on-site, and it provides a good post-earthquake repairable function.


ABSTRACT: Built-up box sections are becoming increasingly popular for column members in cold-formed steel (CFS) construction; uses of such sections include CFS trusses, space frames, and portal frames. In this article, the built-up box sections are formed through two identical lipped channels connected at their flanges with self-drilling screws. In such an arrangement, independent buckling of the individual channels is prevented by the screws. This paper presents an experimental investigation on axial capacity of built-up CFS box sections. Tests were conducted for different values of slenderness from short to slender columns. In total, the results from 16 experimental tests are reported. Of these, 8 tests were conducted on built-up CFS box sections and the remaining 8 tests were conducted on single channel sections. Load-axial shortening relationship, and failure modes are discussed for built-up columns. Nonlinear finite element (FE) models were developed for built-up CFS box sections and single channels. FE models considered material nonlinearities, initial imperfections and modeling of intermediate fasteners. FE results showed good agreement against the test results. A parametric study was conducted which comprises 148 models to investigate the effect of fastener spacing on axial capacity of built-up CFS box sections. Both FE and test results were compared against the design strengths calculated in accordance with the American Iron and Steel Institute (AISI) and Australian and New Zealand Standards (AS/NZS). From the comparison, it was observed that the AISI & AS/NZS are conservative by around 17% while determining the axial capacity of such built-up CFS box columns.


ABSTRACT: The continuous strength method (CSM) adopts base curves which relate the deformation capacity to its overall cross-section slenderness to take into account the element interaction and employs elastic, linear hardening material models to exploit the strength enhancement from strain hardening. This paper extends the CSM for structural design of hot-finished and cold-formed high strength steel tubular sections under bending. Results of 146 tests in the literature were compiled and a parametric study on 660 high strength steel tubular beams was conducted using validated finite element models. Base curves and resistance functions were proposed for non-slender and slender high strength steel circular hollow sections (CHS), elliptical hollow sections (EHS), square hollow sections (SHS) and rectangular hollow sections (RHS). Bi-linear and tri-linear material models were adopted for cold-formed and hot-finished steel tubular sections, respectively. Experimental and numerical results of 806 tubular beams were used to assess the proposed CSM, the direct strength method (DSM) and codified design methods. The resistance prediction of the proposed CSM is more accurate and less scattered.
ABSTRACT: The cooling tower is a very important building for the thermal power plant. The large steel cooling tower is proposed to overcome the serious challenges that arise from modern cooling towers being higher, larger, and more complex. In this study, for the large-scale hyperbolic steel cooling tower, seven different latticed shell systems with different grid forms, including five double-layer systems and two single-layer systems, were designed and studied in detail. For different heights, grid sizes, and shell thicknesses, numerous parametric analyses (792 models) of the structures were performed. The static behaviors—including the steel quantity, peak displacement, and peak stress—of the seven structural systems were obtained and compared. The variation laws of the steel quantity and peak displacement with respect to the parameters were presented, and the reasonable range of the parameters for the steel cooling tower with different heights were obtained. The results show that the optimal structural system is different for the steel cooling towers with different heights. Additionally, based on the nonlinear stability analysis, a reasonable strengthening scheme was proposed for the single-layer system with poor stability. The results will be of great help for further research on large steel cooling towers and provide guidance for actual engineering design of the structures.

ABSTRACT: Application of high-strength steel can serve improving structural efficiency as well as solve structural problems when traditional materials are inapplicable due to strength limitations. Innovative structural solutions, however, are facing problems related to the absence of corresponding design procedures and reliable constitutive models. Cold-formed profiles are frequently used as structural elements in buildings. The enhancement of a material strength in the profiles with nominal geometry increases slenderness of the cross-section that can cause a local increase of deformations due to high stress concentrations. The increase is a consequence of web crippling often followed by failure of the flange. The investigation of the combined web crippling and flange failure effects is rather complicated due to localized deformed behaviour that is not a trivial subject for experimental identification. The premature deformation increase in a critical cross-section is not necessarily caused failure of the profile that continues to carry further loads. This paper investigates local deformation effects in cold-formed square tubular profiles subjected to bending load. A four-point bending test was used to estimate the effect of local nonlinear deformation on the overall deformation behaviour. The profiles made of high strength steel S700 and S900 grades were considered. Similar profiles made of the steel S355 were tested for the reference. A digital image correlation system was used to monitor deformations of the web surface. A nonlinear finite element model was developed to investigate the local deformation effects on the overall deformation behaviour and load-bearing capacity of the profiles. The model was customized with the reference to the experimental results. After the verification, it was used to illustrate deformation analysis procedure of a continuous tubular beam.

ABSTRACT: The structural behavior of cold-formed steel (CFS) built-up beams that are gaining interest in the construction industry is investigated in this study. As per the current American Iron and Steel Institute's (AISI) CFS structural members specifications (direct strength method), there are no explicit guidelines or procedures for the types of built-up sections being evaluated in this research. The present study, therefore, examines the suitability of using the current AISI design specifications for the design of CFS built-up beams. The built-up beams investigated in this study are assembled using two identical sigma sections, and interconnected face-to-face by discrete spot welding. The test parameters studied include the length of the member (L) and spacing (s) between the interconnecting spot welds. Based on the failure modes observed in experiments, new limitations for the interconnection spacing (s) of the face-to-face connected built-up beams that failed in distortional buckling is suggested. The design strength prediction (Mdes) for the tested built-up beams is calculated using current AISI design procedure for the purpose of verification and to extend the current design procedure for the
built-up beams. The comparison between experimental tests and design predictions ($M_{cr}$ vs. $M_{ds}$) indicates that the design results are unconservative and unreliable due to the incorrect failure mode prediction and overestimation of the critical elastic buckling stresses in the elastic buckling analysis which is a key input to the direct strength method of design calculations. Hence, modified design procedures and design equations were suggested for the CFS built-up beams after carrying out a comprehensive investigation on failure modes and numerical study that are vulnerable to fail in local and distortional buckling. It was also shown that the newly suggested procedures and equations are reliable for the design of CFS built-up beams.

Keyng Ning (1,2), Lu Yang (1,2), Huanxin Yuan (3) and Menghan Zhao (1,2)
(1) The Key Laboratory of Urban Security and Disaster Engineering of Ministry of Education, Beijing University of Technology, Beijing 100124, China
(2) Beijing Engineering Research Centre of High-rise and Large-span Prestressed Steel Structures, Beijing University of Technology, Beijing 100124, China
(3) School of Civil Engineering, Wuhan University, Wuhan 430072, China


ABSTRACT: A comprehensive experimental and numerical study on flexural buckling behaviour of welded stainless steel box-section beam-columns is presented in this paper. A total of ten test specimens were prepared and tested subjected to eccentric compression. The cross-section and length of the test specimens were carefully designed by referring to existing design specifications to be insusceptible to local buckling. The full experimental load versus deformation and load versus strain curves were obtained. Prior to member testing, both material tests and geometric imperfection measurements were conducted and reported in detail. Finite element (FE) models were developed and validated against the obtained beam-column test results afterwards, which were utilised to perform parametric studies on the flexural buckling behaviour, generating sufficient numerical data points. Based on the obtained test and FE results, the design methods provided in EN 1993-1-4+A1 and AISC DG 27 were assessed. It was shown that both EN 1993-1-4+A1 and AISC DG 27 provided generally conservative and scattered predictions for the buckling resistance of welded stainless steel box-section beam-columns. Moreover, a newly revised proposed interaction factor was proposed in the framework of EN 1993-1-4+A1, and strength predictions with reduced scatter were therefore achieved.

Federico Gusella (1), Giovanni Lavacchini (2), Maurizio Orlando (1) and Paolo Spinelli (1)
(1) University of Florence, Dept. Civil and Environmental Engineering, Italy
(2) Studio Giovanni Lavacchini, Borgo San Lorenzo (FI), Italy


ABSTRACT: Steel bracing systems are usually introduced to assure the structural stability and seismic resistance of steel storage pallet racks, whose height over the last years has increased more and more to improve warehouse efficiency. In the present paper, the axial response, under monotonic and cyclic load, of perforated cold-formed steel diagonals of concentric bracing systems is investigated through experimental tests. To satisfy the design and detailing rules required by the capacity design approach, such as the ratio between overstrength coefficients and the value of the non-dimensional slenderness, tested diagonals are equipped with additional holes at one end. Results of monotonic tests, under compression and tensile load, provide useful information about the influence of the number and shape of holes on the ultimate strength, ductility and buckling load of bracings. Cyclic tests highlight how the member slenderness and the class of its cross-section affect hysteresis loops and energy dissipation. Finally, some novel considerations are presented concerning the influence of the shape, dimensions and distance of additional holes, in addition to member geometrical features like the cross-section class, on the cyclic response of tested members. In the framework of the “Design Assisted by Testing”, results could be adopted for the capacity design of perforated concentric cold formed diagonal bracings as those adopted in steel storage pallet racks.

Sen Yang (1,2), Dongzhi Guan (1), Liang-Jiu Jia (3), Zhengxing Guo (1) and Hanbin Ge (2)
(1) School of Civil Engineering, Southeast University, Nanjing 210096, Jiangsu Province, China
(2) Department of Civil Engineering, Meijo University, Nagoya 468-8502, Japan

ABSTRACT: This paper describes a restraint tube local bulging study of newly developed small-type buckling-restrained braces (SBRBs). An analytical calculation model for the restraint tube stress distribution is established by the shell theory and the Fourier series. It is demonstrated that the stress concentration lies mainly in a region with a length of $2R$, which is approximately equal to the tube middle surface diameter. A simplified design method including a safety factor and recommended thickness-radius ratio is then proposed based on the analytical study. To verify the accuracy of this calculation method, four SBRB specimens with different tube thicknesses were tested under quasi-static cyclic loading. The calculation results are in reasonable agreement with the test results and can predict the local bulging occurring instant with acceptable accuracy.

Yu-Tao Guo (1), Xin Nie (1), Mu-Xuan Tao (1), Ran Ding (1), Liang Tang (2) and Jian-Sheng Fan (3)
(1) Key Laboratory of Civil Engineering Safety, Durability of China Education Ministry, Dept. of Civil Engineering, Tsinghua University, Beijing 100084, China
(2) Highway Bridges National Engineering Research Centre, CCCC Highway Consultants Co., Ltd, Beijing 100088, China
(3) Beijing Engineering Research Center of Steel and Concrete Composite Structures, Dept. of Civil Engineering, Tsinghua University, Beijing 100084, China


ABSTRACT: The steel-concrete (SC) or steel-concrete-steel (SCS) composite structures are widely used in large-scale structures like immersed tunnels, protection structures, etc., due to their superior performances in capacity, ductility, waterproofness, construction efficiency, etc. The steel plates in these structures are usually stiffened with ribs to increase the out-of-plane rigidity and to improve the local buckling performance. While there have been several applications, the buckling design of the composite stiffened plates, based on the methods for steel structures, is still immature and conservative. To deal with this problem, a selected series method (SSM) based on the theory is proposed, which could both be utilized in composite stiffened plates and steel stiffened plates. The special series shape functions, which could efficiently and accurately represent the 3-dimensional spatial buckling deformation of the stiffened plates with multiple stiffeners, are selected. The explicit high-order solutions for the buckling stress of stiffened plates are derived. Furthermore, a finite element model (FEM) is established. Based on the FEM, a numerical database including most common design parameters is derived, and extensive numerical analyses are conducted to modify and verify the proposed SSM. It is found that, for steel structures, the SSM has a 10%–20% improvement in accuracy compared with the existing methods, and for composite structures, the SSM fills the blank in this area and has acceptable accuracy for design. Finally, from the above studies, the design suggestions are given and discussed.

Saeed Eyvazinejad Firouzsalari (1), Hossein Showkati (2) and Jason M. Ingham (1)
(1) Department of Civil and Environmental Engineering, The University of Auckland, New Zealand
(2) Department of Civil Engineering, Urmia University, Urmia, Iran


ABSTRACT: Much research has been conducted on circular hollow steel tubes subjected to indentation loads, but the response of a circular hollow steel tube when subjected to a combination of an indentation load (the load applied by an indenter) acting together with other loading conditions has received markedly less appraisal. An experimental study was conducted on two groups of circular hollow steel tubes that were either free-spanning or base-supported. These tubes were first subjected to a uniform axial pre-compression, which is the most common service load across many tube applications, followed by the application of indentation loads while the magnitude of axial pre-compression was maintained. Strength, top surface and mid-height cross-sectional deformation, longitudinal and circumferential strains, and the failure mechanism of the tubes were compared,
with a significant difference found between the response of the two groups of tests, and with this difference increasing as the magnitude of axial pre-compression and indenter displacement were increased. Additionally, it was identified that for the same level of absorbed energy, a deeper dent was produced for base-supported tubes than for free-spanning specimens. Moreover, analytical equations available in the literature were compared to the experimental results and good correlation was found between the experiments and the predictions.

N. Degtyareva (1), P. Gatheeshgar (2), K. Poologanathan (2), S. Gunalan (3), M. Lawson (4) and P. Sunday (5)
(1) Institute of Architecture and Construction, South Ural State University, Chelyabinsk, Russia
(2) Faculty of Engineering and Environment, Northumbria University, Newcastle, UK
(3) School of Engineering and Built Environment, Griffith University, Gold Coast, QLD 4222, Australia
(4) Department of Civil and Environmental Engineering, University of Surrey, Surrey, UK
(5) Department of Civil and Environmental Engineering, Imperial College London, London, UK

ABSTRACT: Cold-formed steel studs and purlins with staggered slotted perforations in webs are used in building structures to produce a better thermal performance of the profiles and for the energy efficiency of structures. On the other hand, the slotted webs result in an unfavourable effect in terms of the structural performance of the element, prominently their shear, bending and combined bending and shear strengths. Relatively little research has been reported on this subject despite its importance. Many research studies have been undertaken to examine the behaviour of conventional cold-formed steel (CFS) channel sections subject to combined bending and shear. To date, however, no research has been carried out to investigate how CFS channels with staggered slotted perforations behave under combined bending and shear actions. An extensive study on this area is therefore essential. Finite element (FE) models of CFS channels with staggered slotted perforations were developed to investigate their combined bending and shear capacity. A parametric study was conducted in detail by developing FE models based on the validation process with available experimental data. This paper presents the FE analysis details of CFS channels with staggered slotted perforations subject to combined bending and shear actions and the FE results. New design equations were also proposed to predict the combined bending and shear capacity of steel channels with staggered slotted perforations.


ABSTRACT: The paper presents a test programme on cold-formed high strength steel tubular T-joints with fully supported chord members. The T-joints consist of brace members made up of square, rectangular and circular hollow sections, while chord members were made up of square and rectangular hollow sections. The T-joints were fabricated by both brace and chord members made up of square and rectangular hollow sections as well as circular hollow section braces were welded to square and rectangular hollow section chord members. The brace and chord members were welded by semi-automatic gas metal arc welding process. The steel grade of 900 MPa was used for the square, rectangular and circular tubular members, while the steel grade of 960 MPa was used for the square and rectangular tubular members only. A total of 22 tests was conducted where an axial compression was applied through the brace members, while the chord members were resting on a solid flat base. The ratio of brace-to-chord width (β) ranged from 0.33 to 1, brace-to-chord thickness (δ) from 0.53 to 1.27, chord width-to-thickness (2δ) from 20.6 to 38.7, and chord side wall slenderness (h/t) from 12.7 to 38.6. The test results were compared with the nominal strengths obtained from the Eurocode 3 (EC3) and CIDECT for the assessment of the existing design rules for tubular T-joints with fully supported chord members. It is found that the existing design rules are not applicable for the design of cold-formed high strength steel tubular T-joints with fully supported chord members.

Minhao Dong (1), Mohamed Elchalakani (1), Ali Karrech (1), Sabrina Fawzia (2), Mohamed Sadakkathulla Mohamed Ali (3), Bo Yang (4) and Shao-Qian Xu (4)

ABSTRACT: The research on rubberised concrete (RuC) could promote the recycling of end-of-life tyres and reduce natural resource extraction. To mitigate the greatly reduced compressive strength and fully utilise the desirable characteristics such as improved ductility and energy absorption of RuC, confinement through a steel outer tube could be adopted. This paper investigated the effect of using circular steel tube as confinement of the RuC under axial, flexural and combined loading conditions. A total of 4 circular hollow tube sections with \( \delta t \) (depth/thickness) ranging from 18 to 36 was used in this study. Three rubber replacement ratios (0%, 15%, 30%) by mass of the total aggregates were examined, along with 4 load eccentricities (0, 0.25\( \delta \), 0.5\( \delta \) and bending) used to construct the interaction diagrams. As a result of the steel confinement, the difference in load capacity between RuC and normal concrete significantly reduced compared to the plain concretes. Additionally, RuC filled steel tube (RuCFST) members were more ductile than their normal concrete counterparts. The circular cross-section showed superior load carrying capacities compared to the square sections, due to a relatively uniform stress distribution in the cross-section. The interaction diagrams of RuCFST members could be reasonably predicted in terms of accuracy and safety of design. The tested moment capacity of RuCFST also greatly exceed the predicted values. This study has demonstrated the possibility of using RuCFST in applications where high energy absorption and ductility capacities were sought, for example, the structural members in seismic regions and flexible roadside barriers.


ABSTRACT: The main purpose of this paper is to present the experimental investigation on the axial behaviour of concrete-filled steel tube columns using semi-lightweight aggregate concrete as an infill type. The paper describes the effect of variation in the diameter (D), width (B), thickness (t) and length-to-diameter (L/D) ratio of steel tube with a special type of core concrete on the ultimate axial load (\( N_u \)) and the associated axial shortening (\( \delta_u \)) for both the circular and the square CFST columns. The experimental campaign involves, finding the mechanical properties of steel, concrete and the Axial compression tests conducted on the CFST specimens. The 2-factorial design; a DOE approach is implemented primarily. Subsequently ANOVA, a statistical tool is used to analyze and compare the different combinations for reducing the error variance and finding the most influential factor on \( N_u \) and \( \delta_u \). Basic prediction models are proposed to predict the response \( N_u \) and \( \delta_u \) for the CFST columns and further, the Response surface method is implemented to revise the models for interaction between the different combinations. Comparisons are made with the existing design codes like ANSI/AISC 360-10 and EN-1994 (Eurocode 4) to validate. The proposed model predictions thus, validate the experimental results with good accuracy. The tests confirmed the considerable influence of semi-lightweight aggregate concrete on the performance of CFST columns. In addition, the confinement improves the strength of the infill concrete and thus validates the use of semi-lightweight aggregate concrete as an infill to the CFST columns for structural purpose and particularly for reduced self-weight.


ABSTRACT: This study conducted progressive collapse tests of Keiwitt-6 (K6) and three-way diagonal grid (TD) single-layer latticed domes. Progressive collapse tests of single-layer latticed domes were performed to examine the dynamic responses, collapse mechanisms, and collapse modes of different structural types after the
failure of multiple structural members. The results indicated the following: 1) Under the same test conditions, two types of structures exhibited the same collapse mode: local collapse occurred first at the destructive part of the structures; then, with increases in the number of failed members, the collapse range continuously expanded, and the structures ultimately exhibited complete collapse. Some of the members at the supports exhibited cracks or necking. 2) The K6 and TD single-layer latticed domes relied on the compression and beam mechanisms, respectively, to resist progressive collapse. 3) The K6 single-layer latticed dome exhibited better resistance to progressive collapse as compared to that of the TD single-layer latticed dome. 4) The progressive collapse resistances of K6 and TD single-layer latticed domes were significantly improved by increasing the bending stiffness of radial members.

Han Fang (1) and Tak-Ming Chan (2)
(1) School of Civil, Environmental and Mining Engineering, The University of Adelaide, South Australia 5005, Australia
(2) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China


ABSTRACT: The global buckling resistance of welded high strength steel box section members subject to combined compression and bending was investigated through a numerical modelling programme. Finite element models were developed with the capability to accurately replicate the experimental results of the box section members under combined compression and bending. Extensive parametric studies were carried out to examine the global buckling behaviour of welded high strength steel box section members with a wide range of dimensions and member slenderness and steel grades of S460, S690 and S960 and subject to varying combinations of compression and bending. The effects of residual stresses and ultimate tensile strength-to-yield strength ratio on the global buckling behaviour of those members were investigated. The applicability of existing design rules to welded high strength steel box section members subject to combined compression and bending was evaluated using the results from parametric studies and the available experimental results in literature. The European, American and Australian standards provide conservative strength predictions for the structures. More accurate and safe strength predictions can be obtained based on European standard using the suggested column curves for the members while the design methods in Australian and American standards are safely applicable to the members.


ABSTRACT: There are numerous parameters that influence the behavior of built-up steel columns. This paper reports an experimental investigation carried out on cold-formed steel (CFS) built-up columns composed of four unstiffened CFS equal angle sections connected by lacings intermittently along their heights. The main parameters varied in the test specimens were the width of end plate, the lacing slenderness ratio, the chord flat width-to-thickness ratio and the lacing configurations. Six pin-ended test specimens were tested under monotonically increasing concentric axial loading. The test result output viz. ultimate column strengths, load vs. displacement response, mode of failure, and deformed shapes were used to investigate the effect of above-mentioned parameters on the axial behavior of CFS built-up laced columns. The current standards for CFS structures were used to predict the column strengths for the sake of comparison. Furthermore, a numerical validation of the test results was carried out using a finite element software ABAQUS. Test results indicate that the lacing slenderness, the lacing configuration, and the end plate width affect the column behavior in CFS laced built-up columns significantly.

ABSTRACT:
This paper described the experimental results of 9 steel-concrete-steel (SCS) sandwich panels subjected to biaxial tension compression. Specific specimens and loading modes were designed to simulate uniform loading in SCS panels. 8 LVDTs were used to measure the biaxial averaged principal strains. The test parameters were compression to tension ratio (C/T), steel plate ratio ($\rho_s$) and tie bar space to steel plate thickness ratio (Bt/t). Test results show that SCS panels feature high strength and good ductility even under high C/T. The ultimate strengths of SCS panels are compared with previously established failure criteria. It was found that, in the principal tension direction, for SCS panel elements under high C/T, the averaged concrete stress between cracks may turn from tension to compression, which is supposed to be caused by the rapid enlargement of Poisson's effects of the concrete subjected to combined tension and compression. According to the test results, confinement effect and compression softening effect coexist in the principal compression direction; tension weakening effect rather than tension stiffening effect happens in the principal tension direction. These two new findings will help us further understand the mechanical behavior of concrete in SCS panels in the future research.

Jie Liu (1), Ting Zhou (1,2), Zhiyong Lei (3), Xiandong Chen (1) and Zhihua Chen (1)
(1) Tianjin University, Tianjin, China
(2) Tianjin Key Laboratory of Architectural Physics and Environmental Technology, Tianjin University, Tianjin, China
(3) National Government Offices Administration, Beijing, China

ABSTRACT: To study the uniaxial eccentric compression properties of slender L-shaped column composed of concrete-filled steel tubes (CFST) connected by steel linking plates, a compression test on four L-shaped CFST columns with different eccentricities was designed in this study. The ultimate bearing capacity, ductility, and deformation capacity of the L-shaped CFST columns were obtained by analyzing the failure phenomenon, load–axial displacement curves, load-lateral deflection curves and load–strain curves. Experimental results were verified by ABAQUS finite element analysis software, and the N–M correlation curves of the L-shaped CFST columns were calculated by using a full-section plasticity method. The calculation formulas of eccentric compression ultimate bearing capacity of L-shaped CFST columns was proposed, which provided a reference for engineering design.

Fatmir Menkulasi (1) and Nahid Farzana (2)
(1) Department of Civil and Environmental Engineering, Wayne State University, Detroit, MI 48202, USA
(2) Department of Civil Engineering, Louisiana Tech University, Ruston, LA, USA
“Web compression buckling capacity prediction for unstiffened I-sections with opposite patch loading”, Journal of Constructional Steel Research, Vol. 162, Article 105728, November 2019,
https://doi.org/10.1016/j.jcsr.2019.105728

ABSTRACT: Two web compression buckling capacity prediction methods are introduced for unstiffened steel I-sections subject to opposite patch loading applied to the flanges. The methods are generally posed as a function of loaded width to web depth ratio, and are applicable for opposite patch loading applied at the interior of a wide flange section or at the end of it, where the web has a free edge. The proposed methods include three parts: 1) an expression for predicting the squash load, 2) an expression for predicting the elastic buckling load, and 3) a resistance function. The squash load is calculated using an empirically derived effective width concept based on observations at the ultimate load from an extensive experimental database and validated numerical simulations. Web slenderness is defined as the square root of the ratio of the web squash load to the web critical elastic buckling load. The critical elastic buckling load is defined consistently with that obtained with a plate buckling energy solution for patch loading on infinitely long strips and considers the shortened web buckling half-wavelength resulting from flange rotational restraint provided to the web. The methods are validated with existing experimental data and shell finite element collapse simulations, and are shown to be more accurate and more widely applicable than current American Institute for Steel Construction (AISC) Specification provisions.

ABSTRACT: An experimental investigation on steel tube confined concrete (STCC) stub columns with circular, square and octagonal cross-section shapes under monotonic axial compression was conducted. Different concrete grades were examined with measured compressive cylinder strengths ranging from 38MPa to 112MPa. The nominal yield strength of the steel tube was 355MPa. The load capacity, load-axial shortening curves and axial-hoop strain behaviour of the STCC stub columns are compared to that of the counterparts, concrete filled steel tubes (CFST), with different cross-section shapes based on the same material and geometric properties. Comparisons indicated that the load capacity of STCC stub columns are very close to that in the CFST with circular and octagonal cross-sections, while the performance of square STCC is not as good as the CFST counterparts due to low effectiveness of confinement. According to the experimental results of lateral behaviours of STCC, CFST and plain concrete columns, it was concluded that with very high strength concrete (cylinder strength over 100MPa), the axial performance of STCC stub columns is better than that in CFST. A design assessment was also conducted on STCC stub columns and shows that the current design formulae for load capacity of CFST are also applicable to that of STCC stub columns.

Lucile Gérard (1), Liya Li, (1) Markus Kettler (2) and Nicolas Boissonnade (1)
(1) Université Laval, Québec, Canada
(2) Graz University of Technology, Graz, Austria

ABSTRACT: The resistance and design of steel sections such as I and H-shapes usually depends in great extents on their ability to resist buckling, as a result of high width-to-thickness b / t ratios in the plates constituents. Consequently, these sections remain quite sensitive to imperfections. Information on imperfections, a key data for F.E. simulations, is however quite lacking in design standards, either for material imperfections or for geometrical imperfections. Accordingly, an extensive numerical study on hot-rolled and welded I and H-sections was carried out with the aim of providing reliable and efficient recommendations for the F.E. modelling of initial geometrical imperfections. Several sets of imperfections were investigated including the use of (i) sine-shape functions and of (ii) the 1st buckling mode shape. Reliable recommendations based on modification of nodes coordinates by means of sine-shape functions could be proposed afterwards.

Jun Wang (1), Xianfeng Cheng (2), Chao Wu (1) and Chuan-Chuan Hou (1)
(1) School of Transportation Science and Engineering, Beihang University, 37 Xueyuan Road, Beijing 100191, China
(2) Hua Da Highway Engineering Consultant and Supervision Co., LTD., Tuanjie East Road No.21, Gaobeidian, Hebei 074000, China

ABSTRACT: Dodecagonal CFDST columns have been used in power transmission towers in China due to their lighter weight and lower manufacturing cost. In this paper, the axial compressive behavior of dodecagonal concrete-filled double skin tubular (CFDST) columns was investigated by finite element analysis. The different behaviors between dodecagonal CFDST columns and circular CFDST columns were compared through the load-deformation curves, contact pressure, longitudinal stress distributions in concrete and ultimate capacity. The developed finite element model was validated against experimental results in terms of load-displacement curves, failure modes, stress distributions and the ultimate strength of the tested specimens. Then a parametric analysis was performed by the verified finite element model on parameters including slenderness ratio, hollow ratio and diameter of the outer steel tubes. Research results showed that the confinement effects and the ultimate strength of dodecagonal CFDST columns were relatively weaker than those of the corresponding circular
CFDST columns. At last, a design equation for the compressive capacity of dodecagonal CFDST columns was derived, and accurate predictions were obtained compared with the experimental results.

Nelson Loaiza (1), Carlos Graciano (1) and Euro Casanova (2)
(1) Universidad Nacional de Colombia, Facultad de Minas Sede Medellín, Departamento de Ingeniería Civil, A.A. 75267 Medellín, Colombia
(2) Universidad del Bío-Bío, Departamento Ingeniería Civil y Ambiental, Avenida Collao 1202, Concepción, Código Postal 4051381 Concepción, Chile


ABSTRACT: In the current edition of the EC3 Part 1–5, the design provisions for longitudinally stiffened plate girders subjected to patch loading result in an enhanced resistance for an increasing distance of the stiffener, measured from the loaded flange. This is in contrast to the actual behavior observed experimentally, which shows a decreasing resistance for an increasing distance of the stiffener. The problem lies in the determination of the critical buckling load, which increases with the stiffener location, also affecting the calculation of the slenderness of the plate girder. At ultimate load level, the longitudinal stiffener restricts the vertical and the out-of-plane displacements of the web panel. This paper investigates the impact of various hypotheses regarding these displacements on the determination of the critical buckling load of plate girder webs with a single longitudinal stiffener. At first, the study is performed through linear buckling analysis using the finite element method, in which various displacements restrictions are applied to investigate their influence on the buckling response of the stiffened girders. The results show that a full restriction of the displacements of the stiffener in the vertical, as well as in the out-of-plane direction, lead to an improvement in the determination of the slenderness of the web panel, and hence the resistance to patch loading at ultimate load level. Finally, experimental results are compared to those obtained with a validated methodology attaining a good agreement.

Yao Sun (1), An He (1), Yating Liang (2) and Ou Zhao (1)
(1) School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
(2) School of Engineering, University of Glasgow, Glasgow, UK


ABSTRACT: The present paper describes an in-depth experimental and numerical investigation into the in-plane flexural behaviour and bending moment capacities of S690 high strength steel welded I-section beams. The experimental investigation was conducted on six different welded I-sections fabricated from the same batch of 5mm thick S700MC high strength steel hot-rolled plates by means of gas metal arc welding, and involved initial local geometric imperfection measurements and twelve in-plane four-point bending tests, with six performed about the cross-section major principal axes and another six conducted about the cross-section minor principal axes. Following the experimental study, a numerical investigation was performed, where the developed finite element models were firstly validated against the test results and then used to perform parametric studies to generate further structural performance data over a broader range of cross-section sizes. The obtained experimental and numerical results were carefully analysed and then adopted to evaluate the accuracy of the existing slenderness limits (for classifications of plate elements and cross-sections) and local buckling design rules for S690 high strength steel welded I-sections in bending, as set out in the European, Australian and American standards. The results of the evaluation revealed that the codified slenderness limits are generally safe when used for the classification of the constituent plate elements of the examined S690 high strength steel welded I-section beams, except for that given in the American specification for slender/non-slimmer outstanding elements in compression. All of the three considered design standards were shown to yield accurate cross-section bending moment capacity predictions for compact (Class 1 and 2) S690 high strength steel welded I-section beams bent about both the principal axes and non-compact (Class 3) S690 high strength steel welded I-section beams bent about the major principal axes, but resulted in a rather high level of conservatism in predicting the cross-section bending moment capacities for non-compact (Class 3) S690 high strength steel welded I-sections in bending about the minor principal axes and slender (Class 4) S690 high strength steel welded I-sections subjected to both major-axis bending and minor-axis bending.
ABSTRACT: To investigate the failure mechanism of restrained stainless steel H-section columns under axial compression during fire exposure, the mechanical properties of S30408 (EN1.4301) austenitic stainless steel at normal and elevated temperatures were obtained by the tensile tests, and 7 restrained stainless steel H-section columns under axial compression were tested in fire. By high temperature steady-state test, the elastic modulus, ultimate strength, yield strength and stress-strain curve under different temperatures were obtained. Comparing on the mechanical properties of stainless steel at normal and elevated temperatures, the mechanical property reduction factors under different temperatures were proposed. The influences of axial/rotational restraint stiffness ratio, load ratio and slenderness ratio on the fire resistance were analysed. The failure modes, temperature curves, axial displacement curves, mid-span lateral displacement curves, buckling temperatures and critical temperatures of the specimens were presented. The result shows that axial/rotational restraint stiffness ratio, load ratio and slenderness ratio all have great influences on the fire resistance of restrained stainless steel H-section columns under axial compression.


ABSTRACT: This paper examines the elastic and inelastic seismic behaviour of single layer steel cylindrical lattice shells. The main dynamic characteristics for this form of structure are firstly examined through a parametric assessment, which also leads to proposed expressions for estimating the fundamental period and mode of vibration. The seismic response of five typical shell configurations, representing a wide range of rise to span ratios, is then assessed within the linear elastic range under selected earthquake excitations. Particular focus is given to the relative influence of the horizontal and vertical seismic components on the internal actions. In order to provide a means for evaluating the underlying inelastic behaviour, a simple pushover approach, which is suitable for this structural form, is suggested using the forces obtained from the fundamental mode shape. The peak angle change is proposed as a damage parameter within the nonlinear analysis for characterising the inelastic global and local demands in shells of different geometries. Incremental dynamic analysis is subsequently carried out in order to evaluate the detailed nonlinear time history response. The results provide detailed insights into the influence of the horizontal and vertical excitations on the nonlinear seismic response, and illustrate the suitability of the peak angle change as an inelastic deformation measure for shells of different geometric configurations. The main findings from the linear and nonlinear assessments are highlighted within the discussions, with a view to providing guidance for performance based assessment procedures as well as simplified design approaches.

Amin Nabati (1) and Tohid Ghanbari-Ghazijahani (2)
(1) Sahand University of Technology, Tabriz, Iran
(2) School of Civil, Environmental & Mining Engineering, The University of Adelaide, Australia


ABSTRACT: This paper experimentally and numerically investigates the effect of strengthening circular steel tubes with cutout using Carbon Fibre Reinforced Polymer (CFRP) under compression. Tests were performed for unstrengthened and strengthened specimens and the results were compared to the numerical data. The numerical study was then extended through designing nine strengthening layouts with various CFRP layers and orientations and the results were compared aiming to find optimal solutions in remediation of the capacity. It was found that utilising CFRP in certain locations with specific dimensions and layers transfers the stress concentration from critical areas, hence remedies the lost capacity resulted from the presence of the cutout. References listed at the end of the paper:
6 M. Shariati, M.M. Rokhi, Numerical and experimental investigations on buckling of steel cylindrical shells with elliptical cutout subject to axial compression, Thin-Walled Struct., 46 (11) (2008), pp. 1251-1261
7 M. Shariati, M.M. Rokhi, Buckling of steel cylindrical shells with an elliptical cutout, Int. J. Steel Struct., 10 (2) (2010), pp. 193-205
9 H. Han, et al., Numerical and experimental investigations of the response of aluminum cylinders with a cutout subject to axial compression, Thin-Walled Struct., 44 (2) (2006), pp. 254-270
12 C.A. Dimopoulos, C.J. Gantes, Experimental investigation of buckling of wind turbine tower cylindrical shells with opening and stiffening under bending, Thin-Walled Struct., 54 (2012), pp. 140-155
17 P. Feng, et al., Compressive bearing capacity of CFRP–aluminum alloy hybrid tubes, Compos. Struct., 140 (2016), pp. 749-757
19 M.M.A. Kadhim, Z. Wu, L.S. Cunningham, Experimental study of CFRP strengthened steel columns subject to lateral impact loads, Compos. Struct., 185 (2018), pp. 94-104
24 ABAQUS-V6.12, Dassault Systemes.

M. Anbarasu (1) and M. Adil Dar (2)
(1) Department of Civil Engineering, Government College of Engineering, Salem, 636011, Tamil Nadu, India
(2) Department of Civil Engineering, Indian Institute of Technology Delhi, New Delhi, 110016, India
"Improved design procedure for battened cold-formed steel built-up columns composed of lipped angles”, Journal of Constructional Steel Research, Vol. 164, Article 105781, January 2020,
https://doi.org/10.1016/j.jcsr.2019.105781

ABSTRACT: The present paper reports the numerical parametric study on the structural behaviour of battened cold-formed steel built-up box columns composed of four lipped angles. The validated numerical model with the experimental results reported by the author in the comparison paper was employed to carry out parametric studies to produce numerical data over a wider range of global column slenderness by varying the sectional compactness of the lipped angle section, batten spacing, and global column slenderness. The numerically derived results were employed to check the accuracy of the current design rules. The results of the assessment revealed the limitation of the current design rules in the prediction of the capacity of the CFS built-up battened box columns, which was mainly associated with the influence of unbraced chord slenderness and interconnector
stiffness on the buckling behaviour. Therefore, improved design procedure was proposed in the framework of AS/NZS specifications (AS/NZ 4600:2018) and European standards (EN1993-1-3:2006) for the safe, less scattered and reliable design strength predictions of battened CFS built-up columns composed of four lipped angles.

References listed at the end of the paper:
1 T.A. Stone, R.A. LaBoube, Behavior of cold-formed steel built-up I-sections, Thin-Walled Struct., 43 (12) (2005), pp. 1805-1817
7 D.C. Fratamico, S. Torabian, X. Zhao, K.J.R. Rasmussen, B.W. Schafer, Experimental study on the composite action in sheathed and bare built-up cold-formed steel columns, Thin-Walled Struct., 127 (2018), pp. 290-305
8 J. Zhang, B. Young, Numerical investigation and design of cold-formed steel built-up open section columns with longitudinal stiffeners, Thin-Walled Struct., 89 (2015), pp. 178-191
10 J. Whittle, C. Ramseyer, Buckling capacities of axially loaded, cold-formed, built-up C-channels, Thin-Walled Struct., 47 (2) (2009), pp. 190-201
21 AS/NZ 4600, Cold-formed Steel Structures, Australian/New Zealand Standard, Standards Australia (2018)
ABSTRACT: The membrane residual stress and strain formations of roller-bent steel members, comprising Circular-Hollow-Sections (CHS), are examined in the present study. Detailed finite element models are developed to simulate the curving procedure of CHS workpieces in a reliable manner, by means of implicit analyses accounting for geometric, contact and material nonlinearities. A mesh convergence study is carried out, followed by an extensive parametric study aiming at assessing the influence of the main roller-bending characteristics on the developed stress/strain distributions. The examined parameters include the CHS diameter and thickness, the radius of curvature, the steel yield stress, the bending length, the diameter of bending rolls and the encapsulating angle of bending dies. Variations are encountered in the locked-in stress formations, attributed to the presence of shear and transverse stresses in the CHS workpiece within the three-point-bending length. The obtained residual stress distributions are summarized, and a characteristic distribution is proposed on the basis of the locked-in formations that are encountered most commonly.

References listed at the end of the paper:

2 C. King, D. Brown, Design of Curved Steel, The Steel Construction Institute, Berkshire (2001)
3 European Committee of Standardization, EN 1993-1-1 Eurocode 3: Design of Steel Structures - Part 1-1: General Rules and Rules for Buildings, (2005), Belgium
6 P.W. Key, G.J. Hancock, A theoretical investigation of the column behaviour of cold-formed square hollow sections, Thin-Walled Struct., 16 (1993), pp. 31-64
Jia-Bao Yan (1), Xin Dong (1) and Tao Wang (2)

(1) School of Civil Engineering / Key Laboratory of Coast Civil Structure Safety of Ministry of Education, Tianjin University, Tianjin, 300350, China

(2) Key Laboratory of Earthquake Engineering and Engineering Vibration, Institute of Engineering Mechanics, CEA, Harbin, 150080, China


ABSTRACT: This paper evaluates the low-temperature compressive behaviours of square CFST stub columns (SCFST-SCs) in steel-concrete composite structures. 21 compressive tests were firstly performed on 14 SCFST-SCs and seven rectangular CFST stub columns (RCFST-SCs) at low temperatures of 20, -30, -60, and -80 °C. The key parameters in this testing program are low temperatures, wall-thickness of steel tube, and shape of the cross section. Concrete crushing, outward local buckling of steel tube, and tensile fracture at the corner of steel tube were three observed failure modes in the compressive tests. The SCFST-SCs and RCFST-SCs exhibited linear, elasto-plastic, and recession working stages. The test results showed that the ultimate compressive resistance and initial stiffness were increased, but the ductility was decreased for the square CFST stub columns as the temperature decreases from 20 to -80 °C. The wall-thickness of steel tube showed equivalent contributions on the improvements of ultimate compressive resistance due to different low temperature, but its influences on ductility tends to be weakened as temperature decreases. Modified Eurocode 4 code equations have been proposed for the predictions on ultimate compressive resistances of SCFST-SCs at low temperatures, and their accuracies were checked by 21 reported test results.

References listed at the end of the paper:

Mei Liu, Mengdie Liang, Qijie Ma, Peijun Wang and Changwei Ma (Civil Engineering College, Shandong University, Jinan, Shandong Province, 250061, China), “Web-post buckling of bolted castellated steel beam

ABSTRACT: This paper presented numerical investigations on the behavior of a Bolted Castellated Steel Beam (BCSB) with octagonal web openings. Instead of welding the upper and the lower Tee-sections of a Castellated Steel Beam (CSB) together in the factory, they were connected using high strength bolts at the construction site. Thus, the upper and the lower Tee-sections can be transported separately, especially being convenient for a castellated steel beam with great section height. The residual stresses in the web-post induced by welding could also be avoided. The shear buckling behavior of the web-post in a BCSB with octagonal openings was studied using a verified finite element model. The buckling mode and the buckling strength of the web-post in a BCSB were compared with those of a traditional Welded Castellated Steel Beam (WCSB). Research results showed that web-posts in a BCSB with octagonal web openings had as good structural performance as those in a WCSB. Studied parameters of the BCSB included the bolt diameter, the width-to-thickness ratio of the web-post and the bolt layout. To increase the buckling strength of the web-post, a BCSB using stiffened connection plate was proposed. The Strut Model for predicting the buckling strength of the web-post in a traditional WCSB was employed for calculating that in a BCSB. Comparisons of buckling strengths obtained by Strut Model predictions and finite element simulations showed that the Strut Model could be used to predict the web-post buckling strength of a BCSB.

References listed at the end of the paper:
7 S. Demirdjian, Stability of Castellated Beam Webs, Department of Civil Engineering and Applied Mechanics, McGill University (1999)

Chu Chengyi, Tong Genshu and Zhang Lei (Dept. of Civil Engineering, Zhejiang University, Hangzhou 310058, Zhejiang, China), “In-plane nonlinear buckling analysis of circular arches considering shear
ABSTRACT: A new theory for the buckling and nonlinear analysis of circular arches with shear deformation is developed, the theory is based on the variational principle in which the nonlinear strain energy of all stress components are included. For arches subjected to a uniform constant-directed radial load, internal forces and deformations including shear deformation are determined, then the buckling of arches only considering uniform axial forces and incorporating the effect of pre-buckling deformations and all internal forces are respectively carried out, with the results of the latter are fully validated by FE predictions, thus the proposed theory is verified. The buckling of arches with shear deformation is then viewed as an interactive buckling between flexural and shear buckling. Simplified formulas for the critical loads and the critical axial forces of arches for 4 types of loads are presented, the comparison shows excellent agreement between the proposed formulas and FE analysis.

References listed at the end of the paper:
9 G.S. Tong, Lei Zhang, Transverse stresses in thin-walled beams and their effect on strength and stability, Adv. Struct. Eng., 6 (2) (2003), pp. 159-167

Jia-Bao Yan (1), Yan-Yan Yan (1) and Tao Wang (2)
(1) Key Laboratory of Coast Civil Structure Safety of Ministry of Education/School of Civil Engineering, Tianjin University, Tianjin 300350, China
(2) Key Laboratory of Earthquake Engineering and Engineering Vibration, Institute of Engineering Mechanics, CEA, Harbin 150080, China

ABSTRACT: Firstly, this paper proposed a type of steel-concrete-steel (SCS) sandwich composite shear wall with J-hook connectors (SCSSWJ) and boundary concrete-filled-steel-tube (CFST) columns. Five full-scale cyclic tests were performed to study seismic performances of SCSSWJs. The studied parameters were connectors’ spacing and axial force ratio. Test results showed that flexure failure occurred to these five SCSSWJs with boundary CFST columns, which is characterized by tensile fracture of boundary steel tube, local buckling in the edge tube and faceplates, and concrete crushing. The test results revealed that increasing the spacing of J-hook connectors from 100 mm to 160 mm and 200 mm firstly slightly improves but then compromised the seismic behaviour of SCSSWJ due to early buckling of steel faceplate; increasing the axial force ratio significantly compromised the seismic behaviours of SCSSWJ. This paper also developed theoretical models to evaluate lateral peak shear resistance of SCSSWJ. The validations proved that the developed models predicted well lateral peak shear resistance of SCSSWJ with boundary CFST columns.

References listed at the end of the paper:
15 J.B. Yan, J.Y.R. Liew, Design and behavior of steel–concrete–steel sandwich plates subject to concentrated loads, Compos. Struct., 150 (2016), pp. 139-152
ABSTRACT: This paper investigates the axial load capacity of concrete encased steel composite stub columns with high strength concrete and steel materials. A total of 14 column specimens with varying material strengths and different steel section shapes were tested under concentric compression load. The test results revealed that the design methods in EN 1994-1-1 and JGJ 138-2016 overestimate the axial load capacity of high strength concrete encased steel columns. Adding a small percentage of steel fiber in the high strength concrete was found to improve the compression resistance of the composite section. A new test database consisting of 51 partially encased composite sections and 82 fully encased composite sections was established, covering a wide range of section geometric and material grades. Parametric study was then carried out to assess current design methods in predicting the axial capacity of such composite columns with respect to material strengths, steel contribution ratio, reinforcement ratio, section slenderness ratio, confined concrete area ratio, and concrete confinement efficiency. The effectiveness of concrete confinement in partially encased composite column was evaluated and a simplified method was proposed to compute the enhanced concrete strength based on regression analysis. For fully concrete encased composite columns, a concrete strength reduction factor was proposed to be used with EN 1994-1-1 to predict the compression resistance. Design recommendation was made considering the early cover spalling of high strength concrete and the material compatibility between steel and concrete in composite column design.

References listed at the end of the paper:
41 E. Ellobody, B. Young, D. Lam, Eccentrically loaded concrete encased steel composite columns, Thin-Walled Struct., 49 (1) (2011), pp. 53-65
64 Canadian Standard Association (CSA) A23.3, Design of Concrete Structures, Mississauga, Canada, (2014)
67 ACI (American Concrete Institute) Innovation Task Group (ITG), 4.3 R-07, Report on Structural Design and Detailing for High Strength Concrete in Moderate to High Seismic Applications, American Concrete Institute (2007)
ABSTRACT: Externally anchored prestressed cables can be employed to enhance the stability of steel truss compression elements significantly. To demonstrate this concept, a system comprising a tubular strut subjected to an external compressive load and a prestressed cable anchored independently of the strut is studied. Energy methods are utilized to define the elastic stability of the perfect and imperfect systems, after which the first yield and rigid–plastic responses are explored. The influence of the key controlling parameters, including the length of the strut, the axial stiffness of the cable and the initial prestressing force, on the elastic stability, the inelastic response and the ultimate strength of the system is demonstrated using analytical and finite element (FE) models. To illustrate the application of the studied structural concept, FE modelling is employed to simulate the structural response of a prestressed hangar roof truss. A nearly two-fold enhancement in the load-carrying capacity of the truss structure is shown to be achieved owing to the addition of the prestressed cable.

References listed at the end of the paper:
ABSTRACT: Owing to the lack of an analytical research on the evaluation of mode change of web panels in addition to the need for shear design curves of unstiffened plate girder web panels exposed to shear buckling especially at elevated temperatures, the present article considers the mentioned topics. To this end, the web panel shear design relationships mentioned in AISC360-16 are modified to be used in fire conditions. This is achieved by direct utilization of steel stress-strain reduction factors in EN1993-1-2 at elevated temperatures. Analytical equations and design curves are developed to estimate the ultimate shear strength, failure mode and critical limiting temperature for the web panels under the action of a specific shear load. The results based on the curves are compared to the findings of current paper numerical analysis, existing experimental and numerical studies, indicating a good agreement between the results.

References listed at the end of the paper:
6 A. Reis, N. Lopes, P.V. Real, Ultimate shear strength of steel plate girders at normal and fire conditions, Thin-Walled Struct., 137 (2019), pp. 318-330
8 B. British, Standards Institution, Structural Use of Steelwork in Building: Code of Practice for Design-Rolled and Welded Sections, BSI (1990)

Gh Pourmoosavi (1), S.A. Mousavi Ghasemi (1), B. Farahmand Azar (2) and S. Talatahari (2)
(1) Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran
(2) Department of Civil Engineering, University of Tabriz, Tabriz, Iran


ABSTRACT: This research aims at developing a new simple but rational analytical model to predict web crippling strength of cold formed steel Z beams. Results of the developed analytical model were verified experimentally and numerically utilizing the finite element non-linear analysis. Web crippling strengths obtained by the proposed analytical model, tests and numerical analysis were compared to the corresponding strength calculated by the equations of AISI-2016 and Eurocode 1–3. Both codes adopt empirical equations for estimating the web crippling resistance. Comparison showed that, the predicted web crippling strength using the developed model compare well with the experimentally and numerically calculated strength. On the other hand, it was found that the design equations adopted by the AISI-2016 and Eurocode 1–3 overestimate the web crippling strength compared to the experimental and analytical strength. Accordingly, it is recommended to adopt the proposed equation as a rational formula for estimating web crippling strength of cold formed Z-sections.

References listed at the end of the paper:
2 B. Young, G.J. Hancock, Cold-formed steel channels subjected to concentrated bearing load, J. Struct. Eng., 129 (8) (August, 2003)  
3 B. Young, G.J. Hancock, Design of cold-formed channels subjected to web crippling, J. Struct. Eng., 127 (10) (October, 2001)
Moreover, a numerical model built in the general-purpose code ABAQUS is presented and verified against the...
test results regarding initial stiffness, ultimate resistance and failure mode. Numerical simulations (FEA), based on the test panel geometry, the measured initial geometric imperfections and elasto-plastic material characteristics from tensile tests, demonstrate very good agreement with experimental results.

References listed at the end of the paper:
13 J.K. Seo, C.H. Song, J.S. Park, J.K. Paik, Nonlinear structural behaviour and design formulae for calculating the ultimate strength of stiffened curved plates under axial compression, Thin-Walled Struct., 107 (2016), pp. 1-17, 10.1016/j.tws.2016.05.003
30 M. Mahendran, Local plastic mechanisms in thin steel plates under in-plane compression, Thin-Walled Struct., 27 (1997), pp. 245-261, 10.1016/S0263-8231(96)00040-7
Yu-Tao Guo (1), Ju Chen (2), Xin Nie (1), Mu-Xuan Tao (1), Jia-Ji Wang (1) and Jian-Sheng Fan (3)
(1) Key Lab. of Civil Engineering Safety and Durability of China Education Ministry, Dept. of Civil Engineering, Tsinghua University, Beijing, 100084, China
(2) Department of Civil Engineering, Zhejiang University, 310058, China
(3) Beijing Engineering Research Center of Steel and Concrete Composite Structures, Dept. of Civil Engineering, Tsinghua University, Beijing, 100084, China


ABSTRACT: Steel–concrete–steel composite structures with bidirectional steel webs (SCSBWs) are used in large-scale immersed tunnels, and have been shown to have high capacity, ductility, waterproofness, and impact resistance compared to traditional structural types. Moreover, versatile construction procedures can be utilised to improve construction efficiency, because the steel plates can function as a framework during concrete casting. Recent studies have shown that there are multiple shear mechanisms in SCSBWs, and the shear resistance of these structures deserves further investigation to achieve more rational designs. Based on previous experimental and theoretical studies, numerical investigations are carried out in this study to investigate the shear resistance of an SCSBW, and an elaborate three-dimensional nonlinear finite element method (FEM) model is proposed. Based on this elaborate FEM model, a series of analyses are conducted to investigate the loading process, stress development, concrete cracking, stress state, and interfacial behaviour of SCSBWs under shear. Mutual verifications are obtained between results of the FEM model, experiments, and theory. Based on the analysis of the interfacial properties, the FEM model is simplified, and the simplified model is shown to be accurate and efficient. Further, parametric analyses are conducted, revealing that the concrete, axial web, flanges, and shear–span ratio have a significant influence on the shear resistance. Finally, a modified theoretical method is proposed to consider the influences of dowel action and small shear–span ratios, with which the accuracy of predicting the shear resistance of SCSBWs can be improved.

References listed at the end of the paper:
26 Research Subcommittee on Steel-Concrete sandwich Structures, Concrete Committee, Design Code of Steel-Concrete Sandwich Structures, JSCE (1992), Concrete Library No.73
30 K.M.A. Sohel, J.Y.R. Liew, C.G. Koh, Numerical modelling of lightweight Steel-Concrete Sandwich composite beams subjected to impact, Thin-Walled Struct., 94 (2015), pp. 135-146
ABSTRACT: This paper presents an approach for evaluating fire performance of composite box bridge girders. The model takes into account critical parameters, namely, fire scenario, fire exposure length, load level, numbers of longitudinal stiffeners in web and bottom flange and web pattern, that influence fire performance of bridges. A three dimensional finite element model, developed in the computer program ANSYS, is applied to model the fire response of composite box bridge girders. The finite element model is validated by comparing predicted sectional temperatures and deflections from the model with test data generated from a test on box bridge girder. The applicability of the numerical model in practical application is illustrated through numerical analysis on a composite box bridge girder subjected to simultaneous structural loading and fire exposure. Results from the numerical study clearly show that fire severity, fire exposure length, load level, number of longitudinal stiffeners and web slenderness have significant influence on the fire resistance of composite bridge girders. Provision of longitudinal stiffeners can result in lower deflections; thus enhancing fire resistance. Further, inclined web configuration incorporated into sectional shape can enhance fire resistance of composite box bridge girders.
ABSTRACT: This paper presents the results from a comprehensive study of the in-plane shear behavior and ultimate shear strength of steel-faceplate composite (SC) shear walls with flanges or boundary elements. The proposed analytical approach can be used to calculate the entire in-plane shear force-shear strain response, including the ultimate shear strength and corresponding shear strain, of SC walls with flanges or boundary elements. A series of SC shear panel tests in the literature are modeled and analyzed using nonlinear inelastic finite element models. The analysis results including the detailed responses of the composite section, steel faceplates, and concrete infill are compared with experimental results, and used to calibrate the composite shell theory approach. The proposed, calibrated analytical approach is further verified using the existing database of tests conducted on SC shear walls with flanges or boundary elements. Both the finite element model and the proposed analytical approach can be used to calculate the entire in-plane shear force-shear strain response of SC shear walls with reasonable accuracy.

Terence Ma and Lei Xu (Department of Civil and Environmental Engineering, University of Waterloo, 200 University Avenue West, Waterloo, ON, N2L 3G1, Canada), “Effects of column imperfections on capacity of steel frames in variable loading”, Journal of Constructional Steel Research, Vol. 165, Article 105819, February 2020, https://doi.org/10.1016/j.jcsr.2019.105819

ABSTRACT: The presence of column initial imperfections in a steel frame can increase deflections and decrease its load carrying capacity. A method is proposed for evaluating the lateral stiffness, inter-storey displacement and deflected column shapes in a semi-braced, semi-rigidly connected planar storey frame subjected to gravity loading and column initial imperfections. An equation is proposed for calculating the inter-storey displacement, which contains the notional load associated with out-of-plumbness imperfections, in addition to a new notional load term associated with out-of-straightness imperfections. Additionally, when the lateral stiffness calculated by the proposed method diminishes, the frame is considered unstable. Different gravity loading scenarios can exist that equally result in the various criteria of capacity being reached defined as either instability, the maximum permissible deflection associated with structural integrity, or the onset of yielding in columns. The proposed method extends the variable loading approach to identify the worst- and best-case scenarios of gravity loading for this to occur. Unlike traditional proportional loading analyses, loads are varied independently of each other in the variable loading approach. Numerical models for the frame subjected to variable loading with accounting for the presence of column initial imperfections are established. It is demonstrated that although the presence of column initial imperfections does not affect the buckling loads of frames, it increases deflections and can significantly reduce the capacity even if the frames are constructed within the allowable tolerances for initial imperfections.


ABSTRACT: This paper deals with the strength and deformation characteristics of short circular Concrete-filled Steel Tube (CFST) stiffened columns. The intermittently welded vertical stiffener plates are used to
strengthen the steel tubes. Plates are attached to the inner surface of the tube by welding it from outside through the predrilled holes in the tube. The stiffener plates improve the bonding between the steel tube and the concrete and also enhance the confinement in the concrete. The variables of the experimental study are spacing of the weld between the stiffener plate and the circular tube and number of vertical stiffener plates. The weld spacing of 10t, 15t, 25t, 35t and 50t, where t is the tube thickness and 3, 4 and 5 numbers of vertical stiffener plates are used in this study. The number of specimens cast and tested in this study is 29. The test results indicate that the strength and deformation of the circular CFST column are significantly influenced by the intermittently welded stiffener plates. The ultimate axial load-carrying capacity of the CFST columns is found to increase by 26% when the spacing of weld is reduced to 10t from 50t. A strength prediction model is developed for the CFST columns which are intermittently welded stiffeners. The prediction is found to be in good conformity with the corresponding test data.


ABSTRACT: The overall buckling behaviour of welded π-shaped columns have been investigated in this study. Twenty-five pin-ended specimens made of Q345 steel with several cross sections and a wide range of lengths were tested under axial compression. The material properties, initial imperfections and longitudinal residual stresses were all examined. The deformed shapes of test specimens involved overall flexural buckling and overall flexural-torsional buckling. The ultimate strengths, deformations and strain distributions of specimens were obtained in the test. The finite element models were established and validated by test results, and then were adopted to carry out a series of parametric studies. The buckling strengths were compared with the design strengths predicted by the current design specifications for steel structures. Reliability analyses were conducted to evaluate the existing design column curves and π-shaped column curve. It is shown that column b-curves in both Eurocode 3 and Chinese standard provide generally conservative predictions for the strengths of π-shaped members, whereas ANSI/AISC specification provides marginally unsafe predictions. A new column curve is proposed and can provide more accurate and reliable predictions for the strengths of welded π-shaped members.


ABSTRACT: For circular steel sections, axial slenderness limits are typically defined in terms of the diameter-to-thickness ratio and indicate whether the member will first yield or locally buckle under axial compression. The common opinion is that filling a hollow structural section with concrete would enhance its resistance against local buckling by restraining its inward deformations. On the basis of this concept, the axial slenderness limits stipulated by most international design standards are notably higher for filled sections when compared to their hollow counterparts. Although there is extensive evidence in support of this approach for box sections, the available data for circular sections is limited and, in some cases, inconsistent. While some studies and most international design standards suggest that filled circular sections should have a notably higher axial slenderness limit compared to hollow circular sections, a number of studies argue that the concrete infill is in fact not very effective in increasing the local buckling strength of circular sections. Such studies are however very limited in the literature and often incomplete. Consequently, a comprehensive numerical study with over 140 analyses is conducted herein considering different material types, a wide range of slenderness values, and five initial imperfection modelling techniques to clarify the role of concrete infill in the local buckling behaviour of circular sections. Results of the study strongly suggest that the concrete infill has limited effect on enhancing the local buckling strength of circular tubes. The enhancement is found to be much lower than that implied in international design standards. The roots for this discrepancy are identified and recommendations are proposed in light of the findings of the study. The results suggest that the axial slenderness limit for hollow circular tubes can be significantly relaxed to bring it closer to that of filled circular tubes.

Qazi Inaam and Akhil Upadhyay (Department of Civil Engineering, IIT Roorkee, Roorkee, Uttarakhand 247667, India), “Behavior of corrugated steel I-girder webs subjected to patch loading: Parametric study”, Journal of
ABSTRACT: The double-corrugated-plate shear wall (DCPSW) is composed of two identical corrugated plates that are assembled using connecting bolts. The DCPSW can exhibit much greater shear resistance than the ordinary steel corrugated plate shear wall (SCPSW) since the former forms a series of closed-sections while the latter is with open sections. In this paper, the shear resistant behavior of the DCPSWs is investigated. By using a validated FE modeling scheme, a parametric study of aspect ratio, bolt column number, corrugated plate thickness and yield stress of the DCPSWs is performed to investigate their effects on the shear resistant behavior. By analyzing the FE results, the ultimate shear resistance factor $\phi$ and the residual strength factor $\phi_r$ which corresponds to a final state with a drift angle of 2.0% of the DCPSW are obtained. It is found that both factors are negatively related to the normalized slenderness ratio $\lambda$. The $\phi-\lambda$ and $\phi_r-\lambda$ relationships obtained in this study are capable of providing conservative predictions of the ultimate shear resistance and post-ultimate residual strength for the DCPSWs. Finally, the shear resistant curves between shear load and drift angle of the DCPSWs with the variable of the normalized slenderness ratio $\lambda$ are established. These shear resistant curves are regarded as simplified constitutive models when performing the required push-over elastoplastic analysis of the DCPSWs under severe earthquake excitation.

Merih Kucukler (1), Zhe Xing (2) and Leroy Gardner (2)
(1) School of Engineering, University of Warwick, Coventry CV4 7AL, UK
(2) Department of Civil and Environmental Engineering, Imperial College London, London SW7 2AZ, UK
ABSTRACT: The flexural buckling behaviour and design of stainless steel I-section columns at elevated temperatures are investigated in this paper. Finite element models able to accurately replicate the response of structural stainless steel columns in fire are created and validated. The models are then utilised to carry out extensive numerical parametric studies considering a broad range of stainless steel grades, cross-section geometries, slendernesses and elevated temperature levels. Using the results from the parametric studies, the safety and accuracy of existing design rules provided in the European structural steel fire design code EN 1993-1-2 for stainless steel columns in fire are assessed. It is observed that the existing design rules provide rather scattered and inaccurate ultimate strength predictions for stainless steel columns at elevated temperatures. For the purpose of establishing an accurate and practical means of designing stainless steel columns in fire, a new design approach, compatible with existing design rules in EN 1993-1-2, is proposed. The safety, accuracy and reliability of the proposed approach are illustrated for a wide range of cases against the results obtained through nonlinear finite element modelling. The proposed stainless steel column fire design rules are due to be incorporated into the upcoming version of the European steel fire design standard EN 1993-1-2.
Duy Khanh Pham, Cao Hung Pham, Song Hong Pham and Gregory J. Hancock (School of Civil Engineering, The University of Sydney, NSW 2006, Australia), “Experimental investigation of high strength cold-formed channel sections in shear with rectangular and slotted web openings”, Journal of Constructional Steel Research, Vol. 165, Article 105889, February 2020, https://doi.org/10.1016/j.jcsr.2019.105889

ABSTRACT: Cold-formed steel channels with web openings in shear have been thoroughly investigated mainly with circular and square holes. However, web cut-outs are likely to be enlarged along the span length of members due to a limited web depth to provide more access for the building services in practice. The design of cold-formed sections with elongated web holes in shear was investigated and retained in the AISI S100–16 and the AS/NZS 4600:2018 using the empirical approach. This paper presents an experimental investigation of perforated channel sections with rectangular and slotted web openings in shear using a dual actuator test rig to minimise the effects of bending moments and obtain the predominantly shear capacity with an aspect ratio up to 2.0. The commercially available plain C-lipped channel sections with a depth of 200 mm and a thickness of 1.5 mm were chosen with varying sizes of central cut-outs. A new strategy for determination of the shear yield loads (V) together with the Vierendeel mechanism approach is presented in this study to propose a modified design for perforated channels with web openings having aspect ratios of holes up to 3.0 for the Direct Strength Method (DSM) of design of channel members in shear with elongated web openings. In addition, as required in the DSM method, the shear elastic buckling loads (V) are extracted from the linear elastic buckling analyses using finite element method in this paper.

Tianhua Zhou, Yanchun Li, Hanheng Wu, Yan Lu and Lujie Ren (School of Civil Engineering, Chang'an University, Xi'an 710061, China), “Analysis to determine flexural buckling of cold-formed steel built-up back-to-back section columns”, Journal of Constructional Steel Research, Vol. 166, Article 105898, March 2020, https://doi.org/10.1016/j.jcsr.2019.105898

ABSTRACT: In the current AISI standard, the modified slenderness method (MSM) is proposed for the design of cold-formed steel (CFS) built-up columns. According to the available literature, such a method has been extensively adopted in hot-rolled steel research, and usually generates very conservative strength estimates. Nonetheless, there are few corresponding theoretical studies into CFS built-up columns. In this situation, this paper presents a new analytical approach to establish a computing method for the flexural buckling bearing capacity of the CFS built-up back-to-back section column. To achieve this goal, a new flexural buckling model is proposed to establish the kinematic relationship of single profiles. In addition, shear panels are employed at the location of screws to consider the discrete shear deformation restraint effect. The shear rigidity of the shear panels is determined using the cross-sectional shear stress transfer path. Then, based on the energy method, a computing method is derived. Further, simplifications are made to the formula to allow easier use in practical engineering situations. To verify the derived formula, a finite-element model (FEM) is developed and validated using the available test results. Then, based on the developed FEM, parametric studies are conducted to verify the derived formula. In addition, the performance of the derived formula is further verified by comparing the corresponding ultimate strength based on the direct strength method (DSM) expressions using available test results and FEM parametric studies. The comparison and validation results show the following: (i) the derived formula can predict the critical flexural buckling load as well as the corresponding buckling strength based on the DSM expression, and (ii) with an increase in screw spacing, the MSM will result in very conservative strength estimates for CFS built-up back-to-back section columns.

Fan-Qin Meng (1,2), Mei-Chun Zhu (1), G. Charles Clifton (2), Kingsley U. Ukanwa (3) and James B.P. Lim(2)
(1) Department of Civil Engineering, Shanghai Normal University, Shanghai, China
(2) Department of Civil and Environmental Engineering, The University of Auckland, Auckland, New Zealand
(3) Aurecon, Auckland, New Zealand

ABSTRACT: Fire design guidance for composite columns is based on the performance of these columns when heated uniformly along their lengths. However, it is important to understand the behaviour of these columns when heated non-uniformly as this constitutes a more practicable representation. Here, the performance of square steel-reinforced concrete-filled steel tubular (SRCFST) columns was tested under 4-sided, 3-sided, 2-
sided and 1-sided fires. Six columns were 1.8m in height with pinned-fixed boundary condition. The fire resistance of SRCFST columns under 4-sided and 3-sided fires exposure was found to be similar in the experimental tests and their failure modes significantly different. SRCFT columns under 2-sided and 1-sided fires performed better than expected as these did not reach failure before 240min. The results are used to validate a non-linear elastic-plastic finite element model. Validated numerical and experimental results are compared with available advanced prediction methods. It is shown that none of these is capable of providing accurate fire resistance prediction for SRCFST columns under uniform or non-uniform fire.

ABSTRACT: In this paper, the dynamic crushing responses of polyurethane foam-filled energy absorption connectors with asymmetric pleated plates were studied through drop-weight impact tests and FE simulations, from which three deformation stages were identified according to the formation and rotation of plastic hinges of asymmetric pleated plates. The effects of polyurethane foam filler as well as thickness and geometric parameter k of pleated plate on the energy absorption characteristics of connectors were analyzed quantitatively. The results indicated that filling polyurethane foam and increasing parameter k could result in higher energy absorption and specific energy absorption. In addition, thicker pleated plate could also increase energy absorption and crushing force. The results also showed that filling polyurethane foam and decreasing parameter k could reduce the peak force before densification and thus, improving crush force efficiency. Moreover, a theoretical model, considering strain rate effects of polyurethane foam and steel, was also proposed to predict energy absorption–displacement relationships of the polyurethane foam-filled connectors subjected to impact loading and its correctness was validated by comparing the calculations with experimental results.

ABSTRACT: A complementary study showed that hot-dip galvanizing can sometimes significantly change the residual stress properties of cold-formed rectangular hollow sections (RHS). Hot dipping the RHS specimens in a molten zinc bath maintained at 450°C for 10min provided a partial residual stress relief comparable to the onerous heat treatment specified in ASTM A1085 and CSA G40.20/G40.21. Hence, further research is needed to: (1) quantify the effects of galvanizing, and (2) determine the optimized heat treatment duration for a partial residual stress relief for improvement of column behaviour. In this study, the effects of galvanizing and heat treatments to different degrees on the stub column behaviour of cold-formed RHS has been investigated comprehensively for the first time, by means of 36 stub column tests. The RHS specimens were manufactured by two dominant cold-forming methods: (1) indirect-forming from circular to rectangular, and (2) direct-forming. The nominal yield stresses of the materials ranged from 350 to 690MPa. The RHS stub column test matrix has 10 different width-to-thickness ratios and includes both nonslender and slender sections.

X.W. Chen (1), H.X. Yuan (1,3), E. Real (2), X.X. Du (1) and B.W. Schafer (3)
(1) Hubei Provincial Key Laboratory of Safety for Geotechnical and Structural Engineering, School of Civil Engineering, Wuhan University, Wuhan 430072, PR China
(2) Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya, Barcelona 08034, Spain
(3) Department of Civil Engineering, Johns Hopkins University, Baltimore, MD 21218, United States
ABSTRACT: The behaviour of stainless steel plate girders subjected to combined bending and shear was experimentally studied in this paper. Both tensile and compressive material properties of the two adopted stainless steel alloys, including austenitic grade EN 1.4301 and duplex grade EN 1.4462, were determined by
standard coupon tests. The three-dimensional (3D) optical scanning technology was introduced to acquire an accurate distribution of initial geometric imperfections for each plate girder specimen. A total of six plate girders were fabricated by hot-rolled stainless steel plates, and were tested to failure under combined bending and shear. In-depth analyses of the critical buckling characteristics, the ultimate resistances and the collapse behaviour of the tested specimens were all presented. The obtained ultimate resistances were further employed to assess the existing moment and shear (M-V) interaction design methods in EN 1993-1-5, GB 50017-2017, ANSI/AISC 360-16 and SEI/ASCE 8-02, and the design proposal presented by Jáger et al. It has been found that most of the existing codified M-V interaction formulae can be applicable for both carbon steel and stainless steel plate girders, yet they lead to relatively conservative predictions for stainless steel plate girders, except that the design method in ANSI/AISC 360-16 provides apparently unsafe strength predictions.

Rabee Shamass (1) and Federico Guarracino (2)
(1) Division of Civil and Building Services Engineering, School of Build Environment and Architecture, London South Bank University, UK
(2) Department of Structural Engineering, University of Naples `Federico II’, Via Claudio, 21 - 80125 Napoli, Italy
ABSTRACT: The behaviour of cellular beams made from normal and high strength steel with various geometries is investigated through a large number of finite element analyses and a simple mechanical model for the Web-Post Buckling (WPB) failure is developed and analysed in order to highlight the factors which influence its occurrence and development for both normal and High-Strength (HS) steels. The performed FE analyses and the proposed modelling, once calibrated, allow to shed some light on the characteristics of the phenomenon and to provide the basis of a reliable design method to predict shear buckling of web-post of cellular beams made both of mild and HS steel.

ABSTRACT: This paper aims at investigating the size effect of square steel tube and sandwiched concrete jacketed circular RC columns subjected to axial compression. The experiment part consisted of twenty-seven strengthened columns and three reference specimens, in which the effects of tube size (B) and confinement ratio (\(\beta\)) were studied. The results validated the existence of size effect on various indexes including peak nominal stress (\(\sigma_{\text{u}}\)), peak axial strain (\(\varepsilon_{\text{u}}\)), strength index (SI) and ductility index (DI) of specimens. With increasing specimen size, the corresponding \(\sigma_{\text{u}}, \varepsilon_{\text{u}}, SI\) and \(DI\) exhibited a decreasing trend. A finite element (FE) model was developed to further study the mechanical behaviors of the structure, in which the size effect was considered. The FE results demonstrated that the stress of concrete at the peak load point decreased with the increase of specimen size. Moreover, the size effect of confined concrete was more complex than that of the plain concrete. Not only the material strength of concrete but also the confinement effect was influenced by the size effect. The FE analysis also showed that the size effect on large-sized columns in engineering practice was more obvious than that of the tested specimens. It was found that the predictions of the load bearing capacities by codes including GB50936–2014, AISC 360–16, and BS5400were insufficient in terms of accuracy and safety, especially for large-sized specimen. Hence, a size-dependent model was derived, of which the desirable accuracy and credibility was verified with the experimental and the numerical results.

Ahmed W. Al Zand (1), Wan Hamidon W. Badaruzzaman (1), Marwan S. Al-Shaikhli (2) and Mustafa M. Ali(1)
(1) Smart and Sustainable Township Research Centre, Universiti Kebangsaan Malaysia (UKM), Bangi, Selangor, Malaysia
(2) Civil Engineering Department, Madenat Alelem University College, Baghdad, Iraq

ABSTRACT: The outward steel tube buckling failure of concrete-filled steel tube (CFST) beams is still considered to be a serious concern due to the typical bending loads. This research conducts experimental and numerical investigations on the flexural performance of slender square steel tubes filled with normal concrete. A total of 6 cold-formed square CFST specimens were tested under static bending loads. The cross-sections of 4 specimens were stiffened by single and double V-shaped grooves along the tube cross-sections, and 2 specimens were tested as control specimens (unstiffened square specimens). The results showed that adopting this stiffening concept in the slender square CFST beams led to restriction of the buckling failure of the outward steel tube (at the top flange). Due to the increase in the steel confinement factor of the stiffened square CFST beams, the bending moment capacity, flexural stiffness, and energy absorption capability were improved by 25.4%, 7.2%, and 31.4%, respectively, compared to those of the corresponding unstiffened specimens. Finite element models were also developed to further investigate the performance of the proposed CFST specimens by varying certain chosen parameters. The bending moment capacity and the flexural stiffness results obtained from the experimental and numerical investigations were validated with predicted values from different existing standards.

Alexandre Rossi (1), Felipe Piana Vendramell Ferreira (1), Carlos Humberto Martins (1) and Enio Carlos Mesacas Júnior (2)
(1) Department of Civil Engineering, State University of Maringá, Brazil
(2) Department of Civil Engineering, Federal University of Rio Grande do Sul, Brazil


ABSTRACT: Lateral distortional buckling (LDB) of I-beams is characterized by simultaneous lateral deflection, twist and cross section change due to web distortion. The present study investigates the effect of web distortion in LDB resistance of doubly-symmetric welded I-beams. Elastic stability and physical and geometrical nonlinear analyses are performed, using GBTul and ABAQUS softwares, respectively. The numerical model is calibrated considering experimental tests. The beams are simply supported, with fork supports at the ends, and subject to neutral and destabilizing effects of loading. The beams are subject to uniform bending, mid-span concentrated load and uniformly distributed loads. The parametric study is performed by varying the geometric cross section parameters. The results are compared with international standards and analytical procedures. It is concluded that the occurrence of LDB is responsible for the resistance reduction, especially for the slender web sections. With the elastic stability analysis, it is possible to estimate the critical moment for the calculation of the ultimate moment considering the LDB. It is found that there is no need to propose a new solution for the determination of LDB resistance, since some procedures allow the use of the elastic stability analysis response for the calculation of the ultimate moment, such as EC3. However, some adjustments can be made to the ANSI/AISC 360–16 and AS 4100: 1998 standards, since the results compared to these procedures are not conservative.

Jie Wang (1), O. Kunle Fajuyitan (2), M. Anwar Orabi (3), J. Michael Rotter (2) and Adam J. Sadowski (2)
(1) Department of Architecture and Civil Engineering, University of Bath, United Kingdom
(2) Department of Civil and Environmental Engineering, Imperial College London, United Kingdom
(3) Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong


ABSTRACT: The resistance of cylindrical shells and tubes under uniform bending has received significant research attention in recent times, with a number of major projects aiming to characterise their strength through both experimental and numerical studies. However, the investigated cross-section slenderness ranges have mostly addressed low radius to thickness ratios where buckling occurs after significant plasticity and the influence of geometric imperfections is relatively minor. The behaviour under uniform bending of thinner imperfection-sensitive cylinders that fail by elastic buckling was largely omitted, as was the influence of finite
length effects. The value of such resistance models that are only useful for thicker cylinders is therefore somewhat limited.

This paper offers the most comprehensive known characterisation of the buckling and collapse resistance of isotropic cylindrical shells and tubes under uniform bending. Expressed within the modern framework of Reference Resistance Design (RRD), it holistically incorporates the effects of material plasticity, geometric nonlinearity and sensitivity to realistic and damaging weld depression imperfections. The characterisation was made possible by the authors' recently-developed novel methodology for mass automation of nonlinear shell buckling finite element analyses. A modification of the RRD formulation is proposed which facilitates its application to systems of low slenderness, and offers a compact algebraic characterisation of all potential imperfection amplitudes for this common shell structural condition. A reliability analysis is also performed.


ABSTRACT: This paper investigates the flexural buckling behaviour of axially loaded concrete-infilled double steel corrugated-plate-walls with T-section (T-CDSCWs). The T-CDSCW is composed of flange and web wall elements and vertical boundary elements. The wall element consists of two bolted-connected steel corrugated-plates with concrete infilled. The composite effect of the components in the wall element improves the load-bearing capacities of the T-CDSCW efficiently and leads to a thinner wall. Therefore, the failure mode of the T-CDSCW may be governed by global instability. With the web breadth relatively less than the flange breadth, the first-order elastic buckling mode of the T-CDSCW is flexural buckling about the asymmetric axis. The design issue of the flexural instability of the axially loaded T-CDSCW is investigated experimentally and numerically in this paper. The load-bearing and deformation behaviours were investigated by an experiment of the axially loaded T-CDSCW, based on which refined finite element (FE) models of T-CDSCWs are established and validated. The FE buckling analysis is carried out to investigate the elastic buckling behaviour of the T-CDSCW and propose the elastic flexural buckling load and the borderline between flexural and flexural-torsional buckling. Then, the inelastic flexural instability of the T-CDSCW is investigated by the FE nonlinear analysis, and influences of initial geometric imperfection are discussed. The normalized flexural slenderness ratio derived from elastic flexural buckling load delineates flexural instability pretty well and bases the design formulas of strength reduction factor. The design formulas proposed in this paper help to understand the axial load-bearing behaviour of the T-CDSCW.

Mianheng Lai (1), Chengwei Li (1), Johnny Ching Ming Ho (1) and Man-Tai Chen (2)
(1) School of Civil Engineering, Guangzhou University, Guangzhou 510006, China
(2) Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
“Experimental investigation on hollow-steel-tube columns with external confinements”, Journal of Constructional Steel Research, Vol. 166, Article 105865, March 2020,
https://doi.org/10.1016/j.jcsr.2019.105865

ABSTRACT: Tubular steel members with slender cross-sections in compression are prone to local buckling. Different approaches, such as infilling concrete, installation of internal stiffeners and externally bonding fiber-reinforced polymer reinforcement, have been developed to retard the local buckling of steel tubular sections, and hence to improve the performance of tubular structures. In this study, a total of 35 circular hollow-steel-tube (HST) stub columns with both non-slender and slender cross-sections confined by different types of external confinements, namely steel ring, spiral and jacket confinements were tested in the experimental program. The uni-axial behavior of externally confined HST columns, including the failure mode, ultimate load-carrying capacity, stiffness and ductility, were studied and discussed. The enhancements in strength, stiffness and ductility of HST columns with different external confinements were assessed. The results indicated that the improvements on strength and stiffness of the confined HST columns were insignificant for columns with non-slender cross-sections and were considerable for columns with slender cross-sections, whilst the ductility of the HST columns was substantially enhanced by external confinements. Based on the results, equations for column ductility evaluation considering the effects of cross-section slenderness ratio, steel strength and external confinement, are proposed in this study, which are able to predict the column ductility for unconfined and externally confined HST columns.
Lei Zhang (1), Chen-Xiang Mao (1), Li Xiao-Gang (1), Gen-Shu Tong (1), Ting Jing (2) and Yan-Chao Wang(2)
(1) Department of Civil Engineering, Zhejiang University, Hang Zhou, PR China
(2) TongMSK Architectural and Structural Design Institution, Hang Zhou, PR China
ABSTRACT: The concrete filled narrow rectangular steel tube (CFNRST) member is being increasingly used in the apartment buildings in China. Experimental study is conducted on the behavior of CFNRST members subjected to combined compression and uniaxial bending about the weak axis. Eleven specimens were fabricated considering the variation of key parameters including the slenderness, the width/height ratio of cross-section and eccentricity of compression. Comparisons are made between the predictions of representative solutions of design codes and the test results to examine their capacity for predicting the ultimate load of CFNRST members. New solutions with modifications on two existing solutions are proposed for the ultimate load of CFNRST members subjected to combined compression and uniaxial bending. Good agreements are achieved between the predictions of the proposed solutions and test results.

Mizan Ahmed (1), Qing Quan Liang (1), Vipulkumar Ishvarbhai Patel (2) and Muhammad N.S. Hadi (3)
(1) College of Engineering and Science, Victoria University, PO Box 14428, Melbourne, VIC 8001, Australia
(2) School of Engineering and Mathematical Sciences, La Trobe University, Bendigo, VIC 3552, Australia
(3) School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia
ABSTRACT: Rectangular concrete-filled double steel tubular (CFDST) columns have increasingly been utilized in high-rise buildings to support heavy loads. However, the responses of eccentrically loaded rectangular CFDST short columns have rarely been studied. This paper reports experimental and numerical investigations into the behavior of rectangular thin-walled short CFDST columns composed of a rectangular inner steel tube loaded eccentrically. Tests on rectangular and square CFDST short columns under eccentric loading and axial loading were carried out to examine their responses to various design parameters, including the cross-sectional dimensions, loading eccentricity, and width-to-thickness ratios of the external and internal tubes. The experimental program and results are described. A mathematical model underlying the theory of fiber elements is developed for simulating the moment-curvature responses as well as axial load-moment interaction envelopes of short CFDST columns. The computational model explicitly incorporates the experimentally observed failure mode of the progressive local buckling of the outer thin-walled rectangular steel tube. A computer simulation procedure is proposed for capturing the nonlinear behavior of short CFDST columns loaded eccentrically together with efficient solution algorithms that implement the inverse quadratic method for solving nonlinear equations. The experimental verification of the computer modeling technique is undertaken. The verified modeling technique is utilized to ascertain the significance of various design parameters on the structural behavior of CFDST columns made of rectangular thin-walled sections. It is confirmed that the computer model developed is capable of predicting well the experimentally observed responses of CFDST short columns.

H. Taufiq (1) and R.M. Lawson (2)
(1) Metek UK Ltd, Stonehouse Park, Sperry Way, Stonehouse GL10 3UT, UK
(2) Dept of Civil and Environmental Engineering, University of Surrey, Guildford GU2 7XH, UK
ABSTRACT: This paper addresses the potential use of composite construction in light steel framing in the form of composite columns and walls. It presents the results of tests on composite columns using perforated cold formed steel C-sections to form 100×100mm cross-section columns. Three forms of tests were performed: Short column, long column tests and push tests to determine the shear-bond properties of the perforated web of the C-
sections. The results were compared to predictions to Eurocode 4 based on the effective properties of the C section, which were found to be good. The design method was extended to other heights of columns by finite element models using Abaqus. Some practical applications of this new form of composite construction are identified.

Byung H. Choi (1), Arriane Nicole P. Andico (1) and Sang Hyun Choi (2)
(1) Department of Civil and Environmental Engineering, Hanbat National University, Daejeon 34158, Republic of Korea
(2) Korea National University of Transportation, Gyeonggi-do 16106, Republic of Korea


ABSTRACT: Recent studies have shown that the rotational stiffness of longitudinally installed closed-section ribs increases the local buckling strength of thin plates. Thus, in this study, the equations for the buckling strength of compressively loaded stiffened plates, which reasonably account for the partially restrained effect, were theoretically derived using the principle of minimum potential energy. Through three-dimensional refined finite element analysis performed using ABAQUS that appropriately simulates the buckling of plates stiffened with rotational rigidities along the sides, a series of parametric numerical analyses were conducted to examine the variation in buckling stresses based on the influential parameters revealed from the theoretical formulas. Further simplified and readily applicable formulas for the strength increment factor were derived from a series of rigorous regression analyses on the parametric analysis results. A comparative study of the suggested approximate solutions and the numerical analysis results was carried out to validate the proposed method.

Minghong Li (1,2), Zhouhong Zong (1), Hong Hao (2), Xihong Zhang (2), Jin Lin (1) and Yuchen Liao (1)
(1) School of Civil Engineering, Southeast University, Nanjing 211189, China
(2) Centre for Infrastructural Monitoring and Protection, School of Civil and Mechanical Engineering, Curtin University, Perth, WA 6102, Australia


ABSTRACT: Contact detonations, even with a small charge weight, could cause severe damage to structural columns and result in devastating consequences, associate with significant casualties, economic losses and social impacts. Therefore, to prevent catastrophic structural collapse, the most critical requirement of a blast-damaged column would be the residual axial load bearing capacity. In this paper, the post-blast performance of concrete-filled double-skin steel tube (CFDST) columns subjected to contact explosions was studied by experimental tests and numerical simulations. The experimental study comprised of field blast tests and residual axial load-carrying capacity tests on four CFDST columns. A high-fidelity physics-based numerical model was then developed using the nonlinear dynamic analysis program LS-DYNA and was validated against the test results. It was then used to model the dynamic response and predict the residual axial load-carrying capacity of CFDST columns subjected to contact explosions. An extensive parametric study was then carried out to investigate the influence of charge weight, boundary conditions, axial loading level and column geometries on the column residual axial load-carrying capacity. An empirical formula was derived through multi-variable regression analysis to predict the residual axial bearing capacity of CFDST columns after contact explosions.


ABSTRACT: Slender plate I-girders are steel members widely used in bridges, viaducts and heavy industrial buildings, which are subjected to combined bending and shear, making the web panel susceptible to stability problems. Therefore, longitudinal stiffeners are sometimes placed along the web. This paper aims at investigating the load carrying capacity of girders submitted to patch loading (common in bridge launching), using finite element models. A nonlinear stability analysis was carried out considering the initial geometric imperfection as the first buckling eigenmode, with amplitude defined according to EN 1993-1-5 recommendations. The performance of girders with different stiffener locations was evaluated, discussing the structural behavior and associated failure modes. If the stiffener is effective and properly placed, the failure
mode is the local buckling of the two web subpanels (which increases the patch loading resistance), although it was verified that the optimal position for patch loading is mainly governed by the web crippling resistance of the upper subpanel. The numerical results are in accordance with the experimental results available in the literature. For the studied girder configurations, the optimal stiffener position for patch loading resistance is closer to the loaded flange when compared to girders under dominant bending. Depending on the cross-sectional shape of the buckling mode, the stiffener can be unfavorable to the patch loading resistance for certain range of positions. Furthermore, the definition of positive or negative cross-sectional imperfections, i.e., the inversion of the curvature of the buckling mode shape, has impact on the load capacity for larger patch loading lengths.

Chang Yang (1), Pan Gao (2), Xingxiang Wu (3), Y. Frank Chen (4), Qi Li (1) and Zhao Li (5)
(1) College of Architecture and Urban-Rural Planning, Sichuan Agricultural University, Chengdu 611830, China
(2) School of Civil Engineering, Southwest Jiaotong University, Chengdu 611756, China
(3) Sichuan Communication Surveying & Design Institute CO., LTD, Chengdu 610017, China
(4) The Pennsylvania State University, Middletown, PA 17057, USA
(5) Beijing Urban Construction Design & Development Group Co. Limited, Beijing 100037, China

ABSTRACT: A practical and accurate unified formula for predicting the axial compressive strength of short-long circular CFST columns is proposed based on the regression analysis of 368 available experimental data. The formula is applicable to large, thin-walled, and high-strength circular CFST columns, which was established through two processes: (1) Based on 273 experimental data of short specimens, the axial strength of short columns was determined numerically and normalized with respect to the yielding load of the steel tube, thus showing a superior exponential correlation with the modified confinement index \( \xi \); and (2) The numerical model was improved by considering the effect of length-to-diameter \((L/D)\) ratio for long columns. According to the parametric analysis, the size effect is found to have a certain influence on the axial strength of large CSFT short columns and the primary affecting factors to the size effect are the compressive strength of in-filled concrete \(f_c\) and the outer diameter to thickness \((D/t)\) ratio of the steel tubes. Therefore, the size effect is better to be considered in a strength model, as proposed. The strength reduction caused by the size effect is characterized by \(\xi\) which involves the parameters of \(f_c, D,\) and \(t\). In comparison with the measured strengths from the test specimens, the proposed prediction model provides a more accurate and stable estimate on column design strength than the existing design codes.

ABSTRACT: The present paper investigates the resistance of stainless steel I or H sections as influenced by yield extent and local stability issues. In particular, the influence of a rounded stress-strain law with large strain hardening effects on the buckling response of sections is studied. Extensive shell non-linear numerical parametric studies led to a 750+ dataset that considered various material grades, 50 different section shapes (from compact to slender) and either sections in compression or under major-axis bending. These results allow to assess the merits of a design proposal based on the Overall Interaction Concept (O.I.C.) that is shown to be both very effective and accurate while remaining simple. The various influences of section's slenderness, section shape and steel grade are studied, and comparisons with alternative design proposal and design specifications evidence an increased level of accuracy, consistency and safety.

Tuan Le (1), Mark A. Bradford (1), Xinpei Liu (2) and Hamid R. Valipour (1)
(1) Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, UNSW, Sydney, NSW 2052, Australia
(2) School of Civil Engineering, The University of Sydney, NSW 2006, Australia

ABSTRACT: National constructional steel design standards preclude many high-strength quenched and tempered steel grades, and with the growth update of such steels in structural applications, revision or new guidance is needed. This paper reports experiments and presents numerical studies of welded high-strength steel (HSS) I-section beams fabricated by welding BISPLATE-80 (nominal yield stress $f_y=690$MPa) and BISPLATE-100 ($f_y=890$MPa) plates. For the experimental program, three BISPLATE-80 and five BISPLATE-100 I-sections were fabricated and tested under scenarios of uniform bending and moment gradient. The specimens were designed to develop either lateral-torsional or local buckling modes, with tensile fracture not being observed during the tests. The buckling capacity so obtained significantly exceeded the predictions of Eurocode 3 and of the Australian AS4100, especially for intermediate beam slendernesses, while the ANSI/AISC 360–16 guidelines marginally estimated the buckling resistance of specimens. It was also found that lateral-torsional buckling initiated after partial yielding of the compression flange. The numerical studies consisted of two ABAQUS finite element (FE) models, being a test simulation model as well as a generic representation, to facilitate extending the pool of experimental data, which showed that Eurocode 3 and AS4100 underestimate the buckling strength of intermediate and slender beams, while the ANSI/AISC 360–16 curves overestimate the FE predictions for lateral-torsional buckling capacities of beams in inelastic portions. A parameter that is dependent on the material properties is introduced in the AS4100 beam buckling strength formula and a new curve for the buckling of HSS flexural members is proposed.


ABSTRACT: Hybrid shear walls composed of cold-formed steel (CFS) open sections and square hollow sections (SHS) have recently attracted attention for lightweight midrise buildings, as a result of their relatively strong lateral load-bearing performance. A new hybrid CFS shear wall system with SHS truss skeleton is presented in this study in order to improve the lateral behaviour of lightweight steel frames, in compliance with standard codes. For this purpose, eleven full-scale experimental tests were conducted to assess the shear resistance, stiffness, ductility, and energy absorption of the proposed wall panels. The study also investigates the failure modes of the hybrid walls and suggests solutions for improving the existing structural weaknesses. The results showed that employing the SHS truss configuration for one side of the light steel walls can significantly enhance the energy absorption, compared to the traditional CFS walls. The SHS truss also has a considerable effect on decreasing the chance of chord stud buckling; i.e. load-bearing capacity. Specimens sheathed with gypsum board offer higher strength and ductility ratio with a few minor localized failures, compared to specimens without sheathing board. The results also indicate that the low strength to weight ratio of hybrid walls makes them a practical solution for mid-rise lightweight constructions.


ABSTRACT: In this paper, a modified eigen-buckling algorithm based on eigenvalue analysis was presented for evaluating the in-plane buckling strength of parabolic steel arch bridges. The buckling strength of parabolic arches under uniformly distributed vertical loads was studied. The slenderness parameter was modified to unify the buckling curves. Parametric analysis was carried out to study the applicability of the new algorithm. Finally, a case study regarding the bearing capacity of a steel arch bridge was performed to verify the proposed method. The results showed that the influences of geometric imperfections, rise-to-span ratio, and material yield strength of parabolic arches were taken into account by modifying the slenderness parameter. The buckling strength results of the arches using the modified dimensionless slenderness agreed very well with the straight column buckling curves in the specifications. The modified eigen-buckling algorithm provided very high accuracy in buckling strength assessment for parabolic steel arch bridges when the span was less than 200m. The modified
eigen-buckling algorithm predicted the load-bearing capacities of the arch bridge very well. Hence, the proposed method can be used for preliminary buckling strength evaluations in the bridge design stage.


ABSTRACT: The performance of glass fiber-reinforced epoxy resin (GFRP) reinforced circular steel tubes under axial compression was studied using both numerical and experimental methods. Through axial compression tests, the effects of steel tube thickness, GFRP winding angle (the angle between the axis of the tube and the tangential direction of winding fiber) and specimen length on specimens' failure modes and stability carrying capacity were studied; and proved that GFRP can improve the axial compression behavior of steel tube. A UMAT subroutine for GFRP that could consider 6 initial failure modes (fiber tension or compression failure, resin tension or compression failure and stretch or compression in-layer delamination failure) and damage evolution was developed, and then the axial compression processes of specimens were simulated; moreover, a further parametric analysis to examine specimens of different GFRP thickness and winding angle, steel tube diameter and thickness, as well as specimen length was carried out. A predictive formula was introduced to estimate the buckling load of specimen by modifying the Perry-Robertson equation. Finally, based on the simulation and the equivalent concept, the application of GFRP reinforced circular steel tube in the reticulated mega-structure was discussed.

Yingbo Zhu (1), Shui Wan (1), Kongjian Shen (2), Qiang Su (1) and Muyun Huang (1)
(1) School of Transportation, Southeast University, Nanjing 210096, China
(2) Jiangsu Provincial Transportation Engineering Construction Bureau, Nanjing 210004, China

ABSTRACT: Currently, an increasing number of single-box multi-cell composite box-girders with corrugated steel webs (SBMC-CBGCSWs) have been built in China and Japan. However, the torsional stiffness of SBMC-CBGCSW is dramatically decreased due to the employment of thin corrugated steel webs (CSWs). Investigations of SBMC-CBGCSW under pure torsion are relatively limited, therefore, additional research is needed to investigated to guarantee the safety of such bridges. In this paper, an experimental study on four scaled specimens subjected to pure torsion is conducted to understand the effect of the number of cells and spacing of CSWs on the full torsional response of SBMC-CBGCSW. The failure mode, cracking patterns, and buckling patterns of specimens are presented, and a new shear strain relationship between CSWs obtained from experimental results is proposed to evaluate the contribution of inner CSWs to the torsional behavior of SBMC-CBGCSW. Then, finite element analysis (FEA) models are created to compare with experimental results, such as torque-twist curves, shear strains of CSWs and shear strains of concrete slabs. Finally, a parametric study is performed to examine the effect of geometric factors, such as the ratio of width to height, ratio of width to span length, ratio of width to thickness of slab, number of cells and spacing of CSWs, on such bridges under torsion.


ABSTRACT: The composite steel plate shear wall (CPSW) is a relatively new structural system which attracted many researchers in recent years. The main idea for developing the CPSW system is to improve out-of-plane strength of steel plate shear walls by addition of one or two layers of concrete. This configuration provides high strength and acceptable ductility for this system in comparison with the other lateral load bearing systems. Sometimes due to architectural considerations, it is required to include openings in the shear walls. These openings change performance of the CPSW and reduce its strength and stiffness. Moreover, inclusion of openings offers difficulty in analysis and design of the CPSW system. The main goal of this study is to develop accurate numerical models to analyze CPSW containing opening. Based on the obtained result and
using an evolutionary algorithm named Multi-Expression Programming (MEP), an empirical relation is proposed to calculate equivalent reduced thickness to be used in the analysis of the CSPSW instead of incorporating the opening in the developed models. Accuracy of the developed model and the proposed relation are verified experimentally.

A. Lokman Demirhan (1), H. Erdem Eroğlu (1), E. Okay Mutlu (1), Tolga Yılmaz (2) and Övgür Anil (1)
(1) Gazi University, Department of Civil Eng., Ankara, Turkey
(2) Eskisehir Osmangazi University, Department of Civil Eng., Eskişehir, Turkey

ABSTRACT: A primary failure mode for thin-walled steel members is lateral-torsional buckling (LTB), in which steel cantilever beams experience nonuniform twisting and buckling about their weak axes. Analytical and numerical studies related to the elastic LTB of cantilevers abound. However, comprehensive analytical and experimental studies focusing on the inelastic LTB behaviour of cantilevers are rare. Therefore, this study intends to establish a numerical procedure verified with experimental results to evaluate the inelastic LTB strength of steel cantilevers with an I-section. First, an experimental study was performed, in which nine steel cantilever beams with different slenderness and load-height levels were tested. Load–displacement behaviours of steel cantilevers were investigated by measuring lateral and vertical displacements and rotations under the effect of a monotonic end-point load. Subsequently, a two-step numerical procedure is introduced. The elastic LTB loads and the related mode-shapes were determined in the first step, and the nonlinear load-deflection behaviours were evaluated in the second step based on the Riks method. Finally, numerical and experimental results were compared, thereby demonstrating that the presented numerical analysis can be used for predicting the buckling loads, vertical displacements, and torsional rotations at an acceptable level in the design stage.

Natalia Degtyareva (1), Perampalam Gatheeshgar (2), Keerthan Poologanathan (2), Shanmuganathan Gunalan(3), Konstantinos Daniel Tsavdaridis (4) and Stephen Napper (2)
(1) Institute of Architecture and Construction, South Ural State University, Chelyabinsk, Russia
(2) Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, UK
(3) School of Engineering and Built Environment, Griffith University, Gold Coast, QLD 4222, Australia
(4) School of Civil Engineering, Faculty of Engineering, University of Leeds, Leeds, UK

ABSTRACT: Cold-Formed Steel (CFS) members with slotted perforations in webs are used in civil construction to amplify the thermal and energy performance of structures. However, the slotted webs reduce the structural performance of the element, prominently their shear, bending and combined bending and shear strengths. Many research studies have been undertaken to examine the behaviour of CFS channel sections subject to bending. Yet, no research has been performed to investigate the distortional buckling behaviour of slotted perforated CFS flexural members. Finite Element (FE) models of CFS channels with staggered slotted perforations were developed herein to investigate their distortional buckling under bending stress. A parametric study was conducted in detail by developing 432 slotted perforated CFS FE models based on the validation process with available experimental results. In particular, this paper presents the FE analysis details of CFS flexural members with slotted perforations subject to distortional buckling and results. The reliability of the current Direct Strength Method (DSM) for CFS flexural members with web holes subject to distortional buckling in accordance with the North American Specification (AISI S100) (2016) and the Australian/New Zealand Standards (AS/NZ 4600) (2018) was investigated. Modified DSM formulae for slotted perforated CFS flexural members subject to distortional buckling were also proposed.

Bernard A. Frankl (1) and Daniel Linzell (2)
(1) HDR, 3940 N 8th St, Lincoln, NE 68521, USA
(2) College of Engineering, University of Nebraska Lincoln, 114L Othmer Hall, 844 N. 16th Street, Lincoln, NE 68588-6105, USA
ABSTRACT: Steel plate girders are an attractive choice for horizontally curved geometries because they can be efficiently designed to resist the torsional stresses induced from the curvature. The effects of horizontal curvature on flexural behavior have been extensively studied. However, the behavior and design of horizontally curved, steel, plate girders under shear is still treated as if they were straight. It is of interest to examine the effects of horizontal curvature on plate girder shear strength because it could offer increased shear capacity. A series of companion studies were completed to examine if horizontal curvature increased shear capacity and to develop shear buckling coefficients that accounted for curvature. Summarized herein are steps taken to develop shear buckling coefficients that incorporate horizontal curvature in a form that would be easily adaptable to current American design specifications. Two different coefficients are proposed, the first a simple, curve fitting approaches based on work first published by Batdorf in 1947 and the second derived using energy based approaches that expand on classical work published by Timoshenko and Gere. The accuracy with which the proposed coefficients predict horizontally curved, plate girder shear response was examined via comparison between predicted shear buckling limits and ultimate capacities against values obtained from calibrated finite element models. These comparisons show that shear buckling capacity is enhanced when horizontal curvature is correctly accounted for in shear buckling coefficient derivations, which can enhance plate girder buckling capacity and, in turn, shear strength.

ABSTRACT: A steel tubular friction damper (STFD) is proposed for vibration reduction in large-span spatial structures. The effects of the amplitude of the applied displacement, the pre-tightening force of the high-strength bolts, and the material of the friction plates on the hysteretic behaviour of the STFD are analysed experimentally. The single-cycle energy consumption increases and the equivalent stiffness decreases with increasing displacement amplitude. In addition, the single-cycle energy consumption and equivalent stiffness of the STFD increase with increasing pre-tightening force. Both the single-cycle energy consumption and the equivalent stiffness of the STFD with aluminium alloy or brass friction plates are larger than that of the STFD with steel friction plates. Then, a mechanical model of the STFD is established for further numerical analysis. Several structural members in a 40-m-span double-layer reticulated shell are replaced with STFDs to provide vibration reduction. Optimal arrangement of STFDs is studied based on additional modal damping ratio. The effects of the replacement rate, earthquake intensity and various ground motions on the vibration reduction effect are investigated via numerical analyses. The reduction ratio first increases and then decreases with increasing replacement rate, and the best performance is observed at a replacement rate of 10%. The vibration reduction effect of the STFDs is more obvious for strong ground motions than for weak ground motions. Under various ground motions, the vibration reduction effect of the STFDs is better for the two ordinary ground motions than for the four long-period ground motions selected herein.

Silin Chen (1), Chao Hou (2), Hao Zhang (1) and Ting-Min Mu (4)
(1) School of Civil Engineering, The University of Sydney, Sydney, NSW 2006, Australia
(2) Department of Ocean Science and Engineering, Southern University of Science and Technology, Shenzhen 518055, China
(3) Department of Civil Engineering, Tsinghua University, Beijing 100084, China
(4) Sichuan Province Transportation Department Highway Planning, Survey, Design and Research Institute, Chengdu 610041, China
ABSTRACT: Concrete-filled steel tubular (CFST) truss is now widely used in many large-span constructions. In the past, relevant studies on the reliability of CFST structures mostly focused on structural components such as individual columns and beams. In current practices, a simplified method based on the ultimate axial strengths of the chords is commonly adopted to predict the flexural strength of a CFST truss, since there is no mature system-based design regulations nor reliability evaluations on this complex composite system. This paper aims
to address this gap by advanced structural reliability analysis of CFST truss through numerical approach considering both the structural nonlinearities and random uncertainties. The finite element models are validated against experimental results. Afterwards, a mass finite element simulation, taking into account the material and geometric nonlinearities, random initial imperfections and potential finite element model errors, is conducted to generate the statistics of the flexural strengths of CFST trusses. Reliability analysis is then conducted to calculate reliability indexes in respect of different resistance factors under various load cases based on AASHTO. Finally, reliability-based evaluation on the safety level of CFST truss design according to mainstream design guidelines such as ANSI/AISC 360–16, Eurocode 4:2004 and JGJ/T D65–06–2015 are carried out. Results show that the current component-based strength prediction of CFST trusses meet the target reliability while the current regulations provide uniform reliability.


ABSTRACT: Steel-concrete-steel (SCS) sandwich walls with J-hooks (SCSSWJs) exhibit wide potential applications in both civil and offshore constructions. This paper firstly developed nonlinear finite element models (NFEMs) for SCSSWJs. Two different NFEMs, namely FEM-I and FEM-II, were developed that adopted different simplifying methods on modelling complex J-hooks. Accuracies of these two NFEMs were validated by 11 tests on SCSSWJs under in-plane shear. The validations showed that these two NFEMs were capable of simulating structural behaviours of SCSSWJs subjected to in-plane shear. The FEM-II was finally adopted for the parametric studies considering both numerical accuracy and simulation efficiency. The studied parameters in the parametric studies included concrete core strength, J-hook spacing, thickness of faceplate, wall thickness of steel tube in edge column, and axial force ratio. The effects of these parameters on ultimate lateral shear resistance of SCSSWJs were detailed reported and discussed. Theoretical models have also been proposed to predict the ultimate lateral shear resistance of SCSSWJs. Their capabilities on the predictions of ultimate lateral shear resistance of SCSSWJs have been checked through validations against 22 test results and 60 FE simulated results.

Moussa Leblouba (1), Sami W. Tabsh (2) and Samer Barakat (1)
(1) Department of Civil & Environmental Engineering, College of Engineering, University of Sharjah, P.O. BOX 27272, University City, Sharjah, United Arab Emirates
(2) Department of Civil Engineering, College of Engineering, American University of Sharjah, P.O. BOX 26666, University City, Sharjah, United Arab Emirates

ABSTRACT: Despite their successful use in many bridges across several countries around the world, corrugated web steel girders (CWSGs) haven't been yet recognized formally by mainstream design codes and standards. CWSGs can be an economical alternative to conventional welded plate girders; they can achieve higher shear strengths with lesser material usage. Corrugated webs have been demonstrated to carry about half of their ultimate shear strength after buckling, which is an important reserve strength to overcome sudden collapses of bridge structures. The current design practice combines the latest research in the field with engineering judgment with no regard for reliability-based design. In light of the new developments in the field of bridge design and reliability analysis techniques, this paper revisits first the reliability of welded plate girders in shear and verifies their target reliability index and the corresponding resistance factor as per AASHTO LRFD. Then, and in an attempt to prepare the inclusion of CWSGs shear design in AASHTO LRFD, a probabilistic-based calibration procedure is applied to calibrate the resistance factor for bridges having a range of span lengths and girder spacings, with consideration of different average daily truck traffic. A series of sensitivity analyses were carried out in order to quantify the relative contribution of each design parameter to the overall reliability of CWSGs in shear. The findings of this study suggest that, for CWSGs in shear, a resistance factor of 0.95 is appropriate to ensure a reliability level that is consistently close to the target. The sensitivity analysis showed that the web thickness, web depth, and the yield strength of the web's steel material are the most influential parameters on the reliability index of CWSGs.

ABSTRACT: This paper firstly developed high performance sandwich composite beams with novel J-hooks and ultra-high performance concrete (UHPC), i.e., steel-UHPC-steel sandwich composite beams with J-hooks (SUSSBJs). Nine full-scale two-point loading tests were then performed on SUSSBJs to study their ultimate strength behaviour. The test results revealed that all SUSSBJs exhibited flexural failure even for SUSSSSBJs with short shear span ratio of 2.41 and high spacing of J-hooks of 200mm due to the high performance UHPC. The test results showed the SUSSBJs exhibited a four-stage working mechanism, which were initial elastic, elastic, nonlinear developing, and hardening stage. The test results also detailed reported and discussed the influences of key parameters on flexural behaviour of SUSSBJs. The flexural bending resistance of SUSSBJs was reduced for small shear span ratios; the spacing of J-hooks did not change the flexural failure mode, but reduces its ultimate strength as well as working mechanism; and all the strength and stiffness indexes increase linearly with the increasing thickness of faceplate. Finally, this paper developed analytical models on stiffness and strengths indexes of SUSSBJs, and the validations against nine test results proved their capabilities on predicting these indexes.


ABSTRACT: T-shaped concrete-filled steel tubular (CFST) columns have the advantage of avoiding protrusion from walls and can be used as edge columns. The practical structures may be subjected to the earthquake action from different directions, but little attention has been paid to the behavior of T-shaped CFST columns under diagonal cyclic loading. A total of 14T-shaped CFST columns were tested under constant axial load and lateral cyclic loading. The main variables explored in the test were loading angle, axial load level, concrete compressive strength and section form. The failure mode, lateral load-lateral displacement hysteretic curves, envelope curves, stiffness degradation, ductility, cumulative energy dissipation, deformation and bending moment-curvature curves were investigated. The results show that the hysteretic curves are generally plump and the displacement ductility coefficients are over 3 for the specimens with the axial load levels of less than 0.5. The specimens at 45° and 90° have close envelope curves, while the specimens at 0° exhibit slightly lower lateral ultimate strength and better ductility. The existing codes such as Eurocode 4, AISC 360–10 and DBJ/T 13-51-2010 give obviously higher predictions of initial section flexural stiffness for stiffened specimens without an axial load and conservative predictions for most multi-cell specimens. Furthermore, the existing codes overestimate the serviceability-level section flexural stiffness for most specimens.


ABSTRACT: This paper presents the results of the experimental and finite element study that was performed to analyze the buckling behavior of corroded cold-formed steel beam-columns. Six specimens with different corrosion degrees were tested under compression and major axis bending. The residual thickness distribution and the mechanical properties of the corroded specimens were analyzed. A nonlinear finite element model predicting the buckling behavior of corroded cold-formed steel beam-columns was proposed. Finally, the influence of the parameters on ultimate load and failure mode were discussed, and the parameters include the parts, locations and lengths of the corroded region. The results indicated that when the thickness loss ratio was below 0.467, the decrease of the corrosion reduction factor for the elastic modulus was small, and then
accelerated obviously. The corrosion reduction factor for the yield strength decreased linearly as the thickness loss ratio increased. Local buckling of the web of the corroded specimens was easier to occur than the web of the non-corroded specimen. The corrosion reduction factor for the ultimate load mainly depended on the minimum thickness of the cross-section. The flange corrosion most significantly affected the bearing capacity of the cold-formed steel beam-columns with localized corrosion. The locations and length of the corroded region has a little effect on the ultimate load and failure mode of corroded cold-formed steel beam-columns.

Seyed Mohamad Mahdi Yousef-beik (1), Sajad Veismoradi (1), Pouyan Zarnani (1) and Pierre Quenneville (2)
(1) Department of Built Environment Engineering, School of Engineering, Auckland University of Technology, Auckland, New Zealand
(2) Department of Civil and Environmental Engineering, Faculty of Engineering, The University of Auckland, Auckland, New Zealand
ABSTRACT: It has been shown that having a low post-elastic (secondary) stiffness for conventional structures can be beneficial in terms of putting a limit on base shear of the structure although it could result in having a residual and permanent drift. A well-recognized example can be Buckling-Restrained Braced Frames (BRBFs) offering stable, repeatable and reliable damping while suffering from residual displacements owing to low secondary stiffness. This paper introduces a new type of self-centring brace with a flag-shape behaviour possessing a zero post-elastic (secondary) stiffness, Self-Centring Zero-Stiffness Brace (SC-ZSB), bringing the benefit of systems with minimal secondary stiffness without their deficiency. Basically, the elastic damage-free buckling of the brace is combined with the friction damping to form the intended flag-shape behaviour with zero post-elastic stiffness. The introduced bracing system will recover and re-centre at the end of buckling without any inelastic deformation, strength and stiffness degradation meanwhile providing passive damping. The proposed SC-ZSB is experimentally validated using a scaled self-centring brace. Besides, a comparative study is performed using OpenSeeS software to illustrate the seismic performance of the SC-ZSB in comparison with a BRB Frame. The results demonstrate that SC-ZSB system efficiently limits the base shear of the structure with an almost similar inter-story drift of the BRB frame, while it can eliminate any residual drifts as well.

Zhi-Bin Wang (1), Jian-Bin Zhang (1), Wei Li (2) and Hong-Jun Wu (1)
(1) College of Civil Engineering, Fuzhou University, Fuzhou, Fujian Province 350108, China
(2) Department of Civil Engineering, Tsinghua University, Beijing 100084, China
ABSTRACT: The concrete-filled double skin steel tubular (CFDST) members have been used in many engineering projects. The stiffened outer steel tube could be used to further enhance the structural performance and reduce the steel consumption, while the seismic behaviour of the stiffened member needs investigation. In this study, tests of 6 stiffened CFDST beam-columns were conducted under both constant axial load and cyclic lateral load. Main test parameters were the axial load level and the hollow section ratio. The load, deformation and strain of all specimens were recorded and analysed. The influence of parameters was discussed in terms of the lateral resistance, the ultimate displacement, the ductility and the energy dissipation ability. It showed that the stiffened specimens exhibited good energy dissipation capacity under the cyclic loading. A finite element (FE) model was developed to carry out the mechanism and parametric analysis. The longitudinal stiffeners could effectively reduce the local buckling of the tube wall. The ductility and energy dissipation capacity of stiffened CFDST members are generally higher than that of unstiffened ones. Finally, equations for predictions of the flexural stiffness and strength, as well as the hysteretic model of the load-deformation relationship were proposed for stiffened CFDST members.

ABSTRACT: This paper presents the details of an experimental and numerical study on the effect of warping on the flexural-torsional buckling (FTB) behaviour of axially loaded cold-formed steel lipped channel members. Eleven controlled experiments on two different lipped channel sections are conducted with simply-supported flexural end conditions. A unique scheme of compression loading is evolved, which allows the ends of the member to warp freely. Experimental investigations reveal that warping end conditions play a significant role in the compressive strength and failure modes. The results from the experiments are used to calibrate the numerical model developed using ABAQUS. Parametric studies are conducted on different cross-section sizes of the members to quantify the effect of warping restraint on the FTB strength under compression. Results are compared with the current AISI S100–16 specification using both the effective width method (EWM) and the direct strength method (DSM). The comparison of results reveals that for warping restrained condition, the present DSM framework based on the finite strip method (FSM) predicts FTB strength conservatively. A possible correction factor is identified for members with warping restrained ends, which can be applied over the traditional strength curve in DSM. A reliability study is also carried out on the modified design procedure for the FTB strength of CFS members.

Xianggang Liu (1), Jiepeng Liu (3), Yuanlong Yang (2,3), Guozhong Cheng (3) and Joel Lanning (4)
(1) China Southwest Architectural Design and Research Institute Co., Ltd, Chengdu 610042, China
(2) Structures Dynamic Behavior and Control, Harbin Institute of Technology, Harbin 150090, China
(3) School of Civil Engineering, Chongqing University, Chongqing 400045, China
(4) Civil and Environmental Engineering, University of California, Irvine 92617, USA


ABSTRACT: Design procedures for L-shaped and T-shaped concrete-filled steel tube (CFST) columns subjected to bending and compression loading scenarios were developed through parametric study using finite element (FE) models verified by existing experimental results. The finite element study on this special-shaped CFST column subjected to pure bending considered parameters of steel-to-concrete ratio $\alpha$, steel yield strength $f_y$, concrete strength $f_c$, and column limb width-to-thickness ratio $B/t$. For their behavior under eccentric compression, additional parameters of section stiffening pattern, loading angle $\theta$, eccentricity, and axial compression ratio were included. Parametric analysis results show that steel-to-concrete ratio $\alpha$, steel yield strength $f_y$ and column limb width-to-thickness ratio $B/t$ have obvious influences on the flexural resistances of the special-shaped CFST columns, while concrete strength $f_c$ has a small effect and can be ignored. The column limb width-to-thickness ratio $B/t$, steel to concrete ratio $\alpha$, steel yield strength $f_y$, concrete compressive strength $f_c$, loading angle $\theta$, eccentricity e and section stiffening type have significant effects on the $N-M$ correlation curves, and the convex portion of the $N-M$ curves has a certain symmetry. The column limb width-to-thickness ratio $B/t$ and axial compression ratio $n$ have significant effects on the shape of $M_N$ correlation curves. Based on the FE analysis results, design formulae for calculating sectional flexural resistances were proposed for special-shaped CFST columns. Besides, simplified formulae were provided to conservatively predict the resistances of special-shaped CFST section and column under eccentric compression based on extensive analysis results of FE models.

Hongbo Liu (1), Yu Zhao (1), Lan Wang (2) and Zhihua Chen (1)
(1) Department of Civil Engineering, Tianjin University, Tianjin 300072, China
(2) Tianjin Institute of Fire Protection, Ministry of Emergency Management, China


ABSTRACT: Space frames are mostly steel structures whose material and mechanical properties are largely affected by the high temperature of fire such that the bearing capacity of the structure deteriorates. Welded hollow spherical joints, as the most widely used form of joints in space frames, are the key factors affecting...
structural stress. Thus, the resistance to fire of such joints must be further studied. In this paper, the mechanical properties of welded hollow spherical joints (abbreviated WHSJ) with H-beam under elevated temperature are investigated through experiment and finite element analysis. Axial compression tests at 300°C, 500°C, and 700°C are used to analyze the failure modes of the joints under axial compression at high temperatures. The experiments obtained load–displacement curves, yield and ultimate bearing capacities, ductility, and initial axial stiffness. Furthermore, results are used to validate the finite element model. Through parametric analysis of temperature, steel grade, ribbed or non-ribbed, diameter, wall thickness, and H-beam section, the present study proposes formulas for designing joints with ultimate bearing capacity and initial axial stiffness to withstand high temperatures.

Zhi-wei Shan (3,5), Hui-huan Ma (1,2), Zhi-wei Yu (4) and Feng Fan (3)
(1) School of Civil Engineering, Sun Yat-Sen University, Guangzhou, PR China
(2) Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), PR China
(3) Structures Dynamic Behavior and Control, Harbin Institute of Technology, Harbin, PR China
(4) School of Civil Engineering, Guangzhou University, PR China
(5) Department of Civil Engineering, University of Hong Kong, PR China


ABSTRACT: Bolt-column (BC) joint is an innovative fabricated semi-rigid joint with strong bending stiffness that can meet the need of rapid construction of lattice shell structure. To investigate the dynamic behavior of SLR shells with BC joints subjected to harmonic load and earthquake load, finite element (FE) modeling of SLR shells with BC joint was built taking geometric and material nonlinearity into account, and the simulation method was validated by comparing with the test result on a cylindrical reticulated shell. Based on this model, effect of joint stiffness on the dynamic response was examined and failure modes of SLR shells joined with BC joint subjected to harmonic load and earthquake load were studied. Two failure modes, dynamic strength failure which results from the extensive plastic deformation and dynamic instability failure which is induced by the geometric nonlinearity of the shell, were defined. Subsequently, the criteria on differentiating the two failure modes were derived based on response characteristics indicators. Furthermore, investigation on damaged factor of SLR shells jointed with BC joint was conducted, and according to numerous numerical examples, the damaged index of SLR shells with BC joint was derived, which can be utilized to conduct fragility analysis.

Guochang Li (1), Zhichang Zhan (1), Zhijian Yang (1), Chen Fang (2) and Yu Yang (1)
(1) School of Civil Engineering, Shenyang Jianzhu University, Shenyang, Liaoning 110168, China
(2) Department of Civil and Environmental Engineering, University of Nebraska-Lincoln, Lincoln, NE68588, USA


ABSTRACT: Concrete-filled square steel tubular (CFSST) stub column stiffened with an encased I-section carbon fiber-reinforced polymer (CFRP) is a new composite member that consists of a square steel tube, concrete infill, and an encased CFRP profile. This paper conducted investigations that experimentally and numerically examined the behavior of CFSST stub column with an inner I-section CFRP profile under biaxial bending. Seven column specimens were tested using biaxially eccentric compression tests in the experimental study. The parameters considered in the test were the load eccentricity, steel yield strength, and steel tube thickness. Numerical models were developed to investigate the column load-carrying mechanism using ABAQUS and validated against experimental results. Results indicated that the CFSST column stiffened with an encased CFRP profile has favorable capacity and ductility when subjected to biaxial bending. Furthermore, parametric analyses were performed to assess the effects of steel yield strength, concrete compressive strength, and steel ratio (steel thickness) on the load bearing capacity and $P/P_{M}$ curve of stub column under biaxial bending. Finally, formulas to predict the $P/P_{M}$ curves of the composite column under bi-axial bending were proposed in this study.

A. da S. Sirqueira (1), P.C.G. da S. Vellasco (2), L.R.O. de Lima (2) and F.R. Sarquis (1)
ABSTRACT: Although many mechanical properties of stainless steels are similar to carbon steel, their nonlinear characteristics lead to different design rules that can affect their response to local and flexural buckling. The stainless steel design standard Eurocode 3: Part 1–4 (2006) can, in principle, be used in hot-rolled, welded and cold-formed products, but its provisions are still rather conservative, with a limited application due to the lack of experimental data. One of those areas that require attention and study concerns the behaviour of columns made of hot-rolled stainless steel equal leg angles. This paper describes an experimental campaign made on hot-rolled stainless steel equal-legs angles under axial compression. The adopted cross-sections were: L64 × 64 × 4.8, L76 × 76 × 6.4 and L102 × 102 × 6.4 made of austenitic stainless steel ASTM 304 A276 (1.4301) (with corresponding leg width to thickness ratios, b/t, equal to 13.33, 11.88, 15.94). The longest specimen was 1893mm, and the shortest one 152mm. The collapse involved flexural-torsional and flexural buckling modes. These results were subsequently compared with Eurocode 3–1.4 provisions, and to the CSM – Continuous Strength Method and mDSM – Modified Direct Strength Method predictions. In general, the CSM and mDSM performed better than the Eurocode 3 1–4, but unsafe ultimate load predictions could also be observed in some cases.

Ying Qin (1), Gan-Ping Shu (1), Xiong-Liang Zhou (2), Jian-Hong Han (1) and Hui-Kai Zhang (1)

(1) Concrete and Prestressed Concrete Structures, School of Civil Engineering, Southeast University, Nanjing, China
(2) Zhejiang Southeast Space Frame Group Company Limited, Hangzhou, China

ABSTRACT: Sandwich composite walls are composed of two external steel faceplates and concrete infill and have been increasingly applied in infrastructure to resist either gravity or lateral loads. They combine the advantages of both steel and concrete and offer excellent structural behavior. In this paper, the performance of a new type of T-shaped sandwich composite walls with truss connectors was studied. Three full-scaled specimens with T-section were tested under eccentric compression. The failure mode was identified as the sectional strength failure. Load versus axial and out-of-plane displacement responses, buckling stress, axial stiffness, ductility, and strength utilization were discussed. Based on CECS 159, the interaction model between the compression and bending moment was proposed to estimate the sectional strength of sandwich composite walls under eccentric compression. The comparison between the test data and the proposed curve shows that the proposed method offers reasonable and conservative predictions on the strength of sandwich composite walls.

Jihong Ye (1,3) and Mingfei Lu (2,4)

(1) Jiangsu Key Laboratory Environmental Impact and Structural Safety in Engineering, China University of Mining and Technology, Xuzhou 221116, China
(2) Concrete and Prestressed Concrete Structures, Southeast University, Nanjing 211102, China
(3) Xuzhou Key Laboratory for Fire Safety of Engineering Structures, China University of Mining & Technology, Xuzhou, 221116, China
(4) Jiangsu Public Work Co., Ltd, Nanjing 210008, China


ABSTRACT: Stability is the determining factor in the design of domes. The member section designation and joint stiffness are two important factors that significantly affect the global stability. However, the current design method, which determines member sections and joints in two separate stages, assumes that joints are ideally rigid. This design method neglects the interactions among members and joints. In this paper, the theory of form vulnerability is further extended with the introduction of joint flexibility. The relative gradient of the well-formedness of flexible joints, denoted as gra_r, is defined to reflect the instability mechanism from the perspectives of members and joints. Then, a single-layer dome is taken as an example to illustrate the effect of...
joint stiffness on the stability of the dome. This case study is quantitatively analyzed from the perspectives of the stability of the dome and the gra_r values of the dome. In addition, a reasonable range of joint stiffness values is determined according to the analysis. Next, topology optimization is adopted to develop joints of different sizes with stiffness values within the given range. A set of optimal joints is composed of novel joints with reasonable configurations. Subsequently, the optimization scheme of domes against instability considering the joint stiffness is proposed. The member sections and joint stiffness values are simultaneously taken as the optimization variables to consider the interactive effects of members and joints on dome stability. Maximizing of the lowest gra_r (gra_r_c) is the optimization objective. The steel consumption and design requirements are taken as constraints. The corresponding algorithm is developed, and two domes with different spans are employed to verify the proposed design method. The two illustrative domes demonstrate that the proposed optimization method against instability accounting for joint stiffness can simultaneously optimize the member sections and joint flexibilities. The stability capacities of the optimal domes with flexible joints are as high as those of the optimal domes with rigid joints, but the steel consumption is remarkably reduced compared with that for domes designed using the traditional method.


ABSTRACT: A concrete-filled steel tubular (CFST) x-column is an advanced structural member that can potentially be used in diagrid structural systems. This paper proposes a novel method for strengthening the weak part of the CFST x-column. Axial compression tests are designed and conducted on three through-type and three reinforced-type CFST x-column specimens. The load-bearing process, failure mode, and load-deformation curve of CFST x-columns are recorded during these tests and analysed in detail. The experimental results show that the stiffness of the reinforced-type x-column is greater than that of the through-type x-column, and its peak bearing capacity is approximately 1.85 times that of the through-type x-column. Moreover, better ductility performance is observed in reinforced-type x-columns. Further, a corresponding finite element model (FEM) is established to simulate the entire loading process during axial compression of CFST x-columns. A parametric study on possible parameters affecting specimen loading behaviours is also conducted. Ultimately, theoretical investigations on CFST x-columns are presented, and formulae for calculating the load-bearing capacity of through-type and reinforced-type CFST x-columns under axial compression are proposed.


ABSTRACT: Firstly, this study developed a new type of sandwich composite beam using ultra-high performance concrete (UHPC) and novel enhanced C-channels (ECs). Then, this study developed a nonlinear finite element model (NFEM) for steel-UHPC-steel sandwich beams with ECs (SUSSB-ECs) using general software package ABAQUS. The developed NFEM detailed simulated the novel sandwich composite beams including the complex geometry of ECs, the complex interactions between the ECs and UHPC core, and nonlinear mechanical properties of UHPC and steel. The comparisons of NFEM simulation results with eight four-point bending tests indicated that the NFEM simulated well the ultimate strength behaviour of SUSSB-ECs in terms of load versus strain/deflection curves, deformations and cracks in UHPC, and stiffness/strength indexes. Parametric studies were then performed with the developed NFEM to study the key parameters influencing the ultimate strength behaviour of SUSSB-ECs. The parametric studies showed that increasing the thickness of tension and compression steel faceplates had significant influences, but the spacing of ECs had marginal influences on ultimate strength behaviours of SUSSB-ECs. Reducing the shear span ratio did not change the flexural failure, but reduced the flexural bending resistance of SUSSB-ECs. Increasing the grades of steel faceplates had ignorable influences on the stiffness, but significantly increased the bending resistance of SUSSB-ECs.
ABSTRACT: Concrete-filled galvanized corrugated steel tubular (CFCST) columns have been proposed as new composite members to improve the corrosion resistances and reduce the anticorrosion maintenance costs of concrete-filled steel tubular (CFST) structures. In this study, the axial behaviour of CFCST columns embedded with structural steel (CFCST-S) was investigated using comparative experiments and non-linear finite element analysis accompanied by multiple monitoring and in-depth discussions. The study revealed that, even when they are not configured with transverse reinforcements, the local stability and post-peak behaviour of the CFCST-S are competitive owing to the effectiveness of the confinements provided by the thin-walled corrugated steel tube (CSP). The unique local bending effect in the CSP was verified and discussed to reveal the mechanical nature of CSP-concrete columns. Next, a theoretical model of the non-uniform stress distribution, after fully considering the bidirectional curvature of the CSP, was developed. It is found that the CSP mainly provides hoop confinements for the infilled components instead of bearing the axial load owing to its “circumferential tight effect” and “vertical offset effect”. Based on equivalent simplifications and parametric studies, the current formula to calculate the nominal hoop stress in the CSP was modified. Finally, a design method was proposed for the prediction of the axial bearing capacity of the CFCST-S.

ABSTRACT: New steel-concrete sandwich composite structure using novel enhanced C-channels (ECs) and ultra-high performance concrete (UHPC) was firstly proposed. The ECs offered strong tension separation resistance of faceplates from UHPC core as well as faceplate-UHPC interfacial shear resistance. Then, two-point loading tests on nine steel-UHPC-steel sandwich beams with ECs (SUSSB-ECs) were performed to study their ultimate strength behaviour. The studied parameters are thickness of steel faceplate, spacing of ECs, shear span, and strength of core. From the tests, though the shear span had quite significant influences on the ultimate strength of SUSSB-ECs, but all SUSSB-ECs failed in flexure mode even for the SUSSB-EC with short shear span ratio of 2.41, which confirms the bonding efficiency of ECs and high performance of this novel sandwich composite structures. The faceplate thickness exhibited significant, but the spacing of ECs has marginal influences on ultimate strength behaviour of SUSSB-ECs. Besides the tests, theoretical models were also developed to predict the initial stiffness, elastic stiffness, cracking load, yielding load, and ultimate load of the SUSSB-ECs. The validations of the predictions on stiffness and strength show that the developed theoretical models offer reasonable estimations on the stiffness and strength of SUSSB-ECs with limited errors.

ABSTRACT: The flexural behaviour of the simply supported individual curved round concrete-filled tubular flange girders (CRCFTFGs) and the corresponding curved I-girder (CIG) under concentrated load at mid-span is investigated experimentally and analytically. Two CRCFTFG specimens and one CIG specimen are considered in this study. One of the CRCFTFG specimens is designed with a pair of transverse stiffeners at mid-span. The other one has uniformly arranged seven pairs of transverse stiffeners along the girder span. These specimens are denoted as CRCFTFG-1 and CRCFTFG-2, respectively. A special rolling track device is designed to ensure that the load is in the vertical direction during the test. In the experiment, the failure mechanism of three specimens and the development of strain and displacement with the vertical load at certain critical positions are measured and analysed in detail. Experimental results show that increasing the number of transverse stiffeners can effectively avoid web distortion and enhance the load carrying capacity of CRCFTFGs. CRCFTFGs have much larger load carrying capacity and smaller lateral displacement and cross-sectional rotation than CIG. The finite element (FE) analysis is used in the numerical analysis to model the test specimens. The comparison outcome between the FE models and the experimental results indicated that they are in reasonably good agreement. A parametric study is conducted based on the validated FE models to
investigate the influence of initial geometric imperfections, web distortion, the ratio of span to curvature radius \((L/R)\) and the infilled concrete on the load carrying capacity of CRCFTFGs.


ABSTRACT: Considering the effects of cold-forming and strain hardening in the design of cold-formed stainless steel columns is an effective way to reduce construction costs. This approach has become a common trend in the revision of relevant design codes. A few studies were conducted in the past on two key aspects: (i) predicting the enhanced material properties in cold-formed stainless steel cross-sections and (ii) modifying the design methods to adapt to stainless steel material characteristics. However, in the existing literature, they had been separately studied, and integration of these two aspects to form a complete design method was rarely reported. In this study, a series of column tests were conducted on 19 stub and 32 long columns in rectangular hollow sections. The measured imperfections, material properties, load-displacement curves, and failure modes were reported. A new design method for columns was developed, which could clearly and accurately determine the column capacity over the space encompassed by member slenderness and cross-sectional slenderness values. The proposed design method and the method laid out in the *Design Manual for Structural Stainless Steel* were evaluated against the test data. It was demonstrated that the two design methods were both very conservative in predicting the column capacity when material properties in the annealed condition were used. However, their performances improved when the predicted enhanced material properties were used. Generally, the predictions of the proposed design method matched the test data better. Furthermore, a reliability analysis was conducted, and resistance factors were recommended for the corresponding design methods.


ABSTRACT: This paper focuses on the study of the influence of indentation parameters on the ultimate strength and behavior of the damaged panels for two types of stiffeners, through an experimental-numerical correlation and a parametric study. Experiments were performed using stiffened panels in small-scale models, with stiffener type T and flat-bar, representing typical full-scale bottom and deck panels of a ship, respectively. A series of indentation tests have been carried out in the plate-stiffener intersection of the small-scale models, where the indentation force and displacement pattern are analyzed for each type of stiffener. After indentation, the panel model is submitted to an uniaxial compression test, in order to measure the loss of ultimate strength of the damaged panel in relation to the intact one. Numerical simulations of the ultimate strength behavior for the small-scale panels are performed by a finite element program for both indentation and panel collapse. The results from the numerical-experimental correlation study presented a good agreement. Therefore, a parametric study is performed to analyze the indentation parameters, such as, the dent depth, indenter size, indentation location and the stiffener column slenderness. The research work contributes to a better understanding of the damaged panel behavior in order to define more robust safe design bases, as well as, to support decision on repair procedures.


ABSTRACT: A fiber-reinforced polymer (FRP)-steel composite tubed concrete (F-STC) column is formed by wrapping FRP sheets around a steel tubed concrete column (STC). Both the strength and deformability of the core concrete are improved by the FRP-steel composite tube and the steel tube is prevented from corrosion. A number of studies have been conducted on the prediction of stress-strain behavior of FRP-confined concrete columns and steel tube-confined concrete columns. However, few models focus on the concrete under combined confinement of FRP and steel tube. This paper presents an analytical study on the design-oriented model for F-STC columns. To determine the confining stress, the stress distribution of steel tube was firstly analyzed and the equivalent stress was obtained. In addition, a strain efficiency factor was proposed for the prediction of rupture strain of FRP. Then the peak condition and ultimate condition of F-STC columns were investigated and related predicting models for the load bearing capacity and deformation were proposed.
Finally, design-oriented models were proposed for F-STC columns with different types of axial load-strain curves and generally coincided well with the existing test results.


ABSTRACT: This paper presents a life-cycle based finite element analysis modelling for concrete-filled steel tubular (CFST) stub columns. The effects of initial imperfections (e.g., residual stresses induced by cold forming or welding, and initial geometric imperfections), preloads during the construction process, long-term sustained loads and corrosion are considered in the modelling. To reveal the life-cycle time-dependent behaviour of CFST stub columns, influences of the above factors on the full-range load-displacement relations and the load-transfer mechanism are discussed in regard of five typical working conditions as: Case 0 - short-term loading; Case 1 - initial imperfection with short-term loading; Case 2 - initial imperfection, short-term loading followed by sustained load; Case 3 - initial imperfection, short-term loading followed by sustained load and corrosion; as well as Case 4 - initial imperfection, preload, short-term loading, sustained load and corrosion. Considering the effects of these factors, definition of the ultimate state of CFST stub columns under typical working conditions are discussed. Parametric studies are then carried out to calibrate the simplified design models for CFST stub columns at different loading cases. A database with information of 1096 CFST stub column specimens are established. Reliability analysis proves that the proposed simplified design methods meet the reliability requirements in accordance with current design standards for CFST members under the five discussed cases. Partial factor for axial compressive strength of the composite section is suggested at the end of this paper.


ABSTRACT: This paper investigates the behavior of circular CFRP-steel composite tubed steel-reinforced high-strength concrete columns under eccentric compression. The failure modes and load versus mid-span lateral displacement curves were analyzed comprehensively for the specimens with different test parameters. The experimental results show that the different continuities of the external steel tube has a great impact on failure patterns. The crushing of concrete and bulging of the steel tube in the compression side occurred near the 1/4 height of the specimens with grooves at 25 mm away from the end plates on the external tube, while, for the specimens with no gaps on the steel tube, local buckling was observed around the mid-height of the columns. However, the extent of bulging can be significantly alleviated with the increase of CFRP layers. Finite element (FE) analysis was conducted by using ABAQUS software in this study and the results show that good agreement can be achieved between the test observations and FE results. Based on the valid FE model, the parametric analysis was performed and a new model was proposed to predict the axial-flexural interaction behavior of the composite columns. It is evident that the theoretical predictions agree well with the FE results of the specimens in this paper with a certain safety margin (approximately 15%), which may provide a valuable guideline for the engineering design of CFRP-steel composite tubed steel-reinforced high-strength concrete columns.


ABSTRACT: This paper describes a test campaign concerning the behaviour and strength of cold-formed steel (CFS) lipped channel (LC) beams experiencing local-distortional (L-D) interaction made of G450-G500 high-strength steel grades. This investigation involves the performance of 20 tests on simply supported beams arranged in a “back-to-back” configuration, subjected to four-point major-axis bending and laterally restrained at the loading points. All tested specimens failed in the expected L-D interactive modes and exhibited critical distortional-to-local buckling moment ratios ranging between 1.09 and 1.46 (i.e., prone to “true L-D interaction”). The experimental results obtained and reported consist of beam (i) moment-displacement equilibrium paths, (ii) photos evidencing the evolution of the beam deformed configurations along those equilibrium paths (including the failure modes) and (iii) failure moments - it is found that these results are in
good agreement with recently performed numerical simulations. Finally, the experimental failure moments obtained are compared with their estimates provided by the (i) currently codified Direct Strength Method (DSM) strength curves associated with local and distortional failures, and (ii) other available DSM-based design approaches developed to handle L-D interactive failures. This comparison provides solid evidence that the CFS specifications must include a DSM-based design approach able to handle beam L-D interactive failures - the current L and D design curves clearly overestimate all the experimental failure moments.


ABSTRACT: The lateral torsional buckling behaviour and design of steel beams in fire are investigated in this paper. Finite element models able to replicate the lateral-torsional buckling (LTB) response of steel beams at elevated temperatures are developed and validated. The validated finite element models are used to carry out extensive parametric studies to explore the LTB behaviour of steel beams in fire, considering various cross-section shapes, member slendernesses, steel grades, elevated temperature levels and different fabrication processes. A design equation for the LTB assessment of steel beams at elevated temperatures is developed on the basis of the results from the extensive parametric studies. The high accuracy, safety and reliability of the proposed design approach are illustrated, which is also compared against the beam design rules existing in the European structural steel fire design standard EN 1993-1-2. The design proposals made in this paper are compatible with the new LTB assessment equations that are due to be incorporated into the next version of the European room temperature structural steel design standard EN 1993-1-1 and lead to more accurate ultimate strength predictions relative to the beam buckling design equations existing in EN 1993-1-2.


ABSTRACT: The confinement effect of external and internal steel tubes on sandwiched concrete in concrete-filled double-skin circular steel tubular (CFDST) short columns has a significant impact on the compressive strength and ductility of columns. Limited researches on CFDST columns have only considered the influences of a part of column parameters on the confinement effect, leading to the absence of appropriate compressive strength formulas in international standards. To comprehend the compressive behavior of circular CFDST short columns and suitably evaluate their compressive strength for practical engineering design, it is necessary to further launch the experiments on circular CFDST short columns and develop a suitable estimated formula for their compressive strength. The purpose of this paper is to develop a simple and accurate formula for predicting the compressive strength of axially loaded CFDST short circular columns with a wide range of parameters. A total of 24 specimens with outer and inner circular carbon steel tubes that withstand axial compression were tested. A new confinement coefficient reflecting the confinement effect of concrete strength in CFDST columns was proposed on the basis of the test data in the present paper and data collected from literature. Utilizing the proposed confinement coefficient, a novel strength design formula was developed to estimate the compressive strength of CFDST short circular columns. It shows that the proposed confinement coefficient can reasonably reflect the interaction effect between the sandwiched concrete and steel tubes, and the formula suggested in this paper offers better predictions of the compressive strength than current design formulas.


ABSTRACT: This paper presents an experimental investigation on the behavior of stiffened octagonal concrete-filled double-skin tube (CFDST) stub columns subjected to axial compression. A total of eight specimens were prepared and tested under axial compression aiming to study the effects of longitudinal stiffeners and hollow ratio on the elastic-plastic local buckling and ultimate load-carrying capacity of the test columns. The specimens consist of two control specimens without stiffeners (unstiffened columns) and two specimens stiffened with outer-inner tubes welded stiffeners (O-I stiffeners) in four sides of the octagonal steel section. In addition, four specimens were stiffened with two types of stiffeners: O-I stiffeners and outer tube welded stiffeners (O stiffeners) in eight sides of the outer steel tube section. Furthermore, two hollow ratios
were employed. Based on the test results, the ultimate load-carrying capacity, load-displacement curves, load-strain response, ductility, and failure modes were discussed and clarified. The test results indicated that the strength and ductility of the specimens were improved greatly by the presence of the stiffeners. The stiffeners significantly enhanced the confinement and prevented the occurrence of elastic-plastic local buckling of the outer tube. Besides, current design equations were used to predict the ultimate load-carrying capacity of octagonal CFDST stub columns. The test results were then compared with the predicted ultimate capacities of existing design equations. These predictions showed good agreement with the test results.


ABSTRACT: The use of sheathing material as a structural component in the Cold-formed steel (CFS) construction holds great potential for stability of the structure and savings in the construction cost. However, there is no robust design method to account the structural contribution of sheathing boards. This paper presents the experimental results of 107 (including unsheathed and sheathed) CFS wall frame studs subjected to out-of-plane loading to study the feasibility of using gypsum board as a structural bracing sheathing material. The test parameters include various shapes and slendernesses of the CFS frame stud, thickness of the sheathing board and spacing between the sheathing bracing connections. The out-of-plane loading is applied as it causes lateral torsional buckling in the CFS structural members thereby creates pull-through failure at the sheathing bracing connections. Moreover, the suitability of the current AISI and Eurocode specification for the design of sheathing braced CFS structural member is studied. The experimental results indicate that the lateral buckling of the symmetric shaped (against the loading axis) CFS wall frame studs can be inhibited by gypsum sheathing. Whereas most of the singly symmetric and point symmetric CFS studs exhibit lateral torsional buckling and biaxial bending, respectively, due to the inadequate bracing effect of gypsum sheathing resulting in pull-through failure at the sheathing bracing connections. Therefore, a set of limitations for the use of gypsum sheathing as a structural bracing is suggested in the form of a generalized design parameter. Finally, the experimental results indicates that the design strength of the CFS wall frame stud can be increased in the range of 39% to 595% based on the shape and slenderness.


ABSTRACT: The phenomenon of dynamic instability of steel beams under harmonic axial loading is analysed, in particular to identify those elements in equilibrium under static axial loads, i.e. loaded below the Euler load, but that could fail under dynamic conditions, possibly compromising the entire structural stability. In the literature, the general problem of dynamic instability was comprehensively presented by Bolotin, who defined instability regions. Bolotin's method was extended herein through failure at the sheathing bracing connections. Therefore, a set of limitations for the use of gypsum sheathing as a structural bracing is suggested in the form of a generalized design parameter. Finally, the experimental results indicates that the design strength of the CFS wall frame stud can be increased in the range of 39% to 595% based on the shape and slenderness.


ABSTRACT: Using the partially encased composite (PEC) columns is an efficient method for improving the behaviour of steel plate shear wall. The PEC column composed of H-shape steel column, links connecting the
flanges and concrete partially encased in the steel H-section. This paper reports an experimental study on the seismic behavior of the steel plate shear walls (SPSWs) with PEC columns under cyclic lateral loading. Two 1/3-scale single-bay, two-story specimens were constructed. The C-shape links and X-shape links with the inclined angle of 0° and 45° were adopted for the PEC columns of these two specimens respectively and constructed with similar steel consumption. The tests results show that the initial stiffness, maximum energy dissipation and ductility coefficient of the specimen with PEC column reinforced by X-shape links were respectively 35.78%, 13.60% and 15.20% higher than the one constructed by C-shape links. However, the bearing capacity of the two specimens was basically the same. Besides, parametric studies were conducted through numerical simulation so that the contribution of links and concrete can be evaluated. As a result, the concrete in the PEC column can help improve initial stiffness, bearing capacity and ductility of SPSW structure. The effect of links on improving the bearing capacity of SPSW with PEC column is not significant. However, X-shape links are more effective than C-shape links in improving the bending-resistance capacity of the frame columns in SPSW structure and also help prevent the SPSW structure from forming spreaded fracture of outer flange at the column bottom. In general, the PEC columns with X-shape and C-shape links have different seismic behaviors and deserve further study.


ABSTRACT: This paper investigates the axial force-moment (N-M) interaction behaviour of high strength concrete encased steel (CES) composite columns. A numerical method is developed to simulate the nonlinear inelastic behaviour of CES composite beam-columns, which includes concrete cover spalling, concrete confinement effect, buckling of longitudinal reinforcing bars, and stain-hardening of the encased steel section. The numerical model is implemented in a self-developed computer program to generate the load-deflection response, moment-curvature relation, as well as the N-M strength interaction diagrams. The accuracy of the proposed analysis method is validated by comparison with the experimental results report in the companion paper and the test data available in literatures. To further understand the resistance of CES columns consisting of high strength concrete and high strength steel, parametric study is performed to evaluate the effect of concrete compressive strength, steel yield strength, load eccentricity, as well as steel area ratio. Finally, a simplified method is proposed to construct the N-M strength interaction curve of CES composite columns. The proposed method can be used to design CES beam columns for concrete grade up to C100 and steel grade up to S960.


ABSTRACT: This paper evaluates the axial compressive behaviour of concrete stub columns confined by steel tubes (CSC-CSTs) at low temperatures of 30 ~ −80 °C relevant to cold regions. Experiments including ten circular and ten square CSC-CSTs subjected to axial compression at four low temperatures were carried out. The studied parameters included low temperature (T), different grades of NWC (f), wall-thickness of the steel tube (t), and height of the CSC-CSTs (L). The test results revealed that bulge of steel tubes, concrete crushing, and vertical fracture in steel tube (only in square CSC-CSTs) occurred to CSC-CSTs. The load-shortening (P-S) behaviour of CSC-CSTs exhibits similar manner in the first elastic and nonlinear working stage, but varies at their recession stages due to different confinement ratio by steel tube. Low temperatures improved axial compressive behaviours of CSC-CSTs. Increasing concrete strength improved the compressive strength of CSC-CSTs at low temperatures, but reduced their ductility. Thicker steel tube improved the P-S behaviour of CSCCSTs at low temperatures whilst the height of CSC- CSTs exhibited marginal influences on their low-temperature compressive behaviours. Theoretical models were developed to estimate P-S behaviours of CSC-CSTs, and validations against 20 test results confirmed their accuracy.
ABSTRACT: A finite element (FE) investigation into the compressive behaviour of concrete-filled double skin tubular (CFDST) cross-sections with lean duplex and ferritic stainless steel outer tubes is presented. FE models were initially developed and validated against available test results reported in the literature. Upon successful replication of the ultimate capacities, load–deformation histories and failure modes exhibited by the tested CFDST stub columns, a parametric study was undertaken to investigate the influence of key variables, including the local slendernesses of the outer and inner tubes, the concrete strength and the adopted grade of stainless steel, on the ultimate response of the studied CFDST stub columns. Based on the generated FE data pool and the available test results, the applicability of the existing European, Australian and American design provisions for composite carbon steel members to the design of the studied CFDST cross-sections was evaluated. All the examined design rules are shown to yield unduly conservative (less so for the higher concrete grades) and rather scattered capacity predictions. Modifications to the design treatment in relation to the effective area of the outer tubes, to take due account of outward-only local buckling, and the effective compressive strength of the infilled concrete, to reflect the reduced relative effectiveness of higher concrete grades, are considered. The modified design rules are shown to improve the accuracy and consistency of the design capacity predictions. Finally, statistical analyses were carried out to demonstrate the reliability of the modified design approaches.

ABSTRACT: Concrete-filled round-ended (CFRE) steel tubes are widely used in civil infrastructures. Accurate and reliable numerical models of CFRE steel tube are significantly important to mimic the actual behavior. This study presents a fiber beam-column model to simulate nonlinear behavior of CFRE steel tubes. A group of uniaxial hysteretic constitutive models was defined for the properties of the material. To verify the reliability of the presented fiber model, a large number of numerical computations have been performed by the fiber model and a traditional refined finite element model. The results confirm that the proposed fiber model can accurately predict the nonlinear behavior of CFRE steel tubes. Finally, two empirical models for the prediction of the axial bearing capacity of CFRE steel tube columns were developed.

ABSTRACT: To improve the behaviour of conventional L-shaped concrete-filled steel tubular (CFST) columns, experiments and numerical modelling of composite L-shaped CFST columns with inner I-shaped steel under axial compression were conducted. Experiments of thirty-two specimens, including 16 short columns and 16 middle long columns, were carried out with various steel tube confinement index (θ), built-in steel ratio (ρ) and slenderness ratio (λ). The load-average longitudinal strain curves, load-deflection curves and bearing capacity of the specimens were also investigated. The experimental results demonstrate that those specimens with higher values of θ and ρ, and lower value of λ, have higher ultimate bearing capacity. When the height of column remains constant, the strength and ductility can be improved by increasing θ and ρ. With the increase of λ, the local buckling failure is gradually transformed into a combination of local buckling and global buckling. A finite element analysis (FEA) model was developed to investigate the performance of composite L-shaped CFST columns with inner I-shaped steel under axial compression, and the feasibility of the FEA model was verified by the comparison against experiment results. Finally, the formulas were also proposed to estimate the ultimate bearing capacity of short and middle long composite columns and the estimated results match well with the experimental results.

ABSTRACT: In this paper, a high-strength steel framed-tube structure with replaceable shear links (HSS-FTS-RSL) was proposed to improve the seismic performance and recoverability of steel framed-tube structures (SFTS), by introducing the shear link—acting as a sacrificial component—at the mid-span of a deep beam in order to sustain inelastic deformation and dissipate seismic energy. The preliminary design methodologies for the HSS-FTS-RSL and layout principles of the replaceable link were introduced. Six prototype 30-story HSS-FTS-RSL buildings with various layouts of the links and a corresponding conventional SFTS building were designed based on the latest design standards, and their nonlinear numerical models were developed in OpenSees. The modeling approach was verified on experimental data. Nonlinear dynamic analyses were conducted to investigate the feasibility and seismic behavior of HSS-FTS-RSLs. The results indicate that the HSS-FTS-RSL exhibited a superior energy dissipation capacity and lower permanent drifts compared with the conventional SFTS under severe ground motions. In the HSS-FTS-RSL, employing the shear link did not increase the shear lag effect compared with the SFTS. The HSS-FTS-RSLs with various layouts of replaceable links had almost identical fundamental natural periods, but the layout of the replaceable link had a significant effect on their seismic behavior. The inelastic deformation of HSS-FTS-RSL was concentrated in the shear links, whereas deep beams and columns experienced minor or no damage. Therefore, it can be concluded that the HSS-FTS-RSL was a reliable earthquake-resilient structural system that can be quickly recovered by replacing the damaged links after a major earthquake.


ABSTRACT: This study aims to assess the seismic performance of buckling restrained braced frames (BRBFs) using a probabilistic approach and develop multi-level response modification factors for performance-based design of these systems. Unlike traditional seismic design methods, the proposed response modification factors can take into account the seismic conditions of the site as well as the target design performance level. An engineering damage parameter (EDP-Based) is adopted for reliability analysis of 4, 8 and 12 storey BRBFs using systems of parallel and serial components. In general, the results demonstrate the high seismic reliability of BRBFs for high levels of earthquake intensity. Considering the axial strain of the brace core as the local damage index, it is shown that the studied models remain in performance levels higher than life safety under the design hazard level (return period of 475 years). The upper bond response modification factor for the life safety and collapse prevention performance levels is estimated to be around 8.4 and 10.0 with the corresponding intensities of 0.68 and 0.85, respectively. Based on the outcomes of this study, in general, using a response modification factor between 4 and 8 for seismic design of BRBFs would guaranty their adequate performance under both the design basis and maximum considered earthquake levels.


ABSTRACT: Steel plates have great potential in being used as main structural members in single-layer reticulated shells (SLRS). The main advantages of steel plates include high-precision and flexible outline shape fabrication as well as convenient transportation and storage, which make them suitable for curved surface structures. To improve the buckling resistance of plate members, two strengthening methods, i.e., double-limb method and sub-unit method, are introduced. In this study, the stability behavior of a 3.27 m × 3.27 m spherical SLRSs strengthened by using the proposed methods is comprehensively investigated via an experimental test and a finite element (FE) simulation. Specifically, the equivalent FE models for double-limb plate members and semi-rigid joints are proposed. The comparison results indicate that the presented FE model is effective for predicting the development of member stress and the structural ultimate load. Then parametric analysis is conducted, which reveals the effects of the sub-units, the bending stiffness of the joints and the
geometric imperfection on the structural stability. The results obtained in this study may provide guidance for the design and analysis of this type of structure.


ABSTRACT: Torsional and flexural-torsional buckling of compressed steel members are relevant phenomena for monosymmetric and built-up cross-sections frequently employed in bracing systems or in truss structures. Despite the great interest shown by researchers relative to the instability of steel elements in fire, there is a lack of studies on the torsional and flexural-torsional buckling behaviour of steel members in compression at elevated temperature, and no provisions are given in EN 1993-1-2. In this work, a comprehensive numerical investigation of the behaviour of axially compressed angles, Tee and cruciform steel cross-sections at elevated temperature was performed. In this respect, a parametric study was carried out on Class 1 to 3 profiles subjected to uniform temperature distribution. It was found that the buckling curve given in EN 1993-1-2 provides unconservative results for slenderness ranges of practical interest. Improved buckling curves to better predict the behaviour of angles, Tee and cruciform compressed cross-sections at elevated temperature were proposed.


ABSTRACT: Experimental and numerical studies on the fire resistance of cold-formed steel (CFS) columns with built-up box-shape sections were conducted in this paper. A series of coupon tensile tests were also performed before the fire resistance tests of the columns to obtain the stress–strain relationship of the steel plate from 20 °C to 800 °C. As a benchmark, the load-bearing capacity tests of the columns at ambient temperature were conducted first, and then the fire resistance tests were performed for eight specimens considering different load ratios and axial restraining stiffness. Afterward, numerical models, including heat transfer and structural analyses, were developed to reproduce the fire-resistance behavior of the columns and verified via test results. Finally, parametric analyses were performed to investigate the influence of load ratio, axial restraint, and rotational restraint on the fire-resistance behavior of the columns. Results indicated that the primary failure mode of the specimens was a combination of local and global flexural buckling, which was sensitive to the longitudinally non-uniform temperature field. Moreover, the increase in load ratio and axial restraining stiffness led to a significant decrease in the critical temperature and failure time. Moreover, even a low level of rotational restraint could enhance the fire-resistance behavior of the column.


ABSTRACT: This paper aims to investigate different combinations of Bolted Extended End-Plate (BEEP) beam-to-column connections where the column sections are of the built-up box type. Therefore, some allowable combinations of beam-to-column subassemblies were chosen according to the AISC provisions, such as Strong Column-Weak Beam. Since the prequalified BEEP connections are generally attached to wide-flange column sections, there will be some complexities in the erection and bolts fastening processes involved where built-up box columns are used. One of these complexities is the closed inner space of such columns. Thus, a novel connection configuration is proposed to overcome these complexities. Hence, a number of 28 different connection subassemblies were modeled in ABAQUS finite element analysis software and tested under the connection qualification cyclic loading conditions. Hence, after verifying the numerical modeling's acceptable accuracy with two experimental models, the main proposed models were investigated, and their responses were evaluated. The results of this study indicate that this new proposed connection can satisfy the connection qualification criteria. However, further experimental studies are needed to be conducted to approve the practical use of this proposed connection.

ABSTRACT: A novel dual lateral force resisting system consisting of low-yield point steel plate shear walls with diagonal T-shaped-stiffener (LPSW-DTS) was proposed as a promising alternative to improve the buckling stability, seismic behavior, and serviceability of SPSWs. The influence of several key factors on the cyclic performance, failure behavior, and plate–frame interaction characteristics was evaluated using numerical investigations. The optimum configuration of stiffeners was determined to achieve a material-efficient design. The critical values of the column flexibility coefficient were determined to ensure sufficient development of the tension fields inside the infill panel. Finally, the contribution of the boundary frame was quantified by establishing an equation for predicting the proportional shear resistance of the infill panels. The analytical results demonstrated that the hysteretic curves, shear capacity, and energy dissipation of all the overall structure, infill panel, and boundary frame enhanced as the flexural stiffness ratios of the stiffeners increased, demonstrating that the DTS significantly improved both the cyclic performance of LPSW structures and the plate-frame interaction. In addition, the plates of the stiffeners did not experience adverse local instability, indicating the advantages of the T-shaped stiffeners. However, once the flexural stiffness ratio of the stiffeners was sufficiently large, an additional increase in the degree of stiffening had only minor positive effects on the shear capacity and energy dissipation performance. A larger flexural stiffness ratio was required for larger width-to-height ratios, height-to-thickness ratios, or column flexibility coefficients to obtain the expected failure modes and achieve satisfactory shear capacity efficiency and energy dissipation efficiency.


ABSTRACT: This paper describes an experimental and numerical investigation to study the flexural capacity of back-to-back gapped built-up cold-formed steel (CFS) channel sections under four-point bending. The gap between the back-to-back channels was formed through intermediate link-channels which were screwed to the webs of the back-to-back channels. A total of 90 results comprising 18 laboratory tests and 72 finite element (FE) analysis results are reported on the flexural capacity of back-to-back gapped built-up CFS channel sections under four-point bending. Three different types of channels were considered to form the built-up channels: plain channels, channels with one web stiffener and channels with two web stiffeners. Two different beam spans as 1000 mm and 2000 mm were tested. Initial geometric imperfections were also measured prior to bending tests for all test specimens. A nonlinear FE model was then developed, the results of which showed good agreement against the laboratory test results. Using the validated FE model, an extensive parametric study was conducted to investigate the effects of web stiffeners and link-channel spacing on the flexural capacity of such gapped built-up beams. It is shown that design in accordance with the American Iron and Steel Institute, AISI (2016) and Australia/New-Zealand standards, AS/NZS (2018) can be conservative by as much as 27%. The flexural capacity of back-to-back gapped built-up sections with two web stiffeners was increased by 10% on average, when compared to the capacity of gapped built-up beams with plain channel sections.


ABSTRACT: Compared to normal strength steel (NSS), high strength steel (HSS) has many advantages, such as high yield strength, high tensile strength, and high structural reliability. Recently, HSS beams have gradually been employed in practical engineering. In this investigation, eight tests and parametric analyses were carried out to study the lateral torsional buckling (LTB) behavior and capacity of welded Q460 beams. An effective loading system that released the lateral constraint of the loading point was developed. Totally eight tests of welded beams with lateral restraints at two end supports were conducted under a mid-span concentrated force. Among these eight welded beams, one Q235 beam was tested to compare with seven Q460 beams. The flange width-to-thickness ratio changed from 4.6 to 9.6, the web height-to-thickness ratio changed from 28.75 to 47.50, and the beam span was varied from 3 m to 5 m. In addition, a series of parametric analyses considering
initial geometric imperfections were performed to evaluate and investigate the effects of key parameters on the LTB behavior of welded Q460 beams. The experimental and numerical results were compared with the LTB curves from Chinese design codes GB50017-2017 and GB50017-201X, Australian code AS4100, and Eurocode 3. The GB50017-201X, AS4100, and Eurocode 3 for general sections underestimate their LTB capacity. The current GB50017-2017 and Eurocode 3 for rolled and equivalent welded sections are unsafe for evaluating the LTB capacity of HSS beams. Modified design equations that are more appropriate for predicting the LTB capacity of welded Q460 beams are presented.


ABSTRACT: Previously, a series of studies focusing on the response of the oval-ended elliptical concrete-filled steel tubular (OECFT) columns under various single load conditions were performed due to its novel superiorities in flow smoothness, architectural aesthetics and structural efficiency. Nonetheless, the properties of the OECFT column imposed with combined forces have never been addressed. In attempt to fill this gap, this paper aims to present a numerical analysis via ABAQUS solver to explore the torsional behaviour of the axially-loaded OECFT column. Following that, the finite element (FE) modelling was verified by the existing experimental data, and then the comprehensive parametric research on the type of column was conducted. Detailed responses of the OECFT column subjected to combined axial compression-torsion, in aspect of the typical torque ratio (T/T) – angle (θ) curve, failure patterns, contact action and characteristic relationship of relative ultimate torque value (T/Te) versus axial compression ratio (N/Nc), were respectively investigated. The numerical simulation revealed that the torsional resistance of the type of column increased with the increase of the steel strength, concrete strength and steel ratio, while a decrease was obtained with the increase of the aspect ratio. Accompanied by the changes in axial compression ratio, material strength and steel ratio, obvious influences on the T/Te-N/Nc curve were obtained. Finally, a design provision to assess the torsional strength of the OECFT column under combined axial compression-torsion was proposed and was validated in compliance with the aforementioned analyses.


ABSTRACT: More people are living near the polar regions due to the availability of land and emerging job opportunities in these regions. This has led to increased construction activities in these sub-zero temperature regions for which a suitable cost-effective construction material is needed. Although cold-formed steel (CFS) consists of many good features that are required for cold region construction, the knowledge of the structural behaviour and capacity of CFS members at sub-zero temperatures is limited. In this research, low and high strength CFS lipped channel columns subject to local buckling and yielding failures were tested in the temperature range of +20 to −70 °C to understand their behaviour and determine their sub-zero temperature compression capacities. Tests showed that there were no premature failures caused by brittle fracture, even after significant localised deformations during the post-ultimate phase. In all cases the ultimate capacity increased considerably even at temperatures below −50 °C, especially for low strength steel columns. Finite element models were also developed to simulate the local buckling and yielding failures of tested columns, and the models were validated using the test results. The ambient temperature design methods given in the cold-formed steel standards such as AS/NZS 4600 were shown to be adequate to determine the sub-zero temperature compression capacities of CFS columns when sub-zero temperature mechanical properties are used instead of ambient temperature mechanical properties.


ABSTRACT: Cold-formed ultra-thin-walled steel shear wall shows excellent performance. The house constructed using the cold-formed ultra-steel shear wall is composed of continuous single-layer walls, including the floor joints between wall segments. The wall is coordinated to deform through floor joints and the weak part
is located at the floor joints. In this paper the test results of nine TCS walls (upper and lower adjacent composite cold-formed ultra-thin-walled steel shear interior wall including floor joints) are reported. The effects of different factors, including axial compression, section height of stud, type of anchor bolt, under cyclic loading on the shear performance of TCS walls are discussed. The results show that, the existence of the axial compression accelerates the screw failure, resulting in reduced bearing capacity. The section height of the wall stud and axial compression of the wall have greater effect on the bearing capacity of TCS wall. Engineers should pay more attention to the influence of wall axial compression. TCS wall experiences progressive damage of multiple components. The degradation of the bearing capacity and stiffness are relatively slow. Cumulative damage is the reason why the TCS wall could not continue to carry loading. For TCS wall with the two nuts on one anchor bolt, screws bear tension-shear action after anchor bolt tilts, and thus the screws and the anchor bolt fail rapidly. After the addition of spatial steel bar truss at the floor joints, the screws only bear the shear force, which improves the wall resistance to damage.


ABSTRACT: Tapered members produced by robotic fabrication techniques offer architectural and structural advantages and have the potential to become more prevalent than prismatic members. However, the conventional analysis and design methods based on simplified assumptions such as equivalent stiffness cannot be used to accurately evaluate a member's performance. To provide a reliable and practicable stability design method, a direct analysis method of tapered I sections is proposed. A mixed-field tapered beam-column element is derived for use within the modeling of structural frames. The effects of initial geometric imperfection and additional shear stress are directly considered in the element formulation. A polynomial describing the member's critical initial out-of-plumbness is adopted, and an arbitrarily located internal hinge is incorporated in the element to enhance the element's deformation capacity and capture the behaviors of the most critical section. Displacement and force interpolation matrices incorporating the shear deformation are utilized, and the Gauss quadrature method is employed to evaluate the element stiffness matrix. Finally, verification examples demonstrate that the proposed method can be used to accurately and efficiently evaluate the performance of tapered members, indicating that the element can be conveniently employed in member and frame analysis and design.


ABSTRACT: The use of cold-formed steel (CFS) channels with web holes are becoming increasingly popular. Such holes, however, result in sections becoming more susceptible to lower axial compressive resistance. Traditional holes are normally punched at the web and un-stiffened. Recently, a new generation of CFS channels with edge-stiffened holes has been developed by the CFS industry but no information is available in the literature to accurately predict the axial capacity of such sections. The current design guidelines in accordance with the American Iron and Steel Institute (AISI 2016) and Australia New Zealand standards (AS/NZ 4600:2018) do not provide any design rules for CFS channels with edge-stiffened holes. In this paper, a numerical model that accurately simulated results from the experimental testing of CFS channels with edge-stiffened holes under axial compression as published in a previous paper by the authors was employed to carry out a parametric study which involved 348 finite element (FE) models. Variables which were examined included column slenderness, stiffener length, fillet radius, hole size, hole location and hole spacing. A comparison of the numerical results with current design rules for CFS channels with un-stiffened holes revealed that the design equations were not accurate for such sections; design equations are therefore proposed in which an enhancement factor is applied to the original equations. The enhancement factor was obtained using bivariate linear regression analysis. The proposed design equations closely predict the enhanced axial capacity of CFS channels with edge-stiffened holes.
ABSTRACT: Relevant studies into the high load-bearing capacity steel plate shear wall used in the high-rise building are insufficient, especially for steel plate shear walls whose yield load exceeds 3000kN. This paper developed a kind of high load-bearing capacity steel plate shear wall with yield load no less than 3000kN to be applied in the frame-steel plate shear wall structural system which has been utilized in the design and construction of high-rise buildings in China. Low-Yield-Point (LYP) steel was adopted as the shear web plate of the steel plate shear wall. A total of two specimens with same geometric configuration but different loading procedures were designed and tested under the cyclic loading. The stiffness degradation, ductility and energy dissipation characteristics of the LYP steel plate shear wall (LSPSW) were investigated. Furthermore, comparative studies of the cyclic test and FEM analysis were carried out to verify the accuracy of the FE model of the LSPSW and conduct geometrical configuration optimization in the future. The test results indicate that the newly-developed LSPSW has superior ductility and energy dissipation capacity, which confirm that it can be used as an effective lateral force resisting structure system in the future. The yield load and ultimate load of the LSPSW obtained through cyclic tests exceed 3000kN and 5000kN, respectively, which meets the initial design expectation. In addition, numerical analysis results agree well with the test results.

ABSTRACT: Thin-walled steel tube confined reinforced concrete columns are new-type composite members and the static and seismic performance of these columns have been extensively investigated in recent decades. There are, however, very limited studies on the fire behaviour of the steel tube confined reinforced concrete stub columns subjected to axial compression. In this paper, experimental and numerical studies on the fire response of steel tube confined reinforced concrete stub columns under axial compression are presented. A total of eight specimens with varying wall thicknesses of steel tube and load ratios were tested to failure under the ISO-834 standard fire. Temperature distribution, axial deformation, failure modes, and fire duration were recorded in the fire tests. Finite element (FE) models were established using ABAQUS to estimate the fire behaviour and the models were validated by comparing with the measured results. Parametric studies were then performed on the fire resistance of thin-walled steel tube confined reinforced concrete stub columns and the considered parameters include diameter of steel tube, wall thickness of steel tube, load ratio, reinforcement ratio, material strength, and concrete cover thickness. The studies show that the load ratio and diameter of steel tube are two key factors governing fire resistance of thin-walled steel tube confined reinforced concrete stub columns. Based on test and numerical results, a design approach was proposed to predict the temperature distribution and loading capacity of thin-walled steel tube confined reinforced concrete stub columns under ISO-834 standard fire.

ABSTRACT: Owing to a high plastic deformation capacity, low-yield-strength steel (LYS) shear panel dampers have been widely used in structural seismic engineering. Meanwhile, there is still no effective method to evaluate the shear buckling capacity of LYS shear panel dampers under plastic deformation. Thin-walled cylinders approximated as shear panels are adopted to experimentally analyse the plastic buckling. The effects of the shape aspect ratio and the width-to-thickness ratio on the deformation capacity are discussed. The buckling behaviour is directly judged and analysed by measuring the out-of-plane deformation of the specimens. By analysing different plastic modulus during buckling, it is found that the critical plastic buckling stress can only be predicted accurately when the variable deformation theory incorporated with the stable plastic
deformation is adopted. The critical buckling strain of the LYS can be evaluated by the width-to-thickness ratio solely. This study will be of significant value in the analysis of the buckling capacity of LYS in the plastic-deformation range.


**ABSTRACT:** Steel-concrete composite beams, when requested by negative moment, can fail due to Lateral Distortional Buckling (LDB), local buckling, or by the combination of these stability modes. LDB is a mode of stability in which the web must distort in order for the compression flange to displace and twist during buckling. The standard procedures that address this phenomenon use the conventional lateral-torsional buckling theories for the buckling of partially restrained beams or the U-frame model. This study investigates, through the development of refined physical and geometrical nonlinear numerical analyzes with the ABAQUS software, the strength of steel-concrete composite beams under the action of negative moment. The influences of several parameters are analyzed, such as: steel profile cross section, longitudinal reinforcement rate, unrestrained length, presence of the web stiffeners and the distribution of negative moment along the span. The results are compared with standard procedures and analytical methods. It can be concluded that the cross section and the presence of web stiffeners are the parameters that most influence the LDB strength. Regarding the standard procedures, it was found that both those who adopt the conventional lateral-torsional buckling theories and those who use the U-frame model provide conservative results. Therefore, further investigations are necessary to better understand the behavior of these elements under the action of negative moment.


**ABSTRACT:** In the last two decades, civil construction has used steel elements to compose the structural framework. The use of composite elements of steel and concrete in multi-storey buildings has been gaining market share in several countries, mainly due to the possibility of reducing the height of the building, the structure's own weight and the speed of execution. In the early 1990s, due to the development of automated cutting and welding, beams with sequential web openings started to be manufactured. There are many challenges for multi-storey buildings design engineers, such as the height limitations that are stipulated by zoning, and the need to match the height of the floors. In this context, the use of composite beams with web openings is an advantageous tool. The article aims to present the background that has been developed on composite beams with web openings and composite cellular beams, considering conventional floors, in which the concrete slab is placed on the upper flange of steel profile. Studies are presented, considering firstly composite beams with web openings, and later the composite cellular beams, formed by solid and composite slabs. Concluding remarks and future research directions of composite cellular beams are presented.


**ABSTRACT:** In this paper, a new formulation of beam-type finite element for the non-uniform torsion of simple or continuous thin-walled single- or multi-cell box girder with open and closed cross-sections is developed, considering both torsional warping and shear deformation effects (primary shear deformation due to Saint-Venant torsion and secondary shear deformation due to restrained torsion). The warping displacement of the cross-section is defined as the product of warping function representing the warping moment along the girder axis and a series of segmental shape functions describing the warping shape of each wall of the cross-section. Two different warping functions have been defined and incorporated in Model A and Model B. The girder is subjected to arbitrary distributed or concentrated twisting moment and restrained by the general torsional-bending boundary conditions. The governing differential equations pertaining to torsion and torsional warping are obtained through the principle of minimum potential energy and the proposed finite beam element
is refined by selecting closed-form homogeneous solutions of the differential equations as interpolation functions. Numerical examples are presented regarding rectangular hollow section (RHS) girders with open and closed cross-sections and the results obtained are compared with those provided by pioneering work or examined by using commercial finite-element models to validate the proposed beam-type element and to demonstrate the wide range of applicability and the convenience of using it.

ABSTRACT: In this study, a new modular energy dissipater (MED) consisting of an inner assembled core and outer restraining tube was developed. The inner core is fabricated by multiple identical energy dissipation units with threaded couplers in series. The outer tube is used to restrain the overall buckling of the inner assembled core. The MED is characterized by a standardized design, uniform process, modular assembly and units that are easy to replace after an earthquake. Seven energy dissipaters were tested to compare the hysteretic performance and failure mode of the MED with those of a nonmodular energy dissipater (NMED) under a low-cycle loading pattern. Test results showed that the hysteretic curves of the MED were plump in shape without pinching and did not exhibit a significant reduction in strength, and the axial deformation of MEDs is up to 4% before failure. The MED specimens perform an excellent low-cycle fatigue life. The mechanical connection in the assembled core of the MED resulted in significant slip deformation that could improve the low-cycle fatigue life of the MED compared with that of the NMED at the same strain amplitude. By adding the screws in the position of the threaded connection to form a thread-screw connection, the slip deformation could be considerably diminished. Compared with the NMED specimens, the initial axial stiffness of the MED specimens was lower; therefore, a computational formula for the initial elastic stiffness was proposed. All components, including the energy dissipation units, threaded couplers and end connection units, can be detached freely during the experiments, where the threaded couplers and connection units can be reused many times. The performance of the MED shows a minimum relationship with the reused energy dissipation units.

ABSTRACT: This paper presents an experimental and numerical study of stainless steel plate girders with non-rigid end posts. Stereo vision digital image correlation was employed to continuously measure the deformed shape and the corresponding three-dimensional displacements of the lean duplex specimen, which enabled the full deformation history of the whole web of the plate girder to be traced. Following the experimental investigation, a finite element study was conducted and validated. Subsequently, a sensitivity analysis was performed to investigate the effectiveness of all design parameters in order to give directions for improvement. The comparisons showed that the European code leads to acceptable strength predictions, yet further improvements remain possible to more accurately predict the contribution of the flange, and to include the contribution of the stiffness of the non-rigid end post to this instability phenomenon.

ABSTRACT: The New Zealand wine industry has experienced several strong earthquakes over the last decade. The research presented herein documents the damage data to legged wine storage tanks following the Seddon earthquake (New Zealand, M 6.5) on 21 July 2013 and Lake Grassmere earthquake (New Zealand, M 6.6) on 26 August 2013, and the 2016 Kaikoura earthquake (New Zealand, M 7.8). The data covers the damage assessment results of 1512 legged wine storage tanks from the 2013 earthquakes and of 599 legged wine storage tanks from the 2016 earthquake. Several parameters were investigated, including tank capacity, liquid level at the time of the earthquakes, and damage to different elements of legged wine tanks. Frame/leg parts of the legged wine tanks sustained the greatest damage, with 40% of legged tanks sustaining frame/leg damage in the 2013 earthquakes and 44% of legged tanks sustaining frame/leg damage in the 2016 earthquake. Based on the
results, liquid level and tank capacity were identified as parameters that most greatly influenced the seismic performance of legged wine tanks.

ABSTRACT: Multicell concrete-filled steel tube (MCFST) columns are used as vertical members in super high-rise buildings. However, the behavior of MCFST columns under eccentric loading has not been investigated in detail. Hence, seven MCFST column specimens were designed in this study. Experimental tests were performed on the specimens under an eccentric load and design recommendations were proposed. The main parameters investigated included the cross-sectional shape, number of cells, circular steel tube reinforced structure, structure of reinforcement cages, concrete strength, and the eccentricity ratio. The damage mode, bearing capacity, ductility, restoration capacity, and strain development were analyzed. The results showed that the circular steel tubes and reinforcement cage could significantly improve the mechanical behavior. Concrete with a higher strength significantly increased the bearing capacity but decreased the ductility. With an increase in the eccentricity ratio, the bearing capacity decreased, whereas the restoration capacity was reduced. Stress–strain relationships of plain concrete, single-cell concrete-filled steel tubes, and MCFSTs were considered in the fiber-based method to predict the deflection–load curves of the seven specimens. The results indicated that the curves calculated based on the stress–strain relationship of MCFSTs showed good agreement with the experimental results.

ABSTRACT: Cold-formed steel members are commonly perforated with elongated web openings in practice to allow more access for the building service systems. The presence of such extended web holes in the members, when subjected to high shear forces, influences the shear buckling characteristics, the shear failure modes and generally leads to a reduction of shear capacity as well. In order to provide a better insight into the shear behaviour of cold-formed members with elongated web cut-outs, this paper presents a numerical study using finite element method (FEM) models employing ABAQUS/Standard to investigate the elastic shear buckling and post-buckling behaviour of cold-formed members in the form of thin channel sections. A full non-linear FEM model is developed and calibrated against previous shear tests with elongated web holes carried out using a dual actuator test rig. Based on the successful calibration against the tests, a parametric investigation is conducted to extend the resulting database. Further, a new proposal for the Direct Strength Method (DSM) of design of perforated channels in shear with both non-elongated and elongated web holes is further validated by using the results from the parametric study. A comparison between the empirical approach (“q” method) and the new DSM of design derived from the Vierendeel mechanism approach is also provided to enhance the applicability of the new proposal to different cases of perforated channel members in shear with a wider range of sectional dimension and thicknesses.

ABSTRACT: This paper presents an axial compression behavior of bare and concrete-encased cellular steel (CECS) short columns. Three cellular steel configurations with different hole diameters and spacings were fabricated from the parent wide-flange hot-rolled steel shape. Eleven CECS columns using the cellular steel and four concrete-encased steel (CES) columns using the parent steel were tested to investigate the influence of the cellular steel configuration and the spacing between the closed stirrups. The test results of bare cellular steel columns showed that the failure was due to local buckling at the steel flanges and web at the hole section. The bare cellular columns exhibited the load-deformation relationship with less hardening behavior than the parent steel column. The proportional limit loads, yield loads, and maximum loads of all cellular steel columns were less than the parent column. The test results of composite columns showed that the CECS columns exhibited the
failure mode, load-deformation relationship, and load-strain relationship similar to the CES parent columns. The weakening effect due to the circular openings was minimized by the concrete encasement. The compressive strength of CECS and CES columns increased as spacing of the closed stirrups decreased. A modified squash load equation is recommended for both CECS and CES composite short columns made with low-strength concrete, small amount of longitudinal rebars, and maximum stirrup spacing limit based on the ANSI/AISC360–16 specification.


ABSTRACT: Based on size effect law of plain concrete, a size-dependent analytical model for axially loaded CFST column was developed by considering the influence of confinement on size effect. The proposed model can make a similar forecasting precision for CFST specimens in different size ranges, and it was efficient to predict the size effect of axial compression strength, therefore it was used here to conduct the parametric analysis on size effect of CFST column. The analysis results indicated that the size effect of axial compression strength was connected with the confinement level apart from the specimen size. As the steel ratio of the specimen or yield strength of steel tube increased, size effect of axial compression strength tended to become less obvious. Conversely, the size effect was more obvious as the concrete strength increased. Based on parametric analysis, a formula was developed to predict the size effect of axial compression strength for CFST specimens by considering the specimen size and the influence of confinement factor.


ABSTRACT: Conventionally, wind turbine towers are made of thin steel circular cylindrical shells due to the structural efficiency and the ease of construction. But, thin cylindrical shells are highly sensitive to imperfections, and the presence of even slight imperfections reduces their capacity severely. Imperfections are always present in the cylinders, and thus the design methods have the provisions to accommodate the presence of imperfections. As a result, the current practices for designing wind turbine towers that are made by thin circular cylinders are conservative. These conservative design methods have long been an obstacle for cost effective wind turbines, whose demands have been increased recently due to the widespread awareness of the clean source of wind energy. Wavy wind turbine towers are proposed in this study to avoid these roadblocks towards more efficient tall wind turbine towers. The waviness of the cross-section reduces the slenderness ($R/t$) of the towers significantly; consequently, the sensitivity of the towers to imperfections is reduced drastically. In addition, the waviness of the cross-sections works as stiffeners which also results to the reduction of imperfection sensitivity. Imperfection sensitivity of wavy cylindrical shells has been evaluated in the past along with highly promising results. However, no attempt has been made to evaluate the effectiveness of the wavy cylinders in a real application. In this study, the sensitivity of the proposed wavy wind turbine towers to imperfections is assessed. It is found that the sensitivity of the wavy towers is exceptionally small compared to that of the circular towers.


ABSTRACT: Investigations on concrete-filled steel tubular (CFST) members under static loads have been extensively reported. Still, limited researches have been conducted to investigate the behavior of CFST columns subjected to axial impact loading. This paper presents an experimental study on dynamic behaviors of twelve square and rectangular CFST stub columns subjected to axial impact loading using a drop-weight test apparatus. The instantaneous force and deformation states were recorded during the impact tests. Finite element (FE) models were established and verified using the experimental results and existing research data, in which the strain rate effects of steel and concrete were fully considered. Then the effects of cross-section shape, steel
strength, concrete compressive strength, steel ratio and impact energy condition on the dynamic responses of the CFST stub columns were studied using the FE models. The experimental and analytical studies indicate that the circular CFST stub columns perform better than the square and rectangular ones. While, little difference can be found between the square and rectangular CFST stub columns. For all the three shaped CFST stub columns, the average platform impact force increases and the deformation decreases with the increase of steel strength, concrete compressive strength, steel ratio and section area. Based on the parameter studies, a simplified design method was proposed by establishing the relationship between the maximum axial displacement and the impact energy condition to predict the deformation response of CFST stub columns under axial impact.

ABSTRACT: Application of longitudinally profiled (LP) steel plate in the flange of flexural members may provide a good solution to optimize their mechanical performance and to improve the efficiency of steel use, whilst existing design codes provide no design guidance or prediction methodology for such advanced beams in terms of flexural behaviour. To clarify their flexural strength and rotation capacity, tests on two full-scale welded I-section steel beams with longitudinally profiled flanges (LPB members) are carried out herein, as well as two traditional beams with uniform cross-section for comparison. All the specimens exhibit sufficient flexural strength and rotation capacity for seismic plastic design, and specifically, the LPB members possess even better performance in case of identical steel usage. Parametric analyses of 250 beams incorporating a wide range of flange slenderness and steel grades, are conducted by employing the validated nonlinear FE model to investigate the effects of rate of thickness change for the LP flanges. The results show that the effect is limited on the flexural strength but significant on rotation capacity. The existing design provisions for beams with uniform cross-section give generally conservative design results for the flexural strength of the LPB members, but limiting values of flange slenderness needs to be reduced. The research outcomes may provide an important basis for promoting the application of LP plates in flexural members.

ABSTRACT: The behavior of a new type of thin-walled steel-jacketed column under eccentric loading was simulated using two methods: constant confining pressure and variable confining pressure. The influence of the spatial distribution of the confining effect on the performance of such eccentrically loaded columns is discussed. The error between the two types of calculated eccentric bearing capacities was less than 6.3%; however, there are obvious differences in the stress distribution of the core concrete when using the different methods. The proposed columns tested were fabricated by stacking precast segments (PSs) into the tube and then infilling the space with post-pouring concrete (PPC). The PSs were fabricated by incorporating demolished concrete lumps (DCLs). Fourteen specimens were examined in the laboratory under eccentric loading. The experimental results confirm that such columns perform almost the same as traditional concrete-filled steel tubes using DCLs directly. The eccentricity and strength of the PPC are the two most critical determinants of the performance of such columns under eccentric loading. The complete test results are reported.

ABSTRACT: Only limited investigations on mechanical behavior of circular steel-reinforced concrete-filled steel tube (SRCFST) under coupled compression and torsion have been reported in open literature. Therefore, eighteen circular SRCFST members were tested to study the torsional behavior. The effects of various parameters, i.e., sectional forms of steel reinforced, axial compression ratios, loading paths and slenderness ratios were considered, respectively. The failure modes, torsional moment-rotation angle curves and torsional moment-strain curves of SRCFST members derived from the loading tests were investigated and discussed, respectively. Test results show that the development of concrete crack is effectively restrained due to the

ABSTRACT: External pressure is often the decisive load case for empty hydraulic pressure shafts for calculation of the wall thickness of the steel liner. Due to large diameters and thin wall thicknesses the steel liner is susceptible to shell buckling under external pressure. Therefore, the steel liner is often stiffened with circular rings having a rectangular cross section. In the Sixties of the last century comprehensive research activities started, including tests, and analytical formulae were developed for the design. Basically, these formulae are still used nowadays for the dimensioning of the ring stiffened steel liner. This paper sums up the analytical design rules for ring stiffened steel liners, which are very complex and not easy to handle. Two different verifications for buckling of the ring stiffener and for buckling of the cylindrical shell between the rings are necessary. The combined buckling behaviour of the ring stiffeners and the cylindrical shell between the rings can only be performed with a 3D-FEM analysis, which is also presented in the paper for different steel liner geometries used in practice. The distance of stiffeners eₐ is also varied. The results of the FEM analyses are compared with the current design rules. Due to the lack of accuracy of the analytical design rules, a new design model is presented in detail, using the results of the numerical analyses.


ABSTRACT: This paper reports the developments of steel-UHPC-steel sandwich composite walls with novel EC connectors (SUSSCW-ECs). The ECs in SUSSCW-ECs directly linked the two faceplates that enhance the composite action of the composite wall. Axial compression tests on 11 SUSSCW-ECs to investigate their compressive behaviours, and the selected key influencing parameters in the testing program included layout of C-channels, steel faceplate thickness, horizontal and vertical spacing of ECs, and strength of core. Under compression, the SUSSCW-ECs exhibited an elastic-plastic-recession three-stage working mechanism. Tests results show that major local buckling of faceplates ended the elastic stage, and UHPC crushing occurred at the peak compression resistance of SUSSCW-ECs. Installing the ECs with horizontal webs exhibited larger axial compression resistance of SUSSCW-ECs than those with V-web ECs. Increasing the steel faceplate thickness improved compressive behaviours of SUSSCW-ECs. Increasing horizontal and vertical spacing of EC connectors resulted in reduced ultimate compressive resistance of SUSSCW-ECs. Using UHPC improves both peak resistance and elastic stiffness of sandwich composite walls. Finally, this paper developed theoretical models to predict ultimate compressive resistance of SUSSCW-ECs, and validations against 11 test results showed their reasonable estimations.


ABSTRACT: The confinement mechanism in elliptical concrete-filled steel tubular (CFST) columns differs considerably from that in circular or rectangular CFST columns. It is essential to quantify this confinement effect in elliptical CFST columns in order to accurately predict their structural responses. This paper describes a computational model utilizing the method of fiber analysis for the nonlinear simulation of short CFST elliptical columns that are concentrically loaded. Based on available experimental data, a new model of confinement is developed for determining the lateral stresses on the filled concrete in CFST elliptical columns and included in the fiber-based model. A factor of strength degradation is derived that quantifies the post-peak residual strength of concrete. Comparisons with experimental results are made to assess the accuracy of the computer simulation
method developed. Investigations into the performance of CFST elliptical columns with important variables are undertaken by using the computer simulation program. An equation is given that determines the capacities of short elliptical CFST columns recognizing concrete confinement. The applicability of the codified methods for CFST columns of rectangular and circular sections to the design of CFST elliptical columns is investigated. It is found that the computer simulation and design models proposed provide accurate predictions of the structural behavior and strength of short elliptical CFST columns loaded concentrically.


ABSTRACT: Built-up battened columns are lightweight and have a larger moment of inertia when compared with columns made by a single profile. However, these columns have shown poor seismic performance during past earthquakes. In this study, experimental and numerical investigations were focused on the seismic performance of these columns. A full-scale built-up battened column was subjected to quasi-static cyclic loading and its response was recorded. Furthermore, 81 built-up battened columns were simulated in ABAQUS software. The effects of batten spacing, batten thickness, chord distance, and axial force on the cyclic response of simulated columns were investigated. The obtained results indicated that the bulging of chord webs together with the local buckling of chord flanges were the main reason for the failure of columns. Besides, in all columns, the maximum stress in chords was almost twice larger than the maximum stress in battens. Furthermore, an increase in the batten thickness or a decrease in the batten spacing slightly increased the ultimate load of columns. Columns with a thicker batten exhibited a slightly smaller plastic deformation. The displacement ductility ratios of the built-up battened columns were all less than two even when they were subjected to an axial compression ratio smaller than 0.2. It was also observed that, in all columns, the ratio of ultimate load to the effective yield strength was less than 1.4.


ABSTRACT: Cold-formed steel (CFS) back-to-back channels are becoming a popular choice for use in load-carrying members in building structures. These built-up channels often include web holes for installation of services. Traditional web holes are un-stiffened, which can restrict the size and spacing of holes. Recently, a new generation of CFS channels with edge-stiffened holes has been developed and used widely in New Zealand. No research has been reported in the literature to investigate the axial strength of back-to-back channels with edge-stiffened holes. Experiments are required on back-to-back channels with edge-stiffened holes so to understand the effects of composite actions between the back-to-back channels on the axial strength of such channels. This paper presents a total of 162 new results comprising 27 axial compression tests and 135 finite element analysis (FEA) results on the axial strength of back-to-back channels with edge-stiffened holes, un-stiffened holes and plain webs. Prior to compression tests, initial geometric imperfections were measured using a laser scanner. Tensile coupon tests were also conducted to determine the material properties of both the flat and corner portions of the channels. The test results show that for the case of back-to-back channels with edge-stiffened holes, the axial strength increased by 6.6% on average, compared to a back-to-back plain channel. For comparison, the same section with un-stiffened holes had a 12.4% reduction on average in axial strength, compared to a back-to-back plain channel. A nonlinear elasto-plastic finite element (FE) model was then developed, and the results showed good agreement with the test results. The validated FE model was used to conduct a parametric study involving 135 FE models to investigate the effects of column slenderness, diameter of hole, screw spacing, stiffener lengths and stiffener fillet radius on the axial strength of such channels. Finally, the tests and parametric study results were compared against the design strengths calculated in accordance with the American Iron and Steel Institute (AISI) (2016) and Australian and New Zealand Standards (AS/NZS) (2018) for back-to-back plain channels and against the design equations of Moen and Schafer (2011) for back-to-back channels with un-stiffened holes. It was found that the AISI (2016) and AS/NZS (2018) are only 3% conservative to the test results. The Moen and Schafer equations (2008, 2009, 2011) are conservative by 21% on average for back-to-back channels with un-stiffened holes.
ABSTRACT: In this paper, the authors' research group propose a novel double-skin composite wall (DSCW), which is composed of boundary columns, steel faceplates, L-shaped connectors and infill concrete. To further study the seismic performance of DSCW specimens, six high shear-span ratio DSCWs were designed and manufactured for a quasi-static test. In the experiment, the welding spacing, welding forms, and the thickness of the steel faceplate are used to set forth parameters; moreover, the failure mode, deformation performance and energy dissipation capacity of the DSCWs are analyzed. Test results show that the failure mode of each specimen was flexural failure, as shown by the fractured steel plate at the bottom of the boundary columns, the crushed infill concrete at the tear, and the specimens' buckled steel faceplates in different degrees. The average value of the yield drift ratio was 1/177; the average value of ultimate drift ratio was 1/39, and the average value of displacement ductility coefficient was 4.46. A good energy dissipation capacity was shown by the specimens as it increased gradually during the testing process. The results show that the local buckling of the steel faceplate can be delayed by reducing the welding spacing and adopting the blossom-form or dense bottom welding arrangement; thus, improve the ductility and energy dissipation capacity of the specimens. When the thickness of the steel faceplate is increased, the local buckling of the steel faceplate is less likely to occur, and the bearing capacity is improved. Based on the theoretical analysis, a buckling stress calculation model is proposed to calculate the buckling stress of the steel faceplate at the bottom of the specimen.

ABSTRACT: Axial compressive behavior of square CFST stub columns with local corrosion simulated by artificial notch was studied through the combination of experiments and finite element analysis. Fifteen specimens were fabricated and tested. The experimental results showed that the failure modes and the axial compressive behaviors of specimens with notch were different from the intact ones. Compared with the specimen without notch, the compression strength and stiffness of specimens with horizontal notch and sloping notch degraded seriously while the vertical notch had little effect on the compression strength of specimens. Meanwhile, the finite element model was developed by ABAQUS software, whose accuracy was validated by comparing with the experimental results. Further parametric analyses using the developed FE model were conducted to investigate the influence of different parameters on the compression strength of the axially loaded square CFST with notch. Moreover, a formula was proposed for estimating the axial compression strength of the notched square CFST stub columns.

ABSTRACT: Steel plate shear wall (SPSW) buckling-restrained by hat-section cold-formed steel is a new type of lateral bearing system that uses hat-section cold-formed steel members to restrain the buckling deformation of the SPSW. Integration of architectural and structural functions is achieved in this new shear wall system by externally bonding oriented strand board (OSB) and filling sound insulation material. A finite element (FE) model was developed and validated against seven experimental results in terms of failure modes, shear force-story drift angle curves and shear bearing capacities. Upon validation, an extensive parametric study was carried out to investigate the six key parameters including spacing of connecting bolts, geometries of hat-section steel, spacing of hat-section steel, steel material strength, width-height ratio of the SPSW and height-thickness ratio of the SPSW. Based on the 104 numerical results, new design rules are proposed to predict the stiffness, shear yielding strength and shear ultimate strength of this new type of buckling-restrained SPSW structure. By comparing the predicted results with experimental and numerical results, the proposed design method is found to be accurate and consistent. In addition, an equivalent cross-bar model is developed as a simplified substituted SPSW model to be used in theoretical modelling programmes in the future.

ABSTRACT: High strength steel is increasingly used in current engineering structures, because of its high structural efficiency. However, the current design method of the ultimate capacity of lateral-torsional buckling of steel beams is based on the research achievement of normal strength steels. To investigation the lateral-torsional buckling behavior of high strength steel beams, an experimental and numerical study on the ultimate bearing capacity of welded I-section beam with a nominal yield stress of 460 MPa in bending was carried out. The flange width-to-thickness ratios of 5 and 9 and member slenderness ratio of 95 and 155 were adopted in the test. A nonlinear FE model was established with the consideration of initial geometric imperfection and residual stress. The ultimate flexural resistances predicted by FE models agree well with those obtained from the test, which validated the FE model. A series of parametric study with considering various steel grades, cross-sectional dimensions, member slenderness ratio and initial imperfections were taken into account to the influence on flexural-torsional buckling behavior of the beams. The applicability of current design codes for the ultimate capacity of high strength steel I-section beams was evaluated by comparing with experimental and numerical results. The comparison shows that American National Standard (AISC 360–16) can provide an accurate prediction of the flexural resistance of beams fabricated from Q460 steel, while EN1993-1-1 is more conservative than Chinese Standard (GB50017–2017).


ABSTRACT: A comprehensive experimental and numerical study on the axial and flexural behaviour of square concrete-filled steel tubular (CFST) members incorporating S960 ultra-high-strength steels and high-strength concrete (C70 and C100) is reported in the present paper. An experimental programme that consisted of eighteen stub and slender CFST members under various loading conditions was conducted. The test results showed that the nominal compressive and flexural strength of ultra-high-strength CFST members were achieved. Steel coupon tests, concrete compressive strength tests and geometric imperfection measurements were also carried out. In addition, numerical models which accounted for geometric imperfections and residual stresses were developed. A confined concrete model was employed in the numerical analysis to simulate concrete confinement effects. Validation against the experimental results demonstrated the accuracy and reliability of the developed model. A series of parametric studies were performed to evaluate the effects on the ultimate strength by changing the steel yield strength, concrete compressive strength, steel tube width-to-thickness ratio and member slenderness ratios for different loading conditions. Comparisons of the results were made with the current codes of practice including AS/NZS 2327, Eurocode 4 and ANSI/AISC 360, which indicated that all the provisions were conservative in predicting the axial and flexural resistance of CFST members with recommended curves.


ABSTRACT: A finite element collision system model was established by using ANSYS/LS-DYNA for a new type of bridge anticollision device with stiffeners made of steel–polyurethane sandwich plates. The model is composed of the anticollision box, the bridge pier, and the ship. In this paper, a numerical dynamic calculation method was used to calculate the impact force of the box and the pier column, the collision depth of the ship, and the energy absorbed by various parts of the system in the most unfavorable frontal collision condition. Then, the influence of the different types and numbers of stiffening ribs on the anticollision performance of the system was analyzed, so as to properly arrange the stiffeners inside the box. The result shows that this kind of anticollision box can effectively protect the pier. When a frontal collision occurs, it can absorb >70% of the impact energy, while the pier only bears <10% of the impact energy. Among the various components of the anticollision box, the outer steel plate of the sandwich plate absorbs the most energy, and the inner steel plate absorbs the second most. The effect of setting the horizontal stiffeners on the impact force, impact depth, and
absorption energy of each part of the system is larger than that of the vertical stiffeners, and the effect of improving the rigidity of the anticollision box is also better.


ABSTRACT: Welding residual stress is inherent to welding of U-rib stiffened plates and it is a “fact of life” that must be accounted for by designers. In this study, the welding residual stresses of U-rib stiffened plates were investigated through numerical and experimental methods. The influencing factors on the welding residual stress are based on a) two full-scale residual stress tests and b) a series of numerical parameter analyses. Regarding the U-rib residual stress, the maximum tensile stress decreased as the U-rib thickness increased, whereas an opposite trend is observed for the maximum compression stress. For the subpanel residual stress, the maximum compressive stress increased with the increase of the U-rib thickness, while the maximum tensile stress decreased first and then increased. As the subpanel thickness increased, the maximum residual tensile/compressive stress and the maximum U-rib compressive stress decreased, and the U-rib tensile stress increased. The influence of the subpanel thickness on the residual stress is reduced as the U-rib thickness increased. The material yield strength has a minor effect on the extreme value of the residual stress of the subpanel and has a certain effect on the tensile stress distribution interval. The maximum residual tensile stress of the U-rib is approximately proportional to the material yield strength. According to these results, this study presents a simplified distribution diagram for the welding residual stress of the U-rib stiffened plate. It has been verified that the simplified distribution diagram can provide a valuable reference for the design of steel bridges.


ABSTRACT: This paper investigates the failure mechanism and structural behavior of high strength Concrete Encased Steel (CES) composite columns subject to compression and bending. Twelve composite column specimens with C90 concrete and S500 steel section were tested under concentric compression, eccentric compression and four-point bending. All specimens had the same geometry and were reinforced with the same steel section and same amount of reinforcing bars. In some specimens, micro steel fiber was added into concrete mix with 0.5% or 1.0% dosage to delay or prevent the potential premature cover spalling. The load-carrying capacity, load-deformation response, post-peak ductility, flexural stiffness, as well as damage pattern are comprehensively analyzed. Comparison is made between the experimental results and analytical predictions using modern design codes such as EN 1994-1-1 and AISC 360–16. From the four-point bending test, the flexural stiffness obtained from the test seems to be smaller than the codes' predicted values, indicating that modification is needed to achieve better prediction of structural response of composite beams at the service load level. As for the axial force (N)-bending moment (M) strength interaction diagram, it is found AISC 360–16 gives overall more conservative prediction than EN 1994-1-1 method for high strength CES columns with C90 concrete and S500 steel. However, both methods overestimate the axial compression capacity although they can predict their flexural capacity well.


ABSTRACT: Traditional member-based two-step design approaches included in current structural codes for steel structures, as well as more recent system-based direct-design alternatives, require building rigorous structural reliability frameworks for the calibration of partial coefficients (resistance factors) to achieve specified target reliability requirements. Key design parameters affecting the strength of structures and their random variations are generally modelled by nominal or characteristic values in design standards, which are combined with partial coefficients that need to be calibrated from measurements on real samples. While the statistical characterization of material and geometric properties of structural steels has been consolidated over the last decades, information about the characterization of structural stainless steels is virtually non-existent due to the limited pool of available data. Thus, this paper presents the basic ingredient for developing reliability frameworks for stainless steel structures and components by statistically characterizing the main random
parameters affecting their strength through a comprehensive database collected from the literature. Based on the collected data, appropriate probabilistic models are proposed for geometric properties, material properties, imperfections and residual stresses of different stainless steel alloys and cross-section or product types. The data is equally applicable to member-based reliability analyses as described in existing codes and system-based analyses targeted at the direct-design of stainless steel structures by advanced analysis.


ABSTRACT: S600E high-strength stainless steel has outstanding characteristics of high strength, good corrosion resistance and low price. Compared with commonly used stainless steel (e.g. austenitic stainless steel S30408), it has a significant advantage in reducing the cost of material. As a novel structural material, little research has been done on its structural performance. In this study, the local buckling behavior of six box-section and ten I-section S600E high-strength stainless steel welded stub columns were tested under axial compression. Material properties, local geometric imperfections, bearing capacities and typical failure modes of the stub columns were reported. Finite element models were established, and the results were compared with test data to verify its accuracy. Parametric analyses were conducted. The width-thickness ratio limits of stiffened and unstiffened plates were obtained. Formulae of the effective width method were modified to consider the material characteristics of S600E high-strength stainless steel. The predicted strengths using the modified formulae, the American code, the European code, the Chinese specification and the continuous strength method (CSM) were compared with the test results. It indicates that the modified formulae have a better accuracy in predicting the bearing capacity of S600E high-strength stainless steel welded cross-sections.


ABSTRACT: The research deals with structural response and ultimate strength of patch-loaded steel I-girders without longitudinal stiffeners and with largely spaced transverse stiffeners. Part-I of the research, i.e. experimental research is presented in the companion paper. Numerical analysis of load length influence on the ultimate strength of the girder is presented in the current paper. Based on conclusions from the experimental research geometrically and materially nonlinear finite element models of experimentally tested girders were developed. Special attention is paid in modelling the contact between load block and loaded flange and in modelling the approximate geometrical imperfections of the web that best fit the experimentally measured imperfections. Detailed validation of numerical models is done by comparison of numerical and experimental results. Following data are compared: ultimate loads, deflections of loaded flange, vertical strains at measuring points on the web and lateral web deformations. Good agreement between numerical and experimental results is achieved. Quantification of load length influence on ultimate strength as a main objective of the research is made through parametric numerical analysis. Numerical base containing 143 runs is created in which the load length and web thickness are varied. Other geometrical characteristics and material properties of girders, as well as initial geometrical imperfections of the web, are kept constant which could not be provided in the experimental study. By regression analysis of the results of parametric study a simple correction factor for load length is proposed. Accuracy of the proposed expression is proved through statistical analysis over concerned numerical base.

References listed at the end of the paper:
2 M. Rogač, Theoretical and Experimental Research of Stability Problem of Thin-Walled I-Girders Subjected to Patch Loading, Doctoral Thesis (in Serbian), University of Montenegro, Faculty of Civil Engineering, Podgorica (2015)

ABSTRACT: Lateral-torsional buckling (LTB) behaviour of concrete-filled high-strength steel tubular flange beams (HS-CFTFBs) is experimentally and numerically investigated. Six specimens are tested in simple support with a lateral unrestrained concentrated load in mid-span. Among them, two are failure controlled through flexural yielding (FY), whereas the remaining specimens are controlled through LTB. Finite-element (FE) models are then constructed and the comparison with the experimental results indicates that they could reliably and accurately evaluate failure modes, load–displacement relationship and ultimate capacities of HS-CFTFBs. These verified FE models are consequently used to investigate the effect of flange depth, concrete and steel with various span lengths. Results suggest that the ultimate moment capacity evidently decreases as the span length increased, particularly for the high-strength steel beams. The increasing flange depth remarkably improved the LTB strength but merely slightly increased the amount of steel. The infilled concrete could improve the resistance to flange distortion and thus increase the ultimate capacity. However, the strength of concrete exhibits a slight influence on ultimate capacity. Increasing $f_c$ could improve the LTB capacity when the span length is relatively small, but the improvements decrease with increasing span length. When the failure mode is elastic LTB, increased $f_c$ could substantially improve post-buckling stiffness and ductility.
References listed at the end of the paper:

1 G. Shi, F. Hu, Y. Shi, Recent research advances of high strength steel structures and codification of design specification in China, Int. J. Steel Struct., 14 (4) (2014), pp. 873-887


8 C.W. Kurniawan, M. Mahendran, Elastic lateral buckling of simply supported LiteSteel beams subject to transverse loading, Thin-Walled Struct., 47 (1) (2009), pp. 109-119


13 M.F. Hassanein, O.F. Kharoob, Shear capacity of stiffened plate girders with compression tubular flanges and slender webs, Thin-Walled Struct., 70 (2013), pp. 81-92


20 Y. Shao, Y. Wang, Experimental study on static behavior of I-girder with concrete-filled rectangular flange and corrugated web under concentrated load at mid-span, Eng. Struct., 130 (Supplement C) (2017), pp. 124-141


23 M.F. Hassanein, Fundamental behaviour of concrete-filled pentagonal flange plate girders under shear, Thin-Walled Struct., 95 (2015), pp. 221-230


32 Y. Wang, M.A. Bradford, X. Liu, Strength design of welded high-strength steel beams considering coupled local and global buckling, Thin-Walled Struct., 106391 (2019)


34 N. Tondini, A. Morbioli, Cross-sectional flexural capacity of cold-formed laterally-restrained steel rectangular hollow flange beams, Thin-Walled Struct., 95 (2015), pp. 196-207

ABSTRACT: This paper presents the study on shear behavior of stiffened single perforated LDSS rectangular hollow beam, considering various orientations / patterns viz., inclined (IS), vertical (VS), horizontal (HS) and ring (RS); and effect of various cross-sections i.e. flat, angular and semi-circular (considering same material consumption). Based on the study, it has been found that in general, inclined stiffener (with flat cross-section) is relatively most effective in enhancing the shear capacity of perforated beams. For the inclined stiffeners, it is observed that the rate of increase in shear capacity (\(V/V_o\)) increases (in a non-linear trend) with increasing stiffener length for higher stiffener thicknesses. In the case of vertical and horizontal stiffeners, there appears to have no/little significant improvement in shear capacity for both the variation in length, width and thickness. For the ring stiffeners, it is found that, shear capacity increases with increase in both breadth and thickness of the stiffeners. Comparison made between angular and semi-circular sections (keeping the same cross-sectional area) showed that both the sections predicted similar behavior of shear capacity.

References listed at the end of the paper:

1 N.C. Hagen, P.K. Larsen, A. Alberg, Shear capacity of steel plate girders with large web openings, part 1: modeling and simulations, J. Constr. Steel, 65 (1) (2009), pp. 142-150
8 M.F. Hassanein, Shear strength of tubular flange plate girders with square web openings, Eng. Struct., 58 (2014), pp. 92-104
10 Y. Huang, B. Young, Experimental and numerical investigation of cold-formed lean duplex stainless steel flexural members, Thin-Walled Struct., 73 (2013), pp. 216-228

ABSTRACT: Stainless steel offers a range of benefits over conventional carbon steel in structural applications. This paper presents the detailed numerical modelling of shear response of cold-formed stainless steel hollow flange sections using finite element software package, Abaqus. The effect of geometric parameters such as section height and section thickness, and the influence of different steel grades were investigated following the validation of finite element models. From numerical results, the formation of diagonal tension fields can be clearly observed in the webs of rectangular hollow flange sections while more even distribution of the stresses in the webs is seen in triangular hollow flange sections. Further, a plastic hinge type mechanism is formed in triangular flanges at the post-failure region. The evaluation of Eurocode 3 and the direct strength method shear design provisions for stainless steel hollow flange beams is found to be significantly conservative. Therefore, modified provisions were proposed and the comparison of those with finite element results confirmed the accurate and consistent shear resistance predictions over the codified provisions.

References listed at the end of the paper:

ABSTRACT: Ultra-high strength concrete (UHSC) and high strength steel (HSS) have been found to be attractive alternatives to normal strength materials for high-rise construction. The uses of HSS and UHSC can reduce member sizes and payload acting on foundation, which will free up more usable floor space and require less construction materials and handling works. The combination of them to form concrete-filled steel tubular (CFST) columns is more attractive compared with the columns employing either UHSC or HSS due to enhanced strength and stiffness. To better understand the structural behavior of CFST columns using UHSC and HSS, experimental and analytical studies on their fire resistance are presented in this paper. Fire tests were carried out on square S690 HSS tubes infilled with C170/185 UHSC to form the CFST columns. The fire resistance time under Standard ISO fire was recorded and checked against the conventional simple calculation model of EN1994-1-2 and the newly proposed axial force and moment interaction model. It is revealed that the column buckling curve in EN1993-1-1 can be used for fire-resistant design of CFST columns employing UHSC and HSS when the load level is less than 0.65. The use of UHSC is beneficial to improve the fire resistance of CFST columns but the use of high strength steel is not when compared with their counterparts using normal strength materials.

References listed at the end of the paper:
2 J.Y.R. Liew, M.X. Xiong, D.X. Xiong, Design of concrete filled tubular beam-columns with high strength steel and concrete, Structures, 8 (2016), pp. 213-226
3 B.L. Lai, J.Y.R. Liew, M.X. Xiong, Experimental and analytical investigation of composite columns made of high strength steel and high strength concrete, Steel Compos. Struct., 33 (1) (2019), pp. 899-911
7 ANSI/AISC 360-16, Specification for Structural Steel Buildings, American Institute of Steel Construction, Chicago, IL (2016)
8 AJJ, Recommendations for Design and Construction of Concrete-filled Steel Tubular Structures, Architectural Institute of Japan, Japan (1997)
10 M.X. Xiong, J.Y.R. Liew, Mechanical properties of heat-treated high tensile structural steel at elevated temperatures, Thin-Walled Struct., 98 (2016), pp. 169-176
These changes improved accuracy and safety in the design of gusset plates without adding complexity to the current design methods, it was found that the Whitmore width is generally un-conservative in predicting initial yielding of gusset plates. By using the Thornton method with modifications based on FEA observations of gusset plate behavior, a new yield area and compressive strength curve suitable for gusset plates is proposed. These changes improved accuracy and safety in the design of gusset plates without adding complexity to the design process.

ABSTRACT: Catastrophic progressive collapse of long-span spatial structures subjected to non-uniform snow loads is often reported; however, few studies have been performed in this field. In the present study, progressive collapse tests of a scaled single-layer latticed K6 dome subjected to the non-uniform load were conducted. The failure mode, dynamic response, and collapse mechanism of the tested dome were examined. After the FE model was validated, the effects of the degrees and distributions of non-uniformity and rise-to-span ratios on the progressive collapse resistance under non-uniform loads were examined by a series of full-scale models. The results indicate that the failure mode of the tested dome subjected to the non-uniform load is a global collapse. The members connected to the failed joint and other members demonstrate the beam and compression mechanisms, respectively. For K6 domes, under the same mean loading condition (the change of snow height due to wind), the higher non-uniform degree causes a bigger structural response and leads to a lower collapse resistance; under the same maximum loading condition (snow melts locally due to temperature), although the maximum load has not changed and the total load is smaller, the non-uniform load can still result in unfavorable collapse for domes when the maximum load increases to a certain value, meaning that a dome is also dangerous when snow melts locally. Domes are most prone to collapse when the load is distributed non-uniformly along the ring direction (the settlement of snow accumulation), followed by the load distributed non-uniformly about radial members (the change of wind direction). Additionally, a dome with a smaller rise-to-span ratio under non-uniform loads collapses earlier.

References listed at the end of the paper:
5 GSA, Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects, General Services Administration, Washington DC (2013)
Concrete-filled steel tubular (CFST) columns have been used in the construction of modern structures such as high-rise buildings and bridges as well as infrastructures as they provide better structural performance than conventional reinforced concrete or steel members. Different shapes of CFST columns may be needed to satisfy the architectural and aesthetic criteria. In the study, three dimensional FE simulations of circular, square, hexagonal, and octagonal CFST stub columns under axial compression were developed and verified through the experimental test data from the perspectives of full load-displacement histories, ultimate axial strengths, and failure modes. The verified FE models were used to investigate and compare the structural performance of CFST columns with different cross-section shapes by evaluating the overall load-deformation curves, interaction stress-deformation responses, and composite actions of the column. The extent of the ultimate-axial-strength enhancement due to enhanced steel yield strength and concrete compressive strength was evaluated through the parametric studies. At last, the accuracy of available design models in predicting the ultimate axial strengths of CFST columns were investigated. Research results showed that the behaviors of hexagonal and octagonal CFST columns were generally similar to that of the square CFST column as their overall structural performance was relatively improved.

References listed at the end of the paper:

3 M. Dundu, Compressive strength of circular concrete filled steel tube columns, Thin-Walled Struct., 56 (2012), pp. 62-70
8 D. Lam, C.A. Williams, Experimental study on concrete filled square hollow sections, Steel and Composite Structures, 4 (2) (2004), pp. 95-112

ABSTRACT: Eurocode EN 1994-1-1 currently covers design of concrete-filled steel tubular (CFST) columns using normal strength materials with nominal steel yield strength ($f_y$) not more than 460 MPa and concrete characteristic cylinder strength less than 50 MPa. As high strength materials have been increasingly used in construction, this paper aims to extend current design equation for square and rectangular CFSTs in EN 1994-1-1 to incorporate high strength materials. A comprehensive experimental database consisting of 443 square and rectangular CFST stub column test results was developed. Statistical evaluations were undertaken and the results indicate that the current cross-section slenderness limit for square and rectangular CFSTs is too conservative and can be safely relaxed from $[math] to $[math]. The design equation could be extended to incorporate high strength materials). Then, a reliability analysis in accordance with EN 1990 was performed to evaluate the applicability of the proposed design method. It was found that the current partial factors are safe for the design of square and rectangular CFSTs with normal strength materials even after relaxation of the cross-section slenderness limit. However, modification should be applied to the existing design equation for the design of high strength materials to yield an acceptable safety level. Finally, an experimental investigation on 10 stub column tests was carried out to further verify the applicability of the proposed design recommendation. It was found that the proposed design recommendation yields satisfactory predictions when compared to test results.

References listed at the end of the paper:
3 J. Chen, Behaviour and Design of High Strength Circular Hollow and Concrete-Filled Tubular Stub Columns under Uniaxial Compression, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University (2020)
7 M. Tomii, K. Yoshimura, Y. Morishita, Experimental Studies on Concrete-Filled Steel Tubular Stub Columns under Concentric Loading, International Colloquium on Stability of Structures under Static and Dynamic Loads, American Society of Civil Engineers (ASCE), Washington, DC, USA (1977), pp. 718-741
10 A.H. Varma, Seismic Behavior, Analysis and Design of High Strength Square Concrete Filled Steel Tube (CFT) Columns, Lehigh University, Bethlehem, PA, USA (2000)
ABSTRACT: The structural stability of steel arches comprising Circular-Hollow-Sections (CHS) is examined in the present study. Appropriate finite element models are developed, accounting for geometry and material nonlinearities, as well as, incorporating residual stresses and geometric imperfections of roller-bent arches. A verification study is first performed to evaluate the accuracy of the proposed finite element modeling, followed by sensitivity analyses aiming at estimating the effects of residual stresses and geometric imperfections on the structural response. Findings reveal that the magnitude of geometric imperfections and the distribution of residual stresses significantly affect the arch's buckling resistance. An extensive parametric study is carried out to assess the spatial stability of arches comprising a wide range of non-dimensional slenderness, commonly encountered in the civil engineering practice. Based on the results of parametric analyses, suitable parameters are determined for the in-plane and out-of-plane buckling. Finally, stability criteria are proposed via regression analyses, which are used to define relevant buckling curves according to structural steel design standards.

References listed at the end of the paper:

5 C. King, D. Brown, Design of Curved Steel, The Steel Construction Institute, Berkshire, UK (2001)
7 B. Dowswell, Curved Member Design, American Institute of Steel Construction, Chicago, IL (2018)
24 AISC, Specification for Structural Steel Buildings, American Institute of Steel Construction, Chicago, IL (2016)

More papers published in the journal, Computers & Structures (2019 and on):
(See: http://www.sciencedirect.com/science/journal/00457949 )


ABSTRACT: Stiffened curved steel panels are increasingly used in structural applications in civil, naval and offshore engineering. Due to the incorporation of stiffeners these elements are able to withstand substantial loads with low material usage. However, design provisions to predict the strength of these elements are practically non-existent. The aim of this paper is to present a robust semi-analytical procedure for the prediction of the post-buckling behaviour of stiffened cylindrically curved steel panels under uniform uniaxial compression. The semi-analytical procedure is based on an orthotropic model with the number and geometry of the stiffeners properly taken into account. The procedure is based on nonlinear stability models based on large deflection theory incorporating initial imperfections and geometric nonlinearity. The problem is solved and the equilibrium paths are obtained through the Rayleigh-Ritz method. The validity of these computational models is assessed with the results of finite element analyses for different curvatures, aspect ratios, number and geometry of stiffeners yielding good results. Finally, a design-oriented closed-form expression is derived for the second-order elastic behaviour of the stiffened panels.

References listed at the end of the paper:
1 J. Paik, A. Thayamballi, B. Kim, Large deflection orthotropic plate approach to develop ultimate strength formulations for stiffened panels under combined biaxial compression/tension and lateral pressure, Thin-Wall Struct, 39 (3) (2001), pp. 215-246
3 R. Maquoi, C. Massonnet, Théorie non linéaire de la résistance postcritique des grandes poutres en caisson raidies, IABSE Publications (1971), pp. 91-140 [in French]
9 P. Ferreira, F. Virtuoso, Semi-analytical models for the post-buckling analysis and ultimate strength prediction of isotropic and orthotropic plates under uniaxial compression with the unloaded edges free from stresses, Thin-Wall Struct, 77 (2014), pp. 82-94
10 R. Jones, Buckling of circular shells with multiple orthotropic layers and eccentric stiffeners, Am Inst Aeronaut Astronaut J, 6 (12) (1968), pp. 2031-2305

ABSTRACT: In this paper, we present an effective plate formulation based on isogeometric analysis (IGA) and non-classical Kirchhoff plate theory for the study of static bending and buckling behaviors of nanoplates, taking into account microstructure and surface energy effects. In this setting, the modified couple stress theory is used to capture microstructure effect, while the Gurtin-Murdock surface theory is adopted to consider surface energy effect. The C-continuity requirement of the non-classical Kirchhoff plate theory is effectively fulfilled with the aid of inherent high-order continuity of non-uniform rational B-splines (NURBS), which serve as basis functions in IGA. Several numerical examples are presented to illustrate the effects of microstructure and surface energy on mechanical responses of nanoplates. The results reveal that microstructure and surface energy effects increase the nanoplate stiffness, which gives rise to a reduction in bending deflection and an increase in buckling loads. The surface energy effect becomes dominant for ultrathin nanoplates.

References listed at the end of the paper:

17 R. Valiev, Nanostructuring of metals by severe plastic deformation for advanced properties, Nat Mater, 3 (2004), pp. 511-516
18 A.C. Eringen, Nonlocal polar elastic continua, Int J Eng Sci, 10 (1) (1972), pp. 1-16
ABSTRACT: This paper presents a parametric reduced-order model (PROM) combined with component mode synthesis considering the interpolation and selection of substructural modes. For the interpolation-based PROM, mode crossing occurs depending on the change of parameter values. This problem is resolved by applying a congruence transformation to each mode. However, if there is a mode crossing between dominant and residual modes due to the mode selection following the frequency cut-off method, the interpolation of dominant substructural modes generates erroneous results, since there are missing modes at some operating points. In this study, we propose (i) to introduce an intermediate model in the offline stage of the ROM construction to decrease the interpolation error, and (ii) to select proper substructural modes by applying a mode selection criterion for the enhancement of the ROM accuracy, which is realized under the framework of dynamic substructuring. Since the intermediate model is used in the offline stage, there is little loss of efficiency in the online stage. Consequently, the characteristics of interpolation-based PROM is maintained, realizing a near real-time adaptation of the ROM. Various numerical examples, including dynamic response optimization with a high-dimensional parametric input space, are investigated to evaluate the performance of the proposed method.

References listed at the end of the paper:

2 A.K. Noor, Recent advances and applications of reduction methods, Appl Mech Rev, 47 (5) (1994), pp. 125-146
5 K.J. Bathe, J. Dong, Component mode synthesis with subspace iterations for controlled accuracy of frequency and mode shape solutions, Comput Struct, 139 (2014), pp. 28-32
8 D. Amsallem, C. Farhat, Interpolation method for adapting reduced-order models and application to aeroelasticity, AIAA J, 46 (7) (2008), pp. 1803-1813
9 R.R. Craig, M.C.C. Bampton, Coupling of substructures for dynamic analyses, AIAA J, 6 (7) (1968), pp. 1313-1319

13 S. Casciati, L. Faravelli, Quantity vs. quality in the Model Order Reduction (MOR) of a linear system, Smart Struct Syst, 13 (1) (2014), pp. 99-109
14 F. Casciati, L. Faravelli, Sensor placement driven by a model order reduction (MOR) reasoning, Smart Struct Syst, 13 (3) (2014), pp. 343-352
26 W.C. Hurty, A criterion for selecting realistic natural modes of a structure, Technical Memorandum, Jet Propulsion Laboratory, California (1967)
27 D. Givoli, P.E. Barbone, I. Patlashenko, Which are the important modes of a subsystem?, Int J Numer Methods Eng, 59 (2) (2004), pp. 1657-1678
31 J.G. Kim, On the finite element model reduction methods in structural dynamics [dissertation], Korea Advanced Institute of Science and Technology, Daejeon (2014)


ABSTRACT: Delamination is a frequent cause of failure in laminated structures, reducing their overall stiffness and hence their critical buckling loads. Delaminations tend to grow rapidly in postbuckling, causing further
reductions in structural strength and leading ultimately to sudden structural failure. Many studies have investigated the effects of delaminations on buckling and vibration of composite structures. Finite element analysis is often used to model complex geometries, loading and boundary conditions, but incurs a high computational cost. The exact strip method provides an efficient alternative approach using an exact dynamic stiffness matrix based on a continuous distribution of stiffness and mass over the structure, so avoiding the implicit discretization to nodal points in finite element analysis. However due to its prismatic requirements, this method can model damaged plates directly only if the damaged region extends along the whole length of the plate. This paper introduces a novel combination of exact strip and finite element analysis to model more complex cases of damaged plates. Comparisons with pure finite element analysis and a previous smearing method demonstrate the capability and efficiency of this hybrid method for a range of isotropic and composite plates. The effect of damage on the lowest natural frequency is studied.


ABSTRACT: The dynamic stiffness matrix for beams which exhibit coupling between axial and bending deformations is developed from first principle so that their free vibration analysis can be carried out in an accurate and efficient manner. The coupling between the axial and bending motion essentially arises due to non-coincident centroid and shear centre of the beam cross-section. The dynamic stiffness theory is developed first by deriving the governing differential equations of motion of the axial-bending coupled beam using Hamilton’s principle. The differential equations are then solved in closed analytical form giving expressions for axial and bending displacements as well as the bending rotation. The expressions for axial force, shear force and bending moment are obtained from the natural boundary conditions yielded by the Hamiltonian formulation. Finally, the dynamic stiffness matrix is developed by relating the amplitudes of the axial force, shear force and bending moment to the corresponding amplitudes of axial displacement, bending displacement and bending rotation. The ensuing dynamic stiffness matrix is applied to investigate the free vibration characteristics of a carefully selected axial-bending coupled beam. To this end, the Wittrick-Williams algorithm is used as solution technique. The results are discussed and validated with significant conclusions drawn.


ABSTRACT: In this paper, a new numerical method, named as the Free Element Collocation Method (FECM), is proposed for solving general engineering problems governed by the second order partial differential equations (PDEs). The method belongs to the group of the collocation method, but the spatial partial derivatives of physical quantities are computed based on the isoparametric elements as used in FEM. The key point of the method is that the isoparametric elements used can be freely formed by the nodes around the collocation node. To achieve a narrow bandwidth of the final system of equations, elements with a central node are recommended. For this purpose, a new 21-node quadratic element for 3D problems is constructed for the first time. Attributed to the use of isoparametric elements, FECM can result in more stable results than the traditional collocation method. In addition, the elements can be freely formed by local nodes, FECM has the advantage of mesh-free methods to fit complicated geometries of engineering problems. A number of numerical examples of 2D and 3D thermal and mechanical problems are given to demonstrate the correctness and efficiency of the proposed method.

Liping Duan and Jincheng Zhao (School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, China), “A geometrically exact cross-section deformable thin-walled beam finite element based on generalized beam theory”, Computers & Structures, Vol. 218, pp 32-59, 1 July 2019, https://doi.org/10.1016/j.compstruc.2019.04.001

ABSTRACT: A new nonlinear cross-section deformable beam formulation based on generalized beam theory (GBT) is presented for elastic/elastoplastic analyses of thin-walled members undergoing arbitrary deformations, such as large deflections, finite rotations, distortional/local buckling, and out-of-plane warping. For rigorous
numerical analyses of thin-walled structures, considering both the global and local deformation effects, shell finite elements are widely used. This paper aims at providing a more computationally efficient and structurally clarifying alternative to simulate prismatic and curved thin-walled members. Compared to the traditional beam elements and other beam formulations based on higher-order beam theories, we improved the kinematic description of member cross-section displacement field, where the kinematic parameterization is performed on two scales, i.e., global member scale and local wall scale; especially, the local wall deformations are described by means of the predetermined GBT modes which are structurally meaningful and allow for the cross-section deformations. Beam equations of equilibrium are built on the local wall scale in terms of shell-type stress resultants and stress couples; therefore, the present beam formulation owns the feature of a shell model. A Galerkin method based beam finite element is developed to solve the equilibrium equations. Finally, six illustrative examples are examined for the validity of the proposed beam formulation.


ABSTRACT: A locking-free hp-version finite element is presented for linear elasticity problems of thin shells of revolution. The constructed hp-finite element is based on a hybridized dual-mixed variational formulation. The related theoretical model does not rely on the standard hypotheses used in the Naghdi- and Koiter shell theories, thus the unmodified three-dimensional constitutive equation can be applied. Nevertheless, since employing its inverse form, the hp-shell finite element is incompressibility locking-free. Besides, neither the thickness variation nor the membrane stress normal to the shell mid-surface is not eliminated from the shell formulation, thus it can be extended to much complicated (contact) problems of more complex (composite), extremely thin and moderately thick shell structures. The new hp-shell finite element is tested through some representative mixed and pure boundary value problems, namely bending- and membrane dominated situations, for singly and doubly curved shells of negative and positive Gaussian curvature. From the convergence behavior of the relative errors it follows that the developed hp-version shell finite element is insensitive to the decrease of the thickness value, i.e., membrane and shear locking-free, providing excellent numerical results not only for the displacement- but also for the stresses computations.

Bo Zhang, Heng Li, Liulin Kong, Jizhen Wang and Huoming Shen (First author is from: Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong, China), “Strain gradient differential quadrature beam finite elements”, Computers & Structures, Vol. 218, pp 170-189, 1 July 2019, https://doi.org/10.1016/j.compstruc.2019.01.008

ABSTRACT: In this paper, the superiorities of finite element method (FEM) and differential quadrature method (DQM) are blended to construct two types of beam elements corresponding to modified strain gradient - Bernoulli and Timoshenko beam models respectively. The two elements, being independent of shape functions and introducing three kinds of strain gradient effects, possess 3-DOFs (degrees of freedom) and 4-DOFs separately at each node. The Lagrange interpolation formula is employed to establish the trial functions of deflection and or rotation at Gauss-Lobatto quadrature points. To realize the inner-element compatibility condition, displacement parameters of quadrature points are converted into those of element nodes through a DQ-based mapping strategy. Total potential energy functional for each beam model is discretized in terms of nodal displacement parameters. The associated differential quadrature finite element formulations are derived by the minimum total potential energy principle. Specific expressions of element stiffness and mass matrices and nodal vector are provided. Numerical examples concerning with static bending, free vibration and buckling of macro/micro-beams are presented to demonstrate the availability of the proposed elements.


ABSTRACT: A new n-noded polygonal plate element is proposed for the analysis of plate structures comprising of thin and thick members. The formulation is based on the discrete Kirchhoff Mindlin theory. On each side of the polygonal element, discrete shear constraints are considered to relate the kinematical and the independent shear strains. The proposed element: (a) has proper rank; (b) passes patch test for both thin and
thick plates; (c) is free from shear locking and (d) yields optimal convergence rates in $L^2$-norm and $H^1$-semi-norm. The accuracy and the convergence properties are demonstrated with a few benchmark examples.


ABSTRACT: Accurate and efficient response gradients are required in structural reliability, optimization, and system identification applications where the structural system is expected to yield under significant deformations. The direct differentiation method (DDM) is applied to the response sensitivity of displacement-based beam-column finite elements with geometric nonlinearity due to moderate rotations in the basic system. The derived sensitivity equations are implemented in the OpenSees software framework. Stand-alone sensitivity analyses using the DDM and finite difference method (FDM) validate the sensitivity equations for example structures with nonlinear static and dynamic response. Finite element reliability analysis of a steel frame shows that, relative to a geometrically linear formulation, using geometrically nonlinear displacement-based elements increases the probability of failure and affects the importance ranking of the random variables. In addition, for a performance function based on residual capacity at a target lateral displacement, the frame strength at the design point is higher than that obtained when using geometrically linear elements. The developed sensitivity equations increase the number of nonlinear finite element formulations available for gradient-based applications in structural engineering.


ABSTRACT: This paper presents a comprehensive study on developing advanced deep learning approaches for nonlinear structural response modeling and prediction. Two schemes of the long short-term memory (LSTM) network are proposed for data-driven structural seismic response modeling. The proposed deep learning model, trained on available datasets, is capable of accurately predicting both elastic and inelastic response of building structures in a data-driven fashion as opposed to the classical physics-based nonlinear time history analysis using numerical methods. In addition, an unsupervised learning algorithm based on a proposed dynamic K-means clustering approach is established to cluster the seismic inputs in order to (1) generate the least but the most informative datasets for training the LSTM and (2) improve the prediction accuracy and robustness of the model trained with limited data. The performance of the proposed approach is successfully demonstrated through three proof-of-concept studies that include a nonlinear hysteretic system, a real-world building with field sensing data, and a steel moment resisting frame. The results show that the proposed LSTM network is a promising, reliable and computationally efficient approach for nonlinear structural response prediction, and offers significant potential in seismic fragility analysis of buildings for reliability assessment.


ABSTRACT: Over the last decades, fiber composite materials have established themselves especially for problems in lightweight construction. In order to use the structure optimally, a precise knowledge of the maximum load-bearing capacity and possible damage to the structure is necessary. For the calculation of damage in fiber composite laminates, various damage models already exist. Classically, these models are applied within the finite element method (FEM). Localization effects occur which lead to a dependence of the results on the used FE-mesh.

This paper deals with the gradient extension of free Helmholtz energy using global damage variables to eliminate localization effects.

Based on the formulation of the regularized damage model of the single layer, the regularization is transformed into a layered theory for composite shell structures. The associated numerical model within the framework of FEM is explained before the model is illustrated with numerical examples.

ABSTRACT: To realize large-scale or high-resolution structural topology optimization design, a fully parallel parameterized level set method with compactly supported radial basis functions (CSRBFs) is developed based on both the uniform and non-uniform structured meshes. In this work, the whole computation process is parallelized, including mesh generation, sensitivity analysis, calculation and assembly of the element stiffness matrices, solving of the structural state equation, parameterization and updating of the level set function, and output of the computational results during the optimization iterations. In addition, some typical numerical examples, in which the calculation scale is up to 7 million 8-node hexahedral elements, are carried out for verifying the effectiveness of the proposed method. Finally, the computing time is also analyzed in detail. It is found that: (1) In the optimized structures, the thin sheet-like components gradually replace the truss-like ones when refining the mesh, (2) the parameterization process of the level set function will become fast as long as the non-uniformity of mesh is not very high and the supported radius of CSRBF is small enough, and (3) more than 80% of the total computing time is always consumed for solving the structural state equation during the finite element analysis (FEA).


ABSTRACT: In this paper, a new paradigm for Carrera’s Unified Formulation (CUF) based on multiscale structural modelling is accomplished by bridging micromechanics and the advanced CUF one-dimensionalbeam structural theories by means of the Multilevel Finite Element (also known as FE) framework. Under the framework of the FE method, the analysis is divided into a macroscopic/structural problem and a microscopic/material problem. At the macroscopic level, several higher-order refined beam elements can be easily implemented via CUF by deriving a fundamental nucleus that is independent of the approximation order over the thickness and the number of nodes per element (they are free parameters of the formulation). The unknown macroscopic constitutive law is obtained by numerical homogenisation of a Representative Volume Element (RVE) at the microscopic level. Vice versa, the microscopic deformation gradient is calculated from the macroscopic model. Information is passed between the two scales in a FE sense. The resulting nonlinear problem is solved through the Asymptotic Numerical Method (ANM) that is more reliable and less Newton-Raphson’s one. The developed models are used as a first attempt to investigate the microstructure effect on the macrostructure geometrically nonlinear response. The proposed paradigm is used for investigating the effect of microscale imperfections (not straight carbon fibres) on the macroscale response (instability). Results are assessed in terms of accuracy and computational costs towards full FEM solutions. Three factors have been considered for an imperfection sensitivity parametric analysis: the defect wavelength as well as the amplitude and the size of RVE.


ABSTRACT: Thin-walled orthotropic shell structures are used in various fields of engineering, and the process of their deformation is essentially non-linear, which significantly complicates their analysis. A technique for numerically investigation of the process of deformation of such structures under dynamic loading is proposed in this article. The computational algorithm is based on the L.V. Kantorovich method and Rosenbrock method for solution of a stiff ODE system.

A new variation of the mathematical model is based on the functional of total deformation energy, takes into account geometrical nonlinearity, transverse shears, orthotropy of the material, and rotational inertia, and may be used for a study of shells of different geometric forms. Dimensionless parameters are used. The proposed model and the use of mentioned methods allows to produce the most accurate calculations of the buckling of shell structures.

The applicability of this technique is shown: the results of calculations are given for orthotropic shallow shells of double curvature having a square base with cylindrical and conical panels. The load values are derived for
local and total stability loss, for structures made of four different materials. The effect of the rate of loading on the obtained values is shown.

ABSTRACT: Two novel explicit time integration methods are proposed based on displacement-velocity relations in this paper for structural dynamics. They avoid the factorization of damping and stiffness matrices, and are truly self-starting due to the exclusion of acceleration vectors. The first method employs the motion equation of expanded form and a linear relation of the displacement and velocity vectors. The recommended parameters, derived from linear analysis, enable the method to possess first-order accuracy mostly and second-order accuracy in the absence of numerical and physical damping. The second method adopts the idea of composite methods, and employs two motion equations of different expanded forms per step. Theoretical analysis indicates that this method can achieve a maximum stability limit of 4, and provides a single-parameter optimal scheme, controlled by the degree of numerical dissipation, for this method. The resulting scheme is second-order accurate with the stability limit ranged from 3.5708 to 4 for the undamped case, and some numerical experiments show that it has better numerical performance compared with some up-to-date explicit methods.

ABSTRACT: Free vibration analysis of large complex structures with improved Lanczos iteration method is investigated through the finite element method. An important step in the traditional Lanczos iteration method for large generalized eigenvalue problems arising from free vibration analysis is that large-scale sparse linear system must be repeatedly solved within each step of the Lanczos iteration, which generally accounts for 70% to 90% of the calculation time of the eigenvalue problems. In the improved Lanczos iteration method given here, three-level preconditioner is proposed and utilized to improve the computational performance of Lanczos iteration. In this way, the multifrontal block incomplete Cholesky (MFBIC) preconditioner and p-type multigrid preconditioner based on higher-order hierarchical basis functions are proposed and utilized to improve the computational performance and decrease the memory requirements. To further reduce the memory consumption, the block Jacobi preconditioner is introduced in the Lanczos iteration, and a new three-level preconditioner that combines MFBIC, p-type multigrid and block Jacobi is proposed. The accuracy and performance of the improved method has been compared with exact solution, basic method and ANSYS. It is shown that this free vibration analysis method can be extremely useful to design structure dynamic characteristics of large complex structures.

ABSTRACT: The paper provides the general construction principles of a type of composite time integration methods combining the trapezoidal rule (TR) and the backward differential formula (BDF) by discussing the effects of designable parameters on the properties of composite methods. The designable parameters include the number of sub-steps, the number of time difference points used in BDF and the methods used in sub-steps. Through respective changing these parameters, a series of novel composite time integration methods, such as T(2–5)BDF3 and OT3BDF4 and OTBDF3BDF methods etc., are constructed. It follows that increasing both the number of sub-steps and the number of time difference points can improve the low-frequency accuracy, and the composite methods with similar properties can be developed by using the same parameter optimization rules even though different methods are used in sub-steps. Linear and nonlinear numerical experiments are conducted to check the properties of the proposed methods through comparing with some of the existing composite time integration methods and validate the conclusions.

ABSTRACT: An efficiency of the perturbation-based approaches in comparison with semi-analytical symbolic derivation of the probabilistic moments and coefficients has been verified in this work. Truncated equivalents for the classical linearized and iterative perturbation-based schemes have been created to enable considering of random variable probability density function upper and lower bounds in stochastic perturbation scheme. Higher order Taylor expansions have been used also in the derivation of probabilistic characteristics to analyze probabilistic convergence of the perturbation schemes for non-polynomial structural responses. These computations have been completed using the Finite Element Method on the example of the structural state variables of axisymmetric spherical steel skeletal dome structures. Four basic different types (ribbed, Schwedler, geodesic as well as diamic) have been compared here in the context of time-independent reliability assessment in the presence of uncertainty in the structural steel Young modulus. Truncated iterative stochastic perturbation technique (TISPT) has turned out to be the most sufficient approach giving a global gain in the accuracy of the results with perturbation order increase, which is remarkably slower for higher probabilistic characteristics. The most appropriate results have been provided by using the same Taylor expansion of a given response function substituted into the subsequent probabilistic moments formulas.


ABSTRACT: This paper presents a sectional analysis tool which can compute the complete torque-twist behaviour of reinforced concrete beams and shells. The cross section is modelled as a 2-D grid of triaxial elements representing the concrete and uniaxial elements representing the longitudinal reinforcement. Fixed strain patterns based on kinematic assumptions are used instead of using the finite element method to calculate strain distributions corresponding to sectional strains. Constitutive models for the concrete are based on the Modified Compression-Field Theory, though tension stiffening is neglected in the proposed model’s current implementation. A key assumption used in this model is that the shear strain distribution caused by twists obtained from a linear elastic analysis can be used to describe the nonlinear behaviour of a member following cracking. The validity of this assumption when applied to rectangular sections is confirmed based on a study of 115 tests from the literature. Excellent agreement of peak strength and overall torque-twist behaviour are observed when comparing the model predictions and experimental data from these tests. Areas of future work are to improve the capabilities of the model are identified.


ABSTRACT: In this paper, we propose the strain-smoothed MITC3+ shell finite element. The membrane strain field of the continuum mechanics based 3-node triangular shell element (MITC3+) is smoothed using the recently developed strain-smoothed element (SSE) method. The strain-smoothed MITC3+ shell element passes basic tests (patch, isotropy and zero energy mode tests) and shows significantly improved membrane behavior in various numerical examples. The major advantage of the SSE method is that no additional degree of freedom is required for solution improvement.

P. Melo (1), R.F. Vieira (2) and F.B. Virtuoso (2)
(1) A2P Consult, Estudos e Projectos Lda, R. Acácio Paiva 27, 1700-004 Lisboa, Portugal
(2) CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
“A beam-column model for evaluating the effects of residual stresses and geometrical imperfections”, Computers & Structures, Vol. 223, Article 106090, 15 October 2019, https://doi.org/10.1016/j.compstruc.2019.06.007
ABSTRACT: A numerical model within the framework of the finite element method is developed in order to perform second order analyses of steel columns and beam-columns by considering geometrical and material nonlinearities, and taking into account residual stresses and initial geometric imperfections. The model considers a displacement based beam element and adopts a distributed-plasticity formulation for the implementation of the steel nonlinear behaviour together with a Newton-Raphson algorithm for the solution of the resulting nonlinear governing equations. The results obtained from the developed model are compared with the results in the literature that were adopted for the calibration of the formulae in Eurocode regarding the buckling resistance of columns and beam-columns. Thereafter, the model is adopted to evaluate the applicability/accuracy of these formulae regarding the corresponding safety check. A detailed evaluation of the buckling resistance of columns with tubular cross-sections is presented, namely in what concerns the effect of the relative position of the longitudinal fillet weld to the direction of the considered geometric imperfection.


ABSTRACT: Group theory has been used for many years to study phenomena in various branches of physics and chemistry, such as quantum mechanics, crystallography and molecular structure. Within engineering mechanics, it has found application in simplifying the analysis of systems exhibiting symmetry properties, and has been particularly effective in studying vibration, bifurcation and kinematic phenomena. Symmetry properties of physical systems are described by symmetry groups. Given a physical system with multiple symmetry properties, the question arises as to which of the various possible symmetry groups is the most appropriate for computational purposes. This question is particularly relevant for configurations belonging to symmetry groups of high order, which typically are associated with several subgroups. The aim of this paper is to highlight the computational implications of choice of symmetry group, and to present, for the first time, a rational criterion for identifying the most computationally efficient symmetry group for a given problem. The criterion is applied to the problem of a cubic configuration with octahedral symmetry.

Bing Zhao (1,2), Jianhui Hu (1), Wujun Chen (1), Jianwen Chen (3), Zhenyu Qiu (1) and Zhongliang Jing (2)
(1) Space Structures Research Center, Shanghai Jiao Tong University, Shanghai 200240, China
(2) School of Aeronautics and Astronautics, Shanghai Jiao Tong University, Shanghai 200240, China
(3) Department of Civil and Engineering, Nanjing University of Science and Technology, Nanjing 210094, China


ABSTRACT: Inflatable membrane structures with the advantages of light weight, large span, long duration and aesthetical appearance have gained considerable attentions from buildings, super-pressure balloons, airships and deployable antennas. This paper presents a novel computational method for in-situ finite element modeling of inflatable membrane structures based on geometrical shape measurement using photogrammetry for further structural analysis. Firstly, kinematic equations of membrane link structure simplified from the measured inflatable membrane structure are established on force equilibrium between membrane internal and external forces to calculate the tensile forces. Then, computational method for solving zero-stress state is proposed through unloading internal pressure based on equilibrium matrix theory. Finally, true finite element model is established through numerical simulation of reloading internal pressure with considering the zero-stress state as initial model. For verifying purpose, inflated forming and normal working tests of an ethylene-tetrafluoroethylene (ETFE) air-inflated cushion structure were carried out. By comparing geometrical shapes and stress distributions of ETFE cushion between numerical and experimental results, good agreements with 0.72% and 4.76% maximum errors are acquired. These findings strongly confirm the need of in-situ finite element modeling of inflatable membrane structures undergoing long-term service and provide an effective computational method for further structural analysis.

Samir Chawdhury and Guido Morgenthal (Bauhaus University Weimar, Institute of Structural Engineering, Chair of Modelling and Simulation of Structures, Marienstraße 13, 99423 Weimar, Germany), “A partitioned
ABSTRACT: A two-dimensional (2D) partitioned solver is extended for large-displacement fluid–structure interaction (FSI) simulations of thin plate systems, particularly to investigate their potential of aeroelastically driven vibration energy harvesting. The coupled solver is validated on benchmark large-displacement FSI problems such as flag-type flapping of cantilever plates in axial flow and Kármán vortex street. The validated solver is used further to perform a comparative study on different cantilever systems to obtain guidelines for the design of experimental set-ups of prototype harvesters. The changes in aerodynamic behavior and flapping pattern of inverted and T-shaped cantilevers with/without tip mass are investigated. The simulations are performed for increasing wind speeds until the permanent deflection mode occurs. The influences of damping ratios are analyzed as preliminary studies to investigate the electrical damping effects of harvesters. The influential parameters such as response amplitude and oscillating frequency are compared to identify not only efficient cantilever harvesters but also an appropriate combination of physical and electrical parameters depending on target wind speeds.


ABSTRACT: This article presents an evaluation of higher-order p-version plate elements in the mitigation of shear locking phenomenon in the analysis of multi-layered structures. Carrera Unified Formulation (CUF) is employed to construct the refined plate finite element models. The decomposition of strain energy components is introduced and used in the assessment of shear locking. The evolution of the displacement and stress solutions and the strain energy components with the increase of the polynomial degree of the p-version elements are reported. Reduced and selective integration techniques on p-version plate elements to alleviate locking are explored. Numerical results show that plain p-version plate elements with sufficient, higher-order shape functions are capable of mitigating shear locking effectively.


ABSTRACT: In this paper we derive a new finite element method for nonlinear shells. The Hellan–Herrmann–Johnson (HHJ) method is a mixed finite element method for fourth order Kirchhoff plates. It uses convenient Lagrangian finite elements for the vertical deflection, and introduces sophisticated finite elements for the moment tensor. In this work we present a generalization of this method to nonlinear shells, where we allow finite strains and large rotations. The geometric interpretation of degrees of freedom allows a straightforward discretization of structures with kinks. The performance of the proposed elements is demonstrated by means of several established benchmark examples.


ABSTRACT: In this paper, the Eulerian-Lagrangian-Lagrangian (ELL) method is extended to solve fluid-structure interaction (FSI) problem with a very thin flexible structure immersed in the fluid. Such a new approach overcomes the failure of the immersed finite element method (IFEM) in handling the FSI problem when a reduced solid model is used for the thin structure. In this work, a continuum-based (CB) beam theory is adopted to model the 2D flexible thin structure that undergoes large deformation. In the ELL approach, the solid meshes can always coincide with the Lagrangian fluid meshes in a so-called “composite solid” domain that allows the accurate imposing of the changing interface boundary conditions in the FSI zone. The proposed
The approach is verified using three benchmarking problems of flow over a flexible vertical beam, flow over a cylinder beam system and 2D flapping flag in the uniform flow. The results are compared with those from the open literature. Other numerical examples are also computed to demonstrate the effectiveness of the ELL method.


ABSTRACT: This paper is devoted to geometrically linear free vibrations of viscoelastic (VE) Mindlin plates. The governing equations are derived in the Laplace domain. A simple way to take into account the influence of temperature on the damping properties is included using the frequency-temperature superposition principle. The novel approach to the solution of the non-linear problem of free vibrations of VE plates significantly simplifies the procedure reducing it to a linear eigen-value problem and a simple algebraic non-linear equation with one unknown. Several numerical examples involving varying physical parameters of the model are solved and the results are discussed.

Ioannis Doltsinis (1), Michael Reck (1) and Vitor Dias da Silva (2)
(1) University of Stuttgart, Germany
(2) University of Coimbra, Portugal


ABSTRACT: Following the accomplishment of fundamental research on- and the development of improved spring models, this work investigates the utility of spring lattice models in representing actual structures. The study explores the applicability of spring lattice models for the analysis of nonlinear shell structures. Of importance the limits of the approximation of defective bar-spring models, on the one hand, and the attempt of a rigorous representation of the continuum by introducing additional spring elements, on the other hand. Preliminary investigations indicate appropriateness for membrane shells, but reveal weakness in modelling shells with bending stiffness by axial bar elements despite three-dimensional cell arrangements. Therefore the focus here is on membrane structures. A direct insight to the employed triangular spring cells is offered by the approach based on the natural description of the continuum suitting the individual geometry. The investigations address specifically the performance of the spring models when applied to problems involving geometrical and material non-linearity. For this purpose the spring models have been tested against the continuum finite element distinctly in elasticity and in plasticity in the context of large deformations. In addition, the effect of damage is simulated by means of a regularized constitutive model of softening plasticity.


ABSTRACT: The present work analyses the dynamic behaviour of constrained layer damping (CLD) plates with thick viscoelastic layer. The bending modes and transverse response of such plates are obtained by adapting the Kirchhoff–Love thin plate formulation so that it considers the shear stiffness by using a frequency dependent equivalent flexural stiffness. The developed formulation is introduced in a finite element model and compared to the widely used RKU model and a reference 3D solid model in terms of eigenpairs and amplitude of the response for different boundary conditions. It is concluded that the developed formulation can substitute either a 3D or RKU model as it requires less computational resources than the former and provides more accurate results than the latter.

Yan Zhang, Liang Gao and Mi Xiao (Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan, Hubei 430074, China), “Maximizing natural frequencies of inhomogeneous cellular structures by Kriging-assisted multiscale topology optimization”,

https://doi.org/10.1016/j.compstruc.2019.106185
ABSTRACT: This study presents a data-driven approach for developing a one-dimensional thin-walled beam model. In order to analyze complicated deformations occurring in a thin-walled beam by a beam theory, it is important to identify core cross-sectional deformations that are the bases for the one-dimensional beam analysis. In this study, we derive core cross-sectional deformations through data processing using the shell-based static analysis results of a thin-walled beam. We perform a principal component analysis for the data processing, in which the desired core cross-sectional deformations are obtained without specific assumptions pertaining to the behavior of the beam’s sectional deformations. Then, the core cross-sectional deformations can be obtained in explicit functional forms (shape functions) to facilitate the subsequent one-dimensional higher-order beam analysis. Important issues related to the establishment of a well-defined dataset are addressed. Using the data-driven shape functions, a series of static, vibration and buckling analyses are performed for various thin-walled beams. We demonstrate by numerical examples that the present data-driven results agree well with those obtained by shell analysis results. While the shape functions are obtained only from the static analysis results, the vibration and buckling analyses using them were also found to be sufficiently accurate.

ABSTRACT: Additive manufacturing is capable of producing lightweight structures by introducing mesoscale lattice structures in the design without significant additional manufacturing costs. Nevertheless, designing efficient structures including complex lattices remains a challenging task. This paper presents a strategy for the design of additively manufactured structures that is able to simultaneously optimize the shape of the macroscale structure and the functionally graded lattices inside this design. Assuming a separation of scales between the lattice cell size and the macroscale structure, an effective material model based on numerical homogenization is adopted to model the lattice behavior in the analysis of the macroscale structure. While this material model is parametrized by volume densities to mimic functionally graded lattices, the shape of the macroscale structure is represented by a level set function and modeled by the extended finite element method inside the design domain. By adopting an explicit approach to the level set optimization the design problem can be formulated as a single nonlinear programming problem which can be solved with standard optimization algorithms for topology optimization. The proposed formulation avoids degenerate lattice members by excluding small densities in the optimization. Furthermore, the distinct representation of the macroscale structure enables to easily include geometric constraints on the macroscale level such as a minimum feature size or other constraints specific to the additive manufacturing process. The effectiveness of the method is demonstrated in a number of examples.

Jianghuai Li (1), Zhiyu Shi (1), Lei Liu (2) and Chongmin Song (2)
(1) Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
(2) School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW 2052, Australia


ABSTRACT: This paper develops an efficient modeling technique based on the scaled boundary finite element method (SBFEM) for transient vibro-acoustic analysis of plates and shells. For simulating the structural dynamic behaviors, a novel shell formulation based on three-dimensional linear elastic theory is presented where only the bottom surface of the shell is discretized with finite elements while the solution along the thickness is expressed analytically as a Padé expansion. A new scaling idea named normal scaling strategy is introduced to enable the formulation to be applicable to geometrically arbitrary shells. The acoustic field is assumed to be infinite and first truncated by a spherical surface into an interior finite region and an exterior unbounded region. The former is further split into a number of bounded subdomains which are analyzed by the improved continued-fraction approach while the latter is simulated by the improved high-order doubly-asymptotic open boundary. These formulations are consistently constructed within the SBFEM framework. The structural and acoustic domains are discretized independently and a simple and reliable coupling scheme is devised. The Bathe time integration method is employed to perform the transient analysis. Numerical examples are presented to demonstrate the validity and performance of the proposed methodology.


ABSTRACT: This paper presents a multiobjective optimization approach to minimize weight and maximize modal damping in laminated composite panels with Constrained Layer Damping (CLD) treatments. The design variables are the number and position of the CLD patch treatments on the surface of the laminated plate. The Direct MultiSearch (DMS) solver for multiobjective optimization problems is used in this work. DMS is a solver which does not use any derivatives of the objective functions. A previously developed finite element model for sandwich plates with viscoelastic core and anisotropic laminated face layers is adapted to model the plate with the CLD treatments. Applications for L-shaped and T-shaped plates are presented and both trade-off
Pareto optimal fronts and the respective treatment configurations are obtained and the results are analyzed and discussed.


ABSTRACT: A hierarchic optimisation approach is presented for relieving inaccuracies in conforming shell elements arising from locking phenomena. This approach introduces two sets of strain modes: (i) objective strain modes, defined in the physical coordinate system, and (ii) corrective strain modes, representing conforming strains enhanced with hierarchic strain modes. This leads to two alternative families of element, objective and corrective, both arising from minimising the difference between objective and corrective strains. Importantly, the proposed approach not only alleviates shear and membrane locking, but it also addresses locking arising from element distortion. The application of the proposed optimisation approach is demonstrated for a 9-noded quadrilateral Lagrangian shell element, where the membrane, bending and transverse shear strains are separately optimised, all within a local co-rotational framework that extends the element application to geometric nonlinearity. Several numerical examples, including cases with geometric and material nonlinearity, are finally presented to illustrate the effectiveness of the optimised 9-noded shell element in relieving the various sources of locking.


ABSTRACT: Depending on the required solution, this paper presents results for the state of stress and buckling of a uniformly pressurized elastic toroidal vessel of four segments. In the first part of the paper, a closed-form stress solution is formulated for the novel shell form, by adopting the membrane solution as the particular solution of the Reissner-Meissner general bending-theory equations, and an approximate bending solution is used to quantify discontinuity effect at the shell junctions. In the second part of the paper, linearized stability equations are formulated and simplified for the segmented toroidal vessel buckling problem. The membrane results obtained in the first part is used to predict the pre-buckling state and the stability equations are approximately solved for the segments in the middle regions of the toroidal vessel, using the Galerkin’s scheme. This leads to an expression for estimating the critical buckling pressures of pressurized isotropic toroids. Numerical results from the proposed methods are presented and compared with those from a finite element method solution.


ABSTRACT: The current paper presents the formulation of stochastic B-spline wavelet on the interval (BSWI) based wavelet finite element method (WFEM) for beams wherein, the spatial variation of modulus of elasticity is modelled as a homogeneous random field. Stochastic beam element formulations based on both Euler-Bernoulli beam theory and Timoshenko beam theory are proposed. BSWI scaling functions are used for the discretization of the random field and the response statistics are obtained using the perturbation approach. Numerical examples are solved and the results from perturbation approach are compared with that obtained from Monte Carlo simulation (MCS). A parametric study is also done to understand the effect of different coefficient of variation (CV) values and correlation length parameters on the response statistics. The study concludes that the proposed BSWI WFEM based perturbation approach for beams produce accurate response statistics for values of CV less than 15%. A comparative study is carried out between the results obtained from
the proposed stochastic WFEM with stochastic finite element method (SFEM) wherein the random field
discretization is done using Lagrange shape functions. Furthermore, normalized computational times for the
execution of perturbation approach and MCS based on WFEM are evaluated and compared with those obtained for SFEM.

Kyoichi Nakashino, Arne Nordmark and Anders Eriksson, “Geometrically nonlinear isogeometric analysis of a
partly wrinkled membrane structure”, Computers & Structures, Vol. 239, Article 106302, 15 October 2020,
https://doi.org/10.1016/j.compstruc.2020.106302
ABSTRACT: An isogeometric membrane element based on the non-uniform rational basis spline (NURBS)
model is presented that accounts for membrane wrinkling based on tension-field theory. First, the element is
validated by means of a benchmark problem involving a partly wrinkled membrane. It is then applied to the
large deformation of a thin membrane structure using a two-stage procedure that combines dynamic relaxation
and Newton–Raphson iteration. A simple technique is introduced that takes advantage of the geometrical
symmetry of an isogeometric analysis model by using a “one-sided” open knot vector to treat the continuity of
the membrane surface with respect to the symmetry plane. Because NURBS has many suitable features for
representing complex geometries, it enriches the function space of the membrane element. Consequently, the
characteristic mechanical responses of membranes, such as deep folding, are captured appropriately by the
present isogeometric membrane element. In addition, a numerical example demonstrates that the convergence
rate of the isogeometric membrane analysis with respect to refinement of the discretization is much better when
tension-field theory is introduced in the analysis.

Gokhan Serhat, Mirmeyasam Rafiei Anamagh, Bekir Bediz and Ipek Basdogan, “Dynamic analysis of doubly
curved composite panels using lamination parameters and spectral-Tchebychev method”, Computers &
ABSTRACT: Efficient modeling and optimization techniques are required to overcome the high design
complexity and computational costs concerning the engineering of composite structures. In this paper, a
modeling framework for the dynamic analysis of doubly curved composite panels is developed. Lamination
parameters are used to characterize the stiffness properties of the laminate, and the responses are calculated
through the two-dimensional spectral-Tchebychev method. The proposed framework combines the
computational efficiency advantages of both lamination parameters formulation and spectral-Tchebychev
method which is extended for dynamic analysis of curved composite laminates. Compared to the finite element
method, the developed model significantly decreases the computation duration, thereby leading to analysis
speed-ups up to 40 folds. In the case studies, fundamental frequency contours for the doubly curved composite
panels are obtained in lamination parameters space for the first time. The results show that, unlike flat or singly
curved laminates, the maximum frequency design points for doubly curved panels can be inside the feasible
region of lamination parameters requiring multiple layer angles. The fundamental mode shapes for the
maximum frequency designs are also computed to investigate the influence of panel curvatures on the vibration
patterns, which can exhibit mode switching phenomenon.

Yao Chen, Linzi Fan, Yongtao Bai, Jian Feng and Pooya Sareh, “Assigning mountain-valley fold lines of flat-
foldable origami patterns based on graph theory and mixed-integer linear programming”, Computers &
ABSTRACT: Traditional origami design is generally based on designers’ artistic intuition and skills,
mathematical calculations, and experimentations, which can involve challenges for crease patterns with a large
number of vertices. To develop novel origami structures for engineering applications, systematic and easy-to-
implement approaches capable of generating diverse origami patterns are desired, without requiring extensive
artistic skills and experience in origami mathematics. Here, we present a computational method for
automatically assigning mountain-valley fold lines to given geometric configurations of origami structures. This
method is based upon a geometric-graph-theoretic representation approach combined with a graph-theoretic
cycle detection algorithm, taking the subgraphs of a given structure as inputs. Then, a mixed-integer linear
programming (MILP) model is established to find flat-foldable origami patterns under given constraints on the
local flat-foldability and degree of vertices, leading to the identification of crease lines associated with local
minimum angles. Numerical examples are presented to demonstrate the performance of the proposed approach for a range of origami structures with degree-4 or -6 vertices represented by their corresponding subgraphs.


ABSTRACT: This paper presents a comprehensive numerical finite element implementation of the nonlocal strain gradient theory applied to thin laminated composite nanoplates using Kirchhoff theory (known as Classical Laminated Plate Theory or CLPT). Hermite interpolation functions are used to approximate membrane and bending degrees of freedom according to the conforming and nonconforming approaches. To the best of the authors’ knowledge, there is no finite element formulation in the literature able to deal with laminated Kirchhoff plates including the strain gradient theory, which allows to consider general stacking sequences and boundary conditions. A simple and effective matrix notation is employed to facilitate the computer implementation. Benchmarks reported prove the accuracy of the implementation. Novel applications are provided for further developments in the subject.


ABSTRACT: In this study, a novel scheme for modelling and analysis of spot-welded shell structures is presented by placing local spider-web shell meshes representing the weld nugget region in a global shell mesh. Interface shell elements are employed for trimmed shell elements with arbitrary number of nodes created by cutting a global shell mesh with the boundaries of local spider-web shell meshes. Transverse shear and membrane locking phenomena in interface shell elements are effectively alleviated by introducing assumed natural strain fields. Conventional elastic beam elements with six degrees of freedom are used to connect the center nodes of local spider-web shell meshes. The present method can construct high-quality shell meshes around spot welds without any global remeshing, which makes it very efficient and effective for the analysis of spot-welded shell structures.


ABSTRACT: Adaptive growth method is a structural topology optimization approach based on the growth mechanism of natural biological branching systems, and it has been successfully applied for the static reinforcement of three-dimensional box structures. However, due to the effect of structural characteristics towards natural frequencies, it is difficult for adaptive growth method to effectively grow stiffeners inside three-dimensional box structures considering dynamic performance. And this paper proposes an improved version of adaptive growth method to solve this problem. Firstly, apart from the growth mechanism of natural branching systems in the initial adaptive growth method, the morphology of root tips is introduced into the growth process of internal stiffeners. The thickness of stiffeners during the optimization can be divided into four different zones: initial thickness zone, immediate thickness zone, allowable thickness zone and maturation zone. Then, a material interpolation scheme with different thickness zones is introduced to simultaneously penalize the elastic modulus and density of material of internal stiffeners according to their thicknesses. By applying this bio-inspired method, obstacles of the ground structure in dynamic design of stiffeners in three-dimensional box structures can be effectively eliminated. And notably, the internal stiffeners can successfully grow from “seed lines” and gradually bifurcate or degenerate along the optimal direction to improve the natural frequencies of structures with a clear layout pattern. Finally, the effectiveness and advantages of the proposed method are illustrated by several numerical examples.

ABSTRACT: The analysis of three-dimensional (3D) stress states can be complex and computationally expensive, especially when large deflections cause a nonlinear structural response. Slender structures are conventionally modelled as one-dimensional beams but even these rather simpler analyses can become complicated, e.g. for variable cross-sections and planforms (i.e. non-prismatic curved beams). In this paper, we present an alternative procedure based on the recently developed Unified Formulation in which the kinematic description of a beam builds upon two shape functions, one for the beam’s axis, the other for its cross-section. This approach predicts 3D displacement and stress fields accurately and is computationally efficient in comparison with 3D finite elements. However, current modelling capabilities are limited to the use of prismatic elements. As a means for further applicability, we propose a method to create beam elements with variable planform and variable cross-section, i.e. of general shape. This method employs an additional set of shape functions which describes the geometry of the structure exactly. These functions are different from those used for describing the kinematics and provide local curvilinear basis vectors upon which 3D Jacobian transformation matrices are produced to define non-prismatic elements. The model proposed is benchmarked against 3D finite element analyses, as well as analytical and experimental results available in the literature. Significant computational efficiency gains over 3D finite elements are observed for similar levels of accuracy, for both linear and geometrically nonlinear analyses.

ABSTRACT: This paper addresses the free-vibration response of structures coupled with periodically-distributed resonators, generally referred to as locally-resonant structures. The first step is to show that all exact natural frequencies can be calculated by a proper formulation of the Wittrick-Williams algorithm, involving a condensed dynamic stiffness matrix whose size depends only on the number of degrees of freedom of the structure and is independent of the number of degrees of freedom within every resonator. Indeed, the presence of resonators is accounted for in the condensed dynamic stiffness matrix via a pertinent frequency-dependent stiffness, readily obtainable from the resonator motion equations. Within this framework, a novel procedure is proposed to construct the condensed dynamic stiffness matrix of locally-resonant plates, applicable for any number of resonators. Numerical applications show the exactness of the proposed formulation.

ABSTRACT: Research on the control of wave propagation has received continuous attention due to its potentially rewarding applications in the past decades, and numerous methods have been developed for controlling wave propagation in certain materials or structures. Despite previous work has made many innovations in controlling wave propagation, they are limited to the research from a band gap perspective. Herein, this paper presents a gradient-based multi-functional topology optimization for controlling wave propagation in a one-dimensional (1D) structure, which can realize the control of wave propagation from two aspects: band gap and wave propagation speed. To illustrate the method, three case studies are investigated to obtain the following: (1) increasing the band gap width, (2) controlling the wave propagation at target speed, and (3) limiting the propagation of low-frequency waves. By evaluating the results of three case studies, the effectiveness of the proposed topology optimization method is demonstrated. More importantly, the control of wave propagation in the low-frequency range in Case III lends new insight into the vibration isolation structure in engineering applications.

ABSTRACT: The paper presents a locking-free four-node element for laminated composite and sandwich plates based on Refined Zigzag Theory (RZT). Initially, two RZT-based plate elements are derived using four-node and eight-node configurations, achieved by way of standard C° isoparametric shape functions. In addition, with a view on improving the modelling of extremely thin plates, an anisoparametric four-node element is
developed in which the transverse deflection variable is interpolated using quadratic polynomial shape functions, whereas the remaining kinematic variables are bilinear. A straightforward transverse-shear edge-constraint procedure gives rise to a four-node anisoparametric element. A further enhancement is achieved using an Element Shear Correction (ESC) factor that is derived from a strain-energy matching procedure. The resulting four-node element (ZQ4c) uses full Gauss quadrature, consistent load vector, and mass matrix. Furthermore, the ZQ4c stiffness matrix has no spurious zero-energy modes, and the element is extremely robust when modelling ultra-thin plates. Several numerical studies are carried out to demonstrate the predictive capabilities of the four elements examined in this investigation. It is concluded ZQ4c is a highly accurate element over a wide range of material systems and span-to-thickness ratios, and is the best performing element of the four elements examined in this study.

References listed at the end of the paper:


12 M. Di Sciuva, Multilayered anisotropic plate models with continuous interlaminar stresses, Compos Struct, 22 (1992), pp. 149-167, 10.1016/0263-8223(92)90003-U

13 M. Di Sciuva, A general quadrilateral multilaminated plate element with continuous interlaminar stresses, Comput Struct, 47 (1993), pp. 91-105, 10.1016/0040-2211(93)90282-1


17 R.C. Averill, Static and dynamic response of moderately thick laminated beams with damage, Compos Eng, 4 (1994), pp. 381-395, 10.1016/S0925-8388(09)2822-0


23 M. Gherlone, On the use of zigzag functions in equivalent single layer theories for laminated composite and sandwich beams: a comparative study and some observations on external weak layers, J Appl Mech, 80 (2013), 10.1115/1.4023690

31 A. Tessler, Refined zigzag theory for homogeneous, laminated composite, and sandwich beams derived from Reissner’s mixed variational principle, Meccanica, 50 (2015), pp. 2621-2648, 10.1007/s11012-015-0222-0
33 L. Iurlaro, M. Gherlone, M. Di Sciuva, A. Tessler, Refined Zigzag Theory for laminated composite and sandwich plates derived from Reissner’s Mixed Variational Theorem, Compos Struct, 133 (2015), pp. 809-817, 10.1016/j.compstruct.2015.08.004
37 M. Di Sciuva, M. Gherlone, L. Iurlaro, A. Tessler, A class of higher-order C0 composite and sandwich beam elements based on the refined zigzag theory, Compos Struct, 132 (2015), pp. 784-803, 10.1016/j.compstruct.2015.06.071
41 M. Di Sciuva, M. Sorrenti, A family of C0 quadrilateral plate elements based on the refined zigzag theory for the analysis of thin and thick composite laminate and sandwich plates, J Compos Sci, 3 (2019), p. 100, 10.3390/jcs3040100
42 M. Gherlone, Tria and quad plate finite elements based on RZT(m) for the analysis of multilayered sandwich structures, Compos Struct, 220 (2019), pp. 510-520, 10.1016/j.compstruct.2019.04.032

ABSTRACT: In this paper, an efficient time domain formulation is proposed for computing time history dynamic responses of 2D structures, i.e. various types of trusses and frames. Unlike the methods using frequency domain, the proposed method employs the time weighted residual approach to solve the governing differential equations of the axial and flexural wave propagation problems, directly in time. Upon choosing the time step, the solution procedure begins with expressing the variation of axial and transverse displacement components, through the member’s length, as the summations of Fourier exponential basis functions in each time step. The unknown coefficients of the next steps are computed by the implementation of recurrent relations obtained based on a pre-integration process. The equilibrium and necessary continuity conditions at the common nodes/joints of adjacent elements are also fulfilled by introducing an innovative concept utilizing source functions. The role of these source functions is to simulate the boundary effects of the axial and flexural waves propagating within the structural members, simultaneously. The efficiency of the method is demonstrated in the dynamic analysis of some samples of truss and framed structures in terms of accuracy and computational time.


ABSTRACT: Due to the inherent uncertainties in various systems, deterministic approaches may not be able to satisfactorily characterize their response. In such cases, stochastic approaches that can systematically consider uncertainties have to be employed. In the past, many stochastic finite element analysis (SFEA) methods have been developed for uncertainty quantification (UQ), among which the perturbation methods, intrusive and non-intrusive polynomial chaos expansion (IPCE/NIPCE) methods and stochastic collocation (SC) methods have received considerable attention. However, in mechanics, most of the applications of these methods are confined to relatively simple problems, and the applicability and performance of these methods to complex nonlinear mechanics problems are not clear. To this end, this study carried out an investigation on the performance of different SFEA methods in linear and nonlinear problems. Numerical studies show that the NIPCE and SC methods are superior in terms of accuracy among other methods in the linear elastic case. The NIPCE method is also used for UQ in stochastic models with plasticity and nonlocal elastoplastic damage. The results demonstrate that the stochastic averages can be significantly different from the deterministic results, which indicates the necessity of considering UQ for improving response predictions.


ABSTRACT: Large-scale liquid storage tanks are used worldwide for storing water, chemicals and fuels, such as liquefied natural gas (LNG) and oil. Any major damage due to man-made or natural hazards, such as earthquakes, to these critical infrastructures would cause serious socio-economic losses and devastating environmental consequences. Moreover, they should remain functional even after a severe earthquake to support restoration actions, thus, their robust and optimal seismic design is deemed necessary. For this reason, base isolation is generally considered as a highly efficient technique for their seismic protection. Elastomeric bearings, such as lead-rubber bearings (LRB), high damping rubber bearings (HDRB) and friction bearings: single friction pendulum bearings (SFPB), double friction pendulum bearings (DFPB) and triple friction pendulum bearings (TFPB) have been used. In this work, the focus is given on the sizing optimization of the
main parameters of SFPB and TFPB isolators. For this reason, efficient swarm intelligence optimization algorithms are used to derive optimal friction coefficient and radius of curvature values that enhance the dynamic performance of a base-isolated liquid storage tank. The main objective of the proposed formulation is to minimize the accelerations transmitted to the superstructure, while constraints related to damping and vibration period of the system are imposed.

Computers & Structures, Vol. 243, Article 106407, 15 January 2021,

More papers published in the journal, International Journal of Solids and Structures


ABSTRACT: Through a combination of direct measurement and inverse modelling, a route to characterising the main mechanical forming properties of engineering fabric is demonstrated. The process involves just two experimental tests, a cantilever bending test and a modified version of the uniaxial bias extension test. The mechanical forming properties of a twill weave carbon fabric have been determined, including estimates of the in-plane bending stiffness and the torsional stiffness of the sheared fabric. As a result of measuring and incorporating all the main mechanical properties of the fabric in forming simulations (tensile, shear, out-of-plane bending, in-plane bending & torsion), the specimen size-dependent shear kinematics and wrinkling response measured in experiments, is faithfully reproduced in simulations of the uniaxial bias extension (UBE) test.


ABSTRACT: The response of paper to humidity variations is a complex, inherently multi-scale problem. The hygroscopic swelling of individual fibres and their interactions within the fibrous network govern the macroscopic, sheet-level response. At this scale, moisture induced instabilities and out-of-plane deformations may occur, which are critical for a number of industrial applications. This work specifically focuses on several aspects of this important issue. A macroscopic phenomenological hygro-mechanical model is first proposed, which aims at predicting moisture induced out-of-plane deformations in paper sheets. The constitutive model is based on the relation between these deformations and typical irreversible phenomena associated to the history of paper manufacturing, i.e. the release of dried-in strains. The model is used to describe bending induced by moisture gradients through the thickness of the sheet as well as buckling due to moisture variation in the presence of mechanical constraints. The results of the model show that the anisotropic sheet-level hygro-expansion has a strong influence on the instability phenomena. Moreover, a comparison with experiments provides adequate semi-quantitative estimates. An additional step is made towards the multi-scale understanding of paper hygro-mechanics. The fundamental physical mechanisms governing the macroscopic moisture induced response are investigated on the basis of the underlying fibrous network. To this aim, a meso-structural model is developed which consists of a network of fibres randomly positioned in a planar region according to an orientation probability density function. A series of network simulations reveals that upon moisture content variations the expansion of the inter-fibre bonding regions essentially drives the overall deformation. Particularly in the case of anisotropic fibre orientation, this explains the origin of the macro-scale anisotropic hygro-expansion, which is essential for the observed sheet-level instability phenomena.

ABSTRACT: This paper proposes a new method for predicting the compression behaviour of 2D woven fabrics during the consolidation phase of Liquid Composite Moulding processes. A kinematic, multi-chain beam finite element method is first used to simulate the evolution of the internal architecture of a 2D woven fabric during single and multi-layer compaction processes. A hyper-elastic constitutive model, based on the compressive response of a single yarn, is then proposed and implemented into a finite element framework for analysis of the mechanical loading of the dry fabric. This utilises as-woven fabric geometries generated by the kinematic models, thus enabling predictions to be independent of detailed geometric and mechanical characterisation of physical fabric specimens. The model’s ability to predict both the kinematic and mechanical response of the fabric, under compressive loads, is assessed by comparing the model outputs with X-ray Computed Tomography (CT) scans and the experimentally measured compaction response.

References listed at the end of the paper:
27 P. Potluri, T.V. Sagar, Compaction modelling of textile preforms for composite structures, Compos. Struct., 86 (2008), pp. 177-185

ABSTRACT: Wrinkling is to be avoided in the restoration of works on canvas. In the worst cases, it may lead to paint cracking. Visual rendering of the paint may also change because of such mechanism. It is proposed to measure wrinkling under various conditions of contrast and loading via isogeometric stereocorrelation. This method allows low contrasted paints to be analyzed in addition to very large deformations that occur in punch tests on canvas.


ABSTRACT: This paper introduces a shell based finite element (FE) model for predicting the impact response and dominant failure mechanisms of fiber reinforced polymer matrix composites subject to low-velocity impact. The model utilizes Enhanced Schapery Theory (EST) for capturing the matrix non-linearity due to micro cracking as well as macroscopic intra-lamina failure, that is, matrix cracking and fiber rupture in the 1–2 failure plane of a lamina. Discrete cohesive elements (DCZM) are utilized for capturing the inter-lamina failure initiation and propagation. The intra- and inter-lamina damage and failure models are implemented as user subroutines in the commercial finite element solver, ABAQUS Explicit. The model is compared against low-velocity impact experimental data. High fidelity non-destructive inspection (NDI) methods are used to quantify the impact damage for a detailed comparison to the model predictions. The modeling technique shows excellent agreement with experimental results, both for impact response and damage evolution.


ABSTRACT: In this paper, a continuum shell based finite element (FE) model is introduced to predict the impact and compressive strength after impact (CSAI) response of fiber reinforced polymer matrix composite (FRPC) laminates of various traditional and non-traditional layup orientations. The FE model predicts the impact damage in the laminate. The impact results are then directly used to predict the CSAI of the structure. The model uses in-plane progressive damage and failure modeling coupled with discrete cohesive elements to capture the necessary failure mechanisms. Enhanced Schapery Theory captures the non-linearity due to matrix micro cracking as well as macro intra-lamina matrix cracking and fiber failure. Discrete cohesive elements are implemented to capture the inter-lamina failure initiation and propagation (delaminations). The numerical predictions are compared against impact and CSAI experimental data for composite laminates of various layups. A high quality post-impact inspection using ultrasound and micro-computed tomography (microCT) scanning was utilized for detailed comparison between model results and experiments. The modeling technique was seen to be highly capable of predicting the impact response and CSAI of multiple different stacking sequences using a general mesh.


ABSTRACT: This paper describes experiments and analysis of the complete post-buckling behavior of shallow geodesic lattice domes. Although individual members are straight, their geometric arrangement approximates a curved surface and typical behavior is highly nonlinear, including the possibility of sudden jumps in which
there may be multiple discontinuous pops from one equilibrium configuration to another. A number of shallow domes were produced using a 3D printer and tested using a load cell and proximity laser sensor. In contrast to most previous studies, rather than pinned or semi-rigid joints, the lattices studied here incorporate moment-transmitting joints and clamped boundary conditions at the perimeter. Thus, flexure is the dominant mode of deformation under lateral loading and coupled instability behaviors are possible in practice. The complete load-displacement relationship and multiple equilibrium configurations are exhibited both in experiment and in simulation. The experimental data shows a close correlation with nonlinear finite element analysis using path-following techniques. A typical member (coupled) buckling behavior and its influence on the critical load are presented. Conclusions are drawn with respect to symmetry and geometric sensitivity.


ABSTRACT: The suggested before energy barrier criterion for design buckling pressure is extended to the case of clamped shallow spherical caps. It is developed for shells with geometrical imperfections and a new adjusted formula is obtained for design buckling load of imperfect structures. The method is applied to shells with elastic-perfectly plastic material. It is validated by experimental data and proved by numerical analysis based on finite element method. Calculation results were obtained and analysed for different values of shell geometrical parameter. A simple formula for design buckling pressure is suggested and validated.


ABSTRACT: In the present paper a general parameterization of a periodic hexagonal honeycomb with double vertical walls (commercial honeycomb) is proposed and a new analytic model is established. More attention is paid to account for the radius of curvature of the inclined walls, the adhesive layer thickness, and adhesive fillet at nodes. Then, neglecting the skin effect, in plane elastic constants is obtained analytically using the beam theory. The deformation mechanisms of the honeycomb cells include flexure, stretching, shearing and hinging. The mechanism of hinging is included through small fictitious beams in order to balance the local effects which cannot be captured using the beam theory. Hinging can be neglected when the thickness of these beams becomes infinite or optimally chosen by a proper thickness as to minimize the cumulative errors of the analytical assumptions. The new analytic model presented in this paper can be particularized to the extended Balawi and Abot model if some parameters are adequately modified. The finite element modeling of a representative volume element is used for model calibration and validation considering different relative densities of real honeycombs. The numerical results obtained as a reference for the effective elastic constants are discussed by comparing them to the ones given by the analytic model; its advantages and pitfalls are discussed and explained through a case study and some sensitivity analyses. Numerical simulations are also done in order to establish the distribution of the stresses in cell walls and nodes to confirm the hypotheses used for determining the analytical relations and to explain some limits of the analytic model. The results provide new insights into understanding the mechanics of honeycombs and facilitate the design of new types of cellular materials, including composite hexagonal cell cores.


ABSTRACT: Instabilities of bilayered systems with a thin layer on top of a thick substrate have been extensively studied throughout the past decade; yet, the general instability of a thin layer embedded in a matrix with different stiffnesses above and below the layer remains underinvestigated. Here, we characterize the shape instability of a layer embedded in an inhomogeneous matrix of infinite size using linear stability analysis. The layer and the matrix above and below it are composed of three different incompressible neo-Hookean materials subjected to unidirectional plane strain compression. We characterize the critical strain beyond which wrinkling occurs for varying shear moduli of the three materials. For the special case of a homogeneous matrix, a study of the serpentine and pinched modes of wrinkling reveals that serpentine wrinkling is associated with a selected
wavelength if the layer is stiffer than the matrix, whereas no finite wavelength is found in the linear regime for the pinched mode.


ABSTRACT: A Ritz approach for the analysis of buckling and post-buckling of plates with through-the-thickness cracks is presented. The plate behavior is described by the first order shear deformation theory and von Karman’s geometric nonlinearity. The admissible functions used in the displacements approximation are series of regular orthogonal polynomial supplemented with special functions able to describe the discontinuity across the crack and the singularity at the crack tips; boundary functions are used to fulfill the homogeneous essential boundary conditions. Convergence studies and analysis results are presented for buckling and post-buckling of plates with a central through-the-thickness crack evidencing differences in the structural response between pre- and post-buckling regimes, which can substantially affect the plate residual strength. The performed analyses show the efficiency and potential of the method, which provides accurate results in conjunction with a reduced number of degrees of freedom and simplified data preparation.


ABSTRACT: In this paper we study, using finite element simulations, the combined effect of plastic orthotropy and tension-compression asymmetry on the formation of necking instabilities in high-purity α-titanium flat tensile specimens subjected to dynamic loading under a wide range of impact velocities. To this end, the material behaviour is described using the constitutive model developed by Nixon et al. (2010a), which accounts for these specific features of the plastic response of hexagonal-close-packed materials. While numerical studies have shown the effect of material properties and loading conditions on the formation and development of necking instabilities in dynamically loaded tensile specimens, none of them, to the best of our knowledge, has considered the plastic orthotropy and tension-compression asymmetry of the material. The finite element simulations show that the orientation of the specimen with respect to the in-plane symmetry axes of the material plays a key role in the location and characteristics of the neck(s) formed in the sample. Moreover, the results indicate that only for three specimen orientations the main neck formed in the sample contains two localization bands, equally inclined with respect to the specimen axis, which grow at equal speed. For all other orientations, the localization bands have different inclinations, and one grows faster than the other one.


ABSTRACT: Nanotubes are easy to collapse due to van der Waals interactions and the low bending stiffness of their walls. The collapse may significantly alter the mechanical, thermal, and electronic properties of nanotubes, which can lead to many exciting applications of nanotubes in nanoelectronics and nanocomposites. In this paper, a theoretical model based on finite deformation beam theory is established to analyze the collapsing of single- and multi-wall nanotubes. Using this model, the critical diameters and the profile of collapsed nanotubes are predicted, which agree well with those obtained by molecular dynamics simulations. Furthermore, a simple scaling law of the critical collapse conditions of carbon nanotubes is built as a function of geometrical parameters, which can determine whether the carbon nanotube collapse. This scaling law can be easily extended to determine the collapsing state of other nanotube systems with different bending stiffness and binding energy.

ABSTRACT: The wavy structure is a simple, practical, and promising structural design scheme widely used in the field of flexible and stretchable electronics. In the development of the strategies to enable stretchable characteristics in the device, buckling of thin film devices suspended on an elastomeric substrate with surface relief structures provides an alternative tactic for applications that require both high areal coverage and large stretchability without compromising electric performance (e.g., flexible photovoltaics, batteries, supercapacitors, etc.). In this study, we utilize the energy method to reveal the mechanical mechanisms of controlled buckling and postbuckling behaviors of the stiff thin film devices suspended on the elastomeric substrate with trapezoidal surface relief structures. Both two- and three-dimensional models are explored to simulate the buckling behaviors of the thin film devices in the finite element analysis (FEA). Theoretical predictions of the buckling profile and the maximum strain in the thin film devices are compared reasonably well with those obtained from the FEA. The influences of thin film width and the contact width (between the thin film and the structured substrate) on the amplitude and the maximum strain of the buckled thin film devices are discussed. Results show that the amplitude of the buckled thin film device decreases as the contact width increases, whereas the maximum strain in the buckled thin film devices increases with the increasing contact width. The elastic stretchability of the buckled film/substrate system is also discussed. The validated analytical tool provides a powerful basis for further experimental designs.


ABSTRACT: The dynamic instability of electroconductive cylindrical shells interacting with an external magnetic fields is considered in the paper. Two cases of applied external dynamic loads are discussed, namely (i) a harmonic mechanical force, and (ii) a harmonic magnetic field force. Analytical descriptions of the two-dimensional equations and associate conditions of dynamic instability are presented. On the basis of the formulated problems, specific issues related to the dynamic instability of electroconductive cylindrical shells in a magnetic field are offered. The study illustrated the effect of magnetoelastic interaction. Specifically it is shown that there exist a minimum value of the given magnetic field intensity, above which the parametric resonance due to external harmonic force is eliminated; furthermore, in a presence of time-harmonic magnetic field the parametric resonance with a resonance frequency can be generated not only near the first frequency of the external magnetic field (which is equal to the natural frequency of vibrations), but near the double frequency of natural vibrations. When the forced vibrations of conductive shells caused by external forces of non-electromagnetic origin is considered, including the effect of a time-harmonic magnetic field, resonance can occur in the presence of a non-stationary harmonic magnetic field. Results reveal that the rapid increase of the amplitude of vibrations occurs when the frequency of the external magnetic field is in close proximity to the first natural frequency of the magnetoelastic vibrations of the plate, as well as when the frequency of the magnetic field, is equal to half of the shell natural frequency.


ABSTRACT: Wrinkling and buckling of stiff film/soft substrate system has great potential applications in many areas, especially in stretchable electronics. Inspired by the micro-patterns to tune the interfacial adhesion strength, a novel way to tune three buckling configurations (i.e., wrinkling, upward and downward buckling) by using the micro-patterns on the soft substrate was found experimentally. The established governing equations to distinguish the three buckling configurations are consistent with the experimental observations. Results show that the geometries of the micro-patterns, the material properties and the interfacial adhesion between the stiff film and the micro-patterned soft substrate can tremendously influence the final buckling configurations. The proposed analytical governing equations can not only clarify the mechanism of the micro-patterns on the tuning of different buckling configurations, but also be used to design the buckling configurations as desired.

ABSTRACT: This work aims at developing a multiscale model by combining the Fourier-related double scale analysis and the bridging domain method to study membrane instabilities. Towards this end, a Fourier reduced membrane model is firstly established based on the Föppl-Von Karman plate equations, where the initial unknowns are expanded into Fourier series and replaced by their Fourier coefficients. As the latter varies much more slowly than the initial functions, the computational efficiency of the reduced model is significantly improved. However, the boundary effects could not be accurately captured because the prescription of boundary conditions is always questionable in any reduced models. Thus, there is a need to develop a multiscale model, where the full shell model is used near boundaries to capture the local effects, and the Fourier reduced model is used in the rest to reduce the computational cost. These two models are then bridged by the Arlequin method, which permits to couple different mechanical models by Lagrange multipliers. Finally, the proposed multiscale model is implemented into ABAQUS as the user element (UEL) to extend its applicability for more complex membrane instabilities. Numerical results show that this multiscale model is able to simulate the membrane instabilities with high efficiency and accuracy.


ABSTRACT: Under compression, auxetic open cell cellular solids may lose auxeticity due to instability and/or self-contact between the ribs. This study explores the limiting strains for preserving auxetic effects for auxetic open cell materials of two different cellular structures: re-entrant honeycomb and the ‘missing-rib’ type chiral cellular solids. Experiments of the 3D printed specimens, periodicity analysis, and ellipticity analysis showed that, under compressive loads, the auxetic effects and the limiting compressive strain for auxeticity are mutually exclusive. In other words, the limiting compressive strain has to be reduced if larger auxetic effect is desired, vice versa. It was found that compared with re-entrant honeycombs, due to chirality-induced rotation, the chiral cellular solids can preserve auxetic effects under much larger compressive strain (>−10−30%).


ABSTRACT: Deriving the amplitude equation for a buckling mode is an important issue in non-linear elasticity. Focusing on pattern formations in growing tubular tissues, many existing literature often adopted the numerical methods. In this paper, we propose a semi-analytical approach for the bilayer tubular structures under growth to derive the amplitude equation of a single wrinkling mode, from which a transition between supercritical and subcritical bifurcations can be determined. In the framework of finite elasticity, a weakly non-linear analysis is carried out and the amplitude equation is deduced by the virtual work method. A semi-analytical solution is obtained, with an analytical expression whose exact coefficients are determined numerically. Then a parametric study is carried out by use of the semi-analytical solution. When the total growth factor is prescribed, the critical mode number governs the amplitude, and a lower mode corresponds to a higher amplitude. When the incremental growth factor after bifurcation is fixed, it turns out that the dependence of the amplitude on the modulus ratio is non-monotonic if the thicknesses of the two layers are specified. For a given geometry, when the modulus ratio $\xi$>5, the wrinkled amplitude is mainly dominated by the critical mode number, and a smaller critical mode number deepens the wrinkle. However, the amplitude is a decreasing function of $\xi$ when $\xi$<5. The obtained analytical solutions are also validated by the corresponding numerical solutions based on the finite element method. The proposed semi-analytical approach is applicable for most variable coefficient problems arising from cylindrical and spherical structures.

ABSTRACT: This paper presents a new approach for truss optimization against buckling that incorporates both the structural design and the imposed initial imperfections. Euler buckling of slender members, global buckling and stability of sequences of bars are all considered by optimizing the geometric nonlinear response, instead of by imposing a large number of constraints. The proposed optimization problem formulation consists of two alternating steps: (1) Shape optimization that aims to find the worst-case imperfection shape of the joints’ positions; (2) Sizing-topology optimization that aims to find the minimum volume of a buckling-resistant structure with the given optimized imperfection. Sensitivity analysis for the two optimization phases follows the adjoint method and solutions are obtained using first-order sequential approximate methods. It is shown that optimizing the imperfection shape stabilizes the convergence as acute instantaneous buckling is avoided. Several numerical examples demonstrate the capability of the proposed formulation to generate buckling-resistant designs with robustness against imperfections.


ABSTRACT: Snapping mechanisms are investigated for an elastic strip with ends imposed to move and rotate in time. Attacking the problem analytically via Euler’s elastica and the second variation of the total potential energy, the number of stable equilibrium configurations is disclosed by varying the kinematics of the strip ends. This result leads to the definition of a ‘universal snap surface’, collecting the sets of critical boundary conditions for which the system snaps. The elastic energy release at snapping is also investigated, providing useful insights for the optimization of impulsive motion. The theoretical predictions are finally validated through comparisons with experimental results and finite element simulations, both fully confirming the reliability of the introduced universal surface. The presented analysis may find applications in a wide range of technological fields, as for instance energy harvesting and jumping robots.


ABSTRACT: In this work, the post-buckling analysis of thin-walled beams by using the Generalized Beam Theory (GBT) is presented. To this purpose, a geometrically nonlinear GBT finite element is developed by exploiting the features of mixed-stress GBT finite element formulation in the framework of the Implicit Corotational Method (ICM). The application of the ICM to GBT is briefly discussed and the details necessary to successfully transform the linear GBT finite element in its nonlinear counterpart are illustrated. The numerical results show how the proposed finite element can deal with global and distortional geometrically nonlinear phenomena, in good accordance with respect to 3D shell models.


ABSTRACT: This paper presents a solid-shell based nonlinear finite element model for the numerical analysis of the growth of thin-walled soft structures. A multiplicative decomposition of the deformation gradient tensor is employed to describe the total shape change induced by the mass growth and the elastic deformation. Then a solid-shell model with only displacement degree of freedom is developed and the shell kinematics of deformation considering the growth effect are constructed. The enhanced assumed strain and assumed natural strain methods are employed in the finite element algorithm, so that numerical difficulties arising from the Poisson-thickness locking, volumetric locking and shearing locking phenomena can be avoided. In the finite
element formula, an additional term related to the growth in the tangent modulus emerges and an equivalent body force that acts as an additional driving force for the deformation of the materials from the numerical aspect arises. Several representative two- and three-dimensional examples with in-plane and volumetric growth modes are presented to demonstrate the efficiency and accuracy of the proposed model. The model is also proved to be a versatile tool for the modeling of many fascinating growth-induced shape changes and actuating behaviors observed in nature and engineering.


ABSTRACT: For cylindrical shells under axial compression, the essence of initial geometric imperfections is the superposition of local out-of-plane deformations of various forms, which may facilitate the development of buckling deformations, thus leading to a significant knockdown of the load-carrying capacity. It is very challenging for existing methods to provide an accurate prediction of the lower bound on a load-carrying capacity before the structure is fabricated. Therefore, it is crucial to find a type of assumed imperfection that will allow us to approximate lower bounds for shells in the design stage. Five 1-m-diameter unstiffened shells, termed W1-W5, are designed, analysed and tested. The measured imperfection approach, single-perturbation load approach (SPLA), worst multiple-perturbation load approach (WMPLA), and a Combined Approach for measured imperfections and superimposed radial point load imperfections are compared with test results. The results show that the SPLA-based methods produce higher KDFs than the test results and are sensitive to the distribution of the measured imperfections. In contrast, the KDFs predicted by the WMPLA and the Combined Approach are similar to one another and very close to the test results. From the comparison results, it can preliminarily be concluded that the WMPLA is able to envelop the small- and large-amplitude measured imperfections, which has the potential to predict a rational lower bound on the buckling loads of unstiffened cylindrical shells. The WMPLA should be extended to the design of other types of thin-walled structures with caution, because the manufacturing signature may be distinctly changed for different processes, and the buckling tests of other types of structures would be carried out in future study.

Yewang Su, Hongyu Zhao, Siyi Liu, Rui Li, Youhua Wang, Yezhou Wang, Jing Bian and YongAn Huang (First author is from: State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China), ”Buckling of beams with finite prebuckling deformation”, International Journal of Solids and Structures, Vol. 165, pp 148-159, 15 June 2019, https://doi.org/10.1016/j.ijsolstr.2019.01.027

ABSTRACT: The prebuckling deformation of structures is usually very small in conventional concepts, and is always neglected in the conventional buckling theory (CBT) and numerical method (CNM). In this paper, we find a class of structures from the emerging field of stretchable electronics, of which the prebuckling deformation becomes large and essential for determining the critical buckling load. Although great progress has been made for the buckling theory in the past hundred years, it is still challenging to analyze the buckling problems with finite prebuckling deformation (FPD buckling) straightforwardly. Here, the experimental stretch of a series of serpentine interconnects was firstly conducted as a representative example to show the FPD buckling behaviors and inapplicability of the CBT and CNM. The CNM can yield a huge error of 50% on the critical buckling load for the case with thickness-to-width ratio of the cross section $h/b = 0.6$. Most importantly, a systematic and straightforward theory (FPD buckling theory) is developed to analyze the FPD buckling behaviors of beams with the coupling of bending, twist and stretch/compression. As a comparison, various theoretical and numerical methods are applied to three classic problems, including lateral buckling of a three-point-bending beam, lateral buckling of a pure bending beam and Euler buckling. Our FPD buckling theory for beams is able to give a good prediction, while the CBT (by Timoshenko et al.) and CNM (by commercial program packages) yield unacceptable results (with 70% error for a three-point-bending beam with $h/b = 0.8$, for example). Discussion on the FPD buckling of bulk structures is deferred to a following paper.

ABSTRACT: In this study, a general higher-order 1-D theory and its finite element model are presented to analyze the large deformation of thin or thick curved rods or pipes like 3-D structure, which have a space curve as their central axis. The material of these structures is assumed to be that of an incompressible neo-Hookean solid. The displacement field of the cross-section perpendicular to the reference curve is approximated by a rather general approximation function in the polar coordinate system in the cross-sectional plane. The governing equation for the presented theory is obtained in terms of the displacement variables referred to the general curvilinear cylindrical coordinate system. The incompressibility condition is included either by the Lagrange multiplier method or the penalty method through the weak-form finite element model. Several numerical examples are presented to illustrate the application of the theory and its finite element model to analyze curved pipes or other tubular shell structures. The numerical results have been compared with the exact solution (where possible) and numerical solutions obtained with shell finite elements or 3D finite elements of the same problems. The present results are remarkably close to those obtained with the 3-D or shell finite elements, while requiring substantially less computational time.


ABSTRACT: In the application of continuum plate theories for modeling the mechanics of single layer graphene, significant inconsistencies exist in the literature on how to deal with the discrepancy between the continuum assumptions and discrete nature of the graphene lattice, whether using the classical plate theories or the more recent non-local elasticity based plate models. Physically vague properties such as graphene thickness and non-local parameter are often used as fitting parameters for calibrating the numerical results against those obtained from atomistic models or experimental data. However, very often a set of parameters that work well for a particular case can lead to large errors in other cases. This work attempts to answer the following question: can the mechanical behavior of single layer graphene sheets be described accurately and consistently using a continuum plate model? By using the results from atomic lattice mechanics calculations as reference for error analysis, we demonstrate that, when the sources of error in the classical plate model are properly identified, mechanics of single layer graphene can be accurately described by a modified non-local plate model with an interatomic potential based constitutive relation and a corrected boundary configuration.


ABSTRACT: The stability of a spinning thin elastic disk has been widely studied due to its central importance in engineering. While the plastic deformation and failure of an annular disk mounted on a rigid and accelerating circular shaft are well understood, shear-induced elastic buckling of the disk due to this ‘spin-up’ is yet to be reported. Here, we calculate this buckling behavior within the framework of the Föppl–von Kármán equations and give numerical results as a function of the disk’s aspect ratio (inner-to-outer radius) and Poisson’s ratio. This shows that shear-induced elastic buckling can dominate plastic failure in many cases of practical interest. When combined with existing theory for plastic failure, the results of the present study provide foundation results for a multitude of applications including the characterization of accelerating compact disks and deployment of space sails by centrifugal forces.

ABSTRACT: Large-diameter steel pipes, fabricated through the spiral-welding manufacturing process, are extensively used in onshore pipelines for the transmission of energy (hydrocarbon) and water resources. However, their use in demanding applications, such as geohazard areas or in offshore applications has been very limited. Safeguarding the structural integrity in such areas of those pipes requires an efficient strain-based design framework. Bending deformation capacity in the presence of internal pressure is the major loading case under geohazard actions, whereas external pressure capacity governs the mechanical design in moderate-deep offshore applications. To predict accurately the structural performance of spiral-welded pipes, the cold-bending manufacturing process should be taken into account. In the present paper, numerical models are developed simulating both the cold-bending process (decoiling and spiral bending) and the structural response of the pipe subjected to the loading conditions under consideration. The numerical modes have been verified against experimental results of spiral pipes conducted in the framework of a European research project. A parametric analysis is also conducted to examine the effect of spiral cold forming process on the structural behavior of spiral welded pipes. The results from the present study indicate that spiral-welded pipes can sustain significant amount of bending deformation and external pressure, in favor of their use in demanding onshore and moderately deep offshore pipeline applications.


ABSTRACT: The large deflection postbuckling behavior of rings under external pressure was studied theoretically and numerically. Rigid linear strain-hardening property was adopted to approximate the plastic behavior of the rings. Analytical models based on different theories were derived to describe the large deflection properties of postbuckling behavior. The influence of material properties and geometric parameter on the postbuckling response was investigated based on the proposed analytical models. Besides, finite element analyses were carried out to verify the validity of the proposed analytical models and the numerical results showed good agreement with the theoretical ones.


ABSTRACT: Bifurcations in the equilibrium shape of a thick elastic layer attached to a circular rigid cylinder rotating about its axis are investigated analytically and numerically. The centrifugal force breaks the symmetry of the system leading to deformations invariant along the axis as the result of an instability. The instability threshold depends at linear order on the relative thickness of the compliant layer, and on a dimensionless control parameter based on the elastic modulus, the angular velocity and the outer radius. A weakly non linear analysis, carried out for layers following the Mooney–Rivlin constitutive law, points out the discontinuous (sub-critical) features of the bifurcation, except for relative thickness laying in a very narrow range in which the bifurcation is super-critical. Numerical simulations in the fully post-buckled regime yield the absolute instability threshold, and the order in the rotational symmetry of the developed equilibrium shape.


ABSTRACT: We present a numerical-aided experimental study on the buckling of hierarchical beams comprising multiple self-similar modules. Each module consists of multiple elemental beams and is arranged in series to form the hierarchical beam. We show, through a combination of experiments and computations, that these beams exhibit stable and realizable higher-order buckling modes. By contrast to the canonical Euler buckling problem, such modes emerge naturally in the proposed self-similar beams since they correspond to almost identical critical loads. By harnessing the imperfection sensitivity of the hierarchical structures, we 3D-print weakly imperfect polymer samples with a small geometric imperfection corresponding to the desired eigenmode. We subsequently carry out uniaxial compression experiments and show in practice that higher-order patterns can be triggered selectively upon buckling. Moreover, these patterns are preserved in the post-bifurcation regime in many cases and are reversible upon load release. The ability to trigger higher-order buckling modes is found to depend on two main geometrical parameters which lead to scale coupling. Those are
the slenderness of the macroscopic hierarchical beam and the slenderness of the lower-scale elemental beam. With increasing slenderness of the hierarchical beam, we observe a significant softening in the overall stress-strain response and patterns exhibiting curvature localization in the post-bifurcation regime. The numerical finite-strain simulations carried out in the present study are found to be in very good agreement with the experiments and are used to quantify further the observed curvature localization in the hierarchical beams. The present study and the obtained results are geometric in nature and thus can be extended to different scales and hierarchies ad infinitum.


ABSTRACT: Many structures in Nature and Engineering are dominated by the influence of folds. A very narrow fold is a crease, which may be treated with infinitesimal width for a relatively simple geometry; commensurately, it operates as a singular hinge line with torsional elastic properties. However, real creases have a finite width and thus continuous structural properties. We therefore consider the influence of the crease geometry on the large-displacement flexural behaviour of a thin creased strip. First, we model the crease as a shallow cylindrical segment connected to initially flat side panels. We develop a theoretical model of their coupled flexural behaviour and, by adjusting the relative panel size, we capture responses from a nearly singular crease up to a full tape-spring. Precise experiments show good agreement compared to predictions.


ABSTRACT: The paper investigates the energy absorption performance of a new type of thin-walled tubes named as origami concave tubes whose cross-sections are concave polygons. Through the introduction of origami initiators, a reliable and progressive buckling failure mode can be successfully triggered, which is not a common feature for tubes with concave cross-sections. These origami concave tubes can achieve ultra-high energy absorption capability accompanied with relatively low peak forces. A comprehensive numerical, experimental, and theoretical analysis has been performed which shows that origami concave tubes can achieve 3.3 times the specific energy absorption of the comparable square tubes. We have also illustrated that origami concave tubes are approaching the theoretical limit of energy absorption.


ABSTRACT: Peeling of bonded films has applications to many engineering as well as biological systems. While significant prior research describes the mechanics of peeling of bonded homogeneous films, the studies on bonded heterogeneous films were relatively rare. Recently, bonded heterogeneous films have gained attention due to their potential for increasing the load required to propagate a debond without altering the adhesion characteristics of the interface. Although, it is known that the bending rigidity of a bonded heterogeneous film has significant influence on the adhesive toughness, the potential instability during the peeling process does not appear to be fully studied in the literature. In this paper, the heterogeneous film is simplified as a composite Euler-Bernoulli beam in a finite deformation framework. A semi-analytical model based on cohesive zone fracture description is developed, where both displacement-controlled and force-controlled loading conditions are considered. The semi-analytical solution is validated against experimental data in literature as well as finite element simulations. The study also addresses the transfer and distribution of energy in the film structure, and the variation of fracture process zone size with changing bending rigidity of the film. Additionally, comparisons are made between thickness enhancement and material enhancement to improve the peel performance of a heterogeneous film. The developed model provides insight into the mechanics of peeling, and it faithfully captures the instability often observed during debonding of heterogeneous films. The unstable load response to peeling can be leveraged to design systems where fracture toughness and overall reliability is improved without modifying the interface.

ABSTRACT: This paper analyzes the large deflections and stability of an elastic column. The column is supported by a spring at each of its clamped ends, and is also subject to a conservative compressive terminal force. The equilibrium equation is derived from the principle of the minimum total potential energy, and its solution is expressed using Jacobian elliptic functions. The stability is determined with the help of the Jacobi criterion, and the resulting bifurcation diagrams are also determined.


ABSTRACT: In this paper, a novel high-order three-scale (HOTS) computational method is presented to analyze the dynamic thermo-mechanical performance of composite structures with multiple spatial scales. The heterogeneities of composite structures are taken into account by periodic distributions of representative unit cells on the mesoscale and microscale. By virtue of multiscale asymptotic analysis, a new unified micro-meso-macro HOTS approximate solutions are successfully constructed for these multiscale problems. Two classes of auxiliary cell functions are established on the mesoscale and microscale, respectively. Also, two kinds of equivalent material parameters are calculated by up-scaling procedure on the mesoscale and microscale, and the homogenization problems are subsequently defined on global structure. Then, the comparisons of approximate performance are obtained in the pointwise sense for the conventional two-scale solutions, low-order three-scale (LOTS) solutions and HOTS solutions, which illustrate the necessity of developing HOTS solutions for simulating the dynamic thermo-mechanical performance of composite structures with multiple spatial scales. Furthermore, the corresponding HOTS numerical algorithm based on finite element method (FEM) and Finite difference method (FDM) is brought forward in details. Finally, some numerical examples are reported to demonstrate the usability of our HOTS computational method to simulate the dynamic thermo-mechanical behaviors of composite structures with multiple spatial scales. This study offers a unified three-scale computational framework that enables the simulation and analysis of dynamic thermo-mechanical problems of composite structures with multiple spatial scales.


ABSTRACT: The nonlinear mechanical responses of tetrachiral honeycombs under large deformation are theoretically analyzed by employing elliptic integrals, and the results are verified by numerical simulations. The nonlinear relationships between normal stress, shear stress, Poisson's ratio and the strain are derived for the tetrachiral honeycombs. It is found that the Poison's ratio of the tetrachiral honeycombs under large deformation is totally different from that under small deformation. The Poisson's ratio can achieve to a large magnitude of 0.8 in the former case, while remains 0 in the latter case. Moreover, the tetrachiral honeycombs exhibit positive Poisson's ratio under large tensile-deformation, whilst showing negative Poisson's ratio under large compression-deformation. The magnitude of Poisson's ratio depends on both the honeycomb's deformation and the ligament relative length, while it is insensitive to the ligament thickness. Besides, the coupling effect between tensile (or compression) and shear is observed for the tetrachiral honeycombs. In other words, shear deformation appears within the honeycomb under uniaxial loading. The coupling effect depends on both the honeycomb's deformation and the geometric parameters of the cell structure. And the quantitative relationships among them are derived. This special coupling effect of tetrachiral honeycombs provides a new idea for designing more metamaterials.


ABSTRACT: A use of orthotropic materials such as fibre-reinforced composites can introduce into vibro-acoustic performance of cylindrical structures effects that are not feasible when an isotropic material is used. In this paper, free and forced wave propagation in cylindrical structures with helically orthotropic material
properties is analysed to demonstrate these effects. Two models, a thin cylindrical shell and a cylindrical beam lattice, are considered and two methods, an analytical method of the thin shell theory and a numerical Wave Finite Element method, are used. For both models, the symmetry break effect concerned with the location of dispersion curves is captured by means of these methods and explained. The influence of the helix angle and of the material parameters on the location of dispersion curves is investigated. The Green's matrix is formulated for rotating forces and the forcing problems are solved to highlight some unusual waveguide properties of the helically orthotropic cylindrical structures. The results are discussed in view of a possible application for control of energy flow in piping systems exposed to rotating excitation.


ABSTRACT: In the present work, the problem of the semi-infinite strip with traction-free lateral sides is revisited, in order to examine the displacement profile across the semi-infinite strip under an arbitrary normal load distribution on its end. Although the solution of this problem is important even for practical applications (e.g. the prediction of the rocking motion of deformable bodies), only numerical solutions exist until now, which are cumbersome to implement for such cases. In this paper, the displacement profile of the semi-infinite strip under a concentrated normal load is approximated with analytical functions, which must exhibit specific properties. These results are then extended to arbitrary normal load distributions and characteristic cases are presented. Finally, the problem of the determination of the stress distribution across the interface between a deformable rocking body and its base is solved based on the previous derivations.


ABSTRACT: A 2-D micropolar equivalent single-layer (ESL), first-order shear deformation (FSDT) plate model for 3-D web-core sandwich panels is developed. First, a 3-D web-core unit cell is modeled by classical shell finite elements. A discrete-to-continuum transformation is applied to the microscale unit cell and its strain and kinetic energy densities are expressed in terms of the macroscale 2-D plate kinematics. The hyperelastic constitutive relations and the equations of motion (via Hamilton’s principle) for the plate are derived by assuming energy equivalence between the 3-D unit cell and the 2-D plate. The Navier solution is developed for the 2-D micropolar ESL-FSDT plate model to study the bending, buckling, and free vibration of simply-supported web-core sandwich panels. In a line load bending problem, a 2-D classical ESL-FSDT plate model yields displacement errors of 34–175% for face sheet thicknesses of 2–10 mm compared to a 3-D FE solution, whereas the 2-D micropolar model gives only small errors of 2.7–3.4% as it can emulate the 3-D deformations better through non-classical antisymmetric shear behavior and local bending and twisting.


ABSTRACT: A variational model is used to study buckling and initial postbuckling of flexible but inextensible rings made from filaments with or without chirality and subject to two cases of uniform central loading and inverse-square central loading. In contrast to previous works in which only in-plane bifurcation are included, we allow for both in-plane and out-of-plane bifurcation. For a ring made from a filament with no chirality, circular rings subject to uniform central loading or inverse-square central loading undergo, respectively, out-of-plane bifurcation or in-plane bifurcation at critical values of loading lower than or equal to those previously published. Additionally, the relative load difference to attain the post-buckled shapes for the former or the latter is, respectively, greater than or equal to that previously published. For a ring made from a filament with chirality, on the other hand, circular rings undergo coupling between in-plane and out-of-plane bifurcation at critical values of loading lower than those at which buckling would occur with no chirality, regardless of loading scenario considered. Moreover, dependent on the twist-to-bend ratio (torsional rigidity to flexural rigidity of the filaments), the chirality has a softening or stiffening effect on postbuckling behavior of elastic rings in the sense that the relative load difference to attain the post-buckled shapes for both types of central loading is, respectively, lower or greater than that which would attain with no chirality.
ABSTRACT: This work focuses on understanding and quantifying the effect of high temperatures on the compressive response of open-cell aluminum foams. Foam specimens with different cell-size are compressed within an environmental chamber under a range of temperatures $20^\circ C \leq T \leq 300^\circ C$. The localization and evolution of collapse is monitored and analyzed using Digital Image Correlation (DIC) and the overall force–displacement response is measured. The results indicate that increasing temperatures significantly affect all mechanical properties of the foam. Both the limit and plateau stresses were found to decrease linearly with temperature. More importantly, their drop does not follow directly with the corresponding one in the base material's yielding stress. The densification strain, that is a measure of the plateau extension, also follows a linear trend albeit in an increasing manner. This increase is attributed to changes of the collapse mechanism, which at high temperatures involves localization in different zones within the foam, as well as increased compaction at the cell-level caused by the base material softening. Finally, we measure the reduction in the strain energy absorption capacity of the foam caused by high temperatures.

ABSTRACT: This work presents a general unified theory for coupled nonlinear elastic and inelastic deformations of curved thin shells. The coupling is based on a multiplicative decomposition of the surface deformation gradient. The kinematics of this decomposition is examined in detail. In particular, the dependency of various kinematical quantities, such as area change and curvature, on the elastic and inelastic strains is discussed. This is essential for the development of general constitutive models. In order to fully explore the coupling between elastic and different inelastic deformations, the surface balance laws for mass, momentum, energy and entropy are examined in the context of the multiplicative decomposition. Based on the second law of thermodynamics, the general constitutive relations are then derived. Two cases are considered: Independent inelastic strains, and inelastic strains that are functions of temperature and concentration. The constitutive relations are illustrated by several nonlinear examples on growth, chemical swelling, thermoelasticity, viscoelasticity and elastoplasticity of shells. The formulation is fully expressed in curvilinear coordinates leading to compact and elegant expressions for the kinematics, balance laws and constitutive relations.

ABSTRACT: In this paper, the thermal shock resistance of a ceramic foam sandwich (CFS) slab is studied. Two typical thermal shock conditions are considered, i.e., the hot shock and the cold shock. Variations of transient temperature and thermal stress fields with thermal shock time and position are derived. The transient thermal stress intensity factor (SIF) of the thermally induced embedded and edge crack are detected by the developed theoretical model. Simultaneously, the corresponding thermal shock simulation of CFS slab is performed based on finite element (FE) analysis. The results between the presented theoretical model and FE analysis exhibit excellent agreement. Furthermore, the effects of the faceplate thickness and the relative density of the foam core on the thermal shock resistance of CFS slab under hot shock are discussed. Constructive suggestions for the structural optimization design of CFS structures are provided. The study demonstrates the asymmetric fracture behavior under the asymmetric hot shock, and determines the position of the danger zone. Notably, the variations of the influence degree of foam core density on the thermal shock resistance of the CFS slab under cold shock are indicated. The Crack propagation behaviors are investigated and the corresponding crack growth trajectories are provided from the fracture mechanics criterion.

ABSTRACT: We study a bilayer tube subject to inflation and axial stretching to reveal the effects of s, which is the ratio of the shear modulus of the outer layer to that of the inner layer, the interfacial radius D, and different constitutive models on the bulge initiation. By use of the internal volume ratio v as the bifurcation parameter, a parametric study is carried out. It is found that a larger s produces a more stable bilayer tube. If the thickness of the bilayer tube is specified, the composite tube is more stable when the stiffer part occupies the outer layer. Moreover, the critical volume ratio v, as a function of D has a maximum if s > 1 but a minimum if s < 1. We investigate the cases of fixed axial force and fixed axial length using the Gent model and Ogden model. A careful analysis shows that the qualitative characteristic of the variations of v, with respect to the modulus ratio s and the interfacial radius D is almost insensitive to the constitutive model used. Therefore, the effect of s on the bulge initiation is an intrinsic property of a bilayer tube. Furthermore, the maximum radius of a bulge in the propagation stage is studied when the thickness of the bilayer tube is prescribed. In the case of fixed axial force, analytical results based on Maxwell’s equal-area rule agree well with the corresponding numerical ones by utilizing finite element method. However, for the other loading type, only numerical solutions are available. It turns out that a bilayer tube with a higher v, can attain a larger bulge in the propagation stage. In particular, the dependence of the maximum radius on D also has a maximum when s > 1 but a minimum otherwise. The current study provides useful insight into aneurysm formation in human arteries and offers a possible way to control bulge initiation using a bilayer tube.


ABSTRACT: The buckling and the post-buckling of bilayer graphene sheets (BLGSs) on an elastic foundation subjected to an axial compressive load in plane-strain condition are studied. The solutions for the buckling strain and the characteristic wavelength at the onset of the buckling are obtained by using proposed continuum models describing deformations of BLGSs. The buckling analysis reveals that the buckling of BLGSs on an elastic foundation could be categorized into four. When the foundation is very soft, the Euler beam kinematics prevails in the entire BLGSs. On the stiffer foundation, the shear deformation on the cross-section of BLGSs occurs, and the characteristic wavelength changes sensitively as the stiffness of the foundation varies. With the foundation whose stiffness is almost the same as the shear modulus of the graphene interlayer, the buckling strain and the characteristic wavelength are nearly linear versus the elastic modulus of the foundation in logarithmic scale. When the foundation is much stiffer than the rigidities of the graphene interlayer, detachment between graphene layers could occur. Finally, we conduct the post-buckling analysis by using the proposed finite element model and obtain various morphology evolutions which contain detachment between graphene layers, period doubling, localization, period switching, and folding. Also, we present a diagram includes distinct deformation patterns according to the stiffness of the foundation and the magnitude of the applied compressive strain.


ABSTRACT: Regulating surface wrinkles have received considerable attention because of their potential applications in stretchable electronics, microfluidics, bionics, sensors, stamps, optical devices and smart materials. In this work, optical microscopy and atomic force microscopy revealed that tunable film thickness and substrate stiffness effectively regulate localized wrinkle patterns in metal films deposited on soft polymer substrates. Theoretical analysis and numerical simulation found that the high tensile stress developed during the film deposition leads to channel cracks in the film and creates a stripe-like plastic zone around each crack. The subsequently developed compressive stress in the plastic zone is anisotropic, resulting in the formation of localized straight wrinkles perpendicular to the crack. The width of the wrinkle is consistent with the size of the plastic zone, which decreases with increasing the film thickness or substrate stiffness, in good agreement with the experimental observations. The report in this work not only elucidates how the subtle correlation among
crack, plasticity and buckle leads to such localized wrinkling pattern but also demonstrates an efficient way to produce crack-network-guided localized wrinkle patterns.


ABSTRACT: We present a new type of a truly three-dimensional cubic negative stiffness lattice structure that can achieve energy absorption and recover its original configuration under cyclic loading in excess of a strain of approximately 20%. This structure was composed of multiple unit cells exploiting negative stiffness from controlled elastic buckling. Structural properties were designed to be tuned by adjusting geometry. The effective Poisson’s ratio was equal to zero regardless of the constituent material. Geometric parameters that can lead to the desired energy absorption without yielding the structure were determined by finite element analysis. We then fabricated samples representing the lattice structure with different sizes through additive manufacturing and performed cyclic loading experiments to capture stress-strain hysteresis loops. Results clearly showed that the designed structure was capable of absorbing mechanical energy effectively with a full recovery of geometry in three principal directions and that the amount of energy absorbed during cyclic loading increases with its size.


ABSTRACT: Accurate full field stress responses are often necessary to predict the structural performance of composite structures. The Unified Formulation (UF) is a promising approach to realise efficient and accurate 3D stress predictions of beam-like structures by using recently proposed hierarchical Serendipity Lagrange Elements (SLE) for capturing the 2D response of the beam cross-section while the 1D behaviour along the beam axis is captured using the Finite Element Method (FEM). Despite the computational merits of SLE elements, the performance of UF-SLE-FEM model is strongly influenced by FEM mesh discretisation along the beam’s longitudinal axis. With respect to multi-layered beam structures, a high density FEM mesh may lead to loss of efficiency of the UF-SLE-FEM model due to a significant increase in the number of degrees of freedom required to obtain convergence. This study proposes high-order refined formulations of the 1D structure based on strong-form, Differential Quadrature Method (DQM) and weak form, FEM for 3D stress analysis of composite structures. The proposed high-order strong-form DQM and weak-form FEM models, which are benchmarked against exact solutions, lead to significant computational advantages over UF-SLE-FEM models of similar accuracies. However, the symmetry and positive definiteness of the stiffness matrices of FEM models offer a numerical advantage over the strong-form DQM model with non-symmetric, non-positive definite stiffness matrices.


ABSTRACT: Despite the usual belief that only curved micro-structures can behave bi-stably, recently, it has been substantiated that flat micro-structure can also experience this type of behavior. In this way, the present paper aims to investigate snapping behavior in pressurized 2-D flat micro-electro-mechanical plates with a rectangular shape. To this end, a size-dependent and geometric non-linear thin plate model based on the modified couple stress theory is employed. The governing equilibrium equations as well as their corresponding boundary conditions are obtained using the principle of the minimum total potential energy. Employing an efficient Galerkin's discretization procedure, the instability thresholds of the system are determined by vanishing the first and the second variations of the total potential energy expression of the system. The present findings for non-pressurized systems are verified by those published in previous studies. Furthermore, the results concerning the cases under the differential pressures are validated through direct comparison with those extracted from 3-D finite element simulations carried out in COMSOL Multiphysics commercial software. Results reveal that flat micro-plates may experience snap-through instability when they are subjected to some certain values of the differential pressure in the opposite direction of the electrical field. To find the conditions in which a flat micro-plate may face with the snapping behavior, a large number of systems with different
material and geometric properties are analyzed. Employing this detailed parametric study, snapping criteria which provide the combination of the system properties and the level of the applied pressure required for prompting snap-through instability are then introduced.


ABSTRACT: This paper lays stress on the normalized stiffness and stretchability of planar ribbon kirigami. A dimensionless analytical model is proposed based on plane strain beam theory, in which the large curvature curved beam (LCCB) model is considered. The tensile experiments and simulations are performed and compared to validate the analytical model based on four dimensionless parameters. It is found that not all kirigami-based design is conducive to the enhancement of normalized stretchability. Remarkable long arm effect can enhance the normalized stretchability or reduce the normalized stiffness by several orders of magnitude. Finally, an optimization method is used to obtain the maximum normalized stretchability. The results in this paper can be used to guide the kirigami design in future application.


ABSTRACT: We present an analytical modeling framework and its analysis for thin piezoelectric metamaterial plates to enable and predict low-frequency bandgap formation in finite structural configurations with specified boundary conditions. Using Hamilton’s extended principle and the assumptions of classical (Kirchhoff) plate theory, the governing equations and boundary conditions for the fully coupled two-dimensional electromechanical system are obtained. The two surfaces of the piezoelectric bimorph are segmented into non-overlapping opposing pairs of electrodes of arbitrary shape, and each pair of electrodes is shunted to an external circuit. This formulation can be used to study the effect of electrode shape on plate response for topology optimization and other vibration control applications. Using modal analysis, we show that for a sufficient number of electrodes distributed across the surface of the plate, the effective dynamic stiffness of the plate is determined by the shunt circuit admittance applied to each pair of electrodes and the system-level electromechanical coupling. This enables the creation of locally resonant bandgaps and broadband attenuation, among other effects, in analogy with our previous work for one-dimensional piezoelectric structures with synthetic impedance shunt circuits. It is also demonstrated that piezoelectric bimorph plates display significantly improved performance (i.e. electromechanical coupling) over bimorph beams, but require additional electrode segmentation to achieve metamaterial-type performance. The governing equations are also used for dispersion analysis using the plane wave expansion method, enabling the analytical dispersion analysis of unit cells with arbitrary electrode shapes. The modeling framework and approximate closed-form bandgap expressions are numerically validated using finite element analysis.


ABSTRACT: An effective way of protecting offshore lines that carry corrosive hydrocarbons, is by mechanically lining carbon steel pipes with a thin layer of corrosion resistant alloy. A disadvantage of this product, is that when bent to curvatures such as those experienced during reeling the liner can buckle. The sensitivity of this instability to the main problem parameters was previously studied under pure bending. In the present study the problem is examined under the more complex loading experienced as it is wound onto a reel while under some back tension. A large-scale custom numerical model of the winding process of a previously expanded lined pipe is presented capable of dealing with the geometric, material and contact nonlinearities of the problem. The model is used to establish the deformation history experienced by the carrier and liner pipes during winding, the causes of liner instability, and its sensitivity to the main problem parameters. During
reeling, a transition length a few diameters long bends to an increasingly larger curvature until it comes into contact with the reel. Back tension controls the length and curvature of this transition zone safeguarding the line against local buckling. Modest levels of tension are shown to also delay the onset of liner wrinkling. The more complex loading history experienced by the lined pipe as it approaches the reel changes the prevalent buckling mode but its sensitivity to initial geometric imperfections reported under pure bending remains. The liner instability becomes more prevalent as the diameter increases but at the same time smaller diameter lines could be reeable. The recent trend of winding lined pipes under small levels of internal pressure is confirmed to be an effective means of avoiding liner instability.

Lu Lu (1,2), C.Q. Ru (2) and Xingming Guo (1)
(1) Shanghai Institute of Applied Mathematics and Mechanics, Shanghai Key Laboratory of Mechanics in Energy Engineering, Shanghai University, Shanghai 200072, People’s Republic of China
(2) Department of Mechanical Engineering, University of Alberta, Edmonton T6G 2G8, Canada
ABSTRACT: This work shows that a few-layer graphene with two highly-tensioned outermost layers exhibits negative effective mass and behaves like an elastic metamaterial. Actually, our simulations based on simple elastic membrane model confirm the existence of a bandgap in terahertz range within which a tensioned few-layer graphene exhibits remarkable vibration isolation: forced vibration will be highly restricted to a narrow region around the site of the applied excitation while all other parts of the graphene remain essentially static. The values of terahertz bandgap frequencies are determined by the van der Waals interaction coefficient between adjacent layers, while the width of the bandgap is determined by the number of inner layers. This research may provide new perspectives for designing and analyzing graphene-based metamaterials and nanoresonators with potential applications in high-frequency vibration controlling.

ABSTRACT: This work shows that a few-layer graphene with two highly-tensioned outermost layers exhibits negative effective mass and behaves like an elastic metamaterial. Actually, our simulations based on simple elastic membrane model confirm the existence of a bandgap in terahertz range within which a tensioned few-layer graphene exhibits remarkable vibration isolation: forced vibration will be highly restricted to a narrow region around the site of the applied excitation while all other parts of the graphene remain essentially static. The values of terahertz bandgap frequencies are determined by the van der Waals interaction coefficient between adjacent layers, while the width of the bandgap is determined by the number of inner layers. This research may provide new perspectives for designing and analyzing graphene-based metamaterials and nanoresonators with potential applications in high-frequency vibration controlling.

F.O. Falope (1), L. Lanzoni (1) and E. Radi (2)
(1) University of Modena and Reggio Emilia, Dipartimento di Ingegneria “Enzo Ferrari”, DIEF, Via P. Vivarelli 10, Modena, 41125, Italy
(2) University of Modena and Reggio Emilia, Dipartimento di Scienze e Metodi dell’Ingegneria, DISMI, Via G. Amendola 2, Reggio Emilia, 42122, Italy
ABSTRACT: The problem of a compressed Timoshenko beam of finite length in frictionless and bilateral contact with an elastic half-plane is investigated here. The problem formulation leads to an integro-differential equation which can be transformed into an algebraic system by expanding the rotation of the beam cross sections in series of Chebyshev polynomials. An eigenvalue problem is then obtained, whose solution provides the buckling loads of the beam and, in turn, the corresponding buckling mode shapes. Beams with sharp or smooth edges are considered in detail, founding relevant differences. In particular, it is shown that beams with
ABSTRACT: Delamination is one of the most serious failure modes in carbon fiber reinforced composite laminates, because it can reduce the overall stiffness, which further leads to premature structural buckling and failure at loads below the design level. Arbitrary elliptical delamination is the most representative case in engineering practice, and the delamination propagation and failure behaviors are much complicated. To completely evaluate the compressive failure behaviors of composite laminate with arbitrary elliptical delaminations, an extended analytical model was established based on the first order shear deformation theory and brittle fracture mechanics. The analytical model innovatively incorporated the failure evaluation, applicability and accuracy of the analytical model as a highly efficient tool in engineering practices for the most representative arbitrary elliptical delamination problems. It is found that the propagation of the elliptical deamination in composites was fast and unstable, which led to catastrophic failures. The delamination propagation tends to initiate from the delamination boundary points with the maximum transverse coordinates and propagate transversely to the loading direction.

Junhong Guo (1,2), Tuoya Sun (1) and Ernian Pan (2)
(1) Department of Mechanics, Inner Mongolia University of Technology, Hohhot 010051, China
(2) Department of Civil Engineering and Department of Mathematics, University of Akron, Akron, OH 44325, USA

ABSTRACT: Based on the nonlocal theory, three-dimensional (3D) buckling of composite nanoplates with coated one-dimensional (1D) quasicrystal (QC) is analyzed. The nanoplate is embedded in an elastic medium and is under uniaxial or biaxial compression. All edges of the QC nanoplate are simply supported and its interaction with the surrounding medium is simulated by the Pasternak-type model. In terms of the extended displacement and traction vectors, the eigensystem is first derived from the basic equations of nonlocal QC materials. Then 3D analytical solutions of the critical buckling load under compression are derived by using the propagator matrix method and the continuity condition on the interfaces of the nanoplate. The influence of the thickness and length-to-width ratio of the nanoplate, Winkler stiffness and shear modulus of the elastic medium, coating thickness and nonlocal parameter on the critical buckling load is analyzed. For a sandwich nanoplate made of QC and soft metallic aluminium, our numerical results indicate that QC coatings could offer an interesting alternative to surface reinforcement of soft metallic materials in industrial applications. The present 3D buckling model could further serve as a benchmark for various thin-nanoplate theories and for numerical methods in multilayered QC nanoplate modeling with nonlocal effect.

Kangkang Wang (1,2), Libin Zhao (1,2), Haiming Hong (3), Jianyu Zhang (4) and Ning Hu (4)
(1) School of Astronautics, Beihang University, Beijing 100191, China
(2) Key Laboratory of Spacecraft Design Optimization and Dynamic Simulation Technologies, Ministry of Education, Beihang University, Beijing 100191, China
(3) Shenyang Aircraft Design and Research Institute, Shenyang 110035, China
(4) College of Aerospace Engineering, Chongqing University, Chongqing 400044, China

ABSTRACT: Delamination is one of the most serious failure modes in carbon fiber reinforced composite laminates, because it can reduce the overall stiffness, which further leads to premature structural buckling and failure at loads below the design level. Arbitrary elliptical delamination is the most representative case in engineering practice, and the delamination propagation and failure behaviors are much complicated. To completely evaluate the compressive failure behaviors of composite laminate with arbitrary elliptical delaminations, an extended analytical model was established based on the first order shear deformation theory and brittle fracture mechanics. The analytical model innovatively incorporated the failure evaluation, and especially the delamination propagation path into buckling analysis of composite laminate containing an arbitrary elliptical delamination. The predicted results are highly consistent with the outcomes of uniaxial compression tests, thus validating the applicability and accuracy of the analytical model as a highly efficient tool in engineering practices for the most representative arbitrary elliptical delamination problems. It is found that the propagation of the elliptical deamination in composites was fast and unstable, which led to catastrophic failures. The delamination propagation tends to initiate from the delamination boundary points with the maximum transverse coordinates and propagate transversely to the loading direction.


Smooth edges cannot exhibit a rigid-body buckling mode. A limit value of the soil compliance is found for beam with sharp edges, below which an analytic buckling load formula is provided without loss of reliability. Finally, in agreement with the Galin solution for the rigid flat punch on a half-plane, a simple relation between the half-plane elastic modulus and the Winkler soil constant is found. Thus, a straightforward formula predicting the buckling loads of stiff beams resting on compliant substrates is proposed.
ABSTRACT: Each structural designer has to ensure that the load-bearing structure to be designed is geometrically stable; i.e. the structure does not exhibit any spurious kinematic modes. Existing methods evaluating this requirement are either indirect and thus computationally inefficient, or restricted to 2- or 3-dimensional pin-jointed structures or to 2-dimensional general structures. In order to close this gap, a new method is proposed that is able to handle arbitrary spatial structures, consisting of arbitrarily shaped 1-, 2- and 3-dimensional bodies (e.g. truss, beam, plate, shell, solid), which are arbitrarily connected to each other in reference to their types (e.g. rigid, pin-jointed, torsional joint, shear force and bending connection) and their acting spots (at points, along a line or over a plane). The same holds for the support. The proposed method is based on a kinematic approach, where only translational degrees of freedom are considered. It has been proved that 8 different types of kinematic constraints are required to evaluate the geometric stability of a general spatial structure; all these constraints are stated explicitly. With the resulting constraint matrix, the geometric stability can be evaluated, and all existing spurious kinematic modes can be calculated. The new method can simply be added as an extra module to the existing structural analysis software.

Alessandra Bonfanti (1,2), Stavros Syngellakis (2) and Atul Bhaskar (2)
(1) Department of Engineering, University of Cambridge, Cambridge, UK
(2) Faculty of Engineering and the Environment, Southampton Innovation Boldrewood Campus, University of Southampton, Southampton, SO16 7QF, UK

ABSTRACT: The performance of balloon expandable stents during deployment is usually assessed computationally. Most stents have a generic feature that entails wavy rings known as “crowns” which are interconnected via structures known as “bridges”. A mathematically exact analyses of such wavy rings would provide a benchmark to such computations and offer a clear insight into the deformation of stents. In the present work, an analytical model is developed to estimate the elasto-plastic response of a cylindrical periodic structure made of sinusoidal crowns interconnected by bridges. Two different interconnections are considered that give rise to two distinctive behaviours one of which is auxetic. Elastic-perfectly plastic material is considered. The apparent elasto-plastic response of the cylindrical structure is obtained in a closed-form by exploiting the periodicity along its longitudinal and the circumferential direction. A scaling ansatz is proposed that collapses nonlinear response data for different geometries into a family of master-curves. Such relationship suggests that the most efficient way to increase the apparent stiffness of the structure is to decrease the amplitude of the wavy crowns.

Lu Lu (1,2), C.Q. Ru (2) and Xingming Guo (1)
(1) Shanghai Institute of Applied Mathematics and Mechanics, Shanghai Key Laboratory of Mechanics in Energy Engineering, Shanghai University, Shanghai 200072, People’s Republic of China
(2) Department of Mechanical Engineering, University of Alberta, Edmonton T6G 2G8, Canada

ABSTRACT: This work shows that a few-layer graphene with two highly-tensioned outermost layers exhibits negative effective mass and behaves like an elastic metamaterial. Actually, our simulations based on simple elastic membrane model confirm the existence of a bandgap in terahertz range within which a tensioned few-layer graphene exhibits remarkable vibration isolation: forced vibration will be highly restricted to a narrow region around the site of the applied excitation while all other parts of the graphene remain essentially static. The values of terahertz bandgap frequencies are determined by the van der Waals interaction coefficient between adjacent layers, while the width of the bandgap is determined by the number of inner layers. This research may provide new perspectives for designing and analyzing graphene-based metamaterials and nanoresonators with potential applications in high-frequency vibration controlling.

ABSTRACT: Second-order solutions for the pure bending of a beam under finite deformation are obtained in this paper. The equilibrium equations are solved analytically for the second-order displacements, from which the first Piola–Kirchhoff stresses, the curvatures and a bending-stretching parameter are calculated for a cross section with a transverse axis of symmetry. The displacements are dependent on the square of the inverse of elastic constant, whereas the stresses on the inverse of elastic constant. The curvatures and anticlastic curvatures are gradated in the transverse direction. The longitudinal stress is nonlinearly distributed across the section, and exhibits anomalous characteristics in materials with a negative Poisson's ratio. The shear stresses have vanishing force and moment resultants, and bending-twisting coupling does not occur. The normal stresses give rise to force-couple resultants. The longitudinal force resultant representing the bending-stretching effect is dependent on a reduced elastic parameter $\xi$. This effect is present as long as there is finite deformation, even if the material is linearly elastic. A small shear modulus $\mu$ and/or a large third-order elastic constant $l$, $m$ or $n$ will result in a large $\xi$. This study may be applicable to the elasticity design of soft medical and wearable robots, where elastic compatibility with tissues is a primary consideration.


ABSTRACT: The buckling of a gold thin film deposited on a rigid substrate has been numerically investigated by means of static molecular dynamics simulations. Three different regimes of deformation have been identified depending on the values of the adhesion energy of the film on its substrate ($\Gamma_{int}$). For low adhesion energy, the buckling and gliding through dislocation emission into the interface have been observed. For intermediate values of $\Gamma_{int}$, the dissociation of the interfacial dislocations into the film leads to the formation of a Lomer–Cottrell lock that stops the buckle extension, promoting thus the propagation of a crack accompanied by the emission of dislocations. It results in the formation of a twin. For large values of $\Gamma_{int}$, the kinking of the interfacial crack has been evidenced along with dislocation nucleation at its tip leading to twins again. Finally, the different evolutions of the film have been summarized in a “behavior” diagram displayed in the plane of applied strain and adhesion energy variables.

F.O. Falope (1), L. Lanzoni (1) and E. Radi (2)
(1) University of Modena and Reggio Emilia, Dipartimento di Ingegneria “Enzo Ferrari”, DIEF, Via P. Vivarelli 10, Modena, 41125, Italy
(2) University of Modena and Reggio Emilia, Dipartimento di Scienze e Metodi dell’Ingegneria, DISMI, Via G. Amendola 2, Reggio Emilia, 42122, Italy

ABSTRACT: The problem of a compressed Timoshenko beam of finite length in frictionless and bilateral contact with an elastic half-plane is investigated here. The problem formulation leads to an integro-differential equation which can be transformed into an algebraic system by expanding the rotation of the beam cross sections in series of Chebyshev polynomials. An eigenvalue problem is then obtained, whose solution provides the buckling loads of the beam and, in turn, the corresponding buckling mode shapes. Beams with sharp or smooth edges are considered in detail, founding relevant differences. In particular, it is shown that beams with smooth edges cannot exhibit a rigid-body buckling mode. A limit value of the soil compliance is found for beam with sharp edges, below which an analytic buckling load formula is provided without loss of reliability. Finally, in agreement with the Galin solution for the rigid flat punch on a half-plane, a simple relation between the half-plane elastic modulus and the Winkler soil constant is found. Thus, a straightforward formula predicting the buckling loads of stiff beams resting on compliant substrates is proposed.

Junhong Guo (1), Tuoya Sun (1) and Ernian Pan (2)
(1) Department of Mechanics, Inner Mongolia University of Technology, Hohhot 010051, China
ABSTRACT: Based on the nonlocal theory, three-dimensional (3D) buckling of composite nanoplates with coated one-dimensional (1D) quasicrystal (QC) is analyzed. The nanoplate is embedded in an elastic medium and is under uniaxial or biaxial compression. All edges of the QC nanoplate are simply supported and its interaction with the surrounding medium is simulated by the Pasternak-type model. In terms of the extended displacement and traction vectors, the eigensystem is first derived from the basic equations of nonlocal QC materials. Then 3D analytical solutions of the critical buckling load under compression are derived by using the propagator matrix method and the continuity condition on the interfaces of the nanoplate. The influence of the thickness and length-to-width ratio of the nanoplate, Winkler stiffness and shear modulus of the elastic medium, coating thickness and nonlocal parameter on the critical buckling load is analyzed. For a sandwich nanoplate made of QC and soft metallic aluminium, our numerical results indicate that QC coatings could offer an interesting alternative to surface reinforcement of soft metallic materials in industrial applications. The present 3D buckling model could further serve as a benchmark for various thin-nanoplate theories and for numerical methods in multilayered QC nanoplate modeling with nonlocal effect..

Kangkang Wang (1,2), Libin Zhao (1,2), Haiming Hong (3), Jianyu Zhang (4) and Ning Hu (4)
(1) School of Astronautics, Beihang University, Beijing 100191, China
(2) Key Laboratory of Spacecraft Design Optimization and Dynamic Simulation Technologies, Ministry of Education, Beihang University, Beijing 100191, China
(3) Shenyang Aircraft Design and Research Institute, Shenyang 110035, China
(4) College of Aerospace Engineering, Chongqing University, Chongqing 400044, China

ABSTRACT: Delamination is one of the most serious failure modes in carbon fiber reinforced composite laminates, because it can reduce the overall stiffness, which further leads to premature structural buckling and failure at loads below the design level. Arbitrary elliptical delamination is the most representative case in engineering practice, and the delamination propagation and failure behaviors are much complicated. To completely evaluate the compressive failure behaviors of composite laminate with arbitrary elliptical delaminations, an extended analytical model was established based on the first order shear deformation theory
and brittle fracture mechanics. The analytical model innovatively incorporated the failure evaluation, and especially the delamination propagation path into buckling analysis of composite laminate containing an arbitrary elliptical delamination. The predicted results are highly consistent with the outcomes of uniaxial compression tests, thus validating the applicability and accuracy of the analytical model as a highly efficient tool in engineering practices for the most representative arbitrary elliptical delamination problems. It is found that the propagation of the elliptical deamination in composites was fast and unstable, which led to catastrophic failures. The delamination propagation tends to initiate from the delamination boundary points with the maximum transverse coordinates and propagate transversely to the loading direction.


ABSTRACT: Stacking layers of Miura-folded origami sheets has been shown to create a cellular material with attractive properties. It has a rich array of geometric parameters that allow its elastic properties and compressive collapse response to be varied over a wide range, at fixed relative density. It displays tunable anisotropy and auxetic behaviour, and can also be easily conformal to curved surfaces. Because of these attributes, metallic stacked origami materials have shown promise for applications such as impact energy absorption and blast mitigation. However, to date, manufacturability challenges have yet to be adequately solved. Sensitivity to dimensional tolerance, and challenges of layer interfaces, make the material difficult to manufacture via sheet metal forming routes. However, additive manufacturing (AM) techniques offer a route to overcoming these challenges. In this investigation, we use a selective laser melting (SLM) process to allow metallic stacked origami materials to be assessed experimentally for the first time. The as-manufactured characteristics of these cellular materials were investigated via X-ray tomography and microstructural inspection. For comparison, tensile coupons were also fabricated in different orientations with respect to the build plane, in order to investigate material anisotropy resulting from the AM process. Scaling effects, both in terms of manufacturability and mechanical response, were investigated with cellular specimens fabricated with different cell sizes and cell wall thicknesses. The origami specimens were tested under quasi-static compression to provide an assessment of their as-manufactured energy absorbing properties. Finally, a finite element analysis is carried out, in order to assess its predictive accuracy and sensitivity to key modelling decisions.


ABSTRACT: The goal of this paper is to present an analytical solution for large planar displacements of cantilever beams, avoiding the integration of elliptic integrals. The proposed solution takes advantage of a new hypergeometric function of two variables by which it is possible to obtain the parametric solution of the beam displacement. The solution concerns a cantilever beam subjected to an inclined force and a moment applied at the free end; nevertheless, it is easy to extend it to the case of multiple loads applied in intermediate positions of the beam. The beams have a constant section and initial curvature, the material is elastic, isotropic and homogeneous. It is shown how to extend the results to spring-hinged cantilevers or simply supported beams, to loads attached to the beam axis (following forces), or to a cantilever beam having the unsupported end displaced by a rigid cable. Various technical design curves are also provided; these allow an easy and fast estimate of the endpoint displacements. Particular attention is given to the study of the convergence region and speed of this new hypergeometric function. The configurations examined, the methodologies and the procedures to carry on these solutions are explained in detail within the paper. Some comparisons with numerical results support the solution proposed.

ABSTRACT: A tape spring can be held tightly coiled on a circular cylinder by means of a tension force applied at the tip. This paper determines the smallest value of the required tension force by means of analytical methods, experiments and detailed numerical simulations. The minimum force depends on the coiling ratio, defined as the ratio between the transverse radius of the tape spring and the radius of the cylinder. It varies with an inverse quadratic relation for coiling ratios smaller than 1 (bending-dominated regime) and with a linear relation for coiling ratios greater than 3.424 (tension-dominated regime). For coiling ratios between 1 and 3.424 there is an intermediate behavior, and the required tension force is non-unique and rather small.

Chengjun Wang (1), Shun Zhang (1), Shuang Nie (1), Yipin Su (2), Weiqiu Chen (1) and Jizhou Song (1)  
(1) Department of Engineering Mechanics, Soft Matter Research Center, and Key Laboratory of Soft Machines and Smart Devices of Zhejiang Province, Zhejiang University, Hangzhou 310027, China  
(2) School of Mathematics, Statistics and Applied Mathematics, NUI Galway, University Road, Galway, Ireland  
ABSTRACT: The buckling of a stiff thin film on a compliant substrate has been widely studied over the past decade due to its wide applications such as stretchable electronics, micro- and nano-metrology, and surface engineering. Instead of a single-layer compliant substrate, a bi-layer compliant substrate is usually encountered in practical applications. In this paper, the buckling of a stiff thin film on a bi-layer compliant substrate of finite thickness is studied theoretically, numerically and experimentally. The theoretical models based on the small-deformation theory and the simple finite-deformation theory accounting for the geometry change by using the energy method are both developed and presented. The good agreement among theoretical predictions, finite element analysis and experimental measurements of the buckling behavior validates the theoretical model. The influences of finite thickness of the bi-layer substrate and substrate modulus ratio on the buckling wavelength and critical buckling strain are systematically investigated. The buckling configurations at various applied strains are also measured to further validate the theoretical model. These results shed light on the influence of finite substrate thickness on buckling of the bi-layer substrate-supported thin films and are helpful to provide design guidelines in practical applications.

M. Martin (1,2), S. Bourgeois (1), B. Cochelin (1) and F. Guinot (2)  
(1) Aix-Marseille Univ, CNRS, Centrale Marseille, LMA UMR 7031, Marseille, France  
(2) Thales Alenia Space, Cannes La Bocca, France  
ABSTRACT: This work concerns the parallel that can be made between two models involving propagating instabilities: (1) a regularized Ericksen bar model and (2) a rod model with flexible cross-section dedicated to the folding of tape springs. This comparison confirms and complements the estimates obtained by Seffen and Pellegrino (1999) and gives some new insights on the formation and growth of folds, including their number and their location. We begin by studying a regularized Ericksen bar model in statics. The complete bifurcation diagram is analyzed, together with the post-buckling deformed shapes. The influence of the regularization parameter and of the boundary conditions is also studied. Then we propose a simplified model derived from Guinet et al. (2012) and Picault et al. (2014) to account for the folding of shallow tape springs in opposite sense bending. The equations that govern the problem, involving only two kinematic variables, can be easily written in this case. An analytical expression is found for the fundamental solution that is characteristic of an Ericksen bar model and it is shown that higher order terms that appear in the strain energy account for the transition zones. The obvious parallel with a regularized Ericksen bar model is made by proceeding to a complete study of the post-bifurcation diagram. Estimates of the length of the transition zones are proposed and compared to those obtained with a FE shell model. A FE shell model is also used to validate the fundamental solution obtained with the proposed simplified rod model with flexible cross-section. These comparisons lead to good agreements, except for the peak moment of the moment-curvature response for the bending test. An enriched model is then proposed that brings significant improvements.

Riccardo Vescovini (1), Vincenzo Oliveri (2), Davide Pizzi (1), Lorenzo Dozio (1) and Paul M. Weaver (2)
ABSTRACT: In this work, we study the thermo-mechanical behavior of metallic structures designed to significantly change shape in response to thermal stimuli. This behavior is achieved by arranging two metals with different coefficient of thermal expansion (CTE), Aluminum and Titanium, as to create displacement-amplifying units that can expand uniaxially. In particular, our design comprises a low-CTE bar surrounded by a high-CTE frame that features flexure hinges and thicker links. When the temperature increases, the longitudinal
expansion of the high-CTE portion is geometrically constrained by the low-CTE bar, resulting in a large tangential displacement. Our design is guided by theoretical models and numerical simulations. We validate our approach by fabricating and characterizing individual units, one dimensional arrays and three-dimensional structures. Our work shows that structurally robust metallic structures can be designed for large shape changes. The results also demonstrate how harsh environmental conditions (e.g., the extreme temperature swings that are characteristic of extraterrestrial environments) can be leveraged to produce function in a fully passive way.

Jaehun Lee (1), Jun-Sik Kim (2) and Maenghyo Cho (3)
(1) Department of Mechanical, Robotics and Energy Engineering, Dongguk University, Seoul 04620, Republic of Korea
(2) Department of Mechanical System Engineering, Kumoh National Institute of Technology, Gumi 39177, Republic of Korea
(3) Department of Mechanical and Aerospace Engineering, Seoul National University, Seoul 08826, Republic of Korea
ABSTRACT: This paper presents an asymptotic method-based analysis of composite laminates having interfacial imperfections. In general, imperfect interfaces are simply modeled by introducing a linear, spring-layer model, which empirically assumes that the displacement jumps that occur at the weakened interface are proportional to the transverse shear stresses of interface positions. In this study, we propose a composite plate model derived by using asymptotic expansion that does not make any assumptions, other than the scaling of coordinate systems. Within the framework of the asymptotic analysis, the spring-layer model is introduced to describe the effect of weakened interfaces, which is realized by the separation of domains in the through-the-thickness direction, and the integration of piecewise continuous warping functions. As a result, we newly define a spring parameter that is exactly the same as the stiffness of a spring. Therefore, a set of spring elements are added to the through-the-thickness modeling of the microscopic analysis, and the plate equations derived in the macroscopic problem are the same as those of the perfectly bonded laminates. As a consequence, we also derive the proposed plate model with the mathematical rigor that the previous asymptotic models contain. We provide some numerical results verifying that the proposed method shows good agreement with the elasticity and 3D FEM solutions.

Nadine Bejjani (1,2), Pierre Margerit (1), Karam Sab (1), Joanna Bodgi (2) and Arthur Lebée (1)
(1) Laboratoire Navier, UMR 8205, École des Ponts ParisTech, IFSTTAR, CNRS, Université Paris Est 6–8 av. Blaise Pascal, Cité Descartes, Champs sur Marne 77420, France
(2) Unité de recherche Mathématiques et modélisation, Faculté des sciences, Université Saint-Joseph, B.P. 11–514 Riad El Solh, Beyrouth 1107 2050, Lebanon
ABSTRACT: This paper is concerned with the prediction of the propagation of flexural waves in anisotropic laminated plates with relatively high slenderness ratios by means of refined plate models. The study is conducted using the Bending-Gradient theory which is considered as an extension of the Reissner–Mindlin theory to multilayered plates. Two projections of the Bending-Gradient model on Reissner–Mindlin models are also explored. The relevance of the proposed models is tested by comparing them to well-known plate theories and to reference results obtained using the finite element method.

Krzysztof K. Dudek (1), Ruben Gatt (2), Krzysztof W. Wojciechowski (3) and Joseph N. Grima (2)
(1) Institute of Physics, University of Zielona Gora, ul. Szafrana 4a, Zielona Gora 65-069, Poland
(2) Metamaterials Unit, Faculty of Science, University of Malta, Msida MSD 2080, Malta
(3) Institute of Molecular Physics, Polish Academy of Sciences, M. Smoluchowskiego 17, Poznan 60-179, Poland
ABSTRACT: In this work, through the use of Molecular Dynamics simulations, we show the capability of different mechanical metamaterials to induce their own global rotational motion as a result of an internal
deformation. We also show that one of the considered structures, i.e. the hexachiral system, may manifest a superior extent of the global rotation in comparison to other systems. In addition to that, we discuss that the self-induced global rotation can be observed for mechanical metamaterials with a discrete mass distribution which allows to prove that this phenomenon is not limited to macroscopic systems and applications involving the control of the rotational motion of objects such as satellites or wind turbines where the continuous mass distribution of structural elements is normally required. In fact, this study serves as a blueprint to show that a similar effect may also be expected for various systems at very different scales.

Yangjun Luo (1,2), Jian Xing (1), Zhan Kang (2), Junjie Zhan (1) and Ming Li (2)
(1) Province Key Laboratory of Advanced Technology for Aerospace Vehicles, School of Aeronautics and Astronautics, Dalian University of Technology, Dalian 116024, China
(2) State Key Laboratory of Structural Analysis for Industrial Equipment, Dalian University of Technology, Dalian 116024, China
ABSTRACT: Initial thickness imperfections of thin membranes due to manufacturing are inevitable and commonly observed. This paper presents an experimental and numerical investigation on how thickness imperfections affect the wrinkling of stretched membrane structures. With the measured data from a limited number of samples, we model the uncertain deviation of membrane thickness from that of a perfect geometry as a non-probabilistic bounded field with spatial dependency. After representing the bounded field as a linear function of a reduced set of uncertain coefficients by using a series expansion, the effect of thickness imperfections on the membrane wrinkling is investigated. To this end, the upper and lower bounds of out-of-plane displacements for membranes with initial imperfections are evaluated by a mathematical programming. The proposed wrinkling evaluation problem is then solved efficiently by using the Kriging-based optimization algorithm, with validation done by Monte Carlo simulation. The results show that initial thickness imperfections play a critical role in the wrinkling behavior of membranes.

ABSTRACT: Elastic tubes can experience surface instabilities when compressed beyond a critical strain, referred to as Wilkes instability herein. Soft materials may undergo the Rayleigh–plateau instability which is driven by surface tension. However, the surface instability of soft elastic tubes can be impeded by the coexistence of axial compression and surface tension. In this paper, we adopted an analytical framework for predicting the surface instability of an incompressible tube accounting for both axial loading and surface tension. A general solution in a mixed cylindrical coordinate is derived for determining isochoric transformations based on energy variational method. A linear perturbation analysis was performed to find out the critical elasto-capillary number and axial stretch for the onset of the instability. Cylindrical tubes with different thickness, i.e., the ratio of outer to inner radii, are investigated. We find that thinner tubes are more likely to experience surface instability than thicker ones, as validated by finite element simulations. We conclude that a compressive strain could prevent the Rayleigh–plateau instability induced by surface tension, while stretching will favor it. Similarly, the surface tension behaves as a barrier to the formation of compression-induced Wilkes instability.

ABSTRACT: A new sixth order, isotropic elastic and flexural plate theory is presented based on the fourth order equations of Lévy (1877) and Michell (1900). The lack of surface loading in these Lévy–Michell equations is overcome by including the dominant flexural component of Dougal’s (1904) solution for a point load on the surface of a three dimensional isotropic, elastic layer. The augmented plate equations are arranged to fit the form of a consistent sixth order system of isotropic plate equations which include the well known work
of Reissner and static equations of Mindlin. Numerical applications to two three dimensional problems with analytical solutions show good comparative results.

Kuo Tian (1), Xiangtao Ma (1), Zengcong Li (1), Shiyao Lin (2), Bo Wang (1) and Anthony M. Waas (2)
(1) Department of Engineering Mechanics, Structural Analysis for Industrial Equipment, Dalian University of Technology, Dalian 116024, China
(2) Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI 48109-2140, USA


ABSTRACT: In order to explore the global optimizing ability of the surrogate-based stacking sequence optimization of composite shells with multiple cutouts, a multi-fidelity competitive sampling (MFCS) method is developed in this paper, which is composed of a low-fidelity sampling level and a high-fidelity sampling level. In the low-fidelity sampling level, competitive sampling points are determined by means of the prior screening criterion and the further screening criterion in sequence. Based on the POD-based buckling method, a novel reduced-order model is established as the low-fidelity model for fast linear buckling analysis of composite shells with multiple cutouts. In the high-fidelity sampling level, the explicit dynamic method is employed to calculate the post-buckling response of competitive sampling points. Based on these sampling results, a surrogate model is built. Next, a surrogate-based stacking sequence optimization framework is established for minimum material cost of composite shells with multiple cutouts. A simple optimization example of Mishra's Bird test function is performed and the effectiveness of the MFCS method is demonstrated. Finally, the proposed method is used for the surrogate-based stacking sequence optimization of composite shells with multiple cutouts. The optimal result of total material cost by the MFCS method decreases by 23.0% than the optimal result by the traditional sampling method, which indicates that the MFCS method contributes to improving the global optimizing ability of the surrogate-based stacking sequence optimization of composite shells with multiple cutouts.

Z. Vangelatos (1), K. Komvopoulos (1), J. Spanos (2), M Farsari (2) and C. Grigoropoulos (1)
(1) Department of Mechanical Engineering, University of California, Berkeley, CA 94720, USA
(2) Institute of Electronic Structure and Laser (IESL), Foundation of Research and Technology, Hellas (FORTH), Heraklion 70013, Crete, Greece


ABSTRACT: Architected metamaterials exhibit unique properties bestowed by their engineered structure rather than their chemical composition. Extrinsic material properties have been achieved as a result of advances in additive manufacturing. Contemporary fabrication techniques, such as multiphoton lithography and digital light processing, have enabled the fabrication of complex structures with inherent hierarchies at length scales ranging from nanometers to micrometers. However, despite significant insight into the role of buckling in the mechanical behavior of materials reported in earlier studies, particularly strength and energy dissipation, the structural and design principles responsible for the improved mechanical performance were not fully elucidated, thus limiting the design space of these structures. The principal objective of this study was to investigate how controlled three-dimensional assembly and orientation of intertwined lattice members influence localized buckling and the overall mechanical response of such metamaterial structures. The novelty of the present design approach stems from a mechanical metamaterial inspired by the three-compound octahedron and the symmetry variance observed during phase change of crystalline solids. For a specific orientation and tactical joining of the unit cells, this geometry demonstrates unprecedented resilience to large deformations and high energy dissipation capacity. The selective shape modification of specific lattice members is shown to greatly improve the structural integrity of ultralight structures undergoing large deformation. Results from finite element simulations and in situ scanning electron microscopy-microindentation experiments reveal the actual deformation of metamaterial structures with straight and curved lattice members and elucidate the effects of anisotropy and orientation characteristics on the dominant mechanisms affecting the mechanical performance of intertwined lattice structures.
ABSTRACT: A computationally efficient method to study the in-plane and out-of-plane dimensional instability of thin paper sheets under the influence of moisture changes is presented. The method explicitly resolves the bonded and the free segments of fibers in the sheet, capturing the effect of anisotropic hygroexpansion at the fiber level. The method is verified against a volumetric model. The importance of longitudinal fiber hygroexpansion is demonstrated in spite of the absolute value of longitudinal hygroexpansion being an order of magnitude lower than the transverse hygroexpansion component. Finally, the method is used to demonstrate the formation of macroscopic sheet curl due to a moisture gradient in structurally uniform sheets in the absence of viscoelastic or plastic constitutive behavior and through-thickness residual stress profiles.

References listed at the end of the paper:

K. Niskanen (Ed.), Paper Physics (First), Rapet Oy (1998), pp. 242-243

ABSTRACT: In this paper, we present a 3-dimensional elastic beam model for the form-finding and analysis of gridshells subjected to bending deformation at the self-equilibrium state. Although the axial, bending, and torsional strains of the beam elements are small, the curved beams connected by hinge joints are subjected to large-deformation. The directions and rotation angles of the unit normal vectors at the nodes of the curved surfaces in addition to the translational displacements are chosen as variables. Based on the 3-dimensional elastic beam model, deformation of an element is derived from only the local geometrical relations between the orientations of elements and the unit normal vectors at nodes without resorting to a large rotation formulation in the 3-dimensional space. Deformation of a gridshell with hinge joints is also modeled using the unit normal vectors of the surface. An energy-based formulation is used for deriving the residual forces at the nodes, and the proposed model is implemented within dynamic relaxation method for form-finding and analysis of gridshells. The accuracy of the proposed method using dynamic relaxation method is confirmed in comparison to the results by finite element analysis. The results are also compared with those by optimization approach for minimizing the total potential energy derived using the proposed formulation.

References listed at the end of the paper:


ABSTRACT: Spontaneous formation of various buckle-delamination patterns originates from complex interaction between buckles and delamination. However, the impact of large compression and delamination boundary undulation on the morphology of buckle-delamination remains a challenge especially from an analytical approach. Here, a nonlinear solution based on the Föppl–von Kármán (FvK) plate theory for buckle-delamination is derived by using a coordinate transformation technique in combination with perturbation series based on Koiter expansion. The analytical results validated by finite element simulations (FEM) show that the sequential sectional profile of straight-sided (SS) blister with asymmetric secondary buckling instability exhibits a butterfly shape dependent on the compression amplitude even when the delamination boundary is straight. Besides, the wavelength for SS blister after the instability drastically changes with the compression amplitude, which is coincident with the experimental results. Our analysis further demonstrates that the elastic energy of the wavy-sided blister can be significantly lower than that of the SS blister even when the initial equi-biaxial
 compression is a little larger than the Euler buckling stress, significantly lower than the critical stress for secondary buckling instability of SS blisters. This result indicates an alternative mechanism that formation of telephone-cord blister may proceed first by an undulation instability of the delamination boundary.

Yan-Ping Zhao, Lin Li and Ming Jin (Department of Mechanics, School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, PR China), “Stability of the bifurcation point and the initial post-buckling of an elastic column with a flexible support”, International Journal of Solids and Structures, Vol. 193-194, pp 593-600, 1 June 2020, https://doi.org/10.1016/j.ijsolstr.2020.02.038

ABSTRACT: For the investigation of the initial post-buckling of a column built in at one end, clamped in rotation with a flexible support at the other, the stability of the bifurcation point is studied using the Fourier series. The second-order variation of the potential energy is proved to be semi-positive-definite at the bifurcation point. When the disturbance matches the buckling mode, the fourth-order variation is positive for some flexible support stiffness, and negative for other flexible support stiffness. Based on the Koiter's initial post-buckling theory, the condition on the flexible support stiffness conducing to the unstable branch path is derived. The unstable branch paths indicate that the buckling load of the column will be sensitive to the imperfections.

M. Shaat (1), S. Emam (2,3), S. Faroughi (4) and U. Javed (5,6)
(1) Mechanical Engineering Department, Abu Dhabi University, P.O.BOX 1790, Al Ain, United Arab Emirates
(2) Department of Mechanical Engineering, American University of Sharjah, Sharjah, United Arab Emirates
(3) Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
(4) Department of Mechanical Engineering, Urmia University of Technology, Urmia, Iran
(5) Department of Mechanical Engineering, The University of Lahore, Lahore, Pakistan
(6) Department of Engineering, American University of Iraq Sulaimani (AUIS), Sulaimania 46001, Iraq


ABSTRACT: In this paper, we investigate the surface roughness-dependence of buckling of beam-nanostructures. A new variational formulation of buckling of Euler-Bernoulli rough beams is developed based on the Hamilton's principle. The equation of motion of the beam is obtained with a coupling term that depends on the beam surface roughness. Exact solutions are derived for the buckling configurations and the pre-buckling and postbuckling vibrations of simply supported structures. The derived solutions are used to comprehensively explain influence of surface roughness on buckling characteristics of micro/nano-beams. We reveal that the buckling configurations and postbuckling mode shapes are distorted due to surface roughness. Thus, the beam with a rough surface may exhibit a localized buckling configuration where the buckling energy is confined over a small portion of the beam. In addition, the postbuckling mode shape of simply supported beams with rough surfaces is applied load-dependent. We report a value of the applied axial load at which the postbuckling mode shape is completely distorted, and the beam exhibits a mode shape that is identical to its buckling configuration but with a different amplitude. For the first time, we reveal a postbuckling mode inversion due to surface roughness. We demonstrate that the postbuckling mode shape starts to exhibit an inverted form of its original shape at high load values. The findings presented in this study highlight new insights into buckling characteristics of micro/nano-beams.

Ayan Haldar (1), R.M.J. Groh (2), Eelco Jansen (1), Paul M. Weaver (2,3) and Raimund Rolfes (1)
(1) Institute of Structural Analysis, Leibniz Universität Hannover, Appelstraße 9A, Hannover 30167, Germany
(2) Bristol Composites Institute (ACCIS), Department of Aerospace Engineering, University of Bristol, Queens Building, University Walk, Bristol, BS8 1TR, UK
(3) Bernal Institute, School of Engineering, University of Limerick, Castletroy, Ireland


ABSTRACT: Multistable laminates are potential candidates for adaptive structures due to the existence of multiple stable states. Commonly, such bistable shapes are generated from the cool-down process of the unsymmetric laminates from the curing temperature. In this work, we exploit unsymmetric variable stiffness
laminates with curvilinear fiber paths to generate similar bistable shapes as unsymmetric cross-ply laminates, but with the possibility to tailor the snap-through loads. Snap-through is a complex phenomenon in that is difficult to characterize using simple analytical models. An accurate yet computationally efficient semi-analytical model is proposed to compute the snap-through forces of bistable variable stiffness (VS) laminates. The differential equations resulting from the compatibility and the in-plane equilibrium equations are solved with negligible numerical error using the Differential Quadrature Method (DQM). As a result, the in-plane stress resultants and the total potential energy is written in terms of curvatures. The out-of-plane displacements are expressed in the form of Legendre polynomials where the unknown coefficients of the displacement function are found using the Rayleigh-Ritz formulation. The calculated snap-through loads are then compared with the Finite Element (FE) results. A parametric study is conducted to explore the tailoring capabilities of VS laminates for snap-through loads.


ABSTRACT: We assume that the strain energy density, \( W \), for a transversely isotropic and incompressible hyperelastic solid is a complete quadratic function of components of the right Cauchy-Green strain tensor, \( \mathbf{C} \). We first discuss restrictions on the seven material parameters appearing in the expression for \( W \). It is shown that for the reference configuration to be stress-free, both terms linear in \((I - 1)\) and \((I - 1)\) must simultaneously appear in the expression for \( W \) where \( I = \mathbf{A} \cdot \mathbf{C} \mathbf{A} \), \( I = \mathbf{A} \cdot \mathbf{C} \mathbf{A} \), and \( \mathbf{A} \) is a unit vector along the axis of transverse isotropy. Subsequently, we show that for a prismatic body comprised of this material deformed either in dead-load or displacement-controlled uniaxial tension/compression along \( \mathbf{A} \), depending upon the sign of the material parameter \( h \), multiplying the term \((I - 3)(I - 1)\) in the expression for \( W \), the two lateral stretches may bifurcate from being equal to being unequal for a stable solution defined as the one that has lower free energy. Here \( I = \text{tr}(\mathbf{C}) \) where \( \text{tr} \) is the trace operator. This is similar to Kearsley’s instability in an isotropic square Mooney-Rivlin membrane deformed with equal biaxial dead loads on the edges for which the stable deformed configuration shifts from having equal to unequal biaxial stretches.

Jacek Chróścielewski (1), Francesco dell’Isola (2,3), Victor A. Eremeyev (1,3) and Agnieszka Sabik (1)

(1) Gdańsk University of Technology, Faculty of Civil and Environmental Engineering, ul. Gabriela Narutowicza 11/12, 80–233 Gdańsk, Poland
(2) International Research Center on Mathematics and Mechanics of Complex System (M&MOCS), Università degli Studi dell’Aquila, Via Giovanni Gronchi 18, Zona industriale di Pile L’Aquila 67100, Italy
(3) Research Institute for Mechanics, National Research Lobachevsky State University of Nizhni Novgorod, Russia


ABSTRACT: Within the six-parameter nonlinear shell theory we analyzed the in-plane rotational instability which occurs under in-plane tensile loading. For plane deformations the considered shell model coincides up to notations with the geometrically nonlinear Cosserat continuum under plane stress conditions. So we considered here both large translations and rotations. The constitutive relations contain some additional micropolar parameters with so-called coupling factor that relates Cosserat shear modulus with the Cauchy shear modulus. The discussed instability relates to the bifurcation from the static solution without rotations to solution with non-zero rotations. So we call it rotational instability. We present an elementary discrete model which captures the rotational instability phenomenon and the results of numerical analysis within the shell model. The dependence of the bifurcation condition on the micropolar material parameters is discussed.


ABSTRACT: This paper presents a new approach to the optimal design of an axisymmetric membrane with variable thickness, which has potential applications in the development of active optical elements (liquid
lenses). The governing equations are based on the Saint Venant-Kirchhoff material law, which postulates a linear relation between the Green-Lagrange strains and the second Piola-Kirchoff stresses, combined with the exact description of geometric nonlinearity, without any simplifying assumptions. It is shown that the membrane thickness can be designed such that the prestressed membrane subjected to a given uniform liquid pressure deforms into a prescribed rotationally symmetric shape, e.g., a spherical or parabolic cap. For the special but important case of a spherical cap, a closed-form solution is derived. A numerical procedure is developed for the general case, and its high accuracy and efficiency is demonstrated by examples. The sensitivity of the optimal design to material parameters and prestressing displacement is assessed.


ABSTRACT: Lithium-ion batteries (LIBs) often suffer from capacity fading and poor cyclic performance due to mechanical degradation of the solid-electrolyte interphase (SEI). Here we perform numerical simulations and theoretical analysis to elucidate the role of plasticity in wrinkling and ratcheting behaviors of an SEI/electrode system. A coupled diffusion and finite deformation framework is formulated and numerically implemented as a user-element subroutine (UEL) to describe transient lithium diffusion and accompanying elastic–viscoplastic deformation of the electrode. It is found that concentration dependent properties and plastic deformation facilitate wrinkling in such a system. A wrinkled morphology may further lead to ratcheting and related failure under cycling. A phase diagram of four types of cyclic behaviors is identified in terms of the charging rate and time. Our analysis suggests several potential strategies to avoid wrinkling and ratcheting instabilities, such as charging/discharging the electrode at a sufficiently slow rate, and/or introducing a thick artificial SEI with a pre-tension.


ABSTRACT: The nonlinear dynamic pulse buckling of imperfect composite plate with embedded delamination is investigated numerically in this article. The dynamic buckling load is computed using Tsai-Wu quadratic interaction criterion. The laminated composite plate is modeled using layerwise theory with jump discontinuities in the form of heaviside step function to represent delamination at layer interfaces. The B-spline function is used as an interpolation function in finite element to analyze the plate subjected to unidirectional in-plane compressive pulse loading. The effect of type of pulse loading i.e., sinusoidal, exponential and rectangular, and plate boundary condition on the shock spectrum is explored. Response of delaminated plates is also computed for various delamination percentages at different layer interfaces. Sublaminates open up at the zone of delamination around peak displacement. Moreover, the same percentage of delamination at outer interface results in higher relative displacement of sublaminates compared to the delamination at inner interfaces. Dynamic load factor (DLF) is computed for different percentages of delaminations at middle interface.


ABSTRACT: The paper addresses several existing versions of mathematical models describing stiffened shell structures (accounting for the interaction between stiffeners and skin “along a line”, and “along a strip”, and a method for “smearing” the stiffness of stiffeners over the entire structure). The authors suggest a new, most accurate version to account for stiffness properties of stiffeners, based on introducing various modular ratios along various coordinate axes. For stiffeners perpendicular to the direction under consideration, the authors introduce a modular ratio equal to the ratio between the width of stiffeners in this direction and the linear dimension of the shell in the direction under consideration. For analysis, the authors use an algorithm based on the Ritz method and the best parameter continuation method. Three versions of models, taking into account the
discrete introduction of stiffeners, are compared. Analysis is performed for isotropic shallow doubly curved shells reinforced with an orthogonal grid of stiffeners.


ABSTRACT: In structural engineering, buckling is usually associated with compressive stress and/or shortening deformation states. Recently, several works came to light alerting to the propensity of some structural systems to buckle under tension. Within this context, the present work examines the buckling and post-buckling behaviours of repetitive rods systems under tensile axial loading, and comprises three distinct parts. At first, the tensile stability behaviour of a single rigid rod with an edge section supported by a slider that is forced to follow a pre-established path, developed in the literature that lays behind us, is revisited and related to the buckling behaviour of an alternative two rods system whose buckling propensity arises from a secondary compressed bar overlapping the tensioned one. In the second part of the paper, overlapping is used to create innovative repetitive frames that buckle under tension, in the present case a sequence of lined up rigid rods connected by rotational joints. The tensile critical load shows little change as new modules are added to the system, in clear contrast with the compressive case. The tensile post-buckling behaviour is also assessed, in some cases showing original shapes, and overlapping is used to create repetitive frames with negative thermal expansion coefficient as well. In the third part of the paper, the effects of applying global gradients to the relevant mechanical properties, in the form of smooth variations of the joints rigidities and rods lengths as the module is repeated, on the stability behaviour under tension are assessed. Although these variations are smooth and kept within small values, they provoke significant changes on the tensile buckling load, on the buckling type and on the type of buckling as well. The findings pave the way to the development of innovative repetitive frames, cellular materials, polymer chains and origami structures showing original constitutive behaviours under tension.


ABSTRACT: Approaches to systematic analysis of essentially nonlinear structures with multistable responses, controlled buckling and snapping behavior have received much attention recently in the context of mechanical metamaterials design. A snapping bistable element is generally a highly efficient damper, performing well even at very low forcing frequencies. In this paper, we transfer basic tools of the metamaterials analysis to macroscopic systems relevant to civil and mechanical engineering applications. Such systems are comprised of only several bistable elements. Followed by analysis of a single snapping bistable axial (two-force) element, we consider a combination of two elements with antisymmetric properties and demonstrate a robust tristable performance of the resultant structure in low-frequency or quasistatic tension-compression loading cycles. The tristability provides an overall response that is symmetric for tension and compression, which makes it interesting for applications in machinery and large-scale seismic structures.


ABSTRACT: In this paper we study the behavior of two buckled beams when they are pushed toward each other. The elastica model is adopted in the theoretical formulation. In the early stage, the buckled beams contact each other at one point. It then evolves to line contact when the external pushing force increases. The line-contact segment can be straight or curved. It is shown that there is no distributed force within the line-contact segment. In order to determine the stability of the deformation, the vibration method is adopted. To account for change of contact points during vibration, the equations of motion are reformulated into Eulerian forms and the squares of natural frequencies are solved. If any of the squares of natural frequencies is negative, the equilibrium is unstable. Experiments are conducted to measure the relation between the pushing force and the top clamp-line movement. For each stable deformation, several of the lowest natural frequencies are recorded
and compared with the theoretical predictions. In displacement control the lowest two natural frequencies agree very well with the theoretical prediction. However, the measurement of natural frequencies for load control is less successful. Generally speaking, the deformation evolutions observed in experiments follow the load-deflection curves predicted theoretically for both displacement and load-control procedures.


ABSTRACT: The effect of self-contacting surface defects generated by largely compressing metals on the ductile-to-brittle transition observed in metallic structures is investigated. In order to analyse such an effect, a finite element model of a half-space plane-strain material block with an imperfection was subjected to different levels of compression followed by reverse tensile straining. Experimentally validated associative J, and porous plasticity models were used to describe the mechanical response of the pipeline steel employed as a baseline material for this investigation. Both models predicted onset of creasing at compressive strains of around 70%. To ascertain whether the creases created large and sharp enough defects to trigger the ductile-to-brittle transition during the tensile straining phase, a bifurcation analysis implemented within a user material subroutine was used as fracture initiation indicator. This confirmed that at compressive strains above 70% the self-contact defect acted as a crack during the tensile straining phase.

References listed at the end of the paper:
10 E. Hohlfeld, L. Mahadevan, Scale and Nature of Sulcification Patterns, Phys. Rev. Lett., 109 (2012), Article 025701
14 M. Kristoffersen, Impact Against X65 Offshore Pipelines, Department of Structural Engineering, Norwegian University of Science and Technology (NTNU) (2014)
20 B. Li, Y.-P. Cao, X.-Q. Feng, Growth and self-similar unfolding of esophageal mucosa: a biomechanical model, J. Biomech., 44 (2011), pp. 182-188
ABSTRACT: Articulated surface wrinkling patterns can be induced through the mechanical instability of patterned stiff films with periodic stiffness distributions (including periodic material and/or film thickness distributions) on a compliant substrate. To explore this articulated surface wrinkling, the governing equations are established by energy minimization, and the theoretical results are consistent with those from experiment and finite-element simulations. Morphology transitions from articulated wrinkling to trapezoidal or sine–trapezoid hybrid wrinkling are observed when the geometrical or material property parameters beyond a specific interval. Phase diagrams are established for the formation of articulated wrinkling morphology with respect to the geometrical and material parameters. The results show that articulated wrinkling is observed for a patterned film on a compliant substrate, depending on the periodic segment dimensions of the patterned film compared to the sinusoidal wrinkle wavelength of the corresponding homogeneous film. Compared to the sinusoidal wrinkling of a homogeneous film, articulated wrinkling has notably larger wrinkling wavelength and normal traction at the interface (approximately double when $L_1 = L_2$), however, has slightly smaller amplitude and film strains (membrane and bending peak strains). This study is a good reference for designing articulated surfaces with potential applications in many areas, especially energy harvesting devices, because of the controlled deformation location and strain distribution of such surfaces.

ABSTRACT: A model for the prediction of localised necking in plates subjected to dynamic biaxial loading is presented. The proposed model extends the classic two-zone localisation analysis introduced by Marciniak and Kuczyński (1967) to include the contribution of inertia. Several examples of computations are presented to illustrate the influence of inertia, material rate-dependence and yield surface shape on plate necking under dynamic biaxial loading. It is found that inertia may significantly delay the occurrence of localised necking and increase the apparent ductility of the material. The results of the proposed model are compared to those of three-dimensional finite element simulations and a very good agreement is observed.


ABSTRACT: Axial splitting and curling behaviour of circular sandwich metal tubes with metal foam core is investigated analytically and experimentally. The sandwich tubes split axially and the strips curl outward by prefabricated cracks at the distal end of the specimens. Axial compression experiments of circular sandwich metal tubes are carried out and deformation modes are found. A theoretical model is developed to predict the axial splitting and curling behaviour of the circular sandwich metal tubes including effects of the tearing of the cracks, plastic bending, curling, foam compression and friction. It is shown that the analytical predictions capture the experimental results reasonably. Effects of the tube thickness, foam strength, foam thickness, the number of the prefabricated cracks, and the semi-angle of the die are of vital importance in energy absorption devices by the axial splitting and curling of circular sandwich tubes.


ABSTRACT: Composite laminates are usually made of anisotropic viscoelastic materials with layer-dependent properties. Although such structures are advantageous over the traditional single-material structure, their interfacial damage/failure is a great concern. In this paper, we present the general formulation and the corresponding solution to enhance our understanding on the guided waves in such laminates with imperfect interfaces. The formulation is based on the modified dual variable and position (DVP) method combined with a powerful and accurate root-finding algorithm. While the former overcomes the numerical instability when handling layered structures, the latter finds all the roots of the dispersion equation in a complex domain providing the full three-dimensional (3D) dispersion curves. After the proposed formulation is validated by the semi-analytical finite-element (SAFE) method for the perfect interface case, the present solution is applied to analyze the dispersion curves and mode shapes for a bilayer laminate with imperfect interface. Numerical examples demonstrate the detailed evolution mechanisms on wave features from perfect interface to complete delamination in the bilayer with imperfect interface. The results presented in this paper provide important insight to guide the in-situ monitoring of the evolution processes of the wave mode shapes and dispersion curves from perfect interface to complete delamination.


ABSTRACT: Concertina folding of tubes used for impact mitigation bends the tube section to tight curvatures that can lead to failures on the tensioned side of the folds. This paper reports results from such axial crushing experiments on Al-6061-T6 circular tubes in which cleft-like features were also observed on the compressed sides of folds. Microscopic examination of the compressed sides of sectioned folds at different stages of bending revealed the following. Compression leads to surface wrinkles that are initiated by small initial surface
roughness. Further bending increases the amplitude of the wrinkles, and at even higher bending the wrinkles morph into folds, creases, and sharp discontinuities. Metallographic examination of these surface undulations revealed that surface wrinkles encompass several grains, which deform conforming to the imposed local geometric changes. With this in mind, the axial crushing was simulated at the continuum level via an axisymmetric finite element analysis coupled with a suitably calibrated non-quadratic elastic–plastic constitutive model. A sufficiently refined mesh and representative initial surface imperfections enabled monitoring of the evolution of surface instabilities on the compressed sides of folds. Surface wrinkles appear at compressive strains of about 50%. As the local bending increases, their amplitude grows, and subsequently they evolve into local folds, and creases that resemble surface features observed in the experiments.

ABSTRACT: Under tension low carbon steel exhibits inhomogeneous plastic deformation. This instability called Piobert-Lüders banding creates fronts of localized strain that propagate in the structure. To date, Lüders banding has been studied experimentally and numerically only in simple geometries like sheets, tubes and normalized fracture mechanics specimens. This paper focuses on architectured materials and specifically lattice structures which can be defined as a tessellation of unit-cells periodically distributed in space. This class of advanced materials draws new mechanical properties from its inner architecture. We investigate the effect of the architecture on the global behavior of the structure. Especially, how bands interact with the lattice and how to control initiation and propagation of localized strain using the architecture. An elastoplastic material model is used in order to simulate the Piobert-Lüders band formation and propagation. The model also considers a large deformation framework for elastoplasticity with periodic boundary conditions in order to represent the architectured material. Initiation and propagation of material instabilities depend on the geometry as well as its on the relative orientation with respect to the loading direction. Propagating and non-propagating behaviors are identified for the Piobert-Lüders bands and related to the different types of geometry. Material instabilities affect the mechanical behavior of the structure as far as they are governed by the architecture. These conclusions are compared to experimental results from tensile tests on laser-architectured specimens made of ARMCO steel.

ABSTRACT: Origami crease patterns are folding paths that transform flat sheets into spatial objects. Origami patterns with a single degree of freedom (DOF) have creases that fold simultaneously. More often, origami patterns have multiple DOFs and several substeps are required to sequentially fold such origami; at each substep, some creases fold and the rest remain fixed. In this study, we combine the loop closure constraint with the Lagrange multiplier method to account for the sequential folding of rigid origami of multiple DOFs by controlling the rotation of different sets of creases during successive substeps. This strategy is also applicable in modeling origami-inspired devices, where creases may be equipped with rotational springs and the folding process thus involves elastic energy. Several examples are presented to verify the proposed algorithms in tracing the sequential folding process as well as searching the equilibrium configurations of origami with rotational springs.

ABSTRACT: Within the framework of the Kirchhoff-Love theory, a thin homogeneous layer (called adhesive) of small width between two plates (called adherents) is considered. It is assumed that elastic properties of the adhesive layer depend on its width which is a small parameter of the problem. Our goal is to perform an asymptotic analysis as the parameter goes to zero. It is shown that depending on the softness or stiffness of the adhesive, there are seven distinct types of interface conditions. In all cases, we establish weak convergence of
the solutions of the initial problem to the solutions of limiting ones in appropriate Sobolev spaces. The asymptotic analysis is based on variational properties of solutions of corresponding equilibrium problems.

ABSTRACT: This paper investigates the variational formulation and numerical solution of a higher-order, geometrically exact Cosserat type beam with deforming cross-section, instigated from generalized kinematics presented in earlier works. The generalizations include the effects of a fully-coupled Poisson’s and warping deformations in addition to other deformation modes from Simo-Reissner beam kinematics. The kinematics at hand renders the deformation map to be a function of not only the configuration of the beam but also elements of the tangent space of the beam’s configuration (axial strain vector, curvature, warping amplitude, and their derivatives). While this complicates the process of deriving the balance laws and exploring the variational formulation of the beam, the completeness of the result makes it worthwhile. The weak and strong form are derived for the dynamic case considering a general boundary. We restrict ourselves to a linear small-strain elastic constitutive law and the static case for numerical implementation. The finite element modeling of this beam has higher regularity requirements. The matrix (discretized) form of the equation of motion is derived. Finally, numerical simulations comparing various beam models are presented.

ABSTRACT: The compressive behaviour of cross-ply laminates with delaminations and matrix cracked layers is investigated by means of an analytical modelling approach. Insight into the post-buckling and damage growth behaviour is obtained owing to comprehensive parametric studies varying delamination length and depth as well as matrix crack density for cross-ply laminates with different layups. The efficient modelling approach comprises the well-known total potential energy principle and the Equivalent Constrained Model for determining reduced stiffness properties depending on the matrix crack density. Thus, unlike previous studies on delamination buckling, the effect of matrix cracked layers is taken into consideration. The analysis of the energy release rates for delamination and matrix crack growth enables the identification of configurations (e.g. delamination depth and length, total thickness of the laminates) which are prone to delamination growth and matrix crack growth, respectively. Beyond that, relationships between post-buckling and damage growth behaviour are identified and discussed.

ABSTRACT: This paper presents a study of the elastic buckling behavior of Triangular Rollable And Collapsible (TRAC) booms under pure bending. An autoclave manufacturing process for ultra-thin composite booms is presented and the behavior of three test samples is investigated experimentally. Two regimes are observed, a pre-buckling regime and a stable post-buckling regime that ends when buckling collapse is reached. The buckling collapse moment, marking the end of the stable post-buckling regime, is typically four times higher than the initial buckling moment. A numerical simulation of the boom behavior with the Abaqus finite element package is presented and all of the features observed experimentally are captured accurately by the simulation, except buckling collapse. The numerical model is also used to study the effect of varying the boom length from 0.3 m to 5.0 m. It is shown that the pre-buckling deformation of the flanges under compression leads to a constant wavelength lateral-torsional buckling mode for which the critical moment is mostly constant across the range of lengths.

ABSTRACT: Variable Angle Tow (VAT) composite panels, whereby fibre angle distributions vary continuously in-plane, have more scope for tuning structural properties than traditional straight fibre laminated composite materials. Currently, the geometrically non-linear response of such structures is typically modelled using path-following methods implemented in commercial finite element analysis. However the high computational cost given from both the incremental-iterative procedure and fine mesh required for accurate modelling of the variable trajectory of fibre direction, can be excessively time consuming. Driven by these shortcomings, we use a fast multi-modal Koiter asymptotic method for investigating the nonlinear buckling behaviour of VAT cylindrical panels in compression. In doing so, this paper provides new insight into the multi-modal description and nonlinear buckling mode interactions which are responsible for the highly nonlinear behaviour of cylindrical panels in compression with a particular emphasis on the nonlinear components in the mathematical asymptotic description. As such, through an extensive parametric virtual testing programme we construct, for each panel under investigation, an asymptotic solution projecting the equilibrium equations in the subspace of its first 30 buckling modes. Then, at several points of the resulting equilibrium path, the percentage contribution of each of these modes to the solution is measured. On the basis of the percentage obtained, those modes which give the largest contribution to the solution are identified. The main novelty of this work is that these results are used as a priori information for re-projecting the equilibrium equations into a new modal subspace to which only the buckling modes with the largest participation belong. Moreover, for the first time, we observe that in a multi-modal Koiter-inspired description the modal shapes giving the largest contribution to the asymptotic solution have the same degree of symmetry. In this way, for a generic panel under consideration, we show that it is possible to obtain a more computationally-efficient asymptotic description than current approaches. Finally, the new computed equilibrium paths are compared to benchmark results using the commercial finite element software ABAQUS and the computational advantages given by using a priori information in the asymptotic expansion are commented upon.


ABSTRACT: A generalized Reissner theory for axisymmetric problems of thin circular and annular plates is applied to various problems. The plates are assumed to be linearly elastic, and shear deformation is neglected. Large deflections, rotations, and strains are allowed. The plate edges may be clamped or simply supported, movable or immovable. The types of loading considered are uniform pressure, central concentrated load, uniform edge moment, full ponding, and central rigid hub pushed downward (with or without an elastic foundation). In some cases, the effects of Poisson’s ratio and the radius-to-thickness ratio are investigated, and the maximum deflections are compared to those based on von Kármán theory and Reissner theory.


ABSTRACT: In this paper, we present a method for simulating the structural properties of curved-crease origami through the use of a simplified numerical method called the bar and hinge model. We derive stiffness expressions for three deformation behaviors including stretching of the sheet, bending of the sheet, and folding along the creases. The stiffness expressions are based on system parameters that a user knows before analysis, such as the material properties of the sheet and the geometry of the flat fold pattern. We show that the model is capable of capturing folding behavior of curved-crease origami structures accurately by comparing deformed shapes to other theoretical and experimental approximations of the deformations. The model is used to study the structural behavior of a creased annulus sector and an origami fan. These studies demonstrate the versatile capability of the bar and hinge model for exploring the unique mechanical characteristics of curved-crease origami. The simulation codes for curved-crease origami are provided with this paper.

ABSTRACT: We investigate the complex band structure and forced response of flexural waves propagating in an elastic metamaterial thick plate. Mindlin-Reissner thick plate theory is considered. We study the influence of periodic arrays of spring-mass resonators attached to the surface of a homogeneous thick plate on the formation of Bragg-type and locally resonant band gaps. The plane wave expansion and extended plane wave expansion approaches are used to compute the complex band structure and wave shapes of the metamaterial thick plate with attached spring-mass resonators. An experimental analysis is conducted with a 3D-printed metamaterial plate with resonators. Modal shapes, forced response and band structure are computed by finite element and wave finite element methods. Analytical, numerical and experimental results present good agreement.


ABSTRACT: A discrete-to-continuum transformation to model 2-D discrete lattices as energetically equivalent 1-D continuum beams is developed. The study is initiated in a classical setting but results in a non-classical two-scale micropolar beam model via a novel link within a unit cell between the second-order macrorotation-gradient and the micropolar antisymmetric shear deformation. The shear deformable micropolar beam is reduced to a couple-stress and two classical lattice beam models by successive approximations. The stiffness parameters for all models are given by the micropolar constitutive matrix. The four models are compared by studying stretching- and bending-dominated lattice core sandwich beams under various loads and boundary conditions. A classical 4th-order Timoshenko beam is an apt first choice for stretching-dominated beams, whereas the 6th-order micropolar model works for bending-dominated beams as well. The 6th-order couple-stress beam is often too stiff near point loads and boundaries. It is shown that the 1-D micropolar model leads to the exact 2-D lattice response in the absence of boundary effects even when the length of the 1-D beam (macrostructure) equals that of the 2-D unit cell (microstructure), that is, when L = 1.


ABSTRACT: Snapping mechanical metamaterials have garnered significant interest in recent years because of their ability to achieve extremely large strains and shape/configuration changes or recoveries via elastic buckling instability. For 1D snapping 2D periodic structures with planar topological configurations, the snapping mechanisms have been deeply studied. In this article, 1D multistable cylindrical metastructures composed of a periodic arrangement of bistable snapping units with programmable nonlinear mechanical responses are presented. Theoretical analysis, finite element simulations, and experimental verifications are performed to the application for stable and reusable shape-reconfiguration/phase-transformation. Notably, the mechanical characterizations of 2D snapping 2D periodic structures and developed cylindrical configurations are also carried out. The applications for highly stretchable devices and morphable metastructures are proposed. The relationships between geometric parameters as well as the numbers of the unit cells and structure's macroscopic mechanical behavior are concluded. The study significantly expands the ability of snapping metamaterials and opens avenues for the adaptive morphable surfaces as demonstrated by the design of a smart responsive skin that significantly enhances the deformability and programmability.


ABSTRACT: Constitutive models that describe anisotropic mechanical behaviour have generally focused on incompressible materials such as metals. However, many cellular materials such as foams and wood are compressible, and their mechanical response is both direction- and rate-dependent. To describe the anisotropic behaviour of these compressible cellular materials, a rate-sensitive constitutive model is proposed to capture their large deformation, dynamic response to compression, which cellular materials are often subjected to; this is based on a model proposed by the authors (Li et al., 2018). Anisotropy of yielding is captured via a 4th order
tensor, whereby appropriate assumptions enable the 21 parameters to be determined from only six fundamental experimental tests, i.e. uniaxial compression along three principal directions and simple shear corresponding to three principal planes. Anisotropy of the post-yield response is characterized by a hardening matrix containing six hardening functions, and these are also determined by the six basic experimental tests. By inverting the hardening function matrix, the Cauchy stresses are scaled back to define a modified stress space, whereby the yield surface remains stationary; this enables anisotropic post-yield behaviour to be expressed in a simplified form. To incorporate rate-sensitivity, the six hardening functions are cast in terms of both effective plastic strain and strain rate. Assuming that rate-sensitivity of the post-yield response follows that of the yield stress, the proposed model is applied to predict the stress-strain and deformation response of a transversely isotropic crushable polyurethane foam reported in (Li et al., 2019). Good correlation between the predicted and experimental results demonstrates that the proposed model using the assumed form of rate-sensitivity, is able to adequately capture the large deformation mechanical behaviour and rate-dependence of anisotropic cellular materials beyond yield.


ABSTRACT: Pre-assembled scissor structures can be transformed from a compact bundle of elements to a fully deployed configuration, offering a considerable volume expansion. Intended geometrical incompatibilities during transformation can be introduced as a design strategy to obtain bistability, which allows instantaneously achieving some structural stability in the deployed state. Because of these incompatibilities, some specific members bend during transformation, resulting in a controlled potentially tunable snap-through behaviour. Geometric design methodologies were proposed in the literature to obtain a compatible geometry (i.e. with all of the beams straight) in the folded and the deployed configurations. However, most of these approaches do not consider finite hub sizes or introduce extra incompatibilities in the geometry by adding hub legs. In this contribution, deployability conditions are derived taking the finite hub size, i.e. the spacing between the connections of the different beams to the hub, into account to make triangulated bistable scissor modules fully geometrically compatible in the folded and the deployed configuration.


ABSTRACT: This paper details the nonlinear design of adaptive lattices by determination and enhancement of compliant modes and optimizing the designed structure for delivering high amplitude actuation. The particular focus is the kagome lattice geometry—a pattern with some unique and useful actuation properties. Developing a novel design tool, the stiffness matrix of the beam assembly is calculated using a developed second-order geometrically nonlinear beam finite element formulation allowing large rotations. Based on this formulation in conjunction with singular value decomposition of the stiffness matrix, the modal optimization technique reduces the continuous structure with many degrees of freedom to a small number of low energy modes, which form the basis of designing the adaptive structure. For delivering high-amplitude actuation, the designed structure needs to be re-optimized due to changes in the nonlinear stiffness matrix under large deformation. This is performed via Bayesian optimization and by removing some internal members of the lattice. The integrity and feasibility of the optimum design is guaranteed via defining some constraints on removed members.


ABSTRACT: A deployable M cross section thin-walled boom (M boom) can be flattened and coiled elastically around a hub; and can then be self-deployed by releasing the stored strain energy. The M boom has been proposed as the key member of membrane deployable structures. First, the covariant base vectors of geometrical relation of the single type I tape spring were analyzed by establishing three coordinate systems. Second, the constitutive relation between stress and strain was expressed according to the Kirchhoff-Love hypothesis. Third, the equilibrium and controlling equations of the single tape spring were modeled based on Calladine shell theory. Fourthly, the total strain energy model of the single type I tape spring was built by
integration. Fifth, the strain energy of the M boom was modeled by the sum of the strain energies of the six tape springs. Then, the strain energies of the single type II and III tape springs were analyzed. The sum of the strain energies of the six tape springs equals the total strain energy of the M boom. The bending moment model was established based on the minimum potential energy principle. The experimental equipment and four M boom samples were processed. The bending force value of the M booms was tested 20 times. Then, the average peak bending moment was calculated. The relative error between the theoretical and experimental results of the peak bending moment does not exceed 6.5% verifying the accuracy of the theoretical model.


ABSTRACT: We discuss a reduced-order modeling technique based on Fourier series for membrane wrinkling when the orientation of the wrinkles is not uniform. Indeed, the orientation of the wrinkles depends on geometry and loading, for instance in the case of perforated membrane or with non uniform residual stresses. This Fourier-based reduction technique is an extension of the famous Ginzburg-Landau equation and it has been applied to the wrinkling of beams, plates, sandwich structures and film-substrate systems. The obtained reduced macroscopic models can be discretized by finite elements. In this paper, a finite element of type Discrete Kirchhoff Triangle (DKT18) is used in the numerical applications, the starting model being the Föppl von Karman (FvK) or Extended Föppl von Karman (EFvK) shell models.


ABSTRACT: This paper studies the unfolding mechanical behavior of a creased membrane with different crease characteristics under tensile load. The three-dimensional unfolding shape measured by a noncontact test system reflects both panel bending and crease opening. The rotational stiffness of the crease can be characterized based on the test shape. A finite deformation crease–beam model is developed to describe this unfolding mechanism. The predicted results show that the unfolding behavior of the creased membrane is affected by the ratio of the rotational stiffness of the crease to the bending stiffness of the panel. Analysis of the unfolding mechanism for the creased membrane reveals the contributions of three deformation styles—namely panel bending, panel tension, and crease opening—during different unfolding stages. The present results can be used to guide the controllable unfolding of crease-based deployable structures by adjusting the crease characteristics.


ABSTRACT: Coupled magneto-mechanical wrinkling has appeared in many scenarios of engineering and biology. Hence, soft magneto-active (SMA) plates buckle when subject to critical uniform magnetic field normal to their wide surface. Here, we provide a systematic analysis of the wrinkling of SMA plates subject to an in-plane mechanical load and a transverse magnetic field. We consider two loading modes: plane-strain loading and uni-axial loading, and two models of magneto-sensitive plates: the neo-Hookean ideal magneto-elastic model and the neo-Hookean magnetization saturation Langevin model. Our analysis relies on the theory of nonlinear magneto-elasticity and the associated linearized theory for superimposed perturbations. We derive the Stroh formulation of the governing equations of wrinkling, and combine it with the surface impedance method to obtain explicitly the bifurcation equations identifying the onset of symmetric and antisymmetric wrinkles. We also obtain analytical expressions of instability in the thin- and thick-plate limits. For thin plates, we make the link with classical Euler buckling solutions. We also perform an exhaustive numerical analysis to elucidate the effects of loading mode, load amplitude, and saturation magnetization on the nonlinear static response and bifurcation diagrams. We find that antisymmetric wrinkling modes always occur before symmetric modes. Increasing the pre-compression or heightening the magnetic field has a destabilizing effect for SMA plates, while the saturation magnetization enhances their stability. We show that the Euler buckling solutions are a good approximation to the exact bifurcation curves for thin plates.

References listed at the end of the paper:
M. Otténio, M. Destrade, R.W. Ogden, Incremental magnetoelastic deformations, with application to surface instability, J. Elast., 90 (1) (2008), pp. 19-42
A. Shuvalov, O. Poncelet, M. Deschamps, General formalism for plane guided waves in transversely inhomogeneous anisotropic plates, Wave Motion, 40 (4) (2004), pp. 413-426


ABSTRACT: In this article an “hyper-reduced” scheme for the Crisfield’s algorithm (Crisfield, 1981) applied to buckling simulations and plastic instabilities is presented. The two linear systems and the ellipse equation entering the algorithm are projected on a reduced space and solved in a reduced integration domain, resulting in a system of “hyper-reduced” equations. Use is made of the Gappy proper orthogonal decomposition to recover stresses outside the reduced integration domain. Various methods are proposed to construct a reduced bases, making use of simulation data obtained with standard finite element method and a stress-based error criterion for the hyper reduced calculations is proposed. A “greedy” algorithm coupled with this error criterion is used to generate intelligently full standard finite element simulations and enrich the reduced base, demonstrating the adequacy of the error criterion. Finally, numerical results pertaining to elastoplastic structures undergoing finite strains, with emphasis on buckling and limit load predictions are presented. A parametric study on the geometry of the structure is carried out in order to determine the domain of validity of the proposed hyper-reduced modeling approach.


ABSTRACT: Smart soft materials, which can flexibly respond to external multi-physics stimuli, have attracted considerable attention over the past few years. Here, we present tunable wrinkling patterns in cylindrical core–shell systems under thermal load via the orientation of director in nematic liquid crystal polymer (LCP). To quantitatively analyze mechanical behavior and morphological evolution of LCP core–shell cylinders, we develop a core–shell model that accounts for director-induced anisotropic spontaneous strains. By tuning the alignment of liquid crystal director, we explore the effects of anisotropy of spontaneous strains on instability pattern formation and evolution. When the director is along the circumferential direction, wrinkling pattern can be axisymmetric or diamond-like, determined by a single dimensionless parameter C-sub-s which characterizes the stiffness ratio and curvature of the system. When the director is parallel to the axial direction, leading to circumferential expansion upon heating, the core–shell cylinder usually buckles into churro-like mode. For general spatial director alignment, the ultimate wrinkling patterns depending on the anisotropy state of spontaneous strains, can be diamond-like, parallel bead-chain or oblique stripe mode. We draw director-affected phase diagrams to provide an overall view of pattern selection affected by liquid crystal director orientation,
which could be used to quantitatively guide the effective design of wrinkling morphology-related smart surfaces.


ABSTRACT: Deployable membrane structures such as inflatable stratospheric balloons are known to be sensitive to the occurrence of local instabilities such as wrinkles. The wrinkling phenomenon affects the working performances of the membrane and the occurrence of this phenomenon has to be controlled numerically in order to predict the best means of deployment during the inflation of aerospace balloons. To improve their performances and reliability during flight, the balloons also need to be sized appropriately without the stress field being disturbed by the wrinkles. These instabilities originate numerically from the membrane elements which have a negligible bending stiffness. Several wrinkling models have been presented in the literature in order to solve this problem. However, in most of these models an elastic law and the Green deformation approach have been used for this purpose. The new model called the PS-DPS model presented here for correcting the effects of wrinkles on membrane structures was implemented in the in-house finite element software Herezh++. A projection technique based on a Newton–Raphson method is used to control the stress plane and the in-plane contraction. Using the Almansi strain formulation, this model also accounts for the changes in membrane thickness liable to occur during simulations. The problems due to numerical instabilities are overcome by determining the equilibrium with the so-called Dynamic Relaxation method using kinetic damping procedures. Unlike other membrane models of literature, the PS-DPS model can be used with materials showing complex mechanical behaviour of all kinds. Several benchmark problems are analysed with the present wrinkling model and compared with results available in the literature, focusing first on an elastic law and then on a non-linear hyperelastic law. Lastly, the inflation of a square cushion test and that of a Zero Pressure Balloon are simulated with this non-linear law. The results obtained indicate that the PS-DPS model is valid and accurate to take into account the wrinkles in flexible structures with all these linear and non-linear behaviours.


ABSTRACT: In this paper, a lattice structure whose mechanical properties can be systematically designed is presented using tailored sub-unit structures made from curved bars. First, the stiffness of circular-arc curved bars is theoretically studied, and the effects of geometric parameters of the curved bars on the mechanical properties are analyzed. Second, sub-unit structures are designed based on the fractal geometry, and periodic structures for lattice structures assembled from different sub-unit structures are precisely fabricated using 3D printing techniques. Third, mechanical properties of structures are mechanically measured and numerically simulated simultaneously, which present anisotropy of stiffness depending on the loading direction. These results show that the controllable stiffness of lattice structures along different directions can be designed by changing structure geometry and degrees of fractal. This study proposes a new method for the design of lattice structures and potential in versatile industrial and biomedical applications.


ABSTRACT: Equivalent plate properties are obtained for composite corrugated structures using mechanics of structure genome. The method developed in this paper interprets the unit cell associated with the corrugated structure as an assembly of plates, and the overall strain energy density of the unit cell as a summation of the plate strain energies of these individual plates. Mechanics of structure genome is then applied to drop all higher-order terms and the remaining energy is minimized with respect to the unknown fluctuating functions. This has been done by discretizing the two-dimensional unit cell into one-dimensional frame elements in a finite element description. This allows the handling of structures with different levels of complexities and internal geometry within a general framework. Comparisons have been made with existing work to show the advantage the proposed model offers over existing ones.
ABSTRACT: This paper investigates the problem of delamination and buckling of thermoelectric pn-junctions, which have many potential civil and military applications including thermal protection systems in space industry. Based on the compatibility equations of deformation, equilibrium equations of axial force and the strain compatibility equation at the interface of the bonding part are derived. Analytical solution of the delamination energy release rate is obtained. It is noted that there is no energy release rate when the magnitude of the temperature difference between the right end and the left end of the pn-junction is zero. The energy release rate can decrease or increase with the coefficient of thermal expansion. Distributions of the critical temperature differences for the delamination propagation and buckling are presented graphically. The critical temperature differences decrease continually with delamination and buckling lengths. Either a higher temperature difference or a higher electric current density can result in a bigger delamination energy release rate, a larger buckling deflection and a strong axial force. The buckling deflection increases but the axial force decreases with the increase of buckling length.

ABSTRACT: The equilibrium configuration of an engineering structure, able to withstand a certain loading condition, is usually associated with a local minimum of the underlying potential energy. However, in the nonlinear context, there may be other equilibria present, and this brings with it the possibility of a transition to an alternative (remote) minimum. That is, given a sufficient disturbance, the structure might buckle, perhaps suddenly, to another shape. This paper considers the dynamic mechanisms under which such transitions (typically via saddle points) occur. A two-mode Hamiltonian is developed for a shallow arch/buckled beam. The resulting form of the potential energy—two stable wells connected by rank-1 saddle points—shows an analogy with resonance transitions in celestial mechanics or molecular reconfigurations in chemistry, whereas here the transition corresponds to switching between two stable structural configurations. Then, from Hamilton’s equations, the equilibria are determined and linearization of the equations of motion about the saddle is obtained. After computing the eigenvalues and eigenvectors of the coefficient matrix associated with the linearization, a symplectic transformation is given which puts the Hamiltonian into normal form and simplifies the equations, allowing us to use the conceptual framework known as tube dynamics. The flow in the equilibrium region of phase space as well as the invariant manifold tubes in position space are discussed. Also, we account for the addition of damping in the tube dynamics framework, which leads to a richer set of behaviors in transition dynamics than previously explored.

ABSTRACT: We study analytically the case of cylindrical buckling of a plate resting on an incompressible, elastomeric foundation, which is subjected to in-plane uniaxial compression. Our analysis differs from the classical Hetényi solution for a plate resting on a Winkler foundation in that we consider the incompressibility and the continuity of the elastomer foundation. The critical buckling force is derived in terms of the flexural rigidity and the length of the plate, and the modulus and the thickness of the elastomer foundation. The critical buckling force scales with these parameters in a different manner than in the case of a Winkler foundation. The
ratio of the critical buckling load in the present problem to that predicted for its Winkler counterpart is shown to depend strongly on the lateral confinement of the elastomer foundation.


ABSTRACT: An elastic bilayer, consisting of an equibiaxially pre-stretched sheet bonded to a stress-free one, spontaneously morphs into curved shapes in the absence of external loads or constraints. Using experiments and numerical simulations, we explore the role of geometry for square and rectangular samples in determining the equilibrium shape of the system, for a fixed pre-stretch. We classify the observed shapes over a wide range of aspect ratios according to their curvatures and compare measured and computed values, which show good agreement. In particular, as the bilayer becomes thinner, a bifurcation of the principal curvatures occurs, which separates two scaling regimes for the energy of the system. We characterize the transition between these two regimes and show the peculiar features that distinguish square from rectangular samples. The results for our model bilayer system may help explaining morphing in more complex systems made of active materials.


ABSTRACT: The mechanics of swelling and diffusion in fluid saturated elastomers has long interested workers in nonlinear elasticity theory. Here we broaden this subject by presenting a model for thin membranes, derived as the leading-order-in-thickness approximation to the three-dimensional theory.


ABSTRACT: Laminated plate structures are analyzed by a discontinuous finite element method with emphasis on determining the transverse shear and normal stress components at the interface of adjacent layers accurately. A Consistent Orthogonal Basis Function Space is used for the interpolation of the displacement field and the traction field between two adjacent layers. The mass matrix of the laminated plate becomes diagonal. Moreover, it is observed that the basis functions are very similar to the vibration mode shapes, even through we do not solve any eigenvalue problem in their generation. These basis functions are uniquely determined by the structure's configuration and associated boundary conditions. The stress field between the layers can be accurately calculated, even for the region near the boundaries that might have sharp stress gradients. Several numerical examples are studied with different boundary conditions. The results for both the deformation and the stress components are compared with the traditional finite element method, especially in terms of the number of degrees-of-freedom (DOF) used in the proposed method and the classic FEM. It is observed that the proposed method is able to use a much fewer number of DOF than that of commercial FEM software (ANSYS etc) to obtain accurate solutions to both the deformation of the plate and the stress field between adjacent layers.


ABSTRACT: Understanding the effect of mechanical uncertainties can play a significant role in design of the nanocomposites. The uncertain natural frequencies of moderately thick doubly-curved functionally graded composite panels reinforced by carbon nanotube (CNT) are investigated. Specifically, doubly-curved shell panels, including spherical, cylindrical and hyperbolic paraboloid panels are examined. To evaluate uncertainty propagation, uncertainty resources including distribution of the CNT through the thickness as well as the mechanical properties of the CNT and polymer matrix are taken into consideration. To assess the propagated uncertainties in the vibrational characteristics of nanocomposite panels, the interval analysis method is employed while the mechanical properties of nanocomposite panels are predicted using the modified rule of mixture method. Based on the comparison between the results of the present study and those reported in the literature, the accuracy of the results is validated. The sensitivity analysis is performed to distinguish the most
prominent uncertain variables. Furthermore, numerical results reveal the influences of various uncertainty resources on the upper and lower bounds of uncertain frequencies and uncertainty propagation percent.


ABSTRACT: A general higher-order shear deformation zig-zag theory is proposed for predicting the nonlinear aerothermoelastic characteristics of composite laminated panels subjected to supersonic airflow. The von Kármán strains are employed to describe the structural nonlinearity of the panels, and the quasi-steady first-order piston theory is adopted to calculate the aerodynamic loads. The discretized equations governing the aerothermoelastic motion of the panels are established using the nonlinear finite element method. The proposed higher-order shear deformation zig-zag theory employs seven variables to represent the displacement field of the panel in a unified form, which is capable of accommodating various plate theories available in the literature, including the Kirchhoff plate theory, the Mindlin–Reissner plate theory and other higher-order shear deformation plate theories. The validity of the present model is confirmed by comparing the computed results with those solutions available in the literature. The aerothermoelastic behaviors (including the critical buckling, limit-cycle oscillation and flutter boundary) for composite laminated panels with different geometrical dimensions, temperature gradients and fiber orientations are examined. The discrepancies of the aerothermoelastic characteristics of composite laminated panels determined by different structural theories are discussed in detail. Physical insight into the mechanism of the differences among the aerothermoelastic behaviors of the panels determined by different plate theories is provided.

References listed at the end of the paper:
5 LC. Shiau, LT. Lu, Nonlinear flutter of two-dimensional simply supported symmetric composite laminated plates, J Aircraft, 29 (1992), pp. 140-145
6 IR, Dixon, C Mei, Finite element analysis of large-amplitude panel flutter of thin laminates, AIAA J, 31 (1993), pp. 701-707
8 F Ebrahimi, E Salari, Size-dependent thermo-electrical buckling analysis of functionally graded piezoelectric nanobeams, Smart Mater Struct, 24 (12) (2015), Article 125007
10 JF, Abbas, RA, Ibrahim, RF. Gibson, Nonlinear flutter of orthotropic composite panel under aerodynamic heating, AIAA J, 31 (1993), pp. 1478-1488
11 DY, Xue, C Mei, Finite element nonlinear panel flutter with arbitrary temperatures in supersonic flow, AIAA J, 31 (1993), pp. 154-162
13 X Guo, C Mei, Using aeroelastic modes for nonlinear panel flutter at arbitrary supersonic yawed angle, AIAA J, 41 (2003), pp. 272-279
14 X Guo, C Mei, Application of aeroelastic modes on nonlinear supersonic panel flutter at elevated temperatures, Comput Struct, 84 (2006), pp. 1619-1628
16 ZG, Song, FM. Li, Aerothermoelastic analysis of nonlinear composite laminated panel with aerodynamic heating in hypersonic flow, Compos Part B Eng, 56 (2014), pp. 830-839
17 K Abdel-Motaglary, R Chen, C Mei, Nonlinear flutter of composite panels under yawed supersonic flow using finite elements, AIAA J, 37 (1999), pp. 1025-1032
18 MK, Singh, M Ganapathi, A parametric study on supersonic flutter behavior of laminated composite skew flat panels, Compos Struct, 69 (2005), pp. 55-63
19 MA, Kouchakzadeh, M Rasekh, H Haddadpour, Panel flutter analysis of general laminated composite plates, Compos Struct, 92 (2010), pp. 2906-2915
21 S Shivit, V Venedeev, Flutter of rectangular simply supported plates at low supersonic speeds, J Fluid Struct, 69 (2017), pp. 154-173
23 ZG, Song, FM. Li, W Zhang, Active flutter and aerothermal postbuckling control for nonlinear composite laminated panels in supersonic airflow, J Intel Mat Syst Str, 26 (2015), pp. 840-857
24 Y Chai, FM. Li, ZG, Song, CZ. Zhang, Aerothermoelastic flutter analysis and active vibration suppression of nonlinear composite laminated panels with time-dependent boundary conditions in supersonic airflow, J Intel Mat Syst Str, 29 (2018), pp. 653-668
25 H. Zhao, D Cao, A study on the aero-elastic flutter of stiffened laminated composite panel in the supersonic flow, J Sound Vib, 332 (2013), pp. 4668-4679
28 Z. Kaczkowski, Plates, Statical calculations., Arkady, Warsaw (1968)
29 V Panc, Theories of elastic plates, Academia, Prague: (1975)
31 M Levy, Memoire sur la theorie des plaques elastiques planes, J Math Appl, 30 (1877), pp. 219-306
37 AVK, Murty, Toward a consistent beam theory, AIAA J, 22 (1984), pp. 811-816
39 JL Mantari, AS Oktem, C Guedes Soares, A new higher order shear deformation theory for sandwich and composite laminated plates, Compos Part B Eng, 43 (2012), pp. 1489-1499
41 JL Mantari, AS Oktem, C Guedes Soares, Static and dynamic analysis of laminated composite and sandwich plates and shells by using a new higherorder shear deformation theory, Compos Struct, 94 (1) (2011), pp. 37-49
42 E Viola, P Tornabene, N Fantuzzi, General higher-order shear deformation theories for the free vibration analysis of completely doubly-curved laminated shells and panels, Compos Struct, 95 (2013), pp. 639-666
44 M Aydogdu, A new shear deformation theory for laminated composite plates, Compos Struct, 89 (2009), pp. 94-101
50 U Icardi, A three-dimensional zig-zag theory for analysis of thick laminated beams, Compos Struct, 52 (2001), pp. 123-135
52 M Ghelone, A Tessler, M Di Sciuva, C0 beam elements based on the refined zigzag theory for multilayered composite and sandwich laminates, Compos Struct, 93 (2011), pp. 2882-2894
53 JD Rodrigues, CMC Roque, AJM Ferreira, et al., Radial basis functions–finite differences collocation and a Unified Formulation for bending, vibration and buckling analysis of laminated plates, according to Murakami's zig-zag theory, Compos Struct, 93 (2011), pp. 1613-1620
57 R. Melosh, Basis for derivation of matrices for the direct stiffness method, AIAA J, 1 (1963), pp. 1631-1637

ABSTRACT: In this paper the enhanced lattice topology (defined as hourglass), with the improved resistance to tearing of face sheets, is used to improve the underwater blast impact performance of lattice truss structures. The stainless-steel lattices are fabricated by an interlocking and vacuum brazing method, all with a core relative density of about 4%. Their mechanical behaviors are investigated under quasi-static out-of-plane compression and underwater blast impact, in the latter case using an underwater shock simulator. Results show that the quasi-static compressive strength of the hourglass lattice is similar to that of the pyramidal lattice for the relative density chosen in this paper. The failure modes of the hourglass lattice panels subjected to underwater blast impact consist of core truss buckling, node imprinting and stretching of the front face sheets. The obtained results confirm that the hourglass lattice sandwich panel shows an approximately 60% reduction in the maximum panel deflection with respect to a monolithic plate of equal mass per unit area. Furthermore, the underwater blast impact performance of the hourglass lattice panels outperforms that of the pyramidal lattice panels of equal weight per unit area in the sense of resistance to stretching and tearing of the face sheets. Therefore, sandwich structure with the hourglass lattice design is a potential candidate for protective structures.

References listed at the end of the paper:

1. QH Qin, TJ Wang, SZ Zhao, Large deflections of metallic sandwich and monolithic beams under locally impulsive loading, Int J Mech Sci, 51 (11-12) (2009), pp. 752-773
2. QH Qin, C Yuan, JX Zhang, TJ Wang, A simplified analytical model for metal sandwich beam with soft core under impulsive loading over a central patch, Int J Impact Eng, 74 (2014), pp. 67-82
3. XR Liu, XG Tian, TJ Lu, B Liang, Sandwich plates with functionally graded metallic foam cores subjected to air blast loading, Int J Mech Sci, 84 (2014), pp. 61-72
8. W Huang, W Zhang, N Ye, Y Gao, P Ren, Dynamic response and failure of PVC foam core metallic sandwich subjected to underwater impulsive loading, Compos Part B, 97 (2016), pp. 226-238
14. JW Hutchinson, Z Xue, Metal sandwich plates optimized for pressure impulses, Int J Mech Sci, 47 (4-5) (2005), pp. 545-569
19. LF Mori, DT Queheillalt, HNG Wadley, HD Espinosa, Deformation and failure modes of i-core sandwich structures subjected to underwater impulsive loads, Exp Mech, 49 (2009), pp. 257-275

ABSTRACT: This paper studies the three dimensional buckling and post buckling process of compressive long elastic beam confined by cylindrical lateral constraint without friction. Based on theoretical analysis and numerical simulations, four stages are identified and characterized as the compressive axial displacement increases from zero: initial two dimensional shape, small three dimensional shape, three dimensional helix shape and three dimensional alpha shape. Critical axial displacement at the transition points between four deformation shapes are studied, and the effect of geometrical parameters such as beam length and constraint size on critical displacement are examined. Special emphasis is paid to identify the transition points from three dimensional helix shape to three dimensional alpha shape, and the transition can be divided into jump regime (sharp transition) and no-jump regime (smooth transition) based on the criterion whether number of helical periods is larger or smaller than one. At the same time, critical number of helical periods in three dimensional helix shape is linearly correlated with a nondimensional geometrical parameter.

References listed at the end of the paper:

5 Y. Chen, et al., Mechanism of the transition from in-plane buckling to helical buckling for a stiff nanowire on an elastomeric substrate, J Appl Mech, 83 (4) (2016), Article 041011
7 J. Xiao, X. Chen, Buckling morphology of an elastic beam between two parallel lateral constraints: implication for a snake crawling between walls, J R Soc Interface, 10 (85) (2013)
12 J. Xiao, The stability at the solid-solid and liquid-solid Interfaces, in mechanical Engineering., Columbia University, New York (2016)
ABSTRACT: This paper focuses on vibration characteristics of a rotating composite laminated cylindrical shell subjected to both subsonic air flow and hygrothermal effects. Based on Love's nonlinear shell theory, and introducing hygrothermal strains into the constitutive relation of single layer material, the dynamic equations of the shell considering rotation, subsonic air flow and hygrothermal effects are obtained by Hamilton's principle. The frequency parameters of the equations are derived by means of Galerkin's method. Some numerical results are performed to conduct detailed parametric studies on vibration characteristics of the shell. In particular, combined effects of subsonic air flow and hygrothermal environment on natural frequencies of forward and backward travelling waves and critical rotating velocity of the shell are discussed, and the influence of initial hoop tension on those frequencies is also carried out. From the results it is shown that rotating angular velocity, subsonic air flow velocity and hygrothermal effects show the significant influence on vibration characteristics of the shell.

References listed at the end of the paper:

16 P. Malekzadeh, Y. Heydarpour, Free vibration analysis of rotating functionally graded cylindrical shells in thermal environment, Compos Struct, 94 (2012), pp. 2971-2981
18 G. Wei, Discrete singular convolution for the solution of the Fokker–Planck equation, J Chem Phys, 110 (1999), pp. 8930-8942
19 X. Song, J. Zhai, Y. Chen, Q. Han, Traveling wave analysis of rotating cross-ply laminated cylindrical shells with arbitrary boundaries via Rayleigh–Ritz method, Compos Struct, 133 (2015), pp. 1101-1115
21 L. Kollar, Three-dimensional analysis of composite cylinders under axially varying hygrothermal and mechanical loads, Comput Struct, 60 (1996), pp. 525-540
38 M. Biswal, S. Sahu, A. Asha, Experimental and numerical studies on free vibration of laminated composite shallow shells in hygrothermal environment, Compos Struct, 127 (2015), pp. 165-174
39 M. Biswal, S. Sahu, A. Asha, Vibration of composite cylindrical shell shells subjected to hygrothermal loading-experimental and numerical results, Compos Part B Eng, 98 (2016), pp. 108-119
43 F. Sabri, A.A. Lakis, Finite element method applied to supersonic flutter of circular cylindrical shells, AIAA J, 48 (2010), pp. 73-81
References listed at the end of the paper:

1 E.W. Andrews, W. Sanders, L.J. Gibson, Compressive and tensile behaviour of aluminium foams, Mate Sci Eng, 270 (2) (1999), pp. 113-124


ABSTRACT: There is a practical need to elevate both the indentation strength and level of energy absorption of engineering foams by the addition of a stiff and strong face sheet for applications such as packaging and crash mitigation. In this study, the enhancement in the plane strain indentation resistance of a polyvinyl chloride (PVC) foam by the presence of a polycarbonate (PC) face sheet is determined by experiment, finite element analysis and by an analytical model. Plane strain indentation is by a flat-bottom punch or by a cylindrical roller, and the strain distribution within the PC face sheet and in the foam substrate are measured by digital image correlation. With increasing indent depth, the face sheet bends and stretches elastically and then plastically until face sheet or substrate fail. The generation of membrane tension in the face sheet plays a major role in supporting the indentation load when the indent depth exceeds the thickness of the face sheet and leads to a strong hardening behaviour beyond the initial collapse load for indentation. Finite element predictions of the full indentation response are based upon the measured tensile and compressive responses of the PVC foam and PC layer. An analytical model is developed by matching the stretching response of the PC face sheet to the indentation response of the underlying foam, with due consideration for load diffusion from membrane tension of the PC face sheet into the underlying foam substrate. The indentation model is calibrated by ancillary finite element simulations of the load diffusion problem, and they emphasise the role of a shear lag zone in dictating the large indentation resistance. The indentation response of the bi-layer is also compared with that of a sandwich beam in 3-point bending. Experiments, finite element simulations and an additional analytical model for indentation of the sandwich beam in 3-point bending reveal that strong hardening of the post-yield load versus displacement response is now absent, in contrast to that of the bi-layer. The lack of hardening in 3-point bending is traced to the relatively low value of the plastic bending moment of the beam section.
12 M. Hetenyi, Beams on elastic foundation, Waverly press, Baltimore (1946)
16 P.O. Bostrom, Collapse modes of a rigid-plastic beam on a rigid-plastic foundation, Int J Mech Sci, 17 (1) (1975), pp. 73-84
22 Q.H. Qin, T.J. Wang, Plastic anlaysis of metal foam core sandwich beam transversely loaded by a flat punch: combined local denting and overall deformation, J Appl Mech, 79 (4) (2012), pp. 1-12
23 D. Xiao, L. Mu, G. Zhao, Influence of positive gradient metallic cellular core on energy dissipation of sandwich panels under indentation, Arch Appl Mech, 86 (2016), pp. 1901-1911
28 A.M. Boyce, V.S. Deshpande, N.A. Fleck, On the indentation resistance of a PC layer on PVC foam substrate, Adv Eng Mater, 19 (10) (2017), Article 1700075
29 W.T. Koiter, On the diffusion of load from a stiffener into a sheet, J Appl Mech, 3 (2) (1966), pp. 164-178


ABSTRACT: The paper is devoted to simply supported sandwich beams and I-beams of symmetrical structure. Two types of loads are taken into account: three-point bending and uniformly distributed load. Moreover, two models of deformation of planar cross sections of these beams are also considered: zig-zag theory – classical “broken line” hypothesis and nonlinear theory – “polynomial” hypothesis. Based on the principle of stationary total potential energy the differential equations of equilibrium are obtained. The system of the equations is...
analytically solved for two types of loads and the deflections of the beams are calculated for exemplary beams with consideration of the shear effect. The results of the two models of deformation of planar cross sections are compared and specified in Tables.

References listed at the end of the paper:
5. E. Magnucka-Blandzi, K. Magnucki, Effective design of a sandwich beam with a metal foam core, Thin-Walled Struct, 45 (4) (2007), pp. 432-438
10. B. Jiang, Z. Li, F. Lu, Failure mechanism of sandwich beams subjected to three-point bending, Compos Struct, 133 (2015), pp. 739-745
13. E. Magnucka-Blandzi, Bending and buckling of a metal seven-layer beam with crosswise corrugated main core – comparative analysis with sandwich beam, Compos Struct, 183 (2018), pp. 35-41
17. M.J. Smyczynski, E. Magnucka-Blandzi, J. Lewinski, Three-point bending of a sandwich beam with two binding layers – Comparison of two nonlinear hypotheses, Compos Struct, 183 (2018), pp. 96-102
18. P. Paczos, R. Wichtiarena, K. Magnucki, Three-point bending of the sandwich beam with special structures of the core, Compos Struct, 201 (2018), pp. 676-682
20. K. Magnucki, D. Witkowski, J. Lewinski, Bending and free vibrations of porous beams with symmetrically varying mechanical properties – Shear effect, Mech Advanced Mater Struct (16 May 2018) (Published online: ?)
21. K. Magnucki, J. Lewinski, Analytical modeling of I-beam as a sandwich structures, Eng Trans, 66 (2018), Published online: 9 August 2018


ABSTRACT: In this paper, a scale-dependent coupled nonlinear continuum-based model is developed for the mechanical behaviour of imperfect nanoscale tubes incorporating both the effect of the stress nonlocality and strain gradient effects. The scale effects on the nonlinear mechanics are taken into consideration employing a modified elasticity theory on the basis of a refined combination of Eringen's elasticity and the strain gradient theory. According to the Euler–Bernoulli theory of beams, the nonlocal strain gradient theory (NSGT) and Hamilton's principle, the potential energy, kinetic energy and the work performed by harmonic loads are formulated, and then the coupled scale-dependent equations of the imperfect nanotube are derived. Finally, Galerkin's scheme, as a discretisation technique, and the continuation method, as a solution procedure for ordinary differential equations, are used. The effects of geometrical imperfections in conjunction with other nanosystem parameters such as the nonlocal coefficient as well as the strain gradient coefficient on the coupled large-amplitude mechanical behaviour are explored and discussed.
References listed at the end of the paper:
4 U Gul, M Aydogdu, Coaxial vibration and buckling analysis of embedded double-walled carbon nanotubes by using doublet mechanics, Compos Part B Eng, 137 (2018), pp. 60-73
13 A Farajpour, A Rastgoo, M Mohammadi, Vibration, buckling and smart control of microtubes using piezoelectric nanoshells under electric voltage in thermal environment, Phys B Condens Matter, 509 (2017), pp. 100-114
25 MR Barati, AM Zenkour, Investigating post-buckling of geometrically imperfect metal foam nanobeams with symmetric and asymmetric porosity distributions, Compos Struct, 182 (2017), pp. 91-98
28 A Arefi, M Salimi, Investigations on vibration and buckling of carbon nanotubes with small initial curvature by nonlocal elasticity theory. Fuller Nanotub Carbon Nanostruct, 23 (2015), pp. 105-112
39 S Sahmani, M Aghdam, Nonlocal strain gradient shell model for axial buckling and postbuckling analysis of magneto-electro-elastic composite nanoshells, Compos Part B Eng, 132 (2018), pp. 258-274
40 A Farajpour, A Rastgoo, Influence of carbon nanotubes on the buckling of microtube bundles in viscoelastic cytoplasm using nonlocal strain gradient theory, Results Phys, 7 (2017), pp. 1367-1375
41 F Ebrahimi, MR Barati, Vibration analysis of nonlocal strain gradient embedded single-layer graphene sheets under nonuniform in-plane loads, J Vib Control, 24 (20) (2017), pp. 4751-4763
43 M Farajpour, A Shahidi, A Farajpour, A nonlocal continuum model for the biaxial buckling analysis of composite nanoplates with shape memory alloy nanowires, Mater Res Express, 5 (2018), Article 035026
54 Zhang L, Zhang Y, Liew K, Vibration analysis of quadrilateral graphene sheets subjected to an in-plane magnetic field based on nonlocal elasticity theory, Compos Part B Eng, 118 (2017), pp. 96-103
55 K Mercan, Ö Çivalek, Buckling analysis of Silicon carbide nanotubes (SiCNTs) with surface effect and nonlocal elasticity using the method of HDQ, Compos Part B Eng, 114 (2017), pp. 34-45
56 F Mehrdarian, YT Beni, MK Zeverdejani, Nonlocal strain gradient theory calibration using molecular dynamics simulation based on small scale vibration of nanotubes, Phys B Condens Matter, 514 (2017), pp. 61-69
57 F Mehrdarian, YT Beni, MK Zeverdejani, Calibration of nonlocal strain gradient shell model for buckling analysis of nanotubes using molecular dynamics simulations, Phys B Condens Matter, 521 (2017), pp. 102-111
61 MH Ghayesh, H Farokhi, A Farajpour, Chaotic oscillations of viscoelastic microtubes conveying pulsatile fluid, Microfluid Nanofluidics, 22 (2018), p. 72
64 MH Ghayesh, H Farokhi, M Amabili, In-plane and out-of-plane motion characteristics of microbeams with modal interactions, Compos Part B Eng, 60 (2014), pp. 423-439

ABSTRACT: Existing experimental and numerical simulations using the finite element method confirm that the collapse mode of thin-walled columns transforms from diamond to concertina as a result of foam filling. To the authors’ knowledge, no attempt has been made to explain this transition analytically. This paper presents a first effort to analytically establish the effect of foam-filling and column geometry on the transition of the collapse mode. In this study, the foam/column shell interaction is represented as a uniform pressure equaling to the foam plateau stress applied on the interior of the fold walls. The predictions of the newly developed analytical model are compared with FE simulations and experimental findings and reveal good agreement. A mode classification design chart is developed to show the dependence of collapse mode on the ratio of column diameter to thickness and the ratio of filler plateau stress to column yield stress. It indicates that the column will collapse in a diamond mode when the radius-to-thickness ratio is large (>25) and the foam plateau stress/column yield stress is small (<0.15); otherwise it will collapse in a concertina mode.

References listed at the end of the paper:
2 A.A.A. Alghamdi, Collapsible impact energy absorbers: an overview, Thin Walled Struct, 39 (2001), pp. 189-213
7 Ø. Jensen, O.S. Hopperstad, M. Langseth, Transition from progressive to global buckling of aluminium extrusions – a numerical study, Int J Crash, 10 (6) (2005), pp. 609-620
ABSTRACT: An analytical method is presented to investigate the nonlinear dynamic behavior of corrugated graphene/piezoelectric (CGP) laminated structures under electro-mechanical coupling loads, where the corrugated graphene is affixed on a piezoelectric film. An equivalent orthotropic plate method is used to obtain the stiffness coefficients of corrugated graphene sheet, and its accuracy is validated by the finite element method (FEM). The nonlinear dynamic governing equations of CGP laminated films are constructed based on von Kármán nonlinear geometric relations, then is solved by the Galerkin method and iterative homotopy harmonic balance method. Results show that the equivalent orthotropic plate method is reliable in analyzing the resonant frequency of corrugated film, and both geometry nonlinearity and external control voltage exerted on
piezoelectric film have significant effects on the dynamic behaviors of CGP laminated films. Additionally, though corrugated graphene sheet exhibits smaller material stiffness, a significant effect on resonant frequency is observed by affixing corrugated graphene on piezoelectric plate. The meaningful results could serve as references for the applications of soft super-capacitors, stretchable electrode devices, nano-sensors, and etc.

References listed at the end of the paper:
4 Huang Y., Liang J., Chen Y., An overview of the applications of graphene based materials in supercapacitors, Small, 8 (12) (2012), pp. 1805-1834
11 Sun G.F., Jia J.F., Xue Q.K., Li L., Atomic-scale imaging and manipulation of ridges on epitaxial graphene on 6H-SiC (0001), Nano Letters, 20 (35) (2009), Article 355701
21 A. Ferreira, N.M.R. Peres, Complete light absorption in graphene-metamaterial corrugated structures, Phys Rev B, 86 (20) (2012), Article 205401
26 D. Briassoulis, Equivalent orthotropic properties of corrugated sheets, Compt Struct, 23 (2) (1986), pp. 129-138
29 G. Kress, M. Winkler, Corrugated laminate homogenization model, Compos Struct, 92 (3) (2010), pp. 795-810
ABSTRACT: Single-layer graphene sheets (SLGSs) with dimensions of the order of a few nanometres are relatively new, but expected to have several applications. When SLGSs experience displacements that are large in comparison with their extremely small thickness, the membrane forces that develop lead to non-linear behaviour. Knowing the modes of vibration of SLGSs is important, because these modes provide a picture of what one may expect not only in free, but also in forced vibrations. In this paper, the non-linear modes of vibration of flat single-layer graphene sheets are investigated. For that purpose, a Galerkin type formulation, based on classic plate theory with Von Kármán non-linear terms and resorting to Airy’s stress function, is implemented. The formulation takes into account non-local effects, which are thought to be important in very small structural elements. The ordinary differential equations of motion are transformed into algebraic equations of motion via the harmonic balance method (HBM), with several harmonics, and are subsequently solved by an
arc-length continuation method. The combined importance of non-local effects and of the geometrical non-linearity on the non-linear modes of vibration is analysed. They result in alterations of the natural frequencies, variations in the degrees of hardening, changes in the frequency content of the free vibrations, and alterations in shapes assumed along a period of vibration. The main outcome of this work is the finding that the small scale has a major effect on interactions between the first and higher order modes, interactions which are induced by the geometrical non-linearities. It turns out to be possible, e.g., for non-local effects to considerably change the frequencies at which internal resonances occur, or even to eliminate those internal resonances.

References listed at the end of the paper:
8 H.B. Li, Y.D. Li, X. Wang, X. Huang, Nonlinear vibration characteristics of graphene/piezoelectric sandwich films under electric loading based on nonlocal elastic theory, J Sound Vib, 358 (2015), pp. 285-300
11 P. Ribeiro, M. Petyt, Non-linear vibration of beams with internal resonance by the hierarchical finite-element method, J Sound Vib, 224 (1999), pp. 591-624
12 S. Stoykov, P. Ribeiro, Nonlinear free vibrations of beams in space due to internal resonance, J Sound Vib, 330 (2011), pp. 4574-4595
15 P. Ribeiro, O. Thomas, Nonlinear modes of vibration and internal resonances in nonlocal beams, J Comput Nonlinear Dyn, 12 (2017), Article 031017-031017-031011
17 A. Vyas, D. Peroulis, A.K. Bajaj, A microresonator design based on nonlinear 1:2 internal resonance in flexural structural modes, J Microelectromech Syst, 18 (2009), pp. 744-762
30 P. Belardinelli, S. Lenci, M. Brocchini, Modeling and analysis of an electrically actuated microbeam based on nonclassical beam theory, J Comput Nonlinear Dyn, 9 (2014), Article 031016
35 T.R.C. Chuaqui, Linear and non-linear vibrations of single-layer graphene sheets, DEMec, Faculty of Engineering, University of Porto, Porto (2016), p. 93
38 P. Ribeiro, M. Petyt, Multi-modal geometrical non-linear free vibration of fully clamped composite laminated plates, J Sound Vib, 225 (1999), pp. 127-152
42 M. Amabili, Nonlinear vibrations of rectangular plates with different boundary conditions: theory and experiments, Comput Struct, 82 (2004), pp. 2587-2605
49 W. Han, M. Petyt, Geometrically nonlinear vibration analysis of thin, rectangular plates using the hierarchical finite element method.1. The fundamental mode of isotropic plates, Comput Struct, 63 (1997), pp. 295-308
50 P. Ribeiro, Asymmetric solutions in large amplitude free periodic vibrations of plates, J Sound Vib, 322 (2009), pp. 8-14
56 P. Ribeiro, Hierarchical finite element analyses of geometrically non-linear vibration of beams and plane frames, J Sound Vib, 246 (2001), pp. 225-244
65 A.W. Leissa, Vibration of plates, Acoustical Society of America through the American Institute of Physics (1993)

ABSTRACT: This paper investigates the suppression of vibration and sound radiation of a sandwich plate through the use of periodic design. A periodic sandwich plate is constructed and its dispersion relation is calculated. The vibration and sound radiation properties of the periodic sandwich plate are studied. Via the comparison of the periodic and bare sandwich plate, the effects of the periodic design on the vibration and sound radiation are analysed. Further, to know the sound radiation properties better, sound radiation efficiency of the periodic and bare sandwich plates is compared. In addition, the effects of the boundary conditions on the properties of the periodic sandwich plate are analysed. The numerical results demonstrate that the vibration and sound radiation are greatly suppressed over the stop band of the periodic sandwich plate. The suppression can also be obtained in part of pass bands. It is also shown that the periodic design can be an effective method for the reduction of the sound radiation efficiency. The suppression for the vibration and sound is greater than that caused by only increasing the mass of the plate in the designing frequency range.

References listed at the end of the paper:
4 T. Wang, V. Sokolinsky, S. Rajaram, et al., Consistent higher-order free vibration analysis of composite sandwich plates, Compos Struct, 4 (2008), pp. 609-621
10 H. Denli, J.Q. Sun, Structural-acoustic optimization of sandwich structures with cellular cores for minimum sound radiation, J Sound Vib (2007), pp. 93-105
12 T. Wang, S. Li, S.R. Nutt, Optimal design of acoustical sandwich panels with a genetic algorithm, Appl Acoust, 3 (2009), pp. 416-425
16 A.D. Williams, S.E. Franke, B.K. Henderson, Development of a lightweight, low frequency acoustic barrier with spherical particles for fairing noise control, AIAA, Austin, Texas (2005)
17 A.D. Williams, S.E. Franke, B.K. Henderson, Development of a lightweight, low frequency acoustic barrier with spherical particles for fairing noise control, AIAA, Austin, Texas (2005)
18 A.D. Williams, S.E. Franke, B.K. Henderson, Development of a lightweight, low frequency acoustic barrier with spherical particles for fairing noise control, AIAA, Austin, Texas (2005)
19 T. Wang, S. Li, S.R. Nutt, Optimal design of acoustical sandwich panels with a genetic algorithm, Appl Acoust, 3 (2009), pp. 416-425

ABSTRACT: In the present paper, an attempt is made to adopt the variational differential quadrature (VDQ) technique for the large-amplitude vibration analysis of shell-type structures based on the six-parameter shell theory. The functional of energy in quadratic form is derived based on Hamilton's principle which is then directly discretized by the VDQ method. Although the derived formulation is general, the focus of paper is on the cylindrical and spherical shells. The nonlinear vibration problem is solved by means of the time periodic discretization method. The results reveal that the present numerical method can solve the problem accurately. It is also easy to implement due to its compact and explicit matrix formulation. Comprehensive numerical results are presented to study the effects of geometrical properties and boundary conditions on the frequency-response curves of cylindrical and spherical shells. Moreover, comparison studies are presented between the results of the six-parameter shell theory and the first-order shear deformation shell theory.

ABSTRACT: By adopting the variable gauge rolling (VGR) technology and the annealing process, the tailor rolled blanks (TRBs) with both continuously varying thickness and inhomogeneous material properties could be obtained. Through the procedure of subsequent forming and laser welding technology on TRBs, the tailor rolled tubes (TRTs) with axially varying thickness and material properties were successfully produced, and performed by the quasi-static axial crushing afterwards. On the basis of the microstructural transformation at different thickness locations, the relationships between the material properties and thicknesses were analyzed. Moreover, the failure mode and deformation mechanism of TRTs have been discussed. It is noted that the progressively increased distances between the top and bottom of the plastic hinges is the essential characteristic. Combined with the classical crushing theories and models, a novel predictive mathematical model considering the thickness variation, changing material properties and variety heights of folding elements has been established. Compared with the series conventional computing models, this novel model performed better. On this foundation, the effects of different thickness transition form and distribution of material properties on the crushing performances were investigated. Besides, detailed effects of the tube structure and with or without changing material properties on the crushing capacity were also studied by introducing the concept of equivalent strength and equivalent thickness.


ABSTRACT: Thin-walled structures have been widely used in crashworthy structural design due to their advantages of light weight, high energy absorption efficiency, long impact stroke and ease of processing. In this paper, a kind of novel sandwich sinusoidal lateral corrugated tubes (SSLCTs) is proposed. It consists of the outer circular tubes (OCTs), the middle lateral corrugated tubes (LCTs) and the inner circular tubes (ICTs). Sinusoidal function is introduced into the design of the cross-section of middle LCTs. The experiment and numerical simulations of the SSLCTs under axial compression were systematically carried out. It is found that the deformation mode of the middle LCTs has changed significantly compared with its compression alone due to the constraints of the OCTs and the ICTs. The study of interaction effect shows that the LCTs play an important role in improving the crashworthiness. The interaction effect of the SSLCTs in the present study is prominent and the increased value of energy absorption is up to 35.6% compared with the sum of the OCTs (alone), the ICTs (alone) and the middle LCTs (alone). Compared with the sandwich star-shaped tubes (SSTs) proposed in our previous research, the SSLCTs have larger effective crushing displacement, lower initial peak force and better stability in compression. Finally, the numerical simulation of the SSLCTs was carried out, and the influence of structural parameters on the crashworthiness was also analyzed in detail.


ABSTRACT: This article presents a size-dependent vibration analysis of a rotating doubly-tapered sandwich beam in supersonic airflow. The face layers of sandwich beam are made of functionally graded material (FGM) and the core is a magnetorheological (MR) material. The displacement field of face layers is written based on the Euler–Bernoulli beam theory, and aerodynamic pressure due to supersonic flow is considered in accordance with linear piston theory. To obtain the governing equations, the Hamilton's principal in conjunction with modified first strain gradient theory (MFSGT) is applied. The size-dependent differential equations of motion are solved based on the Galerkin method. To evaluate the accuracy of this research, the first five natural frequencies and corresponding loss factors are compared with those reported in the literature. A parametric study is performed in order to understand the effect of various parameters including small scale parameter, intensity of magnetic field, aerodynamic pressure, rotational speed, hub radius, setting angle, power-law index and taper ratio parameters on the natural frequency and corresponding loss factor. The novelty of this research is size-dependent analysis of rotating MR sandwich structures under aerodynamic pressure. The presented results can be useful in the aviation, aerospace, turbomachinery, and instrument industry.

ABSTRACT: Decades of research has led to a comprehensive understanding of the buckling behaviour of thin-walled tubes. Many of these studies have attempted to control the buckling-behaviour of thin-walled tubes by utilising their imperfection sensitive characteristics to guide the deformation process to a predictable buckling mode. However, a key limitation of such techniques is an inability to predict the exact deformed shape of post-buckled tubes. This study presents a new method to control the shape of an elastically buckled medium length thin-walled cylinder by using pre-embedded curved-crease origami patterns. The failure mode is pre-determined as a stabilized high-order elastica surface, which manifests via a diamond buckling mode. A set of prototypes are tested and show that the buckling process can be guided to a range of designed failure modes. The deformed surface is measured and shown to have a near-exact correspondence to the analytical description, where the average absolute surface error is less than half of the 0.3mm sheet thickness. This study then closely explores the driving mechanics of the buckling process and shows that the controllable buckling process exhibits a bistable transition from a higher strain energy tubular state to a lower strain energy curved-crease state.

Xiaochao Chen, Xuanling Zhang, Yixin Lu and Yinghui Li (primarily from: School of Mechanics and Engineering and State Key Laboratory of Traction Power and Applied Mechanics and Structure Safety Key Laboratory of Sichuan Province, Southwest Jiaotong University, Chengdu 610031, PR China), “Static and dynamic analysis of the postbuckling of bi-directional functionally graded material microbeams”, International Journal of Mechanical Science, Vol. 151, pp 424-443, February 2019, https://doi.org/10.1016/j.ijmecsci.2018.12.001

ABSTRACT: In this paper, the static and dynamic responses of bi-directional functionally graded (BDFG) microbeams are investigated. The material properties vary along both thickness and axial directions. Employing Hamilton’s principle, the differential equations are derived based on von-Karman geometric nonlinearity and third-order shear deformation beam theory. The modified couple stress theory is adopted to capture the size effects. The material length scale parameter of microbeam is considered as a function of spatial coordinates and varies with the material gradient parameters. The differential equations and boundary conditions are discretized using differential quadrature method. Subsequently, static bifurcation of microbeams is calculated utilizing pseudo-arc length continuation technique. The free vibration around the postbuckling configuration of microbeams is studied by solving the associated linear eigenvalue problem. The influences of the functional gradient parameters, dimensionless length scale parameter and aspect ratio on the static response and vibration characteristics of buckled BDFG microbeams with various boundary conditions are investigated. It is demonstrated that the buckling of BDFG microbeam occurs through a transcritical bifurcation. The static stable responses of BDFG microbeam are asymmetric due to the stretching-bending coupling that results from the asymmetry of the material distribution in thickness direction of beam. The mode veering phenomenon is detected in postbuckling domain of microbeams. It is examined that the longitudinal dynamic displacement plays a pivotal role in the mode veering phenomenon.


ABSTRACT: By considering the pre-buckling effect and in-plane constraint, an accurate nonlinear buckling analysis of a functionally graded porous graphene platelet reinforced composite cylindrical shells under axial compressive load is performed. The stability equation is established according to a unified shell theory including the classical thin shell theory and the high-order shear deformation theory. Three types of porosity distributions and graphene platelet reinforced patterns are considered, and the modified Halpin–Tsi model and rule of mixtures are employed to determine their effective material properties. Explicit expressions of buckling equations for clamped or simply supported boundary conditions are obtained by the Galerkin’s method. Highly

ABSTRACT: This paper proposes a parallel design which can extremely enhance the in-plane property of honeycombs without adding extra mass. Theoretical analysis of regular hexagonal honeycomb with parallel gradient configuration (HPGC) demonstrates that it can achieve a maximum of more than 70% enhancement of static strength in the x direction compared with uniform honeycomb (UH) of the same relative density. Furthermore, static enhancement coefficient is irrelevant to the average relative density of HPGC, which means the degree of enhancement under certain density gradient is constant no matter what the relative density is employed. This is efficient for fast performance-oriented design. The mechanism of strength enhancement is discussed. Result shows that parallel design is applicable to many cellular solids who are eligible for the special relations (for example, the linear relation between graded variable t and relative density and the nonlinear relation between graded variable t and crushing strength). Dynamic analysis shows that the dynamic crushing strength is also enhanced by parallel design. In addition, parallel design is able to reduce the sensitivity of dynamic crushing strength to the impact velocity. Finite element analyses (FEA) are carried out to verify the theoretical results. This novel design provides huge potentials to cellular solids with high-level strength and lightweight applications.


ABSTRACT: In order to obtain honeycomb structure with higher energy absorption capacity, a novel honeycomb is proposed by adding double arrowhead honeycomb (DAH) cells into star-shaped honeycomb (SSH), and therefore named as star-arrowhead honeycomb (SAH). An analytical model is built to investigate the in-plane elastic properties of the newly proposed honeycomb and the results are in good agreement with the finite element simulations. The in-plane dynamic crushing behaviors and energy absorption capabilities of SAH are studied systematically by finite element method and are compared with that of SSH and DAH. Two plateau stress regions in the stress–strain curves of SAH are observed under low-velocity impact loading, and the second plateau stress is over three times higher than the first one. The in-plane Poisson's ratio of SAH under static and high-velocity impact loading always shows negative value. However, the Poisson's ratio of SAH changes from negative to positive under low-velocity and medium-velocity impact loading. In addition, the Poisson’s ratio of SSH and DAH are negative during the entire dynamic deformation processes. The results of finite element simulations show that SAH can absorb much more energy than SSH with the same relative densities under different impact velocities, especially under low-velocity impact loading. Furthermore, the effects of the cell wall thickness and the impact velocity on plateau stress of SAH are discussed, and therefore a deformation map is summarized. It can be concluded that SAH is a better choice for energy absorption. This study may provide a new design concept for the high performance honeycomb structure with multi plateau stress regions.


ABSTRACT: Analysis of axisymmetric deformability of mechanical transducers and actuators made in the form of composite anisotropic cylindrical shells subjected to axial tension or internal pressure is presented in the paper. The shells are modelled as cantilevers with one end fully clamped and another one free hanging with a
ABSTRACT: Locally resonant metamaterials exhibit sub-wavelength tunable bandgaps that can be exploited for vibroacoustic mitigation. The present work investigates the use of metamaterial plates for the simultaneous control of structural vibration and acoustic sound radiation in an adjacent acoustic cavity. We adopt a coupled fluid-structure finite element model based on a variational mathematical framework in terms of structural displacement and fluid pressure to capture the vibroacoustic characteristics of the coupled system and shed light onto the spatial average pressure levels inside the cavity. The model is used to predict and distinguish between structural and fluid modes within frequency ranges of interest. Furthermore, differences between the

https://doi.org/10.1016/j.ijmecsci.2018.12.045

ABSTRACT: A size-dependent model for free vibration and transient response of rotating functionally graded (FG) microplates is established on the basis of the Kirchhoff plate theory and modified couple stress theory. A microplate made of a two-constituent material with a continuous through-thickness power-law variation is considered. The governing equations of motion as well as boundary conditions containing the von Kármán geometric nonlinearity, Coriolis effect and centrifugal stiffening effect are derived by using Hamilton's principle. An assumed-mode discretization approach is applied to solve these equations numerically. The convergence and comparison studies are presented to prove the effectiveness of the current model. Numerical examples are presented for investigating the effects of the size-dependency, non-dimensional angular velocity, FG index and aspect ratio on dynamic properties of rotating FG microplates. It is revealed that the increase of non-dimensional material length scale parameter increases the stiffness of the plate, which accordingly, results in an increase in natural frequencies and a decline of transient responses. The FG index and angular velocity noticeably affect the size dependency of rotating FG microplates.

https://doi.org/10.1016/j.ijmecsci.2018.12.049

ABSTRACT: The present paper studies the thermo-electro-magnetic mechanical behavior of a flexoelectric nano-plate using a modified flexoelectric theory and application of classical Kirchhoff plate theory. Size and flexoelectric effects are considered. Using the variation method and the principle of minimum potential energy in the coupling form, for the first time, the nonlinear governing differential equations of the nano-plate and the relevant boundary conditions are obtained. The nano-plate is subjected to mechanical, electrical, magnetic and thermal loadings and is simply supported on all edges. Moreover, in the present study, analytical solutions are presented to investigate the effects of length scale parameters, geometric parameters, mechanical loading, and temperature rise of the nano-plate lower surface, the external electric potential, and the external static magnetic flux density on the magneto-thermo-electro-elastic behavior of the nano-plate. In order to verify the presented formulations, the results are compared to analytical results found in the literature. Due to high stain gradients in nano-scales, the results indicate that the flexoelectricity has a larger influence in plates with smaller thicknesses. The results also show that, in the presence of flexoelectricity and static magnetic field, the rigidity of the nano-plate increases. Also, the deflection and the generated electric potential along nano-plate thickness decrease.

https://doi.org/10.1016/j.ijmecsci.2018.12.048

ABSTRACT: Locally resonant metamaterials exhibit sub-wavelength tunable bandgaps that can be exploited for vibroacoustic mitigation. The present work investigates the use of metamaterial plates for the simultaneous control of structural vibration and acoustic sound radiation in an adjacent acoustic cavity. We adopt a coupled fluid-structure finite element model based on a variational mathematical framework in terms of structural displacement and fluid pressure to capture the vibroacoustic characteristics of the coupled system and shed light onto the spatial average pressure levels inside the cavity. The model is used to predict and distinguish between structural and fluid modes within frequency ranges of interest. Furthermore, differences between the
metamaterial’s structural response in the presence and lack of fluid coupling are explained. The pressure changes inside the cavity are discussed in relation to the frequency bandgap range predicted theoretically via a dispersion analysis for a couple of different metamaterial designs. Results obtained from the numerical analysis can be used to set design guidelines to optimally tune locally resonant metamaterials to achieve prescribed acoustic properties in the fluid component of such coupled systems.

ABSTRACT: This paper investigates the thermal post-buckling behavior of sandwich beams with functionally graded (FG) negative Poisson's ratio (NPR) honeycomb cores. Two symmetric FG configurations of re-entrant honeycomb cores along the beam thickness direction are proposed for the first time. The material properties of both face sheets and core of the sandwich beams are assumed to be temperature-dependent. The thermal post-buckling behavior and the variation of effective Poisson's ratio (EPR) of the sandwich beam in the large deflection region are studied by using 3D full scale finite element simulations. Numerical results are presented for the sandwich beams with FG-NPR honeycomb core under a uniform temperature field, from which results for the same sandwich beam with uniform distributed NPR honeycomb core are obtained as a comparator. The EPR-deflection curves are obtained for the first time, and the results reveal that greater bending stiffness could bring about higher EPR-deflection curve. The effects of functionally graded configurations, boundary conditions, facesheet-to-core thickness ratios, cell wall-to-facesheet thickness ratios and length-to-thickness ratios on the thermal post-buckling load-deflection curves and EPR-deflection curves of sandwich beams are discussed in detail.

ABSTRACT: The main purpose of this paper is to study the free vibration of porous square plate, circular plate, and rectangle plate with a central circular hole in the framework of isogeometric analysis (IGA). Generally, the porosity distributions of plates are assumed to happen in the thickness direction. However, the graded distributions of porosity may occur through the in-plane direction of plates. Therefore, porosity distributions along both the thickness direction and in-plane direction are considered in this study. The displacement fields are described by the first order shear deformation theory (FSDT) and the exact geometric models are formulated wholly by non-uniform rational B-spline (NURBS) basis functions, which bear high-order continuity inherently. To ensure the versatility of IGA-FSDT, several numerical examples for isotropic and porous plates with different boundary conditions and various types of porosity distributions are presented. Moreover, some innovative results are presented and discussed, which can be the benchmark data for other algorithm researches. The effects of porosity coefficient, boundary conditions and geometric parameters on the free vibration of porous plates are investigated comprehensively.

ABSTRACT: Pursuing analytic bending solutions of cylindrical shell panels without two opposite simply supported edges is a classic but very difficult type of problems. The main challenge is on the mathematical complexity of the boundary value problems of the governing high-order partial differential equations. In this paper, the first endeavor is made on extending an up-to-date symplectic superposition method to bending of cylindrical panels, with focus on clamped panels and their variants. By introducing the problems into the Hamiltonian system (in physics) and the symplectic space (in mathematics), they come down to the symplectic
eigen problems, which are analytically solved for fundamental analytic solutions of three types of subproblems, followed by superposition for final solutions. The new analytic solutions for the panels with four different combinations of boundary conditions are obtained, with comprehensive results tabulated to serve as benchmarks for future studies, all of which are well validated by the finite element method. The rigorous derivation by the present method without any assumptions/prior knowledge of solution forms may provide an exceptional route to more analytic solutions of some intractable shell problems.


ABSTRACT: Present research aims to analyse the nonlinear dynamic behavior of eccentrically stiffened (ES) circular cylindrical shells with negative Poisson's ratios in auxetic honeycombs core layer on elastic foundations and subjected to blast and mechanical loads. This study considers a three – layer circular cylindrical shells in which the core layer is the auxetic material with negative Poisson's ratio, and the external layers are reinforced by a system of stiffeners. Based on the analytical solution, Reddy's first order shear deformation theory with the geometrical nonlinear in von Karman and Airy stress functions method, Galerkin method and the fourth-order Runge–Kutta method, out explicit expressions can be determined: fundamental frequency, dynamic response and frequency-amplitude curves. Numerical results are provided to explore the effects of geometrical parameters, material properties, elastic foundations, imperfections, eccentrically stiffeners, mechanical and blast loads on the nonlinear dynamic behavior: fundamental frequency, dynamic response and frequency-amplitude curves.


ABSTRACT: In this study, the generalized integral transform method is applied for the first time to get the exact analytical buckling solution of a rectangular thin plate. In solution procedure, according to the boundary conditions of the plate the vibrating beam functions are adopted as the integral kernels to construct the integral transform pairs. Then the integral transformation is applied on the basic governing high order partial differential equation of plate, utilizing some inherent properties of beam function and transformed the title problem into a system of a linear algebraic equation where the exact analytical solution is obtained elegantly. The main advantage of this analytical method is that it is simple and general and does not require any pre-determined deformation function. Therefore, the solution obtained is reasonable and theoretical. To illuminate the correctness of the method the present results are compared with finite element analysis by the commercial software (ABAQUS) as well as the analytical results from the literature which shows good agreement.


ABSTRACT: The effects of changes in the location and the aspect ratio of a flexible disk on natural frequencies and critical speeds of a rotating flexible shaft-disk system are studied. Free vibration analysis of the system is carried out using the assumed modes method. The disk is modeled by Kirchhoff plate theory. The Euler-Bernoulli shaft is supported by two rigid bearings. In modeling the system, gyroscopic moments and centrifugal stiffening effects are taken into account. The results show that the disk flexibility property has a significant influence on the natural frequencies and critical speeds. Moreover, the disk position along the shaft (α) and the aspect ratio of the disk (β) can increase, decrease, or eliminate the disk flexibility effect. Therefore, there are special ranges of α and β in which the effect of the disk flexibility is completely negligible, so, in this case, the disk can be considered as a rigid body. Two new diagrams are presented for the first time in this study, which show the behavior of the critical speeds versus α and β. The results emphasize that in order to present a more detailed comment about the disk flexibility effects these parameters must be considered.
ABSTRACT: The stochastic buckling behaviour of sandwich plates is presented considering uncertain system parameters (material and geometric uncertainty). The higher-order-zigzag theory (HOZT) coupled with stochastic finite element model is employed to evaluate the random first three buckling loads. A cubic in-plane displacement variation is considered for both face sheets and core while quadratic transverse displacement is considered within the core and assumed constant in the faces beyond the core. The global stiffness matrix is stored in a single array by using skyline technique and stochastic buckling equation is solved by simultaneous iteration technique. The individual as well as compound stochastic effect of ply-orientation angle, core thickness, face sheets thickness and material properties (both core and laminate) of sandwich plates are considered in this study. A significant level of computational efficiency is achieved by using artificial neural network (ANN) based surrogate model coupled with the finite element approach. Statistical analyses are carried out to illustrate the results of stochastic buckling behaviour. Normally in case of various engineering applications, the critical buckling load with the least Eigen value is deemed to be useful. However, the results presented in this paper demonstrate the importance of considering higher order buckling modes in case of a realistic stochastic analysis. Besides that, the probabilistic results for global stability behaviour of sandwich structures show that a significant level of variation with respect to the deterministic values could occur due to the presence of inevitable source-uncertainty in the input parameters demonstrating the requirement of an inclusive design paradigm considering stochastic effects.


ABSTRACT: In this study, a modified finite element method (FEM) that can be used to analyse the transverse vibrations of a Timoshenko beam, made of functionally graded materials (FGMs), on a two-parameter foundation and subjected to a variable-velocity moving mass is presented. First, the motion equations of the FGM beam exposed to a moving mass are obtained by combining the mass interaction equations with the beam equations obtained using the first-order shear deformation theory (FSDT). Secondly, to obtain the equation of motion of the beam, mass and foundations, the rigidity of the two-parameter foundations, the Winkler and shear, then combined with the motion equations of the beam and mass using the Hamilton principle. The response of the system is investigated considering the effects of inertia and variable velocity of the moving mass, parameters of the foundations and material constituents of the FGM beam. The changes on the dynamic behaviour of the FGM Timoshenko beam, which are affected by the frequency variation of the considered system are highlighted.


ABSTRACT: Cross-sectional ovalization of thin-walled circular steel tube caused by large plastic bending usually occurs at initial large bending stage in tube's continuous rotary straightening process. When the bending loads have been removed, there must be residual ovalization kept on the tube's cross-section during the whole straightening process, to induce the poor roundness and the reduction of the tube flexural stiffness. So the maximal residual cross-sectional ovalization should be predict accurately in order to be controlled under the allowable limit during the straightening process. In this paper, this issue is studied by the approaches of simulations and theoretical modeling. Firstly the finite element (FE) simulations for thin-walled tube straightening process are carried out on stainless steel tubes with different geometric parameters under different working rolls’ bending radii, to measure the residual cross-sectional ovalization along the circumferential direction. The results imply that the profile of deformed cross-section is not standard ellipse and the appearance of the maximum residual ovalization is usually found in the direction perpendicular to the tube's centroid axis.
Secondly the theoretical modeling procedure is carried out as follows. First of all, the normal strain and stress components are derived using the thin-shell large deformation kinematics. Then the cross-sectional ovalization in loading process is analyzed by the principle of virtual work. And then using the general geometric description without the elliptical assumption, a rational model is derived by the classic unloading rule to predict the maximal residual cross-sectional ovalization of thin-walled tube in straightening process. It is solved iteratively using Matlab ode23s function. The theoretical results are compared with the simulation ones. The relative errors are lower than 10%, which validates the effectiveness of the new model. Meanwhile the influences of tube's material, thickness and bending radius on maximum residual ovalization are found.

Jianjun Zhang (1), Dora Karagiozova (2), Zhong You (3), Yan Chen (4) and Guoxing Lu (1)
(1) Faculty of Science, Engineering and Technology, Swinburne University of Technology, Hawthorn Vic 3122, Australia
(2) Department of Engineering Science, University of Oxford, Parks Road, Oxford, OX1 3PJ, UK
(3) School of Mechanical Engineering, Tianjin University, 92 Weijin Road, Nankai, Tianjin 300072, China
(4) School of Mechanical Engineering, Tianjin University, 92 Weijin Road, Nankai, Tianjin 300072, China


**References listed at the end of the paper:**


https://doi.org/10.1016/j.ijmecsci.2015.05.009


https://doi.org/10.1016/j.ijmecsci.2017.12.026


Hamed Saeidi Googarchin and Kasra Moaazzez (First author is from: Automotive Fluids and Structures Analysis Research Laboratory, School of Automotive Engineering, Iran University of Science and Technology, P.O. Box 16846-13114, Tehran, Iran), “Analytical solution for free vibration of cracked orthotropic cylindrical shells”, International Journal of Mechanical Science, Vol. 153-154, pp 254-270, April 2019,
https://doi.org/10.1016/j.ijmecsci.2019.02.004

ABSTRACT: The most important purpose of the present work is to propose an analytical approach for solving the governing characteristic equations of the free vibrations problem of an orthotropic cylindrical shell with its length much greater than its other dimensions half way along which exist a semi-elliptical surface crack. Governing equations of motion of the problem have been derived using classical shell theories and simplified
ABSTRACT: This paper studies the bifurcation behavior in an inflated bilayer tube of arbitrary thickness under inflation and uni-axial extension. It is assumed that both layers are composed of the Gent material with each layer having its own \( J_1 \), where \( J_1 \) is a material parameter in the Gent model that signifies the maximum extensibility. First, we determine several critical parametrical regions where localized bulging disappears for a single-layer tube. Then we investigate localized bulging in an inflated bilayer tube, where one layer (layer I) of the tube cannot bulge whereas the other part (layer II) can. Surprisingly, we find that such a composite tube is still susceptible to localized bulging and localized bulging can be prevented only if the proportion of layer I exceeds a critical value, no matter whether layer I occupies the inner side or the outer side. Even for a very thin bilayer tube, the same feature holds. The cases of \textit{fixed axial force} and \textit{fixed axial stretch} are both studied, and the critical geometrical parameters marking the transition between bulging and no bulging are determined. Moreover, we carry out a numerical analysis by use of the finite element method to verify the applicability of an explicit bifurcation condition and the predicted bifurcation behavior. This paper offers a possible way to avoid bulging formation in a cylindrical tube while retaining moderate extensibility.
ABSTRACT: This paper deals with the dynamic response of sandwich plates subjected to blast load. The sandwich plate is composed of auxetic honeycombs core layer with negative Poisson's ratio integrated with nanocomposite at the top and bottom surfaces. The nanocomposite layers are reinforced by carbon nanotubes (CNTs) where the effective material properties are calculated by Mori-Tanaka approach considering agglomeration effects. Due to the existence of CNTs, the structure is subjected to magnetic field. Based on the Kelvin-Voigt theory, the viscoelastic properties of the structure are considered. The viscoelastic medium is simulated by orthotropic visco-Pasternak model. Utilizing sinusoidal shear deformation theory (SSDT), the motion equations are derived based on Hamilton's principle. Differential cubature method (DCM) in conjunction with Newmark method is used for obtaining the dynamic deflection of the sandwich structure for different boundary conditions. The effects of various parameters such as structural damping, viscoelastic medium constants, geometric parameters of plates, volume fraction and agglomeration of CNTs, duration of blast pulse, geometrical parameters of auxetic honeycombs core and magnetic field on the dynamic deflection of the sandwich structure are investigated. The results reveal that by reinforcing the structure with CNTs, the dynamic deflection induced by blast load decreases about 59%. In addition, with increasing the geometrical parameters of auxetic honeycombs core, the dynamic deflection will be enhanced.


ABSTRACT: A nonlinear thermoelastic model of a circular plate is presented in the paper. The model, based on the Mindlin plate theory, is extended by taking into account nonlinear geometrical terms. Partial differential equations of plate’s dynamics are derived for a fully coupled thermal and mechanical fields. Then the model is reduced to a set of ordinary differential equations taking into account the first three natural modes and assuming a constant thermal field. The influence of elevated temperature on the resonance curves and the mode involvement due to nonlinear and thermal couplings is presented. The analysis shows that the increased temperature may lead to various bifurcation scenarios. The buckling phenomenon and post-buckling nonlinear regular and chaotic oscillations are studied.


ABSTRACT: In the paper, we study large deflections and the stability of an elastic beam, with one end clamped and the other elastically supported, which is subject to a conservative compressing end force. The basic equilibrium equation is derived from the principle of minimum total potential energy, and its solution is given in terms of Jacobian elliptic functions. The stability is determinate according to the Jacobi test. The post-buckled behavior of the beam is discussed in detail. Results are presented in both tabular and graphical form.


ABSTRACT: Circular tubes under axial load undergoing deformation through inversion phenomena are referred to as invertubes. Inversion phenomena controls high initial peak crush force which is a fundamental requirement of an energy absorbing structure in road vehicles and helps in achieving nearly 100% stroke and crush force efficiencies. This rare combination of these three features offers a good potential for invertubes to be an ideal choice for impact crash energy absorption. Researchers have always attempted to predict inversion forces in invertubes in terms of geometrical and material parameters through empirical relations; and often ignored the geometric imperfections on plastic deformation and their influence on the inversion process. Limited knowledge exist on inversion using stainless steel SS304 material. In this paper, series of attempts are made to evolve a new invertube profile with SS304 material to achieve desirable inversion characterisitics for an ideal energy absorption. In this process, the effect of geometric parameters and their imperfections that contribute to effective inversion of invertubes have been studied in detail through FEA and experiments. A new
ABSTRACT: Most of the research on truncated conical shells focuses on the dynamics with classical boundary conditions. However, less attention has been given to the non-classical boundary conditions due to the lack of a unified displacement function, such as a boundary with point constraint or partial constraint, or a boundary with added mass, which exists in engineering practice. In this study, we investigate the free vibration of the truncated conical shell with arbitrary boundary conditions, including elastic and inertia force constraints. The equations of motion with elastic boundary constraints are formulated by employing Hamilton's principle and the thin-walled shallow shell theory of the Donnell type. The solutions of the shells are obtained using Fourier series in circumferential directions and power series in meridional directions, with various boundary conditions achieved through the choice of stiffness, which is a unified solution procedure. The procedure proposed was validated by comparing the results obtained with results available in the literature on classical boundary conditions and with the finite element method results for the non-classical boundary conditions. Numerical simulations were carried out to illustrate the sensitivity of the shell frequency to the stiffness parameters and the moment of inertia effect on frequency, and to present the circumferential modal jumping phenomena with patterns.


ABSTRACT: This paper proposes a methodology to determine the formability limits of thin-walled tubes and to plot them in principal strain space and in the space of effective strain vs. stress-triaxiality. Digital image correlation (DIC), combined either with time-dependent methodologies or strain-force approaches, is utilized to identify the onset of failure by necking and obtain the corresponding limit strains. Thickness measurements and determination of the gauge length strains across the cracked regions are utilized to characterize the onset of fracture and to evaluate the fracture limit strains. Results show that the utilization of tube expansion with rigid punches and elastomers allow obtaining strain loading paths and fracture loci by necking and fracture across a wide range of tube forming conditions ranging from biaxial stretching in the first quadrant to pure tension in the second quadrant of principal strain space. The fracture forming line (FFL) is the first time ever determined for thin-walled tubes. The forming limit curve (FLC) and the FFL resemble those of sheet and strip materials and their use is of paramount importance in the design and optimization of tube forming processes.


ABSTRACT: In this paper, the nonlinear forced vibration of functionally graded (FG) Timoshenko microbeams under thermal effects and parametric excitation is studied using von Kármán nonlinear theory, Hamilton's principle and the modified couple stress theory. The coupled nonlinear differential equations of transverse vibration modes are obtained by the static condensation and Galerkin scheme. The nonlinear algebraic equations of steady-state responses are presented based on the method of multiple scales, and solved using Newton iterative method. Finally, the internal resonance and principal resonance are proposed, and the influence of system parameters, involving the material parameter, length scale parameter, frequency of parametric excitation and thermal loading on the frequency-response is investigated. The reliability of presented Timoshenko microbeam model is confirmed by comparison with previously published results.

Chenghu Zhang, Lijia Fan and Yufei Tan (School of Architecture, Harbin Institute of Technology; Key Laboratory of Cold Region Urban and Rural Human Settlement Environment Science and Technology, Ministry

ABSTRACT: In this study, we investigate the extended sequential limit analysis for clamped circular membranes involving large deformation subjected to pressure load. Moving coordinate systems were adopted, and a shape and geometry update strategy was proposed to deal with the consideration of plane stress direction change. A sequence of optimization problems formulated on the upper-bound theorem was solved to perform the nonlinear cumulative sequence of load-deflection curves. In the formulation, the rigid-perfectly-plastic behavior were used. Then, some numerical simulations by ABAQUS were conducted to assess the parameters and simplification effect on the sequential upper-bound formulation derived. The results show that the sequential limit analysis gives a good estimation of the plastic limit load and load-deflection behavior. The collapse mechanism assumption and the update strategy of shape and geometry cause little error. Meanwhile, the limit state yield level and bending moment are the main factors that cause the relative error of limit load estimation to decrease as the elastic modulus, yield strength, and thickness increase and the radius decreases. Synthetically, the sequential limit analysis allow a wide range of thickness-radius ratios, especially for low-elastic-modulus materials, and the relative errors can be controlled within 17%, even for materials with extreme parameters.


ABSTRACT: The consideration of nonclassical beam theories beyond Timoshenko beam model is necessary in applications involving complex yarns subjected to transverse compaction, for which the section dilatation and in-plane shear require a detailed kinematic and static modeling. In the present work, new enriched beam elements with additional degrees of freedom are derived from the mechanics of generalized continua, allowing a representation of the in-plane-shear and dilatation of sections. As a novel aspect, enriched beam model called macrodilatation, macroshear, and macrostrain have been constructed on the basis of generalized beam theories but with a more condensed kinematics, assuming uniform hyperstress tensor within the beam. The choice of the adequate extended continuum for a given beam depends on its macroscopic deformation mechanisms. As a result, the developed beam models include modified material parameters (the tensile, shear and bulk moduli for an isotropic beam) involving additional microstructural parameters. These macrobeam models are expected to better describe the in-plane-shear and dilatation of the beam sections along its mean line in comparison to classical beam theories. Numerical illustrative examples show that the microdilatation beam model has the ability to capture the local deformation field around holes, in contrast to Timoshenko beam model. The parameters of the microdilatation beam model provide a very good estimate of the overall porosity.

Mohammad Sadegh Nematollahi and Hossein Mohammadi (School of Mechanical Engineering, Shiraz University, Shiraz, Iran), “Geometrically nonlinear vibration analysis of sandwich nanoplates based on higher-order nonlocal strain gradient theory”, International Journal of Mechanical Science, Vol. 156, pp 31-45, June 2019, https://doi.org/10.1016/j.ijmecsci.2019.03.022

ABSTRACT: In this paper, a new model for studying the effects of small-scale parameters simultaneously, on large amplitude vibrations of sandwich plates is developed using the higher-order nonlocal strain gradient theory. Considering the higher-order theories for capturing the size effects of nanostructures results in a set of nonlinear partial differential (PD) equations, including bi-nonlocal terms. By employing Hamilton's principle, the equations of motion for symmetric and anti-symmetric sandwich plates are derived based on the classical plate theory. The partial nonlinear differential equations of motion are reduced to an ordinary differential equation for transverse vibrations of nanoplates using the Galerkin's method. An analytical solution procedure is employed to obtain the closed-form frequency equation as a function of the vibration amplitude, small-scale parameters and sandwich layers elasticity, density and thickness coefficients. Numerical results are presented in order to investigate the sandwich layers coefficients on nonlinear vibrational behavior of nanoplates as same as small-scale parameters and the amplitude of vibrations. It is found that the vibration amplitude plays the main role in nonlinear vibrational behavior of nanoplates in which, nonlinear frequency and its ratio to linear
frequency will be increased by increasing it. Moreover, there are non-uniform behaviors by increasing the sandwich layers coefficients and small-scale parameters. In addition, in the case of large amplitude vibrations, effects of sandwich layers’ coefficients and small-scale parameters on the nonlinear frequency and its ratio to linear frequency will become more noticeable. In order to validate the present solution procedure, the results are compared with those obtained from molecular dynamics simulations, the higher-order nonlocal strain gradient theory and the higher-order shear deformation plate theory.


ABSTRACT: For the first time, forced resonance vibration of Graphene Nano-Platelets (GNPs) reinforced Functionally Graded Polymer Composite (FG-PC) nanoplates is studied. The effective Young's modulus is determined using the Halpin–Tsai model while the rule of mixture is used to compute the effective Poisson's ratio and mass density. The governing equations, classical and non-classical boundary conditions are obtained through Hamilton's principle for nonlocal strain gradient Kirchhoff plate theory. Employing Navier solution procedure, a closed form solution is introduced for forced resonance vibration of the nanoplate. The influences of the GNPs distribution schemes, nonlocal and strain gradient length scale parameters, weight fraction and the total number of layers of GNPs as well as geometrically parameters are discussed in detail. The results show that the impact of layer's number on the resonance position depends on the reinforcement patterns.


ABSTRACT: Thin-walled shells like cylinders, cones and spheres are primary structures in launch-vehicle systems. When subjected to axial loading, bending or external pressure, these thin-walled shells are prone to buckling. The corresponding critical load heavily depends on deviations from the ideal shell shape. In general, these deviations are defined as geometric imperfections, and although imperfections exhibit comparatively low amplitudes, they can significantly reduce the critical load. Considering the influence of geometric imperfections adequately into the design process of thin-walled shells poses major challenges for structural design. The most common procedure to take into account the influence of imperfections is based on classical buckling loads obtained by a linear analysis which are then corrected by a knockdown factor. The knockdown factor represents a statistical lower-bound with respect to data obtained experimentally for different types of thin-walled shells. This article presents a versatile and simple numerical design approach for buckling of critical shell structures. The new design procedure is based on the reduced stiffness method and leads to significantly improved critical load estimations in comparison to lower-bounds obtained empirically. An analysis example is given which is based on the launch-vehicle stage adapter (LVSA) of NASAs Space Launch-system (SLS).

References listed at the end of the paper:
[9] NASA. Buckling of thin-walled doubly-curved shells. NASA space vehicle design criteria (structures) NASA SP-8032, August

ABSTRACT: A study was made to evaluate the design variables that affect the crashworthiness parameters of an energy absorber while dissipating the crash forces during road vehicle accidents. In order to find out causes, nonlinear crushing analysis is performed with the finite element code of ABAQUS/Explicit software. An investigation was conducted on homogeneous and heterogeneous ply orientation modeled structure of composite materials under axial and oblique impact loadings to find out the suitable model or structure for lightweight vehicle applications according to the crashworthiness. Crashworthiness parameters such as peak force and deformation length were considered, to investigate a composite tube under axial and oblique loading conditions with materials such as carbon fiber reinforced plastic (CFRP), glass fiber reinforced plastic (GFRP). Continuum Damage Mechanics (CDM) approach is used to observe the changes and investigation on the dynamic response of composite material under sudden crashes in a different arrangement. A progressive damage model is adapted to determine the status of damage of elements in each failure with references to predefined energy absorption value. Hashin damage criteria are used, to estimate the reduction of stiffness of the material while crack initiation and its propagation during impacts. Different tube arrangement of fiber orientations (0°, ±45°, 90°) of ply and axial and oblique types of impact loading were mostly affecting results a lot in a crushing analysis. Non homogenous composite tube showed the better crashworthiness parameters than the homogenous structure. In oblique loading analysis, in both cases (CFRP and GFRP), the peak force and the deformation values decrease with increases in oblique angle due to the change of fiber properties, inclination as well as the contact area between the tube and impactor.


ABSTRACT: Increased interest in thermo-electro-elastic during the last decades can be assigned to the fact that the study of thermo-electro-elastic mechanical coupled behavior in smart structure. For instance, the coupled thermo-electro-elastic dynamic factors are meaningful in designing process of some sensors and energy harvesting products. This paper presents the steady-state analytical solutions for the coupled thermo-electro-elastic forced vibrations of piezoelectric laminated beams. Two types of damping, material damping and air damping, are introduced to the coupled vibration system. Based on Erturk and Inman’ work, a novel electric circuit model is developed. Thus, for this model, the electric factor is introduced into the classical coupled thermoplastic vibration problems for the piezoelectric laminated beams. Using the decoupled method solve the three fields of coupling problems by developing a generalized form of Green's functions. The interactions between the thermal and electric factors are obtained analytically. The convergence of the present solutions is firstly verified in the numerical section followed by the FEM results used to validate the achieved solutions. From the sample numerical calculations, it is seen that the two-dimensional temperature field presents different distributions for different electric conditions. Moreover, the optimum heat transfer coefficient is furnished for the energy harvesting problem of the laminated beam.

Ahad Amiri, Rahim Vesal and Roohollah Talebitooti (School of Mechanical Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran). “Flexoelectric and surface effects on size-dependent flow-induced vibration and instability analysis of fluid-conveying nanotubes based on flexoelectricity beam model”,


ABSTRACT: Fluid-conveying micro/nano tubes are key tools, which have great applications in biological devices and especially smart drug delivery in order to target the cancer cells. Furthermore, exploiting the smart materials and their combination with drug delivery systems may positively affect the instability control and improve the efficiency and adaptability of design. Recently a specific size-dependent behavior for piezoelectric materials, known as flexoelectric effect, has drawn a great deal of attention. It is proven that this effect, which is resulted by coupling between the strain field and electric polarization, is of significant importance in structures with nano dimensions. This paper is carried out to investigate the vibrations and instability analysis of fluid-conveying piezoelectric nanotubes on the basis of flexoelectricity approach. The fluid-conveying nanotubes made for drug delivery targets are commonly in contact with soft tissues, which could be modeled as a Kelvin-Voigt foundation. The nonlocal strain gradient theory (NSGT) constitutive relations are employed in order to model the problem. An appropriate electric potential distribution is determined using the Maxwell's equation and Gauss's law. The Euler-Bernoulli beam theory and slip boundary conditions are exploited to derive the governing fluid-structure interaction (FSI) equation, which contains flexoelectric and surface effect terms. Galerkin's principle is hired to discretize the equation leading to an eigenvalue problem. Afterwards, the obtained characteristic equation is solved straightforwardly to gain the eigenvalues. The instability of the nanotube is investigated throughout presenting the eigenvalue diagrams. Some illustrations are employed to analyze the effect of different involved parameters on the vibrations and instability behavior of the system. The reported results in the numerical section of the paper may be helpful to achieve an efficient and accurate design of fluid-conveying nanotubes.


ABSTRACT: A reasonable coupled triggering mechanism has greater potential to produce a progressive crushing mode and improve the crashworthiness of composite absorbers. To clearly understand coupled triggering mechanisms, the crashworthiness of composite tubes triggered by double- and triple-coupled triggers is comprehensively evaluated. Five double-coupled triggers including chamfer/hole, chamfer/slit, chamfer/saw tooth, chamfer/plug, and chamfer/material degradation (C-GMD) triggers are designed. To exhibit better crashworthiness, triple-coupled triggers are designed by coupling each double-coupled trigger with a plug trigger. Based on Finite Element Methods (FEM), comparisons of the crashworthiness of tubes using double- and triple-coupled triggers are conducted. Effects of width and height of plug on failure modes are further studied. From the predicted results, coupled triggering and energy-absorbing mechanisms are extensively revealed. Double-coupled triggers further weaken triggered regions to reduce the initial peak while triple-coupled triggered tubes improve Energy-Absorption (EA). Triple-coupled C-GMD-plug trigger presents 26.62% higher EA than C-GMD trigger. Material folding and buckling mechanisms have great effects on the material accumulating process. Failure modes are highly sensitive to plug width, plug height and a combination of both. Some design proposals for C-GMD-plug trigger are recommended.


ABSTRACT: This study proposed a design strategy of a thin-walled structure with tailored properties for axial crushing. The thin-walled structure was divided into multiple sections and the material properties in each section differ from those in the neighboring sections. The crashworthiness of this structure was affected by distributions and material strengths of sections. Analytical model and finite element model were used to provide predictions of mean and peak crushing forces of the thin-walled structure with tailored properties during axial crushing. An optimal design strategy, in which sections with higher strength are distributed at ridgelines along the longitudinal direction, is recommended not only to increase the mean crushing force but also to acquire acceptable peak crushing force.

ABSTRACT: Thin-walled tubes are extensively employed as energy absorption devices. The extensional mode (EM) of collapse in thin-walled square tube is desirable in terms of energy absorption while facing impact loading. In this paper, a novel tube known as the kirigami crash box (KCB) that is designed by kirigami approach, is proposed to improve the crashworthiness of the tubular structures by collapsing in EM. The experimental and numerical results show that kirigami pattern in KCB serves as both geometric imperfection to reduce the initial peak force \( F_{\text{max}} \) and mode inducer to trigger the desired EM while collapsing. Numerical simulation indicates that the ideal EM is successfully triggered with a 39.7% reduction of initial peak force \( F_{\text{max}} \) and 33.9% increase of mean crushing force \( F \) comparing to conventional square tube (N-CST). Parametric study shows that the collapse mode of KCBs deformed in EM is independent of aspect ratio \( b/t \) within the range of \( b/t \leq 81.3 \), while for CST, the corresponding range is \( b/t \leq 7.5 \). KCB inclines to collapse in EM when the dihedral angle \( \theta \) or the number of modules \( M \) decrease. The \( F_{\text{max}} \), \( F \) and CFEs of KCBs with identical \( M \) increase with the increasing \( \theta \). Whereas, the effect of \( M \) on energy absorption is relatively less important while \( \theta \) remains the same. Moreover, the superiority of energy absorption for KCB subjected to dynamic loading is more significant comparing to quasi-static axial crushing.


ABSTRACT: This work presents an isogeometric Bézier finite element method combined with a \( C \)-type higher-order shear deformation theory for vibration analysis of functionally graded piezoelectric material porous (FGPMP) plates. The FGPMP plate made of a mixture of PZT-4 and PZT-5A/PZT-5H materials is considered in both perfect and imperfect forms. Material properties of FGPMP plates vary continuously through the thickness direction and are computed by a modified power-law formula. Two porosity models including even and uneven distributions are employed. To satisfy the Maxwell's equation in the quasi-static approximation, an electric potential field in the form of a mixture of a cosine and linear variation is adopted. The advantages of present approach are inherited all properties of the conventional finite element method (FEM) and the exact geometry of isogeometric analysis (IGA). The influence of external electric voltages, power-law index, porosity coefficient, porosity distribution; geometrical parameters, aspect ratios, and various boundary conditions on behaviors of structures is studied. Obtained results are compared with the analytical solution as well as those of several available numerical approaches. In addition, several FGPMP plates with curved geometries are studied furthermore. Although these geometries have not had any analytical solutions, they could be considered as reference solutions for future works.


ABSTRACT: Gears with thin rims are broadly applied in aircraft and light-weighted applications. This study will derive the governing equations of cylindrical shells with discrete circumferential stiffnesses based on Hamilton's principle and Flügge shell theory. To derive the governing equations, the discrete circumferential stiffnesses which are displacement coupled are handled as external forces and expressed by Dirac delta function. The circumferential modal function contains multiple components of different circumferential wave number for the existence of discrete stiffnesses. The Galerkin method is adopted to discretize the governing equations. The natural frequencies and vibration modes are studied. The effects of different stiffness, the ratio of thickness and length to radius, number of discrete stiffnesses on natural frequencies and mode shapes are also investigated in this study.


ABSTRACT: Corrugated-core sandwich panels have a great potential in the application to acreage thermal protection system of aerospace vehicles. However, due to their structural complexity, it takes high
computational cost to conduct modal analysis with detailed 3D finite element models and the aeroelastic behaviors of these sandwich structures have not been fully investigated. In this paper, an analytical model of a trapezoidal corrugated-core sandwich panel using homogenization technique and layerwise theory is presented for modal and aeroelastic analysis. The trapezoidal corrugated core is homogenized as an equivalent orthotropic layer based on an energy approach and the overall sandwich panel is treated as a three-layer continuum. The proposed layerwise theory which is developed for a sandwich plate, assumes higher-order displacement field for the core layer and first-order displacement field for the top and bottom layers. The unsteady aerodynamic pressure is evaluated by the supersonic Piston theory. An eight-noded C isoparametric element with 13 degrees of freedom per node is used for finite element method. The accuracy and reliability of the present method are verified by comparing natural frequencies and mode shapes as well as flutter speeds with those obtained from commercial software. Parametric studies concerning different boundary conditions and parametric variables are also conducted. It is shown that the proposed method has sufficient accuracy and requires less computational effort, providing a theoretical basis for the utilization of the trapezoidal corrugated-core sandwich panel in aircraft designing.


ABSTRACT: Mechanical buckling, thermal buckling and free vibration behaviors of functionally graded (FG) porous nanoplates embedded in an elastic medium are investigated via a nonlocal strain gradient theory. Two dimensional (2D) and quasi three dimensional (quasi-3D) sinusoidal shear deformation theories are used in this study. The proposed theories have a displacement field with integral terms which include the effects of both transverse shear and normal deformations. Porosity-dependent material properties of the porous nanoplate are defined via a modified power-law function. Equations of motion are derived based on Hamilton’s principle which includes the effect of the two-parameter elastic foundations. Numerical results are presented to verify the accuracy of the present 2D and quasi-3D shear deformation theories by comparing them with the solutions given in literature with different 2D, quasi-3D and 3D solutions. The effects of many parameters like porosity factor, nonlocal, length scale parameters, plate aspect ratio, side-to-thickness ratio and gradient index on the buckling, thermal buckling and vibration of FG porous nanoplates are all discussed.


ABSTRACT: This work deals with the effective modelling and simulation of the behavior of stiffened panels, when subjected to compressive (buckling) loads. Within the Finite Element Method, two numerical strategies are compared, namely the Riks method and the displacement incremental control method, including damping effects. The capabilities and limitations of both approaches are explored for two distinct benchmarks: a panel with a blade stiffener, and a panel with a T shaped stiffener. In both cases, material (plasticity) and geometrical (large displacements) nonlinearities are considered, together with a modelling strategy based on shell elements. Following previous works of the authors, each panel accounts for initial geometric imperfections coming from friction stir welding operations. The paper shows a number of considerations that must be undertaken when choosing between one of the two modelling strategies. Both benchmarks involve a number of challenges from the point of view of modelling unstable structural behaviors, and therefore the proposed benchmarks can represent a valid set of case studies in the understanding of the capabilities of current numerical simulation codes.


ABSTRACT: Thin-walled structures filled or covered by various materials have been proposed for energy absorption applications in recent years. At this point, additive manufacturing technologies provide an unprecedented opportunity to produce nontraditional low-density filler materials to further improve the energy absorption performance of thin-walled structures. With a similar motivation, novel hybrid structures, in which
thin-walled tubes filled with periodic lattice materials, are proposed and the energy absorption behaviors of these structures are investigated under axial impact loading conditions. Two different types of lattice structures (i.e. body-centered cubic structure and body-centered cubic structure with vertical strut) are considered as filler materials, and the effects of number of lattice unit cell, diameter of lattice member and tube thickness on energy absorption characteristics of hybrid structures are examined using validated nonlinear finite element models. The results show that the tube and lattice structures contribute the buckling and bending resistance of each other during progressive deformation of hybrid structures, and a considerable enhancement in energy absorption performance could be achieved with appropriate selection of tube and filler lattice structure parameters. Particularly, the result revealed that the hybrid structures can absorb up to 115% higher impact energy compared with the sum of individual parts of hybrid structures. Besides, the hybrid structures also show promising performance in terms of crashworthiness parameters such as specific energy absorption and crash force efficiency, and thus these structures are recommended as potential candidates for crashworthiness applications.


ABSTRACT: This paper proposes a new straight-tapered shrink (STS) circular tube, which is planned to be applied on railway coupler for energy absorbing and overload protection. Quasi-static experiment and finite element (FE) simulation were adopted to investigate the crashworthiness performance of the STS tube. In the FE analysis we found that the compressive material properties were more suitable for accurately modeling the STS tube. The results showed that the STS tube can develop two deformation modes, i.e., shrink mode (S-mode) and buckling mode (B-mode), and the B-mode cannot meet the application requirement. Moreover, the distribution of deformation modes under different geometric parameters, namely, wall thickness (t), slope angle (a) and straight zone length (L), were obtained. It was found that the B-mode mainly occurs when t, a and L are all large. The force-displacement characteristics showed that a plateau force occurred in some STS tubes. A theoretical model for predicting the plateau force was then proposed. Finally, the effects of geometric parameters on the peak crush force (Fmax) and specific energy absorption (SEA) were performed. It was found that the increases in the three parameters all result the increases in SEA and Fmax, and a has the most significant effect on the crashworthiness performance of the STS tube.


ABSTRACT: The free vibration of stiffened composite laminated shells of revolution with classical and elastic boundaries is investigated by a semi analytical approach. The energy functionals of the shells and the stiffeners are derived separately. The energy functional of shells of revolution with a free-form meridian and general boundary conditions is formulated based on the first-order shear deformation theory (FSDT). The displacement field of the stiffeners is obtained based on that of the shell without involving extra degrees of freedom in the final mass and stiffness matrices. Based on the three-dimensional curved beam theory, the energy functionals of the stiffeners in both meridian and circumferential directions are introduced in the same form. A modified Ritz approach is employed in this paper to solve the energy functionals. The results obtained by the proposed method show good agreements with those by the finite element method (FEM). Finally, parametric studies concerning some key parameters of stiffened shells are carried out.


ABSTRACT: Buckling of elastomeric materials is recoverable and can be harnessed to provide useful functions. Soft machines enabled by buckling actuators have been demonstrated experimentally, while no efforts have been conducted to model these actuators and machines numerically. This paper fills this blank and presents numerical modelling of buckling actuators and the derived soft machines. Key design parameters are
ABSTRACT: A series of novel open-section origami beams employing origami geometries were developed. These beams overcame the Brazier's effect, and they can provide more constant bending resistance and overall higher energy absorption than conventional open-section beams. Numerical simulations and experiments were used to validate these designs and showed that properly designed origami beams can achieve 23.0–40.0% higher energy absorption and 12.7–20.7% lower load uniformity than conventional beams under quasi-static loading.

ABSTRACT: Surface effects play a significant role in affecting the mechanical behavior of nanosized NEMS such as sensor, actuator, transducer. This paper studies the bending and free vibration of a magnetoelectroelastic plate with surface effects. By incorporating surface effects into the Kirchhoff theory of thin plates, the governing differential equation for bending and vibration of a magnetoelectroelastic plate is derived. Simply supported and clamped circular plates are analyzed for applied mechanical loading, electric voltage, and magnetic potential difference. An analytical method is presented to obtain closed form solutions for static deflection of bending and natural frequencies of free vibration. The well-known results of circular thin plates are recovered if ignoring the surface effects along with coupling coefficients. A comparison of the deflections and the natural frequencies with their counterparts in the absence of surface effects shows that surface residual tension plays a crucial role, which decreases the deflection and increases the natural frequencies. The influence of surface magnetoelectroelasticity is discussed and the small scale effect can be captured. The obtained results are helpful for design and application of NEMS.

ABSTRACT: A unified approach is developed for vibration and flutter analysis of elastically restrained stiffened functionally graded plates. A nonlinear temperature distribution throughout the thickness is considered in this study. The temperature dependent material properties assumed to change continuously along thickness is estimated by the Voigt model combined with a simple power-law distribution. The formulation is based on
generalized variational principle and the first-order shear deformation theory, in which displacement variables of the plate is adopted to express the displacement field of stiffeners by imposing displacement continuous conditions at the interface. According to the linear piston theory the aerodynamic force is obtained. The penalty function method is used for simulation of the general boundary conditions. By selecting a modified Fourier series as the basis for the displacement variables, the solution can be obtained. The present approach is verified by comparisons between calculated results and those from the existing literature. The influence of the stiffener, gradient index, temperature change and elastic restraints on the dynamic behavior of stiffened FGM plates is discussed.


ABSTRACT: Free vibration analysis of laminated composite beams including open transverse cracks is presented by using a shear-deformable thirteen degrees-of-freedom finite element model, which considers extension-twist, bending-twist and bending-extension couplings, and the Poisson's effect. Lagrange's equation is employed to derive the equations of motion. Trial functions are selected as cubic Lagrange polynomials for deflections while quadratic for the others in derivation of element mass and stiffness matrices. Damage is introduced into the beam by reducing stiffness of elements within damaged zone. Comparisons are made with the available literature to show the present element's accuracy. Experimental validation is also performed with through ambient vibration tests on a cantilever laminated composite beam under six damage scenarios. According to the results, the methodology presented in this study provides a simple and quick way in a sufficient accuracy to determine the natural frequencies and mode shapes of laminated composite beams with open transverse non-propagating edge cracks.


ABSTRACT: The architected mechanical metamaterials have garnered significant research attention for a variety of engineering application due to their remarkable mechanical properties and unique deformation behavior. Herein, the in-plane uniaxial compressive response and energy absorption capacity of a novel hybrid configuration, AuxHex structure, which consists of auxetic and hexagonal honeycomb cells, are systematically investigated through theoretical, finite element simulation and experimental methods. A series of AuxHex sandwich core panels have been fabricated with nylon material by using additive manufacturing route. The relationships for Young's modulus and plastic collapse stress along different loading directions are derived and validated through the comparative analysis. In addition, the deformation mechanism and failure modes of the AuxHex structure have also been discussed in detail. The AuxHex structures have exhibited superior Young's modulus, collapse strength and energy absorption than traditional honeycomb structures. In the x-direction, the energy absorption capacity was improved by 38%, which can be attributed to the uniform and stable deformation mode of the unit cell. The theoretical prediction results of Young's modulus and plastic collapse stress are consistent with finite element simulation and experimental results. The AuxHex structures demonstrate a novel design strategy for the architected metamaterials through the combination of various cellular cells. The hybrid structures will play an important role in both the load-bearing and energy-absorbing applications, and it demonstrates a novel design strategy for the architected metamaterials through the combination of various cellular cells.


ABSTRACT: Fibre metal laminates (FML) constitute a group of hybrid materials made of alternating layers of metal and fibre polymer composite. One of the more prospective materials of the next FML generation is a laminate based on titanium and glass or carbon fibres. The use of titanium increases laminate stiffness in comparison to laminates based on aluminium alloys and significantly increases the corrosion resistance and
impact properties. The purpose of the study was a multifaceted and complex analysis of the impact behaviour of hybrid titanium glass fibres laminates (HTGL) based on the experiment and modelling methods. Based on the obtained results of experimental studies it was proven that fibre metal laminates based on titanium and glass-epoxy composite are characterised by high resistance to low-velocity impact within the range of energy of 2.5–30 J at least, expressed by the criteria of maximum force, deformations, work performed by the indenter, impact energy absorption capacity, and the parameters describing the extent of damage after impact. The obtained results of numerical analyses indicate the correctness of the adopted calculation assumptions and the study procedure itself.


ABSTRACT: Buckling of rods with cylindrical constraints is an essential problem in engineering and medical fields. Completely different to the buckling of classical Euler rods, the post-buckling modes for rods with cylindrical constraints involve highly complicated deformations and geometric configurations. In this paper, the rods are discretized into beam elements by finite element method, and the constraint relation between the rods and cylinders is described by gap element. A dynamic relaxation method for static buckling of compressed rods in cylinders is introduced. Numerical simulations have been carried out to investigate the effects of damping, element length, initial contact stiffness and penetration on post-buckling, etc. The characteristic buckling modes include deflection curves with single point, two points, three points and point-line-point contact. For the helical buckling, it is found that the transition section consists of two noncontact sections only, while the perturbed-helix section does not exist. Except the critical load and shear force of helical buckling, numerical simulation results are in good agreement with the analytical solution. By using the dynamic relaxation method, stable helical buckling modes can be obtained directly without undergoing sinusoidal buckling deformation under given compressive loads.


ABSTRACT: Within this study, the free vibration behavior of rotating two-directional functionally graded porous sandwich microbeams is studied based on the modified couple stress theory by employing a transverse shear-normal deformation beam theory. The effects of the thickness to material length scale parameter accompanying with the porosity volume fraction coefficient, boundary condition, aspect ratio, hub ratio, dimensionless rotation speed and gradient index on the dimensionless fundamental frequencies of the two-directional functionally graded porous sandwich microbeams are investigated. It is found that the dimensionless fundamental frequencies are significantly affected by the variation of the thickness to material length scale parameter, hub ratio, dimensionless rotation speed and porosity volume fraction coefficient. The normal deformation effect is very important especially while the variations of the dimensionless rotation speed, hub ratio and gradient index are considered. Moreover, the mode shapes of the rotating two-directional functionally graded porous sandwich microbeams are also influenced with respect to the variation of the porosity volume fraction coefficient. As a result, the optimum design of the microstructures accompanying with the lightweight and low-cost objectives can be achieved by controlling the material and porosity distribution through the body of the microstructure.


ABSTRACT: This study intends to analyze free vibration response of functionally graded material (FGM) plates with complex cutouts. Isogeometric analysis (IGA) method combined with a new quasi-3D higher-order shear deformation theory (HSDT) for the vibration analysis is presented to predict the dynamic behavior. The quasi-3D HSDT is able to account for transverse shear and normal deformations with only four unknown variables using the dissimilar shear and normal shape functions. In the refined quasi-3D hybrid type HSDT, the fully 3D material matrix is employed in the stress–strain relations, and the governing equations for the dynamic
problem are derived through the Hamilton's principle. Validity of the present quasi-3D isogeometric approach is investigated by testing several numerical examples in the open literature and comparing the predicted results with the available reference solutions. It can be concluded that the proposed analysis method is accurate and effective in solving free vibration behavior of FGM plates with complex cutouts. Illustrative examples are also given to examine the effects that the ingredient fraction, plate geometric parameter and boundary condition have on the free vibration behavior. Results demonstrate that there exists a critical plate length-to-thickness ratio above which the natural frequency of the perforated FGM plate does not increase any more even though the ratio becomes larger.


ABSTRACT: This paper proposes a unified approach to study the free vibration of elastically restrained plate with holes. The hole is treated as a virtual plate in which the mass density and the Young's modulus is set to zero. Therefore, the free vibration problem of a plate with holes can be translated into the free vibration problem of the equivalent rectangular plate with non-uniform thickness. The model is derived based on the so-called Spectro-Geometric Method (SGM) in which the displacement of the plate including the holes is invariably expressed as a modified Fourier series expansion. The proposed model allows considering the edges of the plate elastically restrained against both deflection and rotation. The accuracy of the method is validated against the results obtained by the finite element method. Some numerical solutions including the plates with triangular, rectangular holes are investigated.


ABSTRACT: The initial peak crushing force usually causes catastrophic harm to the passengers once vehicle collision accidents happen. In this study, an origami design is introduced and optimized to improve the initial peak crushing force (IPCF) of a thin-walled energy absorption structure. First, by analyzing the basic idea of origami structure, this paper decides twist angle (φ), height (h) and thickness (t) as the control variables. Then, the crashing characteristics of the thin-walled structure are under study and the FE model is validated by an impact test. Further, parametric analysis on the relationships between design variables and target responses (energy absorption and IPCF) is studied. It is found that the twist angle has a negative influence of IPCF and EA, while the t has a positive influence on the impact responses. Particularly, the increase of h cause the increase of IPCF but a decrease of EA. In further, to minimize the IPCF but do not affect the EA, optimization technology with NSGA-II algorithm is employed. The optimization results (i.e., $\phi = 3.24^\circ$, $h = 30$ mm, $t = 4$ mm, $IPCF = 934.28$ kN, $EA = 269.90$ kJ) manifest that IPCF reduces by 29.36% without reducing the ability of energy absorption. For the point of train collision safety, the proposed origami inspired structure is introduced successfully and the optimal structure is of great advantages in improving the IPCF for the energy absorption structure.


ABSTRACT: As an unfavorable factor of machining process, chatter threatens the machined quality of workpiece, which determines the assembly and fatigue performance of the workpiece. During the interaction between machine tool and thin-walled workpiece, the process damping effect, multiple modes response and dynamic changes caused by the material removal of the in-process workpiece (IPW) will make the machining process more complicated and introduce great difficulties to dynamic modeling and performance prediction. In this paper, we considered the process damping determined by the indentation volume between flank face of milling tool and machined surface, and used multi-mode model to describe this behavior. In order to establish the assembled material removal model of the IPW dynamics with multiple modes, the structure dynamic
modification (SDM) and finite element method (FEM) were combined together. The updated third-order full discretization method was applied to solve the dynamic equation in modal space. Then, the three-dimensional stability lobe diagrams (SLDs) with and without material removal along the tool path were obtained respectively by enveloping multiple modes of the IPW and milling tool together. Finally, the cutting tests were carried out. The experiments showed that the assembled model could predict the dynamics of IPW accurately, and the proposed stability analysis model was relatively close to experimental results. Besides, the modes of thin-walled workpiece with weak rigidity do not always play a dominant role in the process of machining. Although the material removal rate is limited by considering the multiple modes of the system, the processing quality can be ensured.


ABSTRACT: Steel-concrete composite beams are widely used in practice because of their economic cross-section design. As sustainability becomes more and more important in the construction industry, the design of composite beams must be adapted to meet the requirements of the circular economy. This calls for demountability and reusability of the structural components, as well as optimized use of materials, for example by using non-prismatic beams. Linear-elastic design and the (optimized) use of demountable shear connectors are key in the design of reusable composite structures. In this paper, analytical prediction models for the elastic behaviour and the first eigenfrequency of non-prismatic composite beams with non-uniform shear connector arrangements are derived. The approach is based on 6- and 2- order differential equations used to define matrix equations for a finite number of linearized composite beam segments. The analytical models are validated using experimental and numerical results obtained with a simply supported tapered composite beam. The analytical models are suitable for comprehensive structural analysis of non-prismatic composite beams with non-uniform shear connection.


ABSTRACT: The energy barrier concept is developed for the case of dynamic loading of spherical shells. Simple semi-analytical formulae were obtained for the energy barrier for perfect shells and structures with geometrical imperfections. They were applied to the case of spatial step pressure to estimate dynamic buckling load of geometrically imperfect shells. It has been shown that dynamic effect can be caught properly by separating additional energy which causes local buckling of the shell. The calculated dynamic knockdown factor was in good agreement with numerical solution and experimental data. The methodology and formulae were also developed for the metastability estimation of real structure and for establishing knockdown factor taking into account possible external perturbations. The suggested approach improves current NASA (SP-8032, 1969) recommendations for design buckling pressure which are overly conservative.


ABSTRACT: The local buckling behavior of pipes under combined external pressure and axial tension is investigated by experiments and FE models in the present study. The tension-pressure interaction collapse envelopes are generated for two different loading paths involving pressure followed by tension and tension followed by pressure. Ten experiments are conducted to study the effect of different loading paths on the collapse pressure of pipes with the same geometric and material parameter. Furthermore, an extensive parametric study of the FE models is performed whose results are in good agreement with the experiments. The results of the experiments and FE models indicate that critical limit load of the $P\rightarrow T$ loading path is more severe than that of the $T\rightarrow P$ loading path. The reason is explained by analyzing the stress distribution and ovalization of the local buckling cross section. Based on the large amount of FE analyses, a new interaction formula is
ABSTRACT: Ballistic impact tests on composite laminated plates were carried out with a preloading device to investigate the impact responses at nominal velocities of 50m/s and 70m/s. Not only the center locations but also the near-edge regions of the laminated plates were impacted. Furthermore, finite element models were developed using three-dimensional solid elements and cohesive elements, and a user subroutine VUMAT of Ladeveze failure criterion was used in support of simulations in ABAQUS Explicit, providing detailed insights into the failure modes and failure mechanisms of composite laminated plates under ballistic impact. Numerical results were compared with experimental results, revealing good agreement, which demonstrates the validity and effectiveness of the proposed finite element model.
into the characteristics of delamination and target response. Results showed that there was a significant
promotion of delamination resistance in the center location when applying appropriate preloads, but some
weakening parts were also generated over large areas at the same time. A competition mechanism between the
increased bending stiffness induced enhancement effect and the interlaminar stresses induced weakening effect
was proposed to explain the influence of the biaxial in-plane tensile preloads on the delamination resistance of
laminated plate. The work in this study may provide guidance for the impact resistance design of composite
aircraft wing skin.

Xiang Xu (1), Yong Zhang (2), Xinbo Chen (1), Zhe Liu (1), Yanan Xu (1) and Yunkai Gao (1)
(1) School of Automotive Studies, Tongji University, Shanghai 201804, China
(2) College of Mechanical Engineering and Automation, Huaqiao University, Xiamen 361021, China

“Crushing behaviors of hierarchical sandwich-walled columns”, International Journal of Mechanical Science,

ABSTRACT: Hierarchical structures have better mechanical properties as a widely observed organization form
in nature. In this paper, a series of sandwich-walled columns (SWCs) with different sandwich cells are proposed
based on hierarchical route for obtaining more weight-effective protective structures. The finite element model
is firstly validated via experiment testing. Then, the crushing behaviors of SWCs, regular multi-cell columns
(MCs) and single-cell column (SC) under axial load are analyzed. The results show that the hierarchical
sandwich design has more remarkable potential to improve mechanical behavior than regular multi-cell design,
and the effect of hierarchical level N is significant for the mechanical properties. Next, the theoretical models of
mean crushing force (Fm), specific energy absorption (SEA) are derived to deeply analyze the collapsing
mechanism of the SWCs, and the low errors of the theoretical predictions indicate their high accuracy.
Furthermore, the technique for ordering preferences by similarity to ideal solution (TOPSIS) evaluates the
crashworthiness performances of all thin-walled structures, the square sandwich cell with N=6 (S-6) is selected
because of its ideal cross-section, and the wall thickness range for optimal crashworthiness in feasible design
space is identified. This study offers a novel idea of designing lightweight structure with high energy absorption
capacity for the crashworthy requirement.

Zixiang Zhang (1), Airong Liu (1), Jie Yang (2) and Yonghui Huang (1)
(1) Guangzhou University-Tamkang University Joint Research Centre for Engineering Structure Disaster
Prevention and Control, Guangzhou University, Guangzhou, China
(2) School of Engineering, RMIT University, PO Box 71, Bundoora, VIC 3083, Australia

“Nonlinear in-plane elastic buckling of a laminated circular shallow arch subjected to a central concentrated
load”, International Journal of Mechanical Science, Vol. 161-162, Article 105023, October 2019,
https://doi.org/10.1016/j.ijmecsci.2019.105023

ABSTRACT: This paper investigates the in-plane elastic buckling of a laminated shallow circular arch
subjected to a central concentrated load based on the classical laminated theory (CLT). Nonlinear equilibrium
equation is established by using the principle of minimum potential energy, from which analytical solutions of
the nonlinear in-plane elastic equilibrium path and buckling load are derived for laminated circular shallow
fixed arches fixed. The critical modified slenderness ratio which switches the buckling characteristics is also
obtained. The finite element (FE) simulation and experiments employing displacement control are conducted to
verify the accuracy of the analytical solutions. A parametric study is then carried out and results are presented in
both tabular and graphical forms to analyze the effects of the ply angle and thickness of laminates, and rise-span
ratio of the arch on the critical bucking load and nonlinear equilibrium path of laminated arches.

Yang Lv (1), Ying Zhang (2), Neng Gong (1), Zhong-xian Li (1,3), Guoxing Lu (4) and Xinmei Xiang (5)
(1) Tianjin Key Laboratory of Civil Structure Protection and Reinforcement, Tianjin Chengjian University,
Tianjin 300384, China
(2) School of Materials Science and Engineering, Tianjin Chengjian University, Tianjin 300384, China
(3) Key Laboratory of Coast Civil Structure Safety of Ministry of Education, Tianjin University, Tianjin
300072, China
(4) Faculty of Science, Engineering & Technology, Swinburne University of Technology, Hawthorn, Vic 3122,
Australia

ABSTRACT: Miura-ori patterned sheets have been recognized as efficient energy absorption devices that can serve as the core of sandwich structures or a layer of metamaterials. In this paper, first, the geometric characteristics of a Miura-ori patterned sheet were examined. Second, a Miura-ori patterned sheet was fabricated using 0.3-mm thick aluminum sheets by three-step compression, and the patterned sheet was used as the core by bonding it between two aluminum skins to make a sandwich panel. The quasi-static out-of-plane compression behavior of both the Miura-ori patterned sheets and their corresponding sandwich panels was investigated experimentally and numerically by using finite element analysis (FEA). The simulation results show a reasonable agreement with the experimental results. A parametric analysis of the Miura-ori patterned sheets was carried out using FEA to demonstrate the effect of cell wall thickness, side length, dihedral angle and sector angle. Empirical formulae were obtained for the peak crushing force and the mean force.

Wentao He (1,2), Shaojia Lu (1,2), Ke Yi (3), Shuqing Wang (1,2), Guangyong Sun (4) and Zhiqiang Hu (5)
(1) College of Engineering, Ocean University of China, Qingdao 266100, China
(2) Shandong Provincial Key Laboratory of Ocean Engineering, Ocean University of China, Qingdao 266100, China
(3) CRRC Zhuzhou Locomotive Co., Ltd., Zhuzhou 412001, China
(4) School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Sydney, NSW 2006, Australia
(5) School of Engineering, Newcastle University, Newcastle Upon Tyne NE1 7RU, UK


ABSTRACT: This paper aims to evaluate the influences of impact-induced damage on the residual flexural strength of honeycomb core sandwich panels with different structural configurations by combining the experimental, numerical and theoretical methods. Low-velocity impact tests and three-point bending tests after impact are carried out to determine and quantify the effects of structural configuration and impact energy on the impact damage and residual flexural strength of such structures. Subsequently, an integrated FE model with the VUMAT subroutine is developed to further investigate the damage states and failure mechanisms for the impact and bending simulation. The numerical results match well with the experimental ones in terms of impact load, absorbed energy, residual flexural strength and failure mechanisms. Results indicate that increasing cell wall thickness or decreasing side length of honeycomb core has significant effects on peak load, while increasing core height has little effect. Specimens with lower core stiffness fail through core buckling and crushing under the bending load, while specimen with higher core stiffness fails by top face sheet fracture. The residual flexural strength reduces markedly even through the impact damage is barely visible, indicating that it has a strong correlation with impact energy and structural configuration of cores.


ABSTRACT: In this study, an analytical solution has been developed for the elastic buckling analysis of stiffened panels subjected to pure bending, and the effect of main geometric parameters of the stiffened panels on buckling strength has been investigated. A simplified model of stiffened panels has been proposed for buckling analysis, where an elastically built-in boundary condition replaces the skin's effect on buckling of the stiffened panels. The equilibrium method with a conventional rigid skin assumption and a new flexible skin assumption is developed for the simplified model to analytically capture the buckling behaviour of the stiffened panels. To consider the non-rigid rotation effect of flexible skin on buckling of stiffened panels, a new parameter, the effective width of stiffened panels, has been introduced, and a finite element (FE) assisted method has been employed to obtain its value for different stiffened panels. The results show that the flexible skin assumption significantly enhances the accuracy of buckling strength prediction compared with the
conventional rigid skin assumption, and the maximum difference between analytical results and corresponding FE simulations is decreased from 12.2% with rigid skin assumption to only 3.9%. Based on the proposed analytical solution, effects of main geometric parameters of the stiffened panels (the stiffened panel length and width, the stiffener height, and the ratio of the skin thickness to the stiffener thickness) on their buckling coefficients have been discussed. Increasing stiffened panel length and/or reciprocal of stiffener height leads to an initial abrupt decrease of the buckling coefficient until reaching a stable level. When the stiffened panel width increases, the buckling coefficient first increases and then remains stable, whereas increasing thickness ratio leads to the increase of the buckling coefficient.


ABSTRACT: A new refined plate theory (RPT) combined with isogeometric analysis (IGA) is proposed for the static and buckling analysis of functionally graded plates (FG plates). The proposed theory uses a new hyperbolic distributed function to describe the distribution of the shear strains and stresses through the plate thickness. It satisfies the shear stress free boundary conditions, so that it does not require shear correction factors. Compared with the higher-order shear deformation theories (HSDTs), the proposed RPT needs only 4 unknown variables, which improves the computational efficiency. The NURBS approximation functions built for proposed theory can easily solve the C1-continuity problem required by RPT. The material properties of the FG plates can be obtained by the rule of mixture and Mori-Tanaka technique. The static bending and buckling analysis results of different FG plates are given, and the effects of the material index $n$ and width-to-thickness ratios on the static bending and buckling behavior of FG plates under different boundary conditions are investigated numerically.

M.H. Jalaei (1), A. Ghorbanpour Arani (2,3) and H. Nguyen-Xuan (4,5)
(1) Young Researchers and Elite Club, Islamshahr Branch, Islamic Azad University, Islamshahr, Iran
(2) Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
(3) Institute of Nanoscience & Nanotechnology, University of Kashan, Kashan, Iran
(4) CIRTECH Institute, Ho Chi Minh City University of Technology (HUTECH), Vietnam
(5) Department of Architectural Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul 05006, Republic of Korea


ABSTRACT: Dynamic instability of temperature-dependent TIMOSHENKO functionally graded (TFG) nanobeam exposed to an axial excitation load and magnetic field in thermal environment is carried out in the present work. The power-law model is utilized to represent the material variations across the nanobeam thickness. In accordance with nonlocal strain gradient theory (NSGT), the equations of motion are derived through Hamilton's principle. Navier and Bolotin's approaches are here employed in order to specify the dynamic instability region of the FG nanoscale beam. The effects of different factors like length to thickness ratio, temperature variation, nonlocal parameter (NP), power-law index, static load factor, magnetic field as well as length scale parameter (LSP) on the dynamic instability boundary are scrutinized through some parametric studies. Based on the outcomes, with increasing temperature change, power-law index and NP, the instability region will be happened at lower pulsation frequencies whereas LSP and magnetic field effects are on the contrary. The obtained results can be useful as reference solutions for future dynamic stability analysis of FG nanobeams reinforced nanocomposites under thermal and magnetic effects.

ABSTRACT: Nonlocal elasticity theory was developed in order to describe some phenomena that cannot properly be described by the classical local elasticity theory. The formalism incorporates the long range interactions between points in continuum media. In this paper, a novel form of the nonlocal spherical shell model is formulated for application to the problem of the free vibration of nanoshells of spherical geometry. In contrast to previous studies which employ the Laplacian of the components of the stress tensor, in this proposed model the expressions for the Laplacian of the stress tensor components are used to drive the governing equations. Using the Legendre and the associated Legendre functions, a general solution for the differential equations of a momentless spherical shell subject to axisymmetric free vibration is presented. In addition, the validity of the present model is tested via some of the existing numerical and experimental results.


ABSTRACT: Nonlocal dynamic torsional response of nanorods embedded in elastic media is investigated. It is considered that mechanical behavior of elastic media is supposed to be like linear foundation model. The nonlocal dynamic torsion equation is obtained according to Hamilton’s Principle. Application of solved motion of equation is performed for nanorod models that have torsional spring attachment at the one end as well as three different general boundary conditions. Moreover, the formulation of nonlocal finite element method (NL–FEM) based on weighted residual that considers stiffness of elastic media and attachment ratio is attained; this finite element formula is new in the literature. The nondimensional torsional frequencies are presented under nanorod length, nondimensional nonlocal parameter, slenderness ratio, nondimensional media stiffness parameter and stiffness ratio of attachment as tables and graphics comparatively with NL–FEM. This study is exhibited that NL–FEM can be used for torsional vibration analysis of nanorods embedded in elastic media.


ABSTRACT: The present article aims to study the non-linear equilibrium paths of an AlO reinforced metal matrix composite (MMC) shallow arch in a thermal environment. The structure is made up of applicable industrial materials having temperature-dependent thermomechanical properties. In order to describe the configuration of shallow arch, two different geometrical models are implemented in which the first model has a symmetrical configuration but the second model has an unsymmetrical one. The concept of symmetric functionally graded (FG) material is implemented in the laminated composite arch by changing the volume fraction of fibers in each lamina. The elasticity tensor is created based on the plane-stress assumption and implementation of the rule of mixture. The mathematical modeling is developed using first-order shear deformation beam theory under specific assumptions i.e., geometrical nonlinearity, neutral axis concept, and uniform temperature gradient. Next, an analytical procedure is established to solve the three coupled nonlinear equilibrium equations for both clamped-clamped and simply-simply supporting conditions. The obtained exact solutions are capable of determining the critical temperature, in which the perturbed pitchfork bifurcation occurs, as well as the thermal equilibrium path of the structure. The influences of geometrical parameters (i.e., the initial curvature shape and amplitude, the thickness-to-length ratio, and the lamination sequences) as well as physical elements (i.e., matrix materials, fiber volume fraction distribution patterns, and temperature dependence of materials) on the thermal behavior of the system are examined. Eventually, in order to verify the analytical results presented in this study, a finite difference method-based numerical solution (bvp4c in Matlab software) is utilized to solve simultaneously the three coupled nonlinear governing equations.

Naveed Ahmed and Pu Xue (School of Aeronautics, Northwestern Polytechnical University, Xi’an, PR China), “Governing the in-plane axial crushing of honeycomb with regular hexagonal symmetric division cells using

ABSTRACT: Dynamic response of honeycomb is characterized by the deformation modes predominantly depending on the cells shape whose geometry, wall thickness and wall angle guide its performance. Without actually modifying the bare honeycomb with regular cell geometry, an idea is presented to divide the honeycomb cells, practically in symmetric half cells using a straight strip of the same material and thickness as of original honeycomb. This strip can guide the deformation modes as per the required performance once the honeycomb mechanical properties are characterized. Dynamic in-plane deformation modes are determined for honeycomb with regular hexagonal symmetric division cells in finite element package ABAQUS for multiple Configurations using proposed straight strip. The energy absorption and formation of X, V and I deformation modes are discussed for the Configuration and its applicability for the controlled and delayed deformation modes is described. An analytical comparison for regular and symmetric division cells is also presented to determine the effect of proposed scheme on modulus and relative density.

Tao Fu (1), Zhaobo Chen (2), Hongying Yu (2), Chengfei Li (2) and Yanzheng Zhao (3)
(1) School of Mechanical Engineering, Jiangsu University of Science and Technology, Zhenjiang 212003, PR China
(2) School of Mechatronics Engineering, Harbin Institute of Technology, Harbin 150001, PR China
(3) Robotics Institute of Shanghai Jiao Tong University, Shanghai 200240, PR China


ABSTRACT: Due to high stiffness and other potential multifunctional application characteristics, truss core sandwich structure offers a promising alternative to traditional stiffened or corrugated sandwich plates used in aerospace and marine industry. And sound radiation from plate structures is a design factor indicating the power reduction, which can help the lattice truss core sandwich structure meet the acoustic requirements for practical engineering design, but the sound radiation performance of this sandwich structure remains unclear. Based on that, the thermal buckling and sound radiation behavior analyses of truss core sandwich structure resting on elastic foundation in thermal environment are presented in this paper. The mechanical behavior of structure–foundation interaction is modeled as two-parameter model including Winkler and shear foundation. The sound radiation due to a concentrated harmonic force in thermal environment is computed by solving the Rayleigh integral. By comparing with numerical simulation results calculated by commercial finite element software, the accuracy and feasibility of theoretical model developed in this paper are validated. The effects of several key parameters including the truss core radius, inclination angle and height, temperature field and elastic foundation stiffness coefficient on thermal buckling and sound radiation behavior have been subsequently investigated.

Heng Li (1), Hao Ran Liu (1), Nan Liu (2), Hong Sun (1), Heng Yang (1) and Bi Ying Liu (1)
(1) School of Materials Science and Engineering, Northwestern Polytechnical University, Xi’an 710072, China
(2) School of Materials Science and Engineering, Xi’an University of Technology, China


ABSTRACT: Wrinkling instability is one of key defects restricting the formability of sheet metallic materials. How to sensitively predict the wrinkling occurring is one of the most fundamental and challenging issues in sheet metal forming operations to ensure defect-free deformation. In the study, taking typical axial compression and draw bending of tubular materials as the cases, the buckling modes of sheet metal forming under less and more degrees of constraints are experimentally compared, then a hybrid integrated prediction framework of wrinkling in sheet metal forming is constructed by introducing evolution of triple nonlinearity in geometry, material and boundary conditions, viz., multiple geometric micro-imperfections (GMI), anisotropic/asymmetric properties (AAP) and explicit FE algorithm, respectively. The results show that transferred wrinkling modes may occur for less constrained process, while the multiple constraints make the wrinkling occur in a higher order buckling mode consuming more energy. Multiple GMI modes constructed by linear buckling analysis are superimposed into explicit FE models, viz., the first three buckling modes superposed for axial compression, while the higher order buckling mode analogous to actual wrinkling selected for draw bending. Three
constitutive models, viz, Mises, normal anisotropic Hill’48-r and stress invariant based anisotropic/asymmetric models (SIM), are comparatively implemented in the explicit FE models. Compared with the perfect model without introducing GMI, the GMI-implemented FE model provides more sensitive prediction of wrinkling for both forming cases. The SIM-implemented FE model predicts the instability more sensitively than other constitutive models in tension-compression asymmetry dominated bending case. By coupling the GMI and SIM into explicit FE models, the desired wrinkling prediction capability for both forming cases is further confirmed since evolution of triple nonlinearity is simultaneously considered.

Mitao Song (1), Lei Chen (1), Jie Yang (2), Weidong Zhu (3) and Sritawat Kitipornchai (4)
(1) Faculty of Civil Engineering and Mechanics, Jiangsu University, Zhenjiang, Jiangsu 212013 PR China
(2) School of Engineering, RMIT University, PO Box 71, Bundoora, VIC 3083 Australia
(3) Department of Mechanical Engineering, University of Maryland, Baltimore County, Baltimore, MD 21250, USA
(4) School of Civil Engineering, The University of Queensland, St Lucia, Brisbane, QLD 4072 Australia

ABSTRACT: This paper investigates thermal buckling and postbuckling behaviors of functionally graded graphene nanoplatelet (GPL)-reinforced composite multilayer beams containing an open edge crack and resting on a Pasternak-type elastic foundation based on the first-order shear deformation beam theory including von Kármán geometric nonlinearity. The material properties of functionally graded GPL-reinforced composites (GPLRCs), which exhibit piece-wise variation along the thickness direction, are evaluated using micromechanics based models. The bending stiffness of the cracked section is estimated by the rotational spring model. The obtained nonlinear partial differential equations of equilibrium are discretized by the differential quadrature method, and then an iterative method is used to obtain the thermal buckling loads and postbuckling load-deflection curves. Detailed parametric studies are conducted to investigate the effects of crack length, GPL distribution pattern, GPL weight fraction, GPL length-to-width and length-to-thickness ratios, boundary conditions, and foundation stiffnesses on the thermal buckling loads and postbuckling response of the cracked GPLRC beams.


ABSTRACT: The mechanical behavior of crashworthy structures is a hot topic. In this study, square tube reinforced with rivets (STR) was firstly put forward to comprehensively investigate the influence brought from local stiffness reinforcement on deformation mode. The axial compression experiments were carried out and the results clearly showed that the collapse pattern and folding sequence of square tube were improved after riveting. Detailed mechanical properties were determined for kinds of STR structures with different rivet designs. Besides, numerical simulations by means of ABAQUS/Explicit were carried out to further analyze the deformation mode evolution. Subsequently, matching effect, local effect and interaction mechanism between basic structure and reinforcing components were investigated. Finally, parametric study involving different geometric configuration, material properties and impact velocity was performed. The proposed structure here will hopefully bring a method to understand the design principle of collapse mode controllability by means of reinforcing structural local stiffness.

Subodh Kumar (1) and Prasun Jana (2)
(1) Department of Mechanical Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad 826004, Jharkhand, India
(2) Department of Aerospace Engineering, Indian Institute of Technology, Kharagpur 721302, West Bengal, India

ABSTRACT: In this work, the dynamic stiffness method (DSM) is implemented to investigate free vibration behaviour of thin rectangular functionally graded material (FGM) plate with the sigmoid (S-FGM) and exponential (E-FGM) property variations along its thickness direction. Both uniform and stepped thickness FGM plates are considered in this study. Classical plate theory in conjunction with the physical neutral surface of the FGM plate is utilized to obtain the governing differential equation of motion including the effect of rotary inertia. Considering Levy type plates, the dynamic stiffness matrix is developed through the application of displacement and force boundary conditions at the appropriate edges. The well-known Wittrick-Williams algorithm is employed to solve this dynamic stiffness matrix in order to compute the natural frequencies of the plate with reasonably high accuracy. It is shown upon comparison with the existing literature that the DSM frequency results are most accurate and can be referred to judge the accuracy of several other numerical solutions applied to thin S-FGM and E-FGM plates. This study also highlights some insufficiently accurate published results and points out the possible reasons for this inaccuracy. Finally, this study reports a set of new results by changing different plate parameters which will be useful in the design of both uniform and stepped FGM plates under considerations.

P.L.N. Fernando (1), Damith Mohotti (2) and Alex Remennikov (3)
(1) School of Civil Engineering, Faculty of Engineering and IT, The University of Sydney, NSW 2006, Australia
(2) Centre for Infrastructure Engineering, Western Sydney University, Penrith, NSW 2751, Australia
(3) Centre for Infrastructure Protection and Mining Safety, University of Wollongong, Wollongong, NSW 2522, Australia


ABSTRACT: This paper presents a comprehensive analysis of the blast response of functionally graded composite metallic plates, fabricated using explosive welding. Explosive welding is a solid-state welding technique, which has previously shown capabilities in bonding metals that have different chemical and mechanical properties. Impedance, which is the product of volumetric mass density and wave propagation velocity for a given material, was chosen as the function when designing the graded composite plates. The performance of two composite plate configurations, namely, Steel-Titanium-Aluminium and Steel-Brass-Aluminium were compared with a monolithic steel configuration of equal overall plate dimensions. The plates were subjected to highly intensive blast loads produced by detonation of the 250 g cylindrical Composition-B charges at standoff distances between 20–65 mm and spherical 1 kg Nitromethane charges at standoff distances of 200 mm and 250 mm. Detailed numerical models of near-field loading of the monolithic and composite plates were developed using the non-linear finite element analysis software LS-DYNA and validated using the experimental deformation measurements. Experimental evaluation of the impedance-graded explosively-welded composite plates has been carried out for the first time and herein lies the novelty of the work presented in the paper. It was observed that the impedance graded composite plates, which were lighter in density than the monolithic plates, resisted the highly intensive blast loads through their enhanced ductility.


ABSTRACT: This paper analytically and numerically investigates the pre-buckling response and in-plane stability boundaries of circular concrete-filled steel tubular (CFST) arches subjected to combined thermal and mechanical loading. The governing non-linear equations of equilibrium are obtained using energy methods and both elastic and inelastic material behaviour is considered. A novel mechanically derived non-discretisation numerical method is proposed for the pre-buckling analysis. The stress-strain relation of the confining steel tube is described using a bi-linear plasticity model, and an inelastic material model is adopted for the concrete core which considers the effects of confinement and transient thermal strain. The result is a system of first-order differential equations which can be numerically solved with known boundary conditions including fixed ends,
pinned ends or crowned-pinned cases. Closed-form solutions are presented for the elastic anti-symmetric bifurcation loads, whilst the inelastic anti-symmetric buckling strength was studied using finite element (FE) analysis. The FE model is verified by comparison to the derived analytical and numerical models which show a high level of agreement. Additionally, a sensitivity analysis is conducted which explores the influence of the constitutive material law for the concrete core and contact model for the steel-concrete interface on critical buckling loads.

Jung-Hwan Kim (1) and Ji-Hwan Kim (2)
(1) Department of Mechanical and Aerospace Engineering, Seoul National University, 1, Gwanak-ro, Gwanak-gu, Seoul 08826, South Korea
(2) Institute of Advanced Aerospace Technology, Department of Mechanical and Aerospace Engineering, Seoul National University, 1, Gwanak-ro, Gwanak-gu, Seoul 08826, South Korea


ABSTRACT: In this work, the thermoelastic damping (TED) effect with the time-lagging is evaluated on the micro- or nano-cylindrical shell. Especially, the mechanism should be considered for the high-frequency ranges in the ultra-low temperature. And thus, the phenomenon can compensate the time-delay of the heat conduction based on the finite speed of heat flux. To develop the mathematical model for the analysis, Love's thin shell theory is basically adopted to derive the equations of motion including the mechanism. Then, the heat conduction equation is considered using the Cattaneo–Vernotte's (CV) theory. To simplify the shell model, an assumption is introduced for transverse-deflection-dominated motion based on Donnel–Muhshtari–Valsov (DMV) approximation. Also, the temperature profile is obtained by the dilatation strain and heat conduction equation. Thus, the complex eigenfrequency of the shell including the TED effect is finally obtained using the boundary conditions of the adiabatic surfaces and transverse vibration mode shape. Numerical results are verified with the previous work, and the trends of quality factors (Q-factors) according to the mode numbers and geometrical shapes are shown as in the graphical data.

Wichaphon Fakkaew (1), Matthew O.T. Cole (2) and Chakkapong Chamroon (1)
(1) School of Engineering, University of Phayao, Phayao 56000, Thailand
(2) Center for Mechatronic Systems and Innovation, Department of Mechanical Engineering, Chiang Mai University, Chiang Mai 50200, Thailand


ABSTRACT: This paper describes a theoretical and experimental study to establish the vibrational dynamics of a rotating thin-walled cylinder with radial bearing supports. The main focus is on the prediction of forced response, and the variation in response behaviour with rotational speed. A shell theory analysis is shown to provide a very complete description of rotodynamic behaviour that predicts various types of natural mode for free vibration. These include in-surface torsional and extensional modes, out-of-surface wall bending modes, as well as the classical beam bending modes exhibited by long flexible rotors. For exact solution of the free vibration problem, the coupled eigenproblems derived from the continuum equations and boundary constraints can be solved numerically. This approach can be applied for any given rotational speed. To avoid having to solve the equations repeatedly, an alternative model is formulated based on the zero-speed mode-shapes which has a simple parametric dependency on rotational speed. The method is applied to the dynamic modelling of an experimental system comprising a 0.8 m long steel rotor with outer diameter of 0.166 m and wall-thickness of 3.1 mm supported by two radial active magnetic bearings. The dynamic behaviour of the system is identified by frequency response testing at different rotational speeds, where excitation forces are applied through the bearings. The results confirm the accuracy and applicability of the developed shell theory model for practical use in rotodynamic prediction and analysis.

N. Mehreganian (1), A.S. Fallah (2) and L.A. Louca (1)
(1) Department of Civil & Environmental Engineering, Skempton Building, South Kensington Campus, Imperial College London, London SW7 2AZ, United Kingdom
ABSTRACT: Modern armour graded thin steel plates benefit from significant elastic strength with high elastic energy storage capacity, which contributes to dissipation of total impulse from extensive blast loads within the bounds of the elastic region. Higher elastic energy storage capability mitigates the probability of catastrophic damage and ensuing large deformations compared to the conventional graded metallic panels. While blast assessment of such structures is important to design and application of protective systems, limited studies are available on their response to localised blasts.

The present paper aims at deducing, from the minimization of Föppl-von Kármán (FVK) energy functional, the dynamic response of localised blast loaded thin elastic square plates undergoing large deformations. The presumed blast load function is a multiplicative decomposition of a prescribed continuous piecewise smooth spatial function and an arbitrary temporal function which may assume various shapes (e.g. rectangular, linear, sinusoidal, exponential).

A kinematically admissible displacement field and the associated stress tensor were considered as a truncated cosine series with multiple Degrees-of-Freedom (DoF’s). From the prescribed displacement field, having simply supported boundary conditions, useful expressions for stress tensor components were delineated corresponding to a unique mode and a series of differential equations were derived. The explicit solutions were sought using the Poincaré-Lindstedt perturbation method. The closed form solutions of each mode were corroborated with the numerical FE models and showed convergence when the first few modes were considered. The influence of higher modes, however, on the peak deformation was negligible and the solution with 3 DOF’s conveniently estimated the blast response to a satisfactory precision.


ABSTRACT: Lattice structures exhibit enormous potential for multi-functional implementations for their high stiffness/strength-to-weight ratio. While Additive Manufacturing (AM) techniques present great opportunities in the application of lattice structures, its process limitations impose challenges in design for AM. This paper develops a concurrent design method of AM fabricated lattice structures and its printing part orientation in natural frequency optimization problems. Specifically, void units are introduced into the design domain for better frequency objectives. Density filtering and projection approaches are designed to consider the Minimum Feature Size and the self-supporting constraints. Further, a concurrent optimization model is constructed to optimize the unit density layout and the part orientation. The proposed method was validated with a fundamental frequency optimization problem. Numerically, the proposed concurrent optimization method achieves high-quality solutions with low computational costs. Experimentally, the structure designed by the proposed method exhibits a higher fundamental frequency than that designed by the comparison method.

Alejandro Pacheco-Sanjuán (1) and Romesh Batra (2)
(1) Department of Mechanical Engineering, Universidad Técnica Federico Santa Maríá. Av. España 1680, Casilla, Valparaíso 110-V, Chile
(2) Department of Biomedical Engineering and Mechanics, Virginia Polytechnic Institute and State University, Norris Hall, Room 333-E, Virginia Tech, 495 Old Turner Street, Blacksburg, VA 24061, United States


ABSTRACT: For interpreting results of an indentation test on a single-layer graphene sheet (SLGS), it is frequently modeled as an elastic, isotropic, and homogeneous membrane. With a small thickness (~10⁻⁹ m) as compared to a characteristic length (~10⁻⁶ m) of specimens used in experiments, the non-dimensional von-Karman factor (vKf ~ 10⁸) for a SLGS predicts negligible flexural rigidity (D ~ 10⁻¹⁶ Nm). Since the membrane
undergoes large deformations under a small force, a direct relationship between the resulting force-displacement curves and elasticities of the graphene sheet is still elusive. Here we compare predicted load-displacement curves for nanoindentation of a SLGS by using a full non-linear theory with St. Venant–Kirchhoff material, and the Föppl–von Karman nonlinear equations with a Hookean material. The nonlinear governing equations in each formulation are numerically integrated by the shooting method. Even though the radial variations of the membrane deflections computed with the two theories differ by at most 1.5%, the stresses, the declination angles, the curvatures and the strain energy densities may reach differences as high as 6.4%, 7.4%, 70% and 25%, respectively. These differences are significant enough to reexamine using the FvK derived solutions to find elastic constants from the test data.

Haibao Liu (1), Brian G. Falzon (2) and John P. Dear (1)
(1) Department of Mechanical Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK
(2) Advanced Composites Research Group, School of Mechanical and Aerospace Engineering, Queen’s University Belfast, Ashby Building, Belfast BT9 5AH, UK

ABSTRACT: In composite aircraft structures, woven carbon-fibre reinforced plies are often used as the surface plies of a monolithic composite panel, made from unidirectional plies, to mitigate damage during drilling and provide a measure of impact damage resistance. This research presents, for the first time, a detailed experimental and numerical study on the crush behaviour of hybrid unidirectional/woven carbon-fibre reinforced composite laminates. Quasi-static crush tests are performed on composite specimens with two different trigger geometries; a bevel-trigger and a steeple-trigger. A computational model, which accounts for both interlaminar and intralaminar damage in hybrid unidirectional (UD)/woven composite laminates, implemented as a user subroutine in ABAQUS/Explicit, was used. A comparison between experimental and numerical results confirms the computational tool's accuracy in predicting the energy absorption and damage mechanisms of hybrid specimens. The proposed approach could significantly reduce the extent of physical testing required in the development of crashworthy structures.

J.W. Yan (1,2,3), L.H. Tong (1), R.J. Luo (2) and D. Gao (4)
(1) School of Civil Engineering and Architecture, East China Jiaotong University, Nanchang, Jiangxi, PR China
(2) Key Laboratory of Product Packaging and Logistics of Guangdong Higher Education Institutes, Jinan University, Zuhai, Guangdong, PR China
(3) State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an, Shanxi 710049, PR China
(4) Ningbo Institute of Technology, Zhejiang University, Ningbo, Zhejiang, PR China

ABSTRACT: The controversy on thickness of monolayer h-BN nanosheets yields scattered elastic properties, and thus scattered flexural rigidity. In this paper, the thickness is exactly determined by fitting the results of classical plate theory and atomistic-continuum approach. Free vibration behaviors of h-BN nanosheets are simulated by the recently developed atomistic-continuum multiscale approach. Also, the results are verified by full atomic simulations. Both two are under the same computational framework of interatomic potential. A slight difference between the above-mentioned two approaches is the former employs a homogenization technique in the whole field, while the latter involves the influence of the dangling bonds at the edge. As a result, this slight difference due to the edge effect yields a difference in studying the natural frequencies. Consequently, it is found that classical thin plate theory can exactly extract the thickness of h-BN nanosheets, by fitting the analytical solutions with the results of atomistic-continuum approach. The thickness is determined to be 0.0906nm, yielding elastic and shear moduli of 3.5802 and 1.5397 TPa, respectively, and a flexural rigidity of 1.4253eV.

Binhui Jiang (1), Wenxiao Tan (2), Xiaobing Bu (2), Linwei Zhang (1), Cunwen Zhou (1), Clifford C. Chou (3) and Zhonghao Bai (1)
The high accuracy of the proposed spectral element model for the rectangular membranes is verified via obtaining the dynamic responses and wave propagations in a membrane, temporal and spatial coordinates, the well-known fast Fourier transform algorithm can be applied for efficiently obtaining the dynamic responses and wave propagations in a membrane, in both the time and spatial domains. The high accuracy of the proposed spectral element model for the rectangular membranes is verified via

ABSTRACT: Nowadays, more bio-inspired structures were proposed and adapted in structural designs to improve their energy absorbing performance. In this paper, a bio-inspired constituent element (BCE) consisting of a hollow cylindrical tube with four panels was studied. Quasi-static tests were conducted to evaluate its energy-absorbing performance using specimens with a thin-walled square tube. A FE model was developed and validated in favorable agreement with the experimental data. Using the FE model, a parametric study of the energy absorbing capability and deformed pattern of the BCE was conducted. The specific energy absorption (SEA) of the BCE is higher than that of traditional angle elements and significantly affected by the wall thickness, radius of cylindrical tube and number of intersecting panels. Finally, analytical (or theoretical) formulae for estimating the mean crushing force of the BCE was derived and correlated favorably with the experimental data.


ABSTRACT: In this paper, the influence of uniform temperature elevation on the vibration of rotating composite beams reinforced with carbon nanotubes which may lead to instability is discussed. For the composite beam which is reinforced by carbon nanotubes, a uniform distribution and two symmetric gradient distributions are considered. The characteristics of these materials are assumed to be temperature dependent and the elastic materials are found by a refined rule of mixtures. The governing equations are based on the Timoshenko beam theory and the von Kármán strain-displacement relation. The natural frequencies are estimated by employing the differential transform method. The current results are validated through comparison with the available outcomes in the literature. The influences of the temperature, the length to the thickness ratio, the rotor radius to the beam length ratio and the rotating speed on the pre-stressed axial deformation, the fundamental natural frequency and the mode shapes are examined for three different boundary conditions. The outcomes demonstrate the instability probability in the clamped-clamped as well as hinged-clamped boundary conditions for rotating beams. The implication is that threshold value of destabilization depends on the carbon nanotube distribution profile, the rotating speed, the temperature, the length to the thickness ratio and the rotor radius to the beam length ratio.


ABSTRACT: This study proposes an exact frequency-domain spectral element model for a rectangular membrane subjected to arbitrary boundary conditions. The frequency-domain general solution of a finite rectangular membrane element is first assumed in the trigonometric Fourier series with the spatial coordinates \( x \) and \( y \). After all the trigonometric Fourier series terms that vanish at the four boundary edges are eliminated, the general solution is expressed in the spectral (i.e., discrete Fourier transform) forms with respect to the spatial coordinates \( x \) and \( y \). By using the projection method, the spatial-domain spectral coefficients of the general solution are related to the spatial cosine/sine series coefficients of the functions specified for the geometric and natural boundary conditions. Lastly, the spectral element matrix (i.e., dynamic stiffness matrix) is formulated from the force–displacement relationships. Owing to the spectral representation of the general solution in both temporal and spatial coordinates, the well-known fast Fourier transform algorithm can be applied for efficiently obtaining the dynamic responses and wave propagations in a membrane, in both the time and spatial domains.
comparison with existing solution techniques, such as the exact theory, modal analysis method, and finite element method.

References listed at the end of the paper:

1 A.W. Leissa, Closed form exact solutions for the steady state vibrations of continuous systems subjected to distributed exciting forces, J Sound Vib, 134 (1989), pp. 435-453
3 S. Durvasula, Natural frequencies and modes of skew membranes, J Acoust Soc Am, 44 (1968), pp. 1636-1646
5 J.A. Masad, Free vibrations of a non-homogeneous rectangular membrane, J Sound Vib, 195 (1996), pp. 674-678
9 P.A.A. Laura, R.E. Rossi, R.H. Gutierrez, The fundamental frequency of non-homogeneous rectangular membranes, J Sound Vib, 204 (1997), pp. 373-376
13 G.W. Wei, Vibration analysis by discrete singular convolution, J Sound Vib, 244 (2001), pp. 535-553
16 P. Amore, A new method for studying the vibration of non-homogeneous membranes, J Sound Vib, 321 (2009), pp. 104-114
27 I. Park, T. Kim, U. Lee, Frequency domain spectral element model for the vibration analysis of a thin plate with arbitrary boundary conditions, Math Prob Eng, 2016 (2016), Article 9475397
29 W.C. Reynolds, Solution of partial differential equations, Department of Mechanical Engineering, Stanford University, CA (1981)
31 D.J. Gorman, Free vibration analysis of the completely free rectangular plate by the method of superposition, J Sound Vib, 57 (1978), pp. 437-447
References listed at the end of the paper:

1. E.M. Kerwin, Damping of oexural waves by a constrained viscoelastic layer, J Acoust Soc Am, 31 (7) (1959), pp. 952-962
17 A.A. Parand, A. Alibeigloo, Static and vibration analysis of sandwich cylindrical shell with functionally graded core and viscoelastic interface using DQM, Compos Part B Eng, 136 (2017), pp. 1-16
24 N. Al-Huniti, F. Al-Faqs, O.A. Zaid, Finite element dynamic analysis of laminated viscoelastic structures, Appl Compos Mater, 17 (4) (2010), pp. 405-414
27 R.S. Masti, M.G. Sainsbury, Vibration analysis of cylindrical shells partially coated with a constrained viscoelastic treatment having a standoff layer, Thin-Walled Struct, 43 (9) (2005), pp. 1355-1379
28 N. Kumar, S.P. Singh, Experimental study on vibration and damping of curved panel treated with constrained viscoelastic layer, Compos Struct, 92 (2) (2010), pp. 233-243
29 Etienne Balmès, Corus M., B. Stephane, Constrained viscoelastic damping, test/analysis correlation on an aircraft engine, Struct Dyn, 3 (2011), pp. 1177-1185
30 W.L. Li, Free vibrations of beams with general boundary conditions, J Sound Vib, 237 (4) (2000), pp. 709-725
31 W.L. Li, Vibration analysis of rectangular plates with general elastic boundary supports, J Sound Vib, 273 (3) (2004), pp. 619-635
32 X. Zhang, W.L. Li, Vibration of rectangular plates with arbitrary non-uniform elastic edge restraints, J Sound Vib, 326 (1-2) (2009), pp. 221-234
33 Y. Chen, G. Jin, M. Zhu, Z. Liu, J. Du, W.L. Li, Vibration behaviors of a box-type structure built up by plates and energy transmission through the structure, J Sound Vib, 331 (4) (2012), pp. 849-867
34 H. Khov, W.L. Li, R.F. Gibson, An accurate solution method for the static and dynamic deflections of orthotropic plates with general boundary conditions, Compos Struct, 90 (4) (2009), pp. 474-481
37 G. Jin, C. Yang, Z. Liu, A unified method for the vibration and damping analysis of constrained layer damping cylindrical shells with arbitrary boundary conditions, Compos Struct, 130 (2015), pp. 124-142
38 G. Jin, C. Yang, Z. Liu, Vibration and damping analysis of sandwich viscoelastic-core beam using reddy's higher-order theory, Compos Struct, 140 (2016), pp. 390-409
40 A. Messina, K.P. Soldatos, Ritz-type dynamic analysis of cross-ply laminated circular cylinders subjected to different boundary conditions, J Sound Vib, 27 (4) (1999), pp. 749-768

Zhixiang Li, Wen Ma, Ping Xu and Shuguang Yao (Key Laboratory of Traffic Safety on Track, Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha, 410075, China), “Crashworthiness of multi-cell circumferentially corrugated square tubes with cosine and triangular configurations”, International Journal of Mechanical Science, Vol. 165, Article 105205, 1 January 2020, https://doi.org/10.1016/j.ijmecsci.2019.105205

ABSTRACT: Multi-cell and multi-corner configurations are the most common methods to improve the crashworthiness performance of thin-walled tubes. However, the crashworthiness of a thin-walled tube combining these two configurations has not yet been evaluated. This paper proposed a series of multi-cell circumferentially corrugated square tubes (CCSTs) in which multi-corner configurations were achieved by
introducing cosine and triangular corrugations. The crashworthiness of these multi-cell CCSTs were investigated under multiple loading angles. The complex proportional assessment (COPRAS) method was used to select the optimal structures. The results showed that the cosine and triangular multi-cell CCSTs with crisscross ribs, namely, C1 and T1 in this paper, exhibited the best performance. Then, two different multi-objective optimization methods were used to determine the optimal geometric parameters of C1 and T1. The results showed that one optimization method mainly balanced the crashworthiness performance at different loading angles but did not improve the performance, whereas the other optimization method significantly improved the crashworthiness of the tubes.

References listed at the end of the paper:
2 Z. Li, S. Yao, W. Ma, P. Xu, Energy-absorption characteristics of a circumferentially corrugated square tube with a cosine profile, Thin-Walled Struct, 135 (2019), pp. 385-399
3 S. Yao, Z. Li, J. Yan, P. Xu, Y. Peng, Analysis and parameters optimization of an expanding energy-absorbing structure for a rail vehicle coupler, Thin-Walled Struct, 125 (2018), pp. 129-139
8 T. Tran, S. Hou, X. Han, W. Tan, N. Nguyen, Theoretical prediction and crashworthiness optimization of multi-cell triangular tubes, Thin-Walled Struct, 82 (2014), pp. 183-195
9 Z. Tang, S. Liu, Z. Zhang, Analysis of energy absorption characteristics of cylindrical multi-cell columns, Thin-Walled Struct, 62 (2013), pp. 75-84
10 A. Alavi Nia, M. Parsapour, Comparative analysis of energy absorption capacity of simple and multi-cell thin-walled tubes with triangular, square, hexagonal and octagonal sections, Thin-Walled Struct, 74 (2014), pp. 155-165
19 S. Pirmohammad, S.E. Marzdashi, Crushing behavior of new designed multi-cell members subjected to axial and oblique quasi-static loads, Thin-Walled Struct, 108 (2016), pp. 291-304
20 F. Tarlochan, F. Samer, A.M.S. Hamouda, S. Ramesh, K. Khalid, Design of thin wall structures for energy absorption applications: enhancement of crashworthiness due to axial and oblique impact forces, Thin-Walled Struct, 71 (2013), pp. 7-17
23 Z. Tang, S. Liu, Z. Zhang, Energy absorption properties of non-convex multi-corner thin-walled columns, Thin-Walled Struct, 51 (2012), pp. 112-120
24 S. Liu, Z. Tong, Z. Tang, Y. Liu, Z. Zhang, Bionic design modification of non-convex multi-corner thin-walled columns for improving energy absorption through adding bulkheads, Thin-Walled Struct, 88 (2015), pp. 70-81
27 X. Deng, W. Liu, Multi-objective optimization of thin-walled sandwich tubes with lateral corrugated tubes in the middle for energy absorption, Thin-Walled Struct, 137 (2019), pp. 303-317
ABSTRACT: The surface to volume ratio becomes significant at nanoscale, so the surface stress plays an essential role in the mechanical responses of nanostructures. The focus of the present study is on an accurate analytical nonlinear primary resonance solution of functionally graded (FG) porous nanoshells under an external soft harmonic excitation including surface stress effects. To this end, the constitutive differential equations are adopted within the framework of the Gurtin-Murdoch theory of elasticity. In order to capture more accurate results, the nonlinear modal interactions between the main oscillation mode and higher symmetric vibration modes with the main oscillation mode into account, the responses associated with the nonlinear primary resonance of FG porous nanoshells incorporating modal interactions are estimated on the basis of the closed-cell Gaussian-Random field scheme. Thereafter, with the aid of the multiple time-scales technique, analytical expressions are expressed for the nonlinear surface elastic-based frequency-responses and amplitude-responses associated with the nonlinear primary resonance of FG porous nanoshells corresponding to various nonlinear modal interactions. It is demonstrated that by taking the modal interaction between higher symmetric vibration modes with the main oscillation mode into account, the frequency-response of FG porous nanoshells changes from the hardening behavior to the softening one. As a consequence, the modal interaction causes to shift the peak of the nonlinear resonance from the excitation frequency range of $\Omega/\omega > 1$ to $\Omega/\omega < 1$.

References listed at the end of the paper:

doi.org/10.1016/j.ijmecsci.2019.105203


ABSTRACT: Hemodynamic forces play an important role in both physiological function and pathological conditions of the cardiovascular system. These forces are sensed by the mechanoreceptors of the vessel wall to give the proper response for homeostasis maintenance. Baroreceptors are a kind of mechanoreceptors which are sensitive to the abnormal stretch magnitudes. Therefore to assess the function of these receptors, predicting the stress and stretch distributions induced by the hemodynamic field to the arterial wall is crucial in the barosensitive regions.

In this study, 3D patient-specific models of the aortic arch and carotid bifurcation which are the common positions of the baroreceptors are presented. Geometries were reconstructed based on MRI images and pulsatile numerical analysis was performed considering fluid-structure interaction. The hemodynamic field containing the velocity, WSS and pressure distributions was discussed in the fluid domain and the stress and deformation fields were analyzed in the solid domain. Comparing the temporal variations of pressure and circumferential stretch at the two barosensitive regions, the circumferential stretch is proposed as the criterion for quantifying the function of baroreceptors.

References listed at the end of the paper:
11 R. Klabunde, Cardiovascular physiology concepts, Lippincott Williams & Wilkins (2011), pp. RA1-RA8
22 Z. Teng, et al., 3D critical plaque wall stress is a better predictor of carotid plaque rupture sites than flow shear stress: an in vivo MRI-based 3D FSI study, J Biomech Eng, 132 (3) (2010), p. 31007
34 G. Howard, et al., Carotid artery intimal-medial thickness distribution in general populations as evaluated by B-mode ultrasound. ARIC investigators, Stroke, 24 (9) (1993), pp. 1297-1304
41 H. Meng, et al., Complex hemodynamics at the apex of an arterial bifurcation induces vascular remodeling resembling cerebral aneurysm initiation, Stroke, 38 (6) (2007), pp. 1924-1931
42 M. Nabaei, N. Fatourae, Computational modeling of formation of a cerebral aneurysm under the influence of smooth muscle cell relaxation, J Mech Med Biol, 12 (01) (2012), Article 1250006
While considering friction, numerical examples of the straight and transitions of the coil configuration during deployment are obtained by solving the equation of motion. Dimensional coil behavior, including large deflection, is expressed by co...
via a catheter demonstrate that the coil forms an ordered loop structure at the initial stage of coil deployment, while axial buckling is found at the part of the coil just released from the catheter during deployment. Although the cause of the axial buckling can be well explained by frictional resistances exerted on the coil placed in the aneurysm, the post-buckling structure of the coil shows two patterns depending on the frictional coefficient. At low friction, the whole coil placed in the aneurysm slides along the aneurysm surface and maintains its ordered structure. At high friction, however, large deflection occurs where the coil has just been released from the catheter and after pushing itself into place in the aneurysm, the ordered coil structure collapses and formation of a disordered structure with uniform distribution ensues. The present model is valuable for interpreting the mechanical behavior of endovascular coils and for estimating the extent of spatial uniformity achieved by a coil in an aneurysm.

Shurui Wen (1), Yuanhao Xiong (1), Shuaimin Hao (1), Fengming Li (1) and Chuanzeng Zhang (2)
(1) College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin 150001, China
(2) Department of Civil Engineering, University of Siegen, Siegen D-57068, Germany
ABSTRACT: In order to enhance the vibration reduction capacity in a wide frequency range, a novel acoustic metamaterial beam with periodically variable cross-sections is designed by combining the mechanisms of the Bragg scattering and the locally resonant band-gaps. The spectral element method (SEM) is extended to investigate the band-gap properties of the novel acoustic metamaterial beam. Based on the exact frequency responses obtained by solving the spectral equations in the frequency domain, it is found that the interaction of the Bragg scattering and the locally resonant band-gaps can enlarge the band-gap widths. More band-gaps can be achieved if the material periodicity is harmonized with the cross-section periodicity. When these two kinds of band-gaps exist simultaneously, the locations of the locally resonant band-gaps do not strictly correspond to the resonator's natural frequencies. The width and the attenuation ability of the Bragg scattering band-gaps become wider and stronger with the increase of the ratio of the cross-sectional sizes of the two sub-cells. The experimentally measured band-gap positions and widths agree very well with the SEM results, which guarantees the correctness of the numerical results.

ABSTRACT: A constitutive model was proposed to predict the deformation and characterize the failure features of fiber-reinforced composite structures under dynamic loading. Primarily, quasi-static and dynamic mechanical tests were carried out on composite laminates with designed plying sequences. The material modulus was found rising as the increase of strain rate, while the ultimate strain exhibits no strain rate dependency. Nonlinear behavior was observed under transverse compression and in-plane shear, and was attributed to the progressive damage of material. Based on the results of uniaxial tests, constitutive relations were established for plane stress case and three-dimensional case respectively. Two damage factors were introduced to describe the nonlinear behavior, and failure criteria based on transversely isotropic invariants were proposed. Additionally, the constitutive model was implemented in Abaqus through user-defined material subroutine and validated by the simulation of uniaxial tests and bird impact tests. Comparing to the traditional model, the constitutive relations presented in this paper was proved to have better accuracy and efficiency in predicting dynamic response and ultimate failure patterns of composite structures under dynamic loading.

ABSTRACT: Impact models can involve either detailed simulation or approximate net-impulse prediction. Net-impulse approaches map pre-impact to post-impact states without solving differential equations. Net-impulse approaches are seldom used for predicting restitution in vibration-dominated impacts with explicit accounting
of vibrations. Here we study impacts of Hertzian balls on four different Euler-Bernoulli beams, with uniform and nonuniform cross sections as well as different boundary conditions. For each beam, initial detailed simulations using modal coordinates are used to compute restitution values for different ball masses and contact locations. Subsequently, a simple method is proposed for approximately predicting the restitution level, given colliding mass and vibration mode information. The key idea is to minimize post impact kinetic energy subject to various linear inequality constraints. These constraints include both fundamental restrictions as well as new outward or rebound-enhancing constraints that constitute the main novelty of the approach. The new approach, referred to as Energy Minimization under Outward Constraints (EMOC), requires solution of a quadratic optimization problem, yields a unique solution using readily available routines, and has three fitted parameters. These parameters, in our examples, are constant for all ball masses and contact locations for a given beam. Physical impossibilities like interpenetration or energy increases are never predicted for any parameter values. Upon parameter fitting, the match between full numerical solution and EMOC is good on average, with key qualitative trends captured correctly. No comparable net-impulse model exists in the vibroimpact literature.


ABSTRACT: Impact force is the load that actual structures often experience, and its localisation and time-history reconstruction are important for structural health and safety monitoring. However, classical inversion techniques for random impact-force identification are time-consuming and infeasible; therefore, they cannot be utilized for engineering applications. This study adopted multiple time-series analyses and a pattern-recognition method to identify unknown random impact forces, and this strategy is known as the pattern-recognition method combined with a similarity metric (PRMCSM). Numerical simulations of the proposed method have been conducted; however, their findings have not been experimentally verified. From an experimental perspective, this study considered suspended steel plate as the research object, impact force as the load input, and acceleration as the response output. The PRMCSM algorithm based on cosine similarity was verified, and the expected results were obtained. Moreover, various similarity metric indices are proposed to implement the feature extraction of time-domain responses, and a novel index that is not lower than cosine similarity was finally determined and was verified based on the PRMCSM strategy. In summary, the method based on pattern recognition achieves the rapid identification of random impact forces and exhibits potential for practical engineering applications.


ABSTRACT: This study employed theoretical analysis and experimental measurements in an exploration of the transient behavior of a cantilever plate subjected to a dynamic impact force. The solution of transient displacement is established as a product of the time function and mode shapes for the cantilever plate. The superposition method was used to obtain the mode shapes and resonant frequencies for free vibrations, and the orthogonality of the mode shapes was used to determine the time function. We demonstrate that the results of transient behaviors including transient displacement, strain, velocity and acceleration of the cantilever plate can be explicitly presented in closed forms. In the experiment, the dynamic external force was produced by the impact of a steel ball on the cantilever plate, and a pair of Polyvinylidene fluoride (PVDF) sensors are used to measure the force history of the impact loading. Fotonic sensor (FS) was also used to obtain the time signals of transient displacement, and PVDF film sensors were used to determine transient strain in the cantilever plate. Our results obtained in the theoretical analysis are highly consistent with experimental measurement and FEM simulations in the time domain. This is a clear demonstration of the effectiveness of pairing theoretical analysis with impact loading histories measured using PVDF sensors in the representation of transient wave propagation behavior in a cantilever plate. Based on the proposed theoretical solution, we established the relationship between transient behaviors and vibrational characteristics that allow us to get more information of the physical phenomenon of the transient response. In transient signal, the contribution of each mode is related to the position of impact point and observation point. The position of exciting force and observation near the nodal
lines of particular mode shapes can reduce the contribution of those modes in the transient waveform. We also investigated the influence on the transient response of a cantilever plate subjected to various impact loading duration, and indicate that the amplitude of transient displacement after the release of external force is depended on the impact force duration. Setting the force released at the time of period for specific mode, which provide the maximum contribution, can suppress the amplitude of oscillation in subsequent transient displacement.

Hesheng Han (1), Lun Liu (2) and Dengqing Cao (1)
(1) School of Astronautics, Harbin Institute of Technology, Harbin 150001, China
(2) Institute of Dynamics and Control Science, Shandong Normal University, Ji'nan 250014, China


ABSTRACT: The explicit expressions of steady-state responses of a coupled bending-torsional Timoshenko beam with cracks and damping effect subjected to external harmonic loadings are presented in this paper. The Green's functions method is employed to obtain the analytical solutions. The beam is split to several segments due to the existence of cracks. General Green's functions of each segment with unknown boundary constants are given by using Laplace transform method. A mixture line-spring is introduced to obtain the compatibility conditions of the cracked cross-section between the segments. Based on the transfer matrix method, those constants in the Green's functions for each segment are determined with those matching conditions, as well as boundary relationships and end boundary conditions. Then, the solutions of the whole cracked beam with one or multiple cracks can be expressed in terms of the piecewise functions. The solutions of the multi-cracked beam cover those of the beam with only one crack and the uncracked beam. The theory developed can be used for the beam with classical boundary conditions, but for illustration, results for a cantilever cracked beam with T shape cross-section are illustrated, emphasizing the effect of cracks on the solutions. Comparisons between results in the published literature and those obtained from the developed method show a good agreement, which confirms the validity and accuracy of the proposed approach. The influences of crack depth, location and number on the natural frequencies are discussed. The changes of the steady-state responses of beam are investigated due to the existence of crack. Moreover, the symmetric property of the Green's functions and damping effect on the amplitude of steady-state responses of the cracked beam are studied particularly.

Kun Tian (1), Yuan Zhang (1), Qi Zhao (1) and Hualin Fan (2)
(1) School of Aerospace Engineering and Applied Mechanics, Tongji University, Shanghai, China
(2) Research Center of Lightweight Structures and Intelligent Manufacturing, State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China


ABSTRACT: Compared with the excellent energy absorption performance under axial loading, thin-walled tubes are vulnerable to instable global bending under oblique loading condition. In this paper, a novel design was developed to improve the energy absorption performance of the thin-walled circular tubes under oblique loading by introducing multiple circumferential grooves with non-uniform depths. Quasi-static experiments and finite element simulations were carried out for tube specimens with different groove configurations. Theoretical models were developed to explain the different energy absorption performance of different tubes. The effects of the loading angle and the friction condition on the energy absorption were also investigated. The results highlight the advantages of the gradually grooved tubes with groove depth decreasing from loading end to fixed end over the uniformly grooved tubes and the original tubes under the oblique loading condition. The work in this paper can provide a guide for the design of advanced energy absorbing devices for arbitrary loading condition.

Jie Xu, Liang Gao, Mi Xiao, Jie Gao and Hao Li (The State Key Lab of Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan, Hubei 430074, China), “Isogeometric topology optimization for rational design of ultra-lightweight architected materials”,
ABSTRACT: Architected materials with the desirable properties, such as the lightweight and the superior stiffness, have accepted considerable attention in recent years. This paper aims to study the design of architected materials but with the ultra-lightweight using an effective and efficient Isogeometric Topology Optimization (ITO) method. An enough smooth and continuous Density Distribution Function (DDF) is constructed using the Shepard function and NURBS basis functions, to describe the topology of the micro-architecture. Later, the homogenization with a simple periodic boundary formulation is numerically implemented by isogeometric analysis (IGA) to predict effective macroscopic properties using the micro information. An ITO formulation with the specific objective function is developed to rationally design 2D and 3D architected materials with the extreme elastic properties using the DDF and IGA-based homogenization, in which the volume fraction needs to be very low to ensure the optimized micro-architectures with the ultra-lightweight. NURBS basis functions offer a unified formula for the structural geometry, the solution space and the micro topology in architected materials. Finally, several numerical examples are provided to display the effectiveness of the ITO method for the ultra-lightweight architected materials, particularly for 3D scenario. A series of novel and interesting 3D ultra-lightweight architected materials are found, which are also prototyped using the Selective Laser Sintering (SLS) technique.


ABSTRACT: In this study, a formulation is developed for investigation of three-dimensional edge stresses in cylindrical composite shell panels under distributed transverse loading. The formulation is obtained by employing the Galerkin weak formulation of the equilibrium equations. The obtained governing equations for the panel are solved via an analytical method for Levy-type boundary conditions including free and clamped edges. The presented formulation is capable of prediction of three-dimensional and boundary layer stresses in the composite panels subjected to transverse loading. The edge stresses in free edge, clamped edge and simple edge of transversely loaded cylindrical composite panel are studied. Comparison of numerical results with the available results of exact elasticity solution in the literature confirms the accuracy and the efficiency of the formulation.

Hong Zhang (1), Rupeng Zhu (1), Dongyan Shi (2), Qingshan Wang (3) and Hailiang Yu (3) (1) National Key Laboratory of Science and Technology on Helicopter Transmission, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China (2) College of Mechanical and Electrical Engineering, Harbin Engineering University, Harbin 150001, PR China (3) State Key Laboratory of High Performance Complex Manufacturing, Central South University, Changsha 410083, PR China “Study on vibro-acoustic property of composite laminated rotary plate-cavity system based on a simplified plate theory and experimental method”, International Journal of Mechanical Science, Vol. 167, Article 105264, 1 February 2020, https://doi.org/10.1016/j.ijmecsci.2019.105264

ABSTRACT: Effective combination of simplified plate theory (SPT) and the improved Fourier-Ritz method, a unified analytical model for the vibro-acoustic property of a laminated rotary plate coupling with an impedance cavity under complex boundary conditions is established in the investigation. The structure-acoustic coupling potential energy generated by the interaction between the flexible laminated plate and the cavity at the interface is added into the energy functional of the structure domain and the acoustic domain, and the energy functional of the plate-cavity coupling system is obtained. The solution equation of the vibro-acoustic coupling property can be gained through Rayleigh-Ritz energy technique. Besides, by introducing external force or internal sound source, the coupling mechanism between the flexible plate and the cavity is explained thoroughly from two aspects. By comparing the results calculated by the classical plate theory (CPT), the finite element method (FEM), the first-order shear deformation theory (FSDT) and Experimental test, the applicability and accuracy of SPT in analyzing the rotary laminated plate-cavity coupling system are verified. Besides, the effects of geometric parameters, material parameters, elastic boundary conditions, acoustic medium on the coupling
system are mainly studied, which provides theoretical guidance for the design and noise control of such engineering structures.

Jun Xu (1), Yandong Chen (1), Yongpeng Tai (2), Xiaomei Xu (2), Guodong Shi (1) and Ning Chen (1)
(1) College of Mechanical and Electronic Engineering, Nanjing Forestry University, Nanjing 210037, People’s Republic of China
(2) College of Automobile and Traffic Engineering, Nanjing Forestry University, Nanjing 210037, People’s Republic of China


ABSTRACT: The vibration analysis of fractional viscoelastic beam structures with complex shapes and boundaries is a difficult task. In this paper, the wave method is applied to analyse the dynamic characteristics and steady-state response of fractional viscoelastic beam structures, and the effects of fractional order on wave propagation, transmission and reflection are discussed. Based on the fractional constitutive equation for viscoelastic materials, a fractional partial differential equation for a uniform viscoelastic beam is established. In the vibration analysis process, the beam is discretized according to the discontinuous feature positions, and then the vibration amplitude of the beam is obtained by a matrix calculation of the wave propagation, transmission and reflection associated with the beam. To verify the effectiveness of this method in studying fractional-order structures, a fractional-order viscoelastic beam is used as an example, and the results obtained by this method are compared with those obtained by the modal superposition method. In addition, the natural frequencies, mode shapes, frequency response function and amplitude response of viscoelastic beams with uniform symmetrical supports and beams with support positions that are optimized by a particle swarm optimization (PSO) are obtained with different fractional constitutive models. Moreover, the relationship between the dynamic characteristics and fractional order is also analysed. Actually, the model of viscoelastic material is changed under external excitation, which can be described by the variation of fractional order. The results show that this method has high accuracy in calculating the vibration properties of fractional viscoelastic beam structures.


ABSTRACT: The application of piezoelectric layers on the outer surfaces of lightweight passive sandwich plates can offer multifunctional smart sandwich plates (MFSSPs). This paper proposes a new MFSSP and studies its critical stability mechanical loads and temperature changes. The smart plate is proposed to include a multifunctional passive sandwich plate integrated with two active piezoelectric layers. The lightweight sandwich plate has a polymeric porous core and two randomly oriented graphene/polymer nanocomposite layers. Different profiles are considered for graphene and porosity distributions in nanocomposite and core layers, respectively. A modified Halpin–Tsai’ approach with efficiency parameters is employed to estimate the material properties of polymer/graphene layers. Reddy's third order shear deformation theory (TSDT) of plates is selected to estimate displacement field and obtain the governing stability equations of the proposed MFSSP. Then, a mesh-free method is developed to solve the obtained mechanical and thermal stability equations. The effect of MFSSP's parameters, including porosity and graphene characteristics, on the stability responses have been studied. The results disclose that the addition of graphene significantly improves the mechanical stability responses of MFSSPs. Furthermore, embedding more pores in core layer can improve the thermal stability of MFSSPs without a considerable reduction in their mechanical stability responses.

Liangliang Chu (1), Yanbin Li (2) and Guansuo Dui (1)
(1) Institute of Mechanics, Beijing Jiaotong University, Beijing, 100044, China
(2) Applied Mechanics of Materials Laboratory, Department of Mechanical Engineering, Temple University, Philadelphia, PA 19122, USA

ABSTRACT: Due to the strong size-dependent property, flexoelectricity is one of the most advantageous applications of piezoelectricity on the micro/nano scale energy harvesting. However, rare researches have been conducted on energy harvesters composed by functionally graded flexoelectric materials (FGFMs). In this paper, the nonlinear vibration of a FGFMs energy harvesting nanobeam with a concentrated mass located at free end is analyzed theoretically while considering the electromechanical coupling effect induced by strain gradients. By referring to the Galerkin's method, the corresponding equations of the coupled system and the approximated closed-form solutions of the electric and the power output are obtained. In numerical part, the influences of the volume ratio of the material components, the gradient index and the loading resistance on the voltage output and power density are studied in detail. It is found that, for FGFMs energy harvester, the effective voltage output and the power density depend enormously on the material constituents, the gradient index, the scaled size and the loading resistance. And the rationality of our proposed model is verified by the numerical results. Thus, we can conclude that, for the energy harvesting triggered by flexoelectricity, the FGFMs may be a good way for device design owing to its easy generation of large strain gradients.

Miao Zhao (1), David Z. Zhang (1), Fei Liu (1), Zhonghua Li (2), Zhibo Ma (1) and Zhihao Ren (1)
(1) State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing, 400044, China
(2) School of Mechanical Engineering, North University of China, Taiyuan, 030051, China


ABSTRACT: Functionally graded (FG) lattice structures have attracted attention for their potential application in lightweighting and energy absorption. In this study, functionally graded sheet (FGS) structures with primitive (P) and gyroid (G) minimal surfaces were fabricated by selective laser melting (SLM) using Ti-6Al-4V powder. The mechanical properties, deformation behavior, and energy absorption performance of uniform sheet (US) and FGS lattice structures were systematically investigated using compression tests and the finite element method (FEM). The FGS structures were found to eliminate abrupt shear failure and to exhibit the predictable layer-by-layer deformation accompanied by sub-layer collapse. The cumulative energy absorption per unit volume of FGS samples increased as a power of strain function throughout the compression process, while the US samples exhibited a linear relationship, thus resulting in an excellent energy absorption capability for FGS structures. The energy absorption of FGS samples was higher than for US samples by approximately 60%. In addition, the results of FEM with the Johnson–Cook models demonstrated a high capability for predicting the deformation behaviors as well as mechanical properties (especially in terms of yield strength, compressive strength and energy absorption) of lattice structures, which can be used to provide guidance on selecting a lattice structure to meet multifunctional demands.


ABSTRACT: Nodal displacements for two dimensional plate-like lattices under static loading are solved in exact analytical form, when periodic boundary conditions are applied to the top and bottom surfaces of the lattice forming a topological cylinder. Discrete Fourier transform converts the governing equation of static equilibrium into a set of one dimensional wavenumber dependent problems. Characteristic solutions are developed for each Fourier mode of deformation. Inverse discrete Fourier transform converts the wavenumber domain function back to the spatial domain by taking a linear combination of the one dimensional harmonic solutions. As an example, the point force is decomposed into a set of wavenumber dependent loading profiles. A linear combination of the displacement solutions for the individual harmonic loading profiles is sufficient to reproduce the overall displacement solution for the point load. This property holds for any type of the load. Nodal displacements, expressed with analytical dependence on the nodal indices n and m, match the results of commercial finite element analysis software. Overall, this paper demonstrates that the static response of discrete
lattices is equivalently represented as a superposition of the wavenumber domain solutions, which is analogous to frequency domain analysis in acoustic metamaterials and phononics.

Chuanhao Lu (1), Shujuan Hou (1), Zheyi Zhang (1), Junning Chen (2), Qin Li (3) and Xu Han (1)
(1) State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, College of Mechanical and Vehicle Engineering, 410082, Hunan University, Changsha 410082, PR China
(2) Department of Engineering, CEMPS, University of Exeter, EX4 4RN, United Kingdom
(3) School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Sydney, NSW 2006, Australia
ABSTRACT: The natural structures inspires human beings to find a new composite material design for the crashworthiness. The mystery of outstanding crashworthiness of a coconut is revealed in its multilayered and multiscale structure, including the macroscopically organized pericarp and microscopically disordered mesocarp. The pericarp consists of parallel fibers well-aligned in the tangential direction. The fibers of coconut pericarp is macro ordered. The mesocarp is the thickest layer among three layers of the pericarp. The coconut mesocarp is micro disorderly. In this paper, the coconut free drop experiments and quasi-static experiments were carried out, and the theoretical analysis was carried out to explain the natural rule of the coconut fiber arrangement, and finally the numerical computational model was built to validate the theoretical analysis. This work shows that the bottom part of the coconut is the impact point to the ground during the free drop experiments without initial angel. The fiber orientation in the coconut fruit can increase the energy absorption ability, and such a fiber arrangement can influence the propagation of the stress wave to protect the coconut endocarp. A bio-inspired template has been provided for the functionally gradient composite material design.

ABSTRACT: Kirigami-patterned designs through photolithography technology present a promising set of strategy for highly stretchable conductors, which have been investigated to open up a wide range of novel technological solutions for various applications, such as stretchable bioprobes and wearable thermotherapy. The kirigami-patterned conductors usually suffer steady temperature difference and consequent thermal load, because of the Joule heating effect under input voltages. The concealed relationships between thermal effects, geometric effects and mechanical responses are of great significance for practical applications. Here, a closed-form analytical solution, considering the thermal effect and large curvature curved beam theory, is developed to study the stretchability and stiffness for a class of ribbon kirigami structures. Both of finite element method and experiments are performed to validate the accuracy and scalability of model. Comparisons of the developed closed-form stretchability and stiffness to the model with thermal effect absent present quantitative characteristic towards the thermal effect, the remarkable underestimate of stretchability (e.g., >8% relatively) and overestimate of stiffness (e.g., >5% relatively) can be induced by the thermal-effect-absent model for many representative ribbon kirigami patterns. Moreover, several demonstrations present the capability of developed model in optimization of ribbon-kirigami-patterned conductors under the thermal effect and practical geometry constraint conditions, achieving the most stretchable devices. This study provides the theoretical guide for kirigami-based conductor designs in applications.

Xiaojie Gu (1), Jun Wang (1), Guoxing Lu (2), Liao Pan (1) and Lixin Lu (1)
(1) Department of Packaging Engineering, Jiangnan University 1800 Lihu Avenue, Wuxi 214122, Jiangsu, China
(2) Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, John Street, Hawthorn, VIC 3122, Australia
ABSTRACT: The in-plane uniaxial crushing behavior of honeycomb paperboard is studied, and three types of deformation modes, namely no debonding mode, partial debonding mode, complete debonding mode, are identified under uniaxial loading along the y-axis direction. The interaction between face paper and honeycomb core is modeled, and the mutual induce effect between the deformation mode of the core configuration and the face paper was combined with the theory of energy conservation to derive the corresponding plateau stress of the honeycomb paperboard structure. A good consistency is obtained through the comparison of the experimental results and theoretical values. The suggested three models may help to reveal the deformation and energy absorption mechanism of paper honeycomb structures.

Hongyong Jiang (1), Yiru Ren (1), Qiduo Jin (1), Guohua Zhu (2) and Zhihui Liu (3)
(1) College of Mechanical and Vehicle Engineering, Hunan University, Changsha, Hunan 410082, China
(2) School of Automobile, Chang'an University, Xi'an 710064, China
(3) School of Aeronautic Science and Engineering, Beijing University, Beijing 100191, China
ABSTRACT: The light-weight and high-strength design concept enables sandwich composite structures (SCS) to maximize specific strength and specific energy-absorption (SEA). To this end, a horizontal stiffener is designed to reinforce the flexural performances of corrugated core SCS for the first time. To explore preferable reinforcement parameters, several stiffeners with different thicknesses, positions and numbers are designed and studied. The flexural responses of SCS are predicted by finite element simulation. The predicted load responses, damage and deformation of face-sheets and core are consistent with experimental observations. From predicted results, the SCS undergoes several stages including elastic deformation, fracture of face-sheet, initial and stable deformation of core. The core with a stiffener obviously exhibits higher SEA than that without a stiffener. Complex reinforcement mechanisms and coupling deformation between pure core and stiffener are revealed. It is found that the stiffener improves not only the EA of pure core but also the EA of face-sheets, which explains the coupling EA. Structural parameters including thickness, position and number have great effects on flexural performances of SCS. Notably, the lightest SCS with 0.25 mm thickness improves the SEA about 23.83%. The SCS with three stiffeners presents an increase in EA of 92.33% but followed by a great increase in mass. Design recommendations are finally concluded through comprehensive evaluations.

A. Ghazi (1,2), C. Tiago (2), B. Sonon (1), P. Berke (1) and T.J. Massart (1)
(1) Building, Architecture & Town Planning Department (BATir), Université libre de Bruxelles (ULB), CP 194/02, Avenue F.D. Roosevelt 50, Bruxelles 1050, Belgium
(2) CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, Lisboa 1049-001, Portugal
ABSTRACT: This contribution addresses the finite element modelling of closed cell metallic foams using Representative Volume Elements (RVEs) based on shell geometries directly extracted from implicitly defined 3D geometries. 3D RVEs of closed cell foam materials are produced by means of a generation strategy allowing a close morphological control reproducing fine scale geometrical features incorporating cell size, cell wall thickness and cell wall curvature distributions. The strategy is built on three computational ingredients: (i) a random packing algorithm based on random sequential addition assisted by neighbour distance control, (ii) a distance field-based shape tessellation (morphing) that allows incorporating cell wall curvatures and varying cell wall thicknesses and (iii) a close control on the shape of the cells. In order to decrease the computational cost of a full 3D finite element model, an original approach is proposed to produce a shell-based geometry directly from 3D information. Extracting the shell geometry from the implicitly defined 3D geometry based on the zero level of distance fields that would represent the cell walls is computationally impossible. Therefore, a novel robust procedure is proposed using careful cutting operations on distance fields for this purpose. The effect of the different microstructural geometrical features of interest on the average mechanical behaviour of
the foam is investigated using shell-based finite element analyses. The computational cost and the accuracy of the proposed shell models are then assessed by comparing their results to full 3D simulations. The macroscopic behaviour of the generated shell-based model under compressive loading is then assessed up to the densification stage (including contact), and compared qualitatively with experiments from the literature. The macroscopic behaviour of the shell-based model is explained by linking it to cell/wall level deformation mechanisms.

Dong Tang (1,2), Fuzhen Pang (3), Liaoyuan Li (4) and Xiongliang Yao (3)
(1) Jiangsu Key Laboratory of Coast Ocean Resources Development and Environment Security, Hohai University, Nanjing, 210098, China
(2) College of Harbour Coastal and Offshore Engineering, Hohai University, Nanjing, 210098, China
(3) College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China
(4) China Ship Development and Design Center, Wuhan, 430064, China


ABSTRACT: A semi-analytical solution for in-plane free waves analysis of rectangular thin plates with general elastic support boundary conditions (BCs) is developed. Based on the classical thin plate theory, the governing differential equations of the rectangular thin plate are introduced. The semi-analytical solution is obtained by superposition of in-plane waves of different patterns and different propagation directions. And it is validated by comparisons of the present results with those given in literatures. Eigensolutions for general BCs and the specific expressions of characteristic equations for various classical BCs are demonstrated. Characteristic curves of the dimensionless wavenumbers of the in-plane longitudinal wave and the in-plane shear wave of the rectangular thin plate with various BCs are presented and discussed. Perfect orthogonality of the in-plane longitudinal wave and the in-plane shear wave of different mode numbers is presented in the characteristic curves of the rectangular thin plate with two opposite sides simply supported. The characteristic curves corresponding to the rest of the classical BCs and all of the non-classical BCs show non-orthogonality of different extents, which reveals the formation mechanism of the variety of the mode shapes of the rectangular thin plate with various BCs. The strengthening and weakening process of the orthogonality and the formation of the intertwining or independence of the characteristic curves of different mode numbers are elaborated through analysis on elastic support BCs intermediate between two classical BCs, which shows the influence of the BCs on the intrinsic characteristics of in-plane waves of the rectangular thin plate.


ABSTRACT: This paper proposes analytical solutions for highly accurate and efficient buckling or wrinkling analysis of rectangular orthotropic plates that are fully clamped, completely guided and completely simply supported. Firstly, the exact general solution of the buckling differential equation of a fully clamped orthotropic rectangular plate is derived by using a one-dimensional modified Fourier series. After symbolic manipulations, a spectral flexibility matrix relating the coefficients of boundary shear forces and boundary transverse displacements is formulated. Then, a generalized version of Wittrick-Williams algorithm is applied directly to the spectral flexibility matrix to compute the critical buckling load parameters, which is demonstrated to be extremely accurate and efficient. In addition, the dependence of critical buckling load parameters on plate aspect ratio, orthotropy ratio, inplane load combination and boundary conditions is investigated comprehensively. Another novelty of this paper lies in that our investigation on the plate reveals two completely different types of buckling modes: a long-wavelength buckling mode and a short-wavelength wrinkling mode. In particular, the short-wavelength modes of a fully clamped plate appear an interference pattern similar to the ‘beat’ phenomenon in acoustics, for which insights on their occurrence and influence factors are gained from both physical and mathematical aspects.

Si-Qin Ye (1), Xiao-Ye Mao (1), Hu Ding (1), Jin-Chen Ji (2) and Li-Qun Chen (1)
(1) Shanghai Institute of Applied Mathematics and Mechanics, Shanghai University, Shanghai 200072, China
(2) School of Mechanical and Mechatronic Engineering, FEIT, University of Technology Sydney, PO Box 123, Broadway, New South Wales 2007, Australia
ABSTRACT: The existing studies of nonlinear vibration of elastic structures are usually focused on straight structures with homogeneous linear boundaries. Differently, this paper investigates the nonlinear transverse vibrations of a slightly curved beam with nonlinear boundary conditions. By using the generalized Hamilton's principle, the governing equation with geometric nonlinearity is obtained for the dynamics of the curved beam. A method of dealing with nonlinear boundaries is proposed, which is considered as a nonlinear concentrated force at the boundary. The normal modes and natural frequencies of the curved beam are determined using two different hypothetical modes based on the derived system. The harmonic balance method in combination with the pseudo arc-length method is employed to obtain the primary resonance response and 1/2 super-harmonic resonance response of the slightly curved beam. It is found that the initial curvature plays a significant role in the characteristics of the nonlinear vibrations of the curved beam. With an increase of the initial curvature, the nonlinear characteristics of softening and hardening types can coexist in the steady-state amplitude-frequency response. Moreover, the results show that the initial curvature can induce 1/2 super-harmonic resonance. Furthermore, it is also found that the nonlinear boundary has a significant influence on the nonlinear vibration of the curved structure. Therefore, the obtained results provide useful information for further studying the nonlinear vibrations of the curved beam with nonlinear and time-dependent boundary conditions.

Hamed Farokhi (1) and Mergen H. Ghayesh (2)
(1) Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne NE1 8ST, UK
(2) School of Mechanical Engineering, University of Adelaide, South Australia 5005, Australia
ABSTRACT: This paper examines the extremely large nonlinear vibrations of a cantilever subject to base excitation in primary and secondary resonance regions for the first time. To predict extremely large vibration amplitudes accurately, a geometrically exact continuous model of the cantilever is developed for the centreline rotation of the cantilever; the proposed model's accuracy is verified for extremely large deformations through comparison to a nonlinear finite element model. The theory of Euler-Bernoulli, along with inextensibility assumption, and the Kelvin-Voigt material damping model are utilised to develop the geometrically exact model. The main feature of the geometrically exact model is that all nonlinear trigonometric terms in the model are kept intact before and after the discretisation process, which itself is performed utilising the Galerkin scheme. The numerical results show that the cantilever undergoes extremely large oscillations even at relatively small base excitation amplitudes. It is shown that for some cases the amplitude of the tip of the cantilever grows so large that it “bends backward”; a behaviour which can only be captured using the proposed geometrically exact model.

ABSTRACT: Curvilinearly stiffened plates can have superior mechanical properties than traditional straight-line stiffened plates. To avoid the shear locking problem in the modeling of stiffened thick plates by Reissner-Mindlin theory when the thickness of plate decrease, discrete shear triangle element was introduced by employing the discrete shear constraints on each side. The discrete shear triangle element is employed for the plate and the Timoshenko beam theory is employed for the curvilinearly stiffeners, respectively. The FE equations are established through displacement interpolation function of plate and the displacement compatibility conditions at the plate-stiffened interfaces. The plate and stiffener are modeled separately in the present method, which allows the nodes of stiffener element not coincide with nodes of the plate's shell-element. Based on the newly proposed modeling technique, the statics, vibration and buckling behavior of curvilinearly stiffened plates are investigated. Numerical and experimental investigations are conducted to
verify the mechanical properties of proposed model for stiffened plates. Results from the proposed method show good agreements with the numerical and experimental results. The present method can conduct static and dynamic analysis for both stiffened thick and thin plates and guarantee the accuracy of calculation with less number of elements.

Xueyan Chen (1, 2), Qingxiang Ji (1, 2), Jianzheng Wei (1), Huifeng Tan (1), Jianxin Yu (1), Pengfei Zhang (1), Vincent Laude (2) and Muamer Kadic (2)
(1) National Key Laboratory of Science and Technology on Advanced Composites in Special Environments, Harbin Institute of Technology 92 Xidazhi Street, Harbin, 150001, PR China
(2) Institut FEMTO-ST, CNRS, Université Bourgogne Franche-Comté, Besançon 25030, France
ABSTRACT: Absorbing mechanical shocks and vibration energy is crucial in industrial, domestic and medical applications. Very often, systems (such as hydraulic cylinders) or structures (such as helmets) are used to achieve energy absorption or protection from impacts or periodic vibrations. In this respect, mechanical metamaterials have received much attention in recent years due to their extraordinary mechanical properties, including outstanding specific stiffness and strength, and energy absorption. Here, we design a stretching-dominated mechanical metamaterial that can absorb very large energies while retaining a low density. In this study, a few examples of metamaterials are considered and we show that a new class of shell lattice (SL) metamaterials has the best mechanical properties for shock absorption they are ultr stiff, ultrastrong, and possess high specific energy absorption at low relative density.

Mingfei Chen (1), Tiangui Ye (1), Jianhua Zhang (2), Guoyong Jin (1), Yantao Xhang (1), Yaqiang Xue (1), Xianglong Ma (3) and Zhigang Liu (1)
(1) College of Power and Energy Engineering, Harbin Engineering University, Harbin 150001, PR China
(2) College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin, PR China
(3) Shanghai Marine Equipment Research Institute, Shanghai 200031, PR China
ABSTRACT: In this paper, the vibration behaviors of variable thickness parallelogram plates with in-plane functionally graded porous materials are investigated by a numerical approach for the first time. The unknown fields and geometry of the in-plane functionally graded porous variable thickness parallelogram plates are established numerically by non-uniform rational B–splines functions under the framework of isogeometric analysis with three-dimensional theory. The porosities of parallelogram plates are assumed to be distributed continually along the in-plane direction with different distribution modes. The weak form requirements with three-dimensional theory can be satisfied by the formulation easily. Fast convergence and good accuracy are demonstrated in several numerical examples. Additionally, some innovative results and parameter effects are carried out in the text. This work can shed some new light on the investigation of complex three-dimensional vibration behavior of in-plane functionally graded porous variable thickness parallelogram plates.

Siham Mittelstedt (1) and Christian Mittelstedt (2)
(1) SOGETI Deutschland GmbH, Hein-Sass-Weg 30, D-21129 Hamburg, Germany
(2) Technische Universität Darmstadt, Department of Mechanical Engineering, Institute for Lightweight Construction and Design, D-64287-Darmstadt, Germany
ABSTRACT: This paper presents a novel semi-analytical approach for the determination of the local buckling loads of moderately thick-walled composite laminated doubly-symmetric I-beams under uniaxial compression. The composite laminates that make up the flanges and webs of the I-beam are assumed to exhibit symmetric orthotropic layups and are further assumed to be moderately thick so that a higher order laminate theory, namely Reddy’s Third Order Shear Deformation Theory, is employed. Contrary to the commonly used approach of discrete plate analysis for local beam buckling calculations, i.e. the separate consideration of flanges and webs, the analysis method that is presented in this paper considers the interaction between webs and flanges by
using series expansions for all buckling degrees of freedom and a subsequent assembly by employing adequate continuity conditions at those locations where adjacent segments of the cross-sections intersect. Such a coupled analysis will be called mixed-mode buckling in the course of this paper. The current analysis method uses the Ritz method in conjunction with the principle of minimum elastic potential of the buckled beam, and it will be shown that the method converges rapidly with a very low number of shape functions in the employed series expansions so that it works with superior numerical efficiency when compared to full-scale finite element computations, however with a comparable results accuracy which makes the present approach especially attractive for any practical application purpose where the local buckling behavior of moderately thick-walled composite laminated beams needs to be considered.

Zhaoye Qin (1,3), Shengnan Zhao (1), Xuejia Pang (2), Babak Safaei (4) and Fulei Chu (1)
(1) State Key Laboratory of Tribology, Department of Mechanical Engineering, Tsinghua University, Beijing, China
(2) The 703 Research Institute of CSIC, Harbin, Heilongjiang, China
(3) Key Laboratory of Vibration and Control of Aero-Propulsion System Ministry of Education, Northeastern University, Shenyang, Liaoning, China
(4) Department of Mechanical Engineering, Eastern Mediterranean University, G. Magosa, TRNC Mersin 10, Turkey


ABSTRACT: In this paper, a unified method is developed to analyze free vibrations of laminated functionally graded shallow shells reinforced by graphene platelets (GPLs) under arbitrary boundary conditions is proposed. General equations are obtained by the first-order shear deformation theory (FSDT) together with artificial spring technique. By adopting orthogonal polynomials via a Gram–Schmidt process to expand shell displacement fields, Rayleigh–Ritz method is applied in deriving the equations of motion for functionally graded GPL reinforced composite (FG-GPLRC) shallow shells. The accuracy of proposed method is verified through comparing the present results with those from literature. Free vibration behaviors of FG-GPLRC shallow shells are studied. The effects of boundary conditions, GPL weight fractions, layer number, and geometric parameters on natural frequencies are investigated. Parametric studies show that variation trends of the natural frequencies of FG-GPLRC shallow shells along with GPL layer number, weight fraction, and geometric properties are similar under different boundary conditions in most cases. However, the frequency values and variation rates are highly dependent on the stiffness values of boundary springs.

Yang Xu (1), Tiejun Yang (1), Christopher R Fuller (2), Yao Sun (3) and Zhigang Liu (1)
(1) College of Power and Energy Engineering, Harbin Engineering University, Harbin 150001, PR China
(2) Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Virginia 240601, United States
(3) College of Energy and Power Engineering, Jiangsu University of Science and Technology, Zhenjiang 212000, PR China


ABSTRACT: An analytical description of active structural acoustical control of vibration isolation with a plate-shell coupled foundation is presented. The vibration isolation system is composed of a two-stage isolation and a flexible supporting plate coupled with an elastic cylindrical shell, which are connected via passive-active mounts. The model of the flexible foundation is derived based on the Spectro-Geometric Method (SGM) in which the displacements of the plate and shell are expressed as a modified Fourier series expansion. The response of the whole structure is available obtained by the Flexible Foundation Rigid Equipment (FFRE) modeling method. Different feed-forward control strategies are applied and their corresponding optimal control forces are calculated, including: (a) Minimizing the acoustic power radiated from the coupled structure, (b) Minimizing the sum of the square velocity of the isolators on the supporting plate, and (c) Minimizing the input power. Numerical results are presented and discussed. The performances of all feed-forward control strategies
are evaluated and compared in terms of the acoustic radiation power, transmission power flow, control force amplitudes and sound pressure directivity. The effects of location of the actuators are also discussed.

Nikhil Garg (1), Nilanjan Das Chakladar (2), B. Gangadhara Prusty (1), Chongmin Song (3) and Andrew W. Phillips (4)

(1) ARC Training Centre for Automated Manufacture of Advanced Composites (AMAC), School of Mechanical and Manufacturing Engineering, UNSW Sydney, Desk No. 12, Room 208, J-17, Ainsworth Building, Sydney 2033, Australia
(2) Department of Mechanical Engineering, Indian Institute of Technology Kharagpur, Kharagpur 721302, India
(3) School of Civil and Environmental Engineering, UNSW Sydney, Sydney, Australia
(4) Maritime Division, Defence Science and Technology Group (DST Group), Melbourne, Australia


ABSTRACT: Scaled Boundary Finite Element Method (SBFEM), a relatively new approach, is investigated for the analysis of the weakly bonded laminated composite plates, under cylindrical bending. A plane strain formulation, which does not require any assumptions on the displacement or stress field, is developed. The interface between two plies is simulated using a linear spring layer model and incorporated in the numerical modelling with the help of zero thickness interface elements. The model is coded and postprocessed in MATLAB to capture general delamination, i.e. separation of the plies at interfaces in both tangential and normal direction. Due to the semi-analytical solution procedure of SBFEM, the model provides highly accurate results. Use of SBFEM reduces the meshing burden and complexities in the discretisation. Moreover, the method can handle hanging nodes, so one can use small interface elements without decreasing the size of adjoining domains. These qualities make the proposed numerical model computationally cheaper as well as very accurate. The presented formulation is demonstrated for a variety of examples in laminated composites including unidirectional laminates, symmetric cross ply laminates and antisymmetric cross ply laminates. The proposed model's close agreement as well as its superiority over the other methods is established for future reference.

L.T. Kibriya (1), C. Málaga-Chuquitaype (1) and M.M. Kashani (2)
(1) Department of Civil and Environmental Engineering, Imperial College London, London, SW7 2AZ United Kingdom
(2) Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, SO17 1BJ United Kingdom


ABSTRACT: Post-tensioned rocking frames have been proposed as damage-free seismic-resistant structures. However, currently available load resisting systems for rocking frames rely on sacrificial yielding components that accumulate damage during strong dynamic action. To address this shortcoming, this study proposes a novel thoroughly damage-avoidance solution by means of bracing elements with carefully controlled buckling behaviour. To this end, a proof-of-concept study is presented, whereby the elastic buckling response of buckling-enabled composite bracing (BECB) elements with circular-arc shaped cross-section is numerically investigated. Varying geometric properties are considered and validated against analytical approximations. Besides, a finite element study of a single-storey steel post-tensioned frame under static and dynamic actions is performed. The case study incorporates BECB elements made from glass-fibre reinforced polymer (GFRP). It is demonstrated that BECB enhances the non-linear static and dynamic response of rocking frames by providing stability and significantly reducing storey drifts and accelerations without accumulating damage.

ABSTRACT: In this numerical study by means of finite element modeling, the concept of hierarchy is considered by employing two series of small tubes placed next to each other (Fully packed, HCT) circular tubes for a configuration with optimum energy absorption. Hierarchical circular tubes (HCTs) are constructed by replacing the wall of an initially single-cell circular tube (SCT) with a series of small tubes placed next to each other (Fully packed, HCT-F) or at a distance apart (partially packed, HCT-P); the total net cross-sectional area and hence the mass is kept the same. The behavior of these new classes of hierarchical tubes under axial crushing is investigated in terms of deformation modes, crushing forces and energy absorption. Two deformation modes are identified and they have different crushing behavior of the HCTs. The initial peak force (PF) remains almost constant after micro-cell tubes are hierarchically introduced, but the mean crushing force (MCF) and hence the specific energy absorption (SEA) can be significantly


ABSTRACT: In this paper, vibration and buckling of two-phase nanobeams embedded in size dependent elastic medium and under thermal load are analyzed. Due to paradoxes of common differential nonlocal elasticity, such as neglecting the size effect of uniform loads, failure to satisfy the constitutive boundary conditions, associated to transformation of integral nonlocal equation to differential one, and incompatibility between the results of differential nonlocal with those of integral nonlocal, the size dependent effects of nanobeam, elastic medium and thermal load are taken into account simultaneously by using two-phase local/nonlocal Eringen's elasticity, for the first time. Governing equations and corresponding boundary conditions are derived using Hamilton's principle. To obtain natural vibration frequencies as well as critical buckling temperature, three different methods of solution are presented, i.e. exact solution, Generalized Differential Quadrature Method (GDQM) and Finite Element Method (FEM) which is based on the integral form of two-phase elasticity. Several comparison studies are conducted to examine the validity of the present formulation and results. The effects of applying two-phase elasticity on elastic medium and thermal load in vibration and buckling of nanobeams with different boundary conditions are investigated in details. Differences appeared in present results, especially in the cases with higher temperature and nonlocality as well as stiffer elastic medium, reveal that the size dependency of elastic medium and uniform thermal load, which is neglected by differential nonlocal, must be considered by employing two-phase elasticity.

Dahai Zhang (1,2), Guoxing Lu (2), Dong Ruan (2) and Qingguo Fei (1)
(1) Institute of Aerospace Machinery and Dynamics, Southeast University, Nanjing 211189, China
(2) Faculty of Science, Engineering and Technology, Swinburne University of Technology, John Street, Hawthorn, VIC 3122, Australia


ABSTRACT: In this numerical study by means of finite element modeling, the concept of hierarchy is incorporated into thin-walled circular tubes for a configuration with optimum energy absorption. Hierarchical circular tubes (HCTs) are constructed by replacing the wall of an initially single-cell circular tube (SCT) with a series of small tubes placed next to each other (Fully packed, HCT-F) or at a distance apart (partially packed, HCT-P); the total net cross-sectional area and hence the mass is kept the same. The behavior of these new classes of hierarchical tubes under axial crushing is investigated in terms of deformation modes, crushing forces and energy absorption. Two deformation modes are identified and they have different crushing behavior of the HCTs. The initial peak force (PF) remains almost constant after micro-cell tubes are hierarchically introduced, but the mean crushing force (MCF) and hence the specific energy absorption (SEA) can be significantly
improved by choosing suitable configurations. It is also demonstrated that partial hierarchy performs better in enhancing the crushing performance of the tubes compared with the full hierarchy.


ABSTRACT: Node-dependent Kinematic (NDK) shell finite element (FE) formulations are presented for the steady-state thermo-mechanical analysis of laminated structures. The displacements and temperature change are treated as primary variables in the FE models and are directly solved through the coupled thermo-mechanical models. The enforcement of distributed temperature boundary conditions on the top or the bottom surface of hierarchical shell elements is conducted through the Linear Least Squares. The effectiveness of the proposed FE approaches is verified by comparing the results against those from the literature. The application of adaptive refinement approach based on the hierarchical elements and NDK to build FE models with optimal efficiency is demonstrated through numerical examples.

Zhen Wang (1), Xihong Jin (2), Qing Li (3) and Guangyong Sun (1,3)
(1) State Key Laboratory of Advanced Design and Manufacture for Vehicle Body, Hunan University, Changsha, 410082, China
(2) CRRC Zhuzhou Locomotive Co., Ltd., Zhuzhou, 412001, China
(3) School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Sydney, NSW 2006, Australia


ABSTRACT: As a class of promising cost-effective lightweight structures, metal-composite hybrid structures has rapidly emerged in automotive industry largely attributable to their outstanding multifunctional and crashworthy characteristics. Recently, continuous efforts have been devoted to the studies on the crashworthiness of various hybrid tubes, which commonly present two typical configurational schemes, namely metal-composite (i.e. a metal outer tube internally filled with an inner carbon fiber reinforced plastic (CFRP) tube) and composite-metal (i.e. an outer composite tube internally filled with an inner metal tube). Nevertheless, rather limited studies have focused on revealing energy absorption mechanisms of hybrid structures; and how to optimize the performance to cost characteristics of hybrid structures still remains an open question in literature to date. This study aimed to maximize the energy absorption of different configurational aluminum/CFRP hybrid tubes. First, the finite element (FE) models were developed and validated by comparing the damage modes and crashworthiness indicators with the dedicated experimental study. Second, the interactive effects of the hybrid tubes were investigated by analyzing the discrepancies in the deformation pattern and internal energy absorption of each material through the validated FE models. For the AL-CF configuration (i.e. CFRP inner tube with aluminum outer tube), changes of deformation mode increased the internal energies of aluminum and CFRP tubes by 43.6% and 17.8% compared to the net aluminum tube and net CFRP tube, respectively; and increased the frictional dissipation energy by 45.6% compared to the sum of that of net aluminum and net CFRP tubes, largely enhancing energy absorption of AL-CF. For the CF-AL configuration (i.e. aluminum inner tube with CFRP outer tube), the internal energy increased by 27.6% for the aluminum tube but decreased 31.9% for the CFRP tube compared to the net aluminum tube and net CFRP tube, respectively; whereas the frictional dissipation energy decreased by 47.6% compared to the sum of that of net aluminum and CFRP tubes, indicating the vital importance of hybrid configuration to energy absorption. Third, the effects of wall thickness, sectional dimension and sectional shape on the energy absorption capacity as well as the performance-cost characteristics of the hybrid tubes were further studied. It was found that from a performance perspective, the hybrid tube with a thicker CFRP tube had higher capacity of energy absorption; whilst from a performance to cost perspective, the hybrid tube with a thinner aluminum tube offered better cost-effective energy absorption characteristics. Moreover, with the same weight, the hybrid tube with a circular sectional shape and a smaller sectional size exhibit a better performance. Finally, a multiobjective discrete optimization was conducted to optimize the AL-CF hybrid tube with various sectional shapes, sizes and wall thicknesses. As a result, the weight, peak crush force (PCF) and cost were finally reduced by 41.3%, 18.0% and 11.2% respectively, while the energy absorption (EA) was enhanced by 48.0% in comparison with the baseline design.

ABSTRACT: Constitutive equations are developed for the elastic behavior of polymer foams under three-dimensional deformations with finite strains. These relations provide an extension of the Danielsson–Parks–Boyce model for a compressible material matrix in a representative volume element, whose volumetric deformation is governed by the specific work of external forces. The mechanical response of foams is described by the governing equations with four adjustable parameters. Two of them are material constants independent of porosity $\phi$. The other two coefficients are functions of $\phi$, for which simple equations are suggested. The model is applied to the analysis of observations on an extensive number of foams. Good agreement is demonstrated between results of simulation and experimental data in uniaxial tensile tests, compressive tests, and tension-compression tests. Predictions of the model for mechanically induced evolution of the microstructure of foams are in accord with available observations.


ABSTRACT: Due to the excellent mechanical and chemical properties at ultra-high temperature, ceramic matrix composite structures have potential applications for thermal protection systems of hypersonic vehicles. This paper presented a PIP method to fabricate C/SiC pyramidal lattice core sandwich panels (LCSPs). Their bending behaviors with different core angles were experimentally studied firstly. Then the critical failure loads of different failure modes, including facesheet crushing or wrinkling, core member crushing, core shear failure and interlayer delamination, were theoretically established to construct the failure mechanism maps. The influence of geometric parameters, such as the length and the core angle of the core strut, and the thickness of the facesheet, on the failure mode was also analyzed. In addition, further failure process under bending load was investigated by finite element analysis (FEA) method. Elastic-damage constitutive model and cohesive element were applied to modeling the behavior of C/SiC composite and interlayer delamination between the sheet of the core and the facesheet. Theoretical and FEA results agreed well with experimental data. This work is believed to be helpful to understand the bending mechanism C/SiC pyramidal LCSPs.

Wei Tian (1,2), Yueming Li (1), Zhichun Yang (3), Ping Li (2) and Tian Zhao (2)
(1) Strength and Vibration of Mechanical Structures, Shaanxi Key Laboratory of Environment and Control for Flight Vehicle, School of Aerospace, Xi'an Jiaotong University, Xi'an, China
(2) Mechanics and Environment Research Center, Xi'an Aerospace Propulsion Institute, Xi'an, China
(3) School of Aeronautics, Northwestern Polytechnical University, Xi'an, China

ABSTRACT: A nonlinear energy sink (NES) enhanced by a giant magnetostrictive material (GMM) energy harvester is proposed to suppress the nonlinear aeroelastic responses of a cantilevered trapezoidal plate in hypersonic airflow. An analytical model of a cantilevered trapezoidal plate coupled to the NES-GMM system is obtained by applying the Rayleigh-Ritz approach and the affine transformation. Nonlinear aerodynamic loadings are obtained by applying the third-order piston theory. Comparisons of the dynamic bifurcation behaviors exhibited by plates with only the NES and by those with NES-GMM show that the latter has a better suppression effect. Using an energy-based analysis approach, the energy transfer mechanism between the plate and the NES-GMM system is examined. Numerical results show that the aeroelastic responses of the plate can be controlled substantially by the targeted energy transfer of the NES in the post-flutter regime. Some of the captured energy can be converted into magnetic energy by the Villari effect and then transformed into electric energy. Furthermore, a parametric design strategy is proposed to improve the nonlinear aeroelastic response suppression and enhance the performance of the NES-GMM. Numerical results indicate that the installation position, mass,
damping, and nonlinear stiffness coefficients of the NES-GMM system significantly affect its suppression performance. This parametric design strategy can achieve the desired objectives of nonlinear aeroelastic response suppression.


ABSTRACT: Variable mass structures exhibit non-stationary characteristics and the corresponding time-varying (TV) dynamics are difficult to represent by explicit dynamic equations or finite element models via mechanism analysis. Operational modal analysis of variable mass structures based on vector response measurements is considered in this paper. In order to solve the practical problem of operational modal analysis for variable mass structures, univariate stochastic parameter evolution (SPE) methods are extended to the multivariate case and validated by a numerical varying mass system. Thereafter, a laboratory liquid-filled cylindrical structure with decreasing filling mass is built and analyzed by using the conventional “frozen-configuration” technique and non-parametric time-frequency analysis method. Finally, the multivariate SPE method is applied to identify the liquid-filled cylindrical structure with decreasing filling mass, and identification results demonstrate that the proposed method is able to obtain the TV dynamic characteristics of variable mass structures under operating conditions by only using the available vector response measurements.


ABSTRACT: Thin-walled metal tubes are the most widely used energy-absorption structures in various industries. Bionics can help engineers to design novel tubular structures to achieve outstanding crashworthiness performance. Inspired by the unique microstructure of a horse-hoof-wall and the concept of vertex-based hierarchy, a novel bio-inspired corrugated tube and its derivative structures with varying vertex configurations were proposed in this paper. Quasi-static compression test and finite element simulation were employed to investigate the mechanical behaviors of these bio-inspired tubes. The results showed that these bio-inspired tubes exhibit good crashworthiness performance, especially in terms of their weight force efficiencies. Moreover, by applying a complex proportional assessment method, the tube with regular octagon vertex configuration was selected as the optimum one among these bio-inspired tubes. A theoretical model was developed to predict the mean crushing force of the proposed tubes. In conclusion, the horse-hoof-wall inspired tubes exhibit a novel perspective on providing superior mechanical properties and pave a way of applications of bio-inspired engineering structures.

Wooram Kim (1) and J.N. Reddy (2)
(1) Department of Mechanical Engineering, Korea Army Academy at Yeongcheon, Yeongcheon-si, Gyeongsangbuk-do 38900, Republic of Korea
(2) J. Mike Walker 66 Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843-3123, USA


ABSTRACT: In this study, four sets of novel and enhanced two-stage explicit time integration schemes are developed based on a unified set of unconventional approximations. For the development of explicit schemes, truncated Taylor’s series expansions of the displacement and velocity vectors are used with adjustable algorithmic parameters. Four different sets of algorithmic parameters are proposed to achieve enhanced accuracy and stability of the proposed schemes. Among the four novel schemes, two schemes can adjust a full range of numerical dissipation through one of the algorithmic parameters, and the other two schemes have noticeably increased accuracies. Three of the new schemes have much smaller period errors than those of any existing time-integration schemes. Various linear and nonlinear test problems are solved by using the proposed

https://doi.org/10.1016/j.ijmecsci.2020.105420

https://doi.org/10.1016/j.ijmecsci.2019.105399

https://doi.org/10.1016/j.ijmecsci.2020.105429
and existing two-stage schemes, and numerical results are compared to illustrate improved performances of the proposed schemes.

Qiang Gao (1), Wei-Hsin Liao (1) and Liangmo Wang (2)  
(1) Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Shatin, Hong Kong, China  
(2) Department of Automotive Engineering, School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, Jiangsu, China  
“An analytical model of cylindrical double-arrowed honeycomb with negative Poisson's ratio”, International Journal of Mechanical Sciences, Vol. 173, Article 105400, 1 May 2020,  
https://doi.org/10.1016/j.ijmecsci.2019.105400  
ABSTRACT: Auxetic structures with negative Poisson's ratio have been widely studied due to their unique mechanical properties. In this paper, a novel auxetic cylindrical double-arrowed honeycomb (DAH) is proposed. First, an analytical model to predict the elastic mechanical properties of DAH structure in the longitudinal and circumferential directions is developed utilizing the Euler-Bernoulli beam theory. Then, the finite element models are utilized to verify the analytical method. However, the results show that the analytical model cannot accurately predict the elastic mechanical properties when the radial width is large. Furthermore, the analytical model is revised to predict elastic properties considering the effect of the radial width. The effect of the geometric parameters on the elastic properties is also investigated. The quasi-static compression experiments of ABS auxetic DAH prototypes are conducted to validate the revised analytical models. It is observed that the revised analytical model can accurately predict the elastic mechanical properties of DAH structures.

Hyeonil Park (1), Se-Jong Kim (1), Jinwoo Lee (1), Ji Hoon Kim (2) and Daeyong Kim (1)  
(1) Materials Deformation Department, Korea Institute of Materials Science, 797 Changwondaero, Changwon, Gyeongnam 515508, Republic of Korea  
(2) School of Mechanical Engineering, Pusan National University, 2 Busandaehak-ro 63beon-gil, Busan 609-735, Republic of Korea  
“Delamination behavior analysis of steel/polymer/steel high-strength laminated sheets in a V-die bending test”, International Journal of Mechanical Sciences, Vol. 173, Article 105430, 1 May 2020,  
https://doi.org/10.1016/j.ijmecsci.2020.105430  
ABSTRACT: Steel/polymer/steel laminated sheets were fabricated by inserting three types of adhesive layers between two 590-MPa grade high-strength steel sheets. V-die bending tests of the laminated sheets were conducted and the results showed that the delamination behaviors depended on the inserted adhesive type. To investigate the mechanical behaviors of the adhesive layers, delamination tests for each adhesive layer along normal and shear directions were performed. Based on the results of the delamination tests, an inverse parameter characterization using an iterative finite element simulation with interface elements was successfully conducted to characterize the cohesive properties for mixed-mode bilinear cohesive zone model that clearly described the measured load–displacement curves. The results of the V-die bending tests were predicted through simulations using the characterized cohesive properties; the delamination patterns, punch force drop, and entire level of punch force agreed well with the experimental results. Delamination mechanisms were deduced based on parametric studies conducted to elucidate the direct effect of cohesive properties on delamination.

Kai Zhou, Zhen Ni, Xiuchang Huang and Hongxing Hua (Institute of Vibration, Shock and Noise, Mechanical System and Vibration, Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai Jiao Tong University, Dongchuan Road 800, Shanghai, 200240, China)  
“Stationary/nonstationary stochastic response analysis of composite laminated plates with aerodynamic and thermal loads”, International Journal of Mechanical Sciences, Vol. 173, Article 105461, 1 May 2020,  
https://doi.org/10.1016/j.ijmecsci.2020.105461  
ABSTRACT: This paper investigates the stationary/nonstationary stochastic responses of composite laminated plates under thermal and aerodynamic loads, where the point random excitation, distributed random excitation and base acceleration random excitation can be considered. The effects of the thermal stress and aerodynamic pressure are taken into account by employing the thermo-elastic theory and supersonic piston theory, respectively. The Hamilton's principle is used to formulate the governing equations of the system, and the
solutions for the dynamic problems of cases having classical and non-classical (elastic) boundary conditions are obtained by the modified Fourier method combined with pseudo excitation method (PEM). To validate the proposed formulation, a sufficient number of numerical and experimental studies are conducted for the free vibration, flutter and stochastic response analysis of composite laminated plates with various boundary conditions. Satisfactory agreements are shown between the computed results and those from the finite element method (FEM), published literature and experiments. Finally, the effect of boundary condition, thermal load, fiber orientation and aerodynamic pressure on the random vibration behaviors of composite laminated plates is also presented.

Yuanlong Wang (1), Yi Yu (1), Chunyan Wang (1), Guan Zhou (1), Aminreza Karamoozian (2) and Wanzhong Zhao (1)
(1) College of Energy and Power Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu, People’s Republic of China
(2) School of Automotive and Traffic Engineering, Jiangsu University, Zhenjiang, Jiangsu, People’s Republic of China

ABSTRACT: Ballistic penetration is a serious threat to military vehicles. Honeycomb structure is one of the most focused solution to improve the ballistic performance due to its great lightweight design and high resistant against impact. There are lots of honeycomb structure topologies. However, no comprehensive comparison on out-of-plane ballistic performance between common honeycomb types had been conducted to our knowledge. Therefore, hexagonal, reentrant, square, triangle and two circular (CS and CH types) honeycomb structures with identical mass and thickness are developed and modelled in this paper. Their relative densities are firstly calculated. Their numerical models and the Lambert-Jonas ballistic model are established. The ballistic performances of these six cases impacted by a blunt nose cylinder projectile from out-of-plane direction are detailed compared through numerical method. Their dynamic response, elastic and plastic deformation, failure mechanism and energy absorption capability are researched. Relations between initial velocity and residual velocity of projectile and the ballistic limit velocities of all cases are also compared. The results indicated that reentrant, square and triangular cases perform worse than hexagonal honeycomb. The fascinating deformation mechanism of CS and CH cases results in a long elastic deformation time and high strength after elastic deformation, which leads to a large decrease in residual velocity. Compared with hexagonal honeycomb, ballistic limit velocities of CS and CH type are improved by 15.2% and 25.0%, respectively. This comparison research provides a useful reference for sandwich honeycomb core design.


ABSTRACT: An analytical method is proposed using the large-deflection theory of thin plates to determine the in-plane impact-induced dynamic elastic buckling behaviour of rectangular transversally isotropic stiffened plates with all edges elastically restrained against rotation. Displacement functions expressed by Navier's double Fourier series satisfy both the elastic boundary conditions and the governing equations of motion. First, the dynamic responses of a rectangular simple-supported plate and a stiffened plate predicted by the present method are compared to those available from literature and finite element results, and good agreement of the results demonstrate the effectiveness of the method. Next, parametric studies are performed in which the effects of rotational restraint stiffness, initial imperfection and impact duration on the dynamic deflection as well as the critical buckling load of the stiffened plates are investigated. The results show that rotational restraint stiffness has a significant impact on the dynamic elastic buckling behaviour of the stiffened plate under in-plane impact loading and thus cannot be neglected.

Beytullah Temel and Ahmad Reshad Noori (Department of Civil Engineering, Çukurova University, Turkey). “A unified solution for the vibration analysis of two-directional functionally graded axisymmetric Mindlin–

ABSTRACT: Full-scale modeling and nonlinear FEA are presented for large amplitude vibration of sandwich plates with functionally graded (FG) auxetic 3D lattice core. For the first time, auxetic 3D lattice metamaterials with FG configurations along the out-of-plane direction are designed, of which the fundamental vibration frequencies are analyzed and verified by experiments using 3D printed specimens. Both results suggested that the effects of FG configurations and strut incline angles are significant, and the FG-X specimen possesses the highest fundamental frequency. Subsequently, by means of full-scale nonlinear FE simulations, the large amplitude vibration characteristics are investigated for the sandwich plates, in which the novel construction of auxetic 3D lattice core with three FG configurations along the thickness direction is proposed. And the constituent material properties are taken to be temperature-dependent. Results revealed that FG configurations have distinct effect on the natural frequencies, nonlinear-to-linear frequency ratios of sandwich plates, along with EPR-amplitude curves, which will become stable when the vibration amplitude is sufficiently large.


ABSTRACT: A method of combining surface texturing with longitudinal or transverse micro-vibration was proposed to further enhance the tribological performance of mechanical components. The influences of vibration parameters and micro-dimple geometrical parameter on the tribological performance were studied to verify the feasibility of tribology enhancement by numerical and experimental methods. Results show that the friction coefficients can be significantly reduced by superimposing longitudinal or transverse vibration on the textured surfaces under different lubrication conditions. The friction coefficient slightly increases with the increase of vibration frequency and significantly diminishes with the increase of vibration velocity amplitude. The improvement of lubrication condition is the main mechanism of friction reduction. Since the vibrations can enhance the average load capacity of the textured surface and drag out the lubricant reserved in the micro-dimples, in turn, enlarge the thickness of lubricant film. These results provide a novel perspective to reduce friction and save energy in mechanical systems and metal processing.

ABSTRACT: The instability of beam-columns with crossarms and externally prestressed cable stays is studied analytically, where the combination of bending and compression is assumed to be derived from the system self-weight acting orthogonally to the applied axial load. A nonlinear analytical model for prestressed stayed beam-columns with doubly-symmetric and mono-symmetric configurations, based on the Rayleigh–Ritz method, is presented that captures modal interactions for perfect geometries explicitly for the first time. It is demonstrated that the theoretical compressive strength enhancements under certain configurations can only be obtained at the expense of triggering a sequence of destabilizing bifurcations. This can give rise to severely unstable interactive post-buckling behaviour including the so-called ‘mode jumping’ phenomenon. Moreover, for mono-symmetric stayed beam-columns, it is shown that the varying levels of prestress within the stays can lead to different buckling modes which all have their own characteristic post-buckling responses. The analytical model is verified using a nonlinear finite element model formulated within the commercial code ABAQUS and excellent comparisons are obtained.

Gaoshen Cai (1), Jin lin Yang (1), Yongfeng Yuan (1), Xiying Yang (2), Lihui Lang (2) and Sergei Alexandrov(3)
(1) Faculty of Mechanical Engineering & Automation, Zhejiang Sci-Tech University, Hangzhou 310018, China
(2) School of Mechanical Engineering and Automation, Beihang University, Beijing 100191, China
(3) Institute for Problems in Mechanics of the Russian Academy of Sciences, Moscow, 119526, Russian Federation

“Mechanics analysis of aluminum alloy cylindrical cup during warm sheet hydromechanical deep drawing”,
International Journal of Mechanical Sciences, Vol. 174, Article 105556, 15 May 2020,
https://doi.org/10.1016/j.ijmecsci.2020.105556

ABSTRACT: To obtain the stress states of the sheet metal and understand the potential forming mechanism under the influences of fluid pressure and temperature during the warm hydroforming of 5A06-O aluminum alloy sheets, mechanics analysis was conducted for the warm hydromechanical deep drawing of a cylindrical cup, taking into account through-thickness normal stress induced by fluid pressure. By considering the additional stress during bending using a variable-stiffness pure bending model as equal to that determined using a bending moment model, the additional stress at the die corner during bending was solved. The force equilibrium equations for the cup near the die corner, which were classified by whether the blank contacted the die, were also established and the results were in good agreement with those obtained via the finite element method. Furthermore, mechanics analysis was also performed for the straight-wall region, and the results revealed that the error was slightly greater when the liquid pressure was used to approximately equal to through-thickness normal stress because the ratio of thickness to radius was not sufficiently large.

Haijiang Kou (1), Tianyu Zhao (2), Jiaojiao Du (1), Li Zeng (1), Xhida Zhu (1), Fan Zhang (1) and Huiqun Yuan (2)
(1) School of Mechanical Engineering, Yangzhou University, Yangzhou, 225127, China
(2) School of Science, Northeastern University, Shenyang, 110819, China

“Geometric nonlinear vibrations of rotating variable thickness plates induced by periodic incoming wakes”,
International Journal of Mechanical Sciences, Vol. 175, Article 105510, 1 June 2020,
https://doi.org/10.1016/j.ijmecsci.2020.105510

ABSTRACT: Incoming wakes significantly affect vibration characteristics of rotating blades in turbomachines. This paper develops a periodic incoming wake mathematical model to consider the influence of pressure variations. Considering thickness variations along both the chord to reduce vibrations and the span to decrease centrifugal stress, a wake-induced vibration model based on rotating large deformation cantilever plates is established. Natural frequencies calculated by different methods show that the present method has a high degree of accuracy. And analysis of incoming wake-induced vibrations indicates the incoming wake model can analyze effects of important parameters of such wakes on vibration characteristics. With the aggravation of wakes induced-vibrations, geometric nonlinear vibrations become more remarkable, which indicates the necessity of large deflection analysis. Discussions on variable thickness demonstrate that increasing thickness on the fixed end or maximum thickness along the chord not only reduces vibrations caused by incoming wakes, but also decreases the centrifugal stress, which are two better ways to reduce this kind of vibrations.
electronics. In this study, theoretical models are developed to investigate the global-buckling and local-folding in the non-uniform thin film of stretchable electronics. The models are capable of giving concise and explicit analytical solutions of the deformed configuration and maximum strain in thin film. The effectiveness and accuracy of analytical solutions are verified by the finite element analyses (FEA) and molecular dynamics (MD) simulations. Our study provides useful guidance for the diverse design and precise control of stretchable electronics.

ABSTRACT: This paper presents a new modal theory for the wrinkling analysis of membranes and discusses the stretch-induced wrinkling behaviour of fixed-ended thin sheets. This modal theory corresponds to an extension of Generalised Beam Theory (GBT) to analyse the wrinkling behaviour of highly stretched sheets. The inherent GBT modal nature adopted in this investigation enables the acquisition of an in-depth knowledge (when compared with the traditional shell finite element analysis) of the behaviour underlying this peculiar buckling phenomena. In order to conduct this study, the work begins by presenting the formulation, describing its main steps and concepts involved in the determination of the “deformation modes” (cross-section analysis), followed by the description of the procedures involved in the development and implementation of the aforementioned formulation that accounts for pre-wrinkling and wrinkling analysis (member analysis). Then, an illustrative example is presented and discussed in detail, which involves the characterisation of the sheet “signature curve” (tensile critical stress vs. length), respective critical wrinkling modes, modal participation diagrams and pre-wrinkling stress distribution patterns. For comparison and validation purposes, refined ABAQUS shell finite element wrinkling results are also reported. Finally, several conclusions are drawn regarding the wrinkling behaviour of stretched sheets, mostly based on the modal nature of this formulation.


ABSTRACT: This paper investigates the early fracture of the ductile metals under cyclic loading due to the occurrence of temperature-induced buckling (TIB). Extensive experiments with cylindrical dog-bone specimens made of SS316 and SS321 subjected to cyclic loading reveal that TIB occurs at a stress level below the buckling strength and before what inelastic cyclic buckling criterion predicts. It is shown that buckling occurs if the operating stress is at or above a critical limit \( \sigma_{\text{cr}} \) and when the specimen's temperature reaches a critical limit, called \( T_{\text{cr}} \). The analysis of the temperature evolution of these materials shows three distinct regions of Pre-TIB, TIB, and rapid failure thereafter. The measured \( T_{\text{cr}} \) for SS316 and SS321 are found to be 100 °C and 130 °C, respectively. The corresponding \( \sigma_{\text{cr}} \) for SS316 and SS321 are 340 MPa and 365 MPa, respectively.

Wenqi Liu (1,2), Junhe Lian (2,3), Sebastian Münstermann (1), Chongyang Zeng (4) and Xiangfan Fang (4)
(1) Integrity of Materials and Structures, Steel Institute, RWTH Aachen University, Intzestraße 1, 52072, Aachen, Germany
(2) Advanced Manufacturing and Materials, Department of Mechanical Engineering, Aalto University, Puumiehenkuja 3, 02150, Espoo, Finland
(3) Impact and Crashworthiness Lab, Department of Mechanical Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA, 02139-4307, USA
(4) Institute of Automotive Light Weight Design, University of Siegen, Breite Straße 11, 57076, Siegen, Germany


ABSTRACT: Experimental and numerical investigations at both lab and structure scales on the plasticity and failure behavior of an automotive dual-phase steel sheet (DP1000) are performed in this study. On the lab level, an extensive experimental program considering the temperature and strain rate effects on the plastic deformation behavior and the stress state dependency of the ductile fracture behavior is designed. On the structural level, dynamic square tube crushing tests are performed on a drop tower. The extended hybrid damage mechanics model is formulated in the study to describe the deformation and damage/fracture behavior of DP1000 considering the influence of temperatures, strain rates, and loading histories. The plasticity and fracture description at the lab scale is used to calibrate the material parameters of the model, which is further applied to
predict the crashworthiness of the square tube crushing tests. The proposed model has been proven to show very good predictive capability at both lab and structure scales. It is further found that for the modern high-strength steels short cracks could be developed in the tube crushing tests and the crack formation mechanics is shearing and local second-level bending caused by the self-contact between folds.

Majid Bakhtiari (1) and Meisam Kheradpisheh (2)
(1) School of New Technologies, Iran University of Science and Technology, Narmak, Tehran 16844, Iran
(2) School of Mechanical Engineering, Iran University of Science and Technology, Narmak, Tehran 16844, Iran
“Dynamics behavior and imperfection sensitivity of a fluid-filled multilayered FGM cylindrical structure”,
International Journal of Mechanical Sciences, Vol. 176, Article 105425, 15 June 2020,
https://doi.org/10.1016/j.ijmecsci.2020.105425

ABSTRACT: The paper aims to investigate the transient response of an air-filled multilayer hollow functionally graded (FGM) cylinder with interlaminar bonding imperfection in the presence of load which is extensively put to use in aerospace structure. The material properties of each layer are assumed to vary continuously within the cylinder along the thickness direction with arbitrary grading pattern. A linear spring model is used to define imperfectly bonded interfaces of the multilayer cylinder. The solution of problem is obtained by means of the laminate approximation theory along with the Durbin’s numerical Laplace transform inversion with regard to the time coordinate. Detailed numerical study of transient response of multilayer FGM cylinder with imperfect bonding under a pulse excitation are presented. In the following, the effect of imperfection on radial and circumferential stresses is presented and in view of the lack of any data, only the obtained results with the perfect bond are compared to those of other researchers have published in the literature. Also, by displaying contours of the internal pressure field, dynamic features in the fluid-structure interaction are investigated. Finally the effect of load duration and various loads, including step load and exponential load on radial and circumferential stresses are examined in detailed and the results obtained show the effect of step load is more critical than exponential load.

X.Y. Li (1), X.H. Wang (1), Y.Y. Chen (1), Y. Tan (1) and H.J. Cao (2)
(1) School of Mechanics and Engineering, Southwest Jiaotong University, Chengdu 610031, PR China
(2) Sichuan Association for the Promotion of Ecological Civilization (SAPEC), Chengdu, Sichuan, China
“Bending, buckling and free vibration of an axially loaded timoshenko beam with transition parameter: Direction of axial force”, International Journal of Mechanical Sciences, Vol. 176, Article 105445, 15 June 2020,
https://doi.org/10.1016/j.ijmecsci.2020.105445

ABSTRACT: This paper aims to investigate the bending, buckling and free vibration problems of an axially loaded Timoshenko beam in a systematic manner. A recently-developed unified model is adopted, where a transition parameter characterizing the direction of the axial force during the deformation is introduced. For beams with various boundary conditions, closed-form expressions of deflections and critical buckling loadings are obtained in an analytical fashion and frequency equations are derived. It is highlighted that the inherent relations of the buckling loadings for the Timoshenko and Euler-Bernoulli beams are explicitly extracted. Numerical calculations are carried out to check the validity of the present solutions and to quantify the effects of the transition parameter. Significant effects of the transition parameter are revealed on the bending, buckling and free vibration of the axially loaded beam. The present analysis is of significance to axially-loaded beam-like mechanical system, especially for determination of the direction of axial force.

Qingya Li (1), Di Wu (2), Wei Gao (1) and Francis Tin-Loi (1)
(1) Centre for Infrastructure Engineering and Safety (CIES), School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW 2052, Australia
(2) Centre for Built Infrastructure Research (CBIR), School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NSW, Australia
“She-size-dependent instability of organic solar cell resting on Winkler–Pasternak elastic foundation based on the modified strain gradient theory”, International Journal of Mechanical Sciences, Vol. 177, Article 105306, 1 July 2020,
https://doi.org/10.1016/j.ijmecsci.2019.105306

ABSTRACT: The present study employs the modified strain gradient theory (MSGT) in conjunction with the refined shear deformation plate theory to explore the buckling behaviour of simply supported and clamped OSC. The Winkler-Pasternak elastic foundation is implemented to idealise the foundation. The size-dependent
effect of the OSC is captured by the three length scale parameters within the MSGT. The Hamilton principle is used to derive the equations of motion and the boundary conditions, and the Galerkin procedure is subsequently implemented to obtain the critical buckling load. Subsequently, the framework is extended to the thermally induced buckling behaviour, and three types of temperature rise patterns, namely uniform, linear and nonlinear temperature variations, along the thickness of the OSC are considered. Several verification studies are conducted to illustrate the accuracy of the present method. Besides, size-dependent material properties are taken into consideration during the numerical experiments. Thorough studies are conducted to demonstrate the difference between critical buckling loads obtained from the MSGT, the modified couple stress theory (MCST), and the classical plate theory (CPT) models. Furthermore, the effects of length scale parameter ($h/l$), the aspect ratio ($a/b$), the length-to-thickness ratio ($a/h$) and the Winkler-Pasternak elastic foundation parameters on the buckling behaviour of the OSC are also revealed by the numerical results.


ABSTRACT: This paper reports a detailed buckling analysis of a free-standing annular sheet subjected to partial shrinkage as one of the strategies of morphing structures, which has received considerable attention lately. The linear buckling problem can be decomposed into in-plane and out-of-plane deformations. The in-plane (Lamé) problem is first analysed to determine the stress distribution and show that in-plane hoop compression due to the competition between shrinkage and non-shrinkage zones can induce buckling despite free boundary conditions at the edges of the sheet. Subsequently, buckling analysis is performed to numerically determine buckling strains, to explore the effect of material and geometrical parameters on their buckling thresholds. A simple scaling argument is used to demonstrate that minimised (critical) buckling strain to the shrinkage radius is obtained when the shrinkage area corresponds to the non-shrinkage area. The results demonstrate that critical buckling mode can switch from a saddle to ripple mode when Young’s modulus in the shrinkage zone is approximately ten times that of the non-shrinkage zone, depending on the shrinkage size and radius ratio of the annuli.


ABSTRACT: In this paper we investigated the mechanics of topography-driven delamination of a thin elastic patch attached to a wrinkling surface of film-substrate system through both theoretical modelling and finite element simulation. The process of topography-driven delamination could be divided into three stages: wrinkling before delamination occurrence, initiation of delamination and evolution of delamination blister. The topography-driven delamination was found to be dominantly induced by interfacial shear traction and initiate at the location in the middle of peak and valley. The analytical expressions of critical strain and the corresponding critical wrinkling amplitude for topography-driven delamination were derived explicitly and rigorously based on a patch-film-substrate trilayer model. The dependence of the size of delamination blister on the compressive strain was obtained as well using an energy minimization method. The theoretical model was compared with finite element simulation results for validation and a close agreement was observed. At last the theoretical prediction was applied to guide the design of flexible electronics on wrinkling human skin and the design of a new class of active anti-biofouling coating through wrinkling surface texture.

E. Salari (1), S.A. Sadough Vanini (1), A.R. Ashoori (1) and A.H. Akbarzadeh (2,3)
(1) Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran
(2) Department of Bioresource Engineering, McGill University, Island of Montreal, QC H9X 3V9, Canada
(3) Department of Mechanical Engineering, McGill University, Montreal, QC H3A 0C3, Canada
ABSTRACT: Present paper deals with the nonlinear thermal bending response, thermal postbuckling behavior, and snap-through phenomenon due to lateral mechanical load in a thermally preloaded functionally graded (FG) porous perfect/imperfect nanobeam subjected to two types of thermal loading, including heat conduction across the thickness and uniform temperature rise. Heterogenous material properties of the porous nanobeams are assumed to be position/temperature-dependent, where dependency is obtained according to the modified rule of mixture and Touloukian formulation. Two types of porosity distribution and also geometrical imperfection of the nanobeam are considered. Assuming the Timoshenko beam model and von-Karman nonlinearity, the nonlinear equilibrium equations are extracted on the basis of the nonlocal theory of elasticity. With the establishment of the principle of virtual displacement and Chebyshev polynomial of the first kind as the basic functions, the Ritz method is utilized to obtain the matrix form of the nonlocal governing equations. Two different strategies, including the Newton-Raphson technique and direct displacement control scheme, are first proposed to extract the nonlinear bending and postbuckling trajectories of the graded porous nanobeam. Afterwards, to trace the snapping behavior beyond limit loads of the graded porous nanobeam with thermal preloading, the cylindrical arch-length scheme as a path-following method is adopted. Numerical parametric investigations are given to discuss the influences of the power-law index, two types of porosity distribution and thermal loads, size-dependent nonlocal parameter, imperfection amplitude, and boundary conditions on the snap-through behavior and the nonlinear thermal stability of the FG nanobeam.

ABSTRACT: A mathematical model for investigating the asymmetric as well as the axisymmetric free vibration behavior of a rotating annular micro-disk is presented for the first time. The disk is assumed to be functionally-graded (FG) along the radial and thickness directions, and is considered to be operating in high-temperature environment. An energy based approach involving minimum potential energy principle and Hamilton's principle is used to derive the governing equations of motion considering Kirchhoff plate theory. The size-effect is addressed employing modified couple stress theory. A novel tangent stiffness based formulation is employed to derive the governing equations of vibratory motion in the neighborhood of the centrifugally and thermally deformed disk configuration. The governing equations are solved following Ritz method. The model captures both the axisymmetric and asymmetric flexural vibration modes, as well as the torsional mode. The model is successfully validated with the available results for some reduced problems. Numerical results are presented in tabular and graphical form for various material and geometric parameters, and some illustrative mode shape plots are presented showing the mode-switching phenomenon. The work presents a generalized model which can be reduced to theoretically model a wide variety of practical problems.

ABSTRACT: Numerical methods have become useful tools for predicting vehicle mobility performance on granular terrain. However, due to the large number of soil particles and complex contact search in tire-granular terrain simulation, time-consuming calculation has become the most critical problem restricting the application of these methods. In this study, an efficient GPU-based DEM-FEM for simulation of the interactions between an off-road tire and granular terrain is implemented to improve computational efficiency. In this method, the main body of calculation is executed on GPU and programmed into an in-house developed code CDFP. The new GPU-based computing framework consists of 14 kernels, including efficient contact calculation between large-scale particles, novel contact calculation between particles and complex tread, contact calculation between particles and boundary wall, internal force calculation of finite elements, and information update. As a result, the efficient contact search and the complex interactions between an off-road tire and granular terrain are accomplished. Based on the self-developed single-wheel test device, an accurate simulation model consistent with the experiment is established. The validity of the proposed method is verified by comparing the simulation results with the experimental results. Finally, the discussion of computational efficiency shows that the proposed GPU-based DEM-FEM can be a powerful tool to simulate the interactions between an off-road tire and granular terrain.
ABSTRACT: A mathematical model based on Eringen's nonlocal elasticity theory is presented to analyze free vibration behavior of rotating nano-beams. The model is capable of studying the flap-wise and chord-wise vibrations as well as the axial vibration of rotating nano-beams. The model is based on Euler-Bernoulli beam theory, and incorporates spin-softening and Coriolis effects. Hamilton's principle is employed to derive the governing equations involving virtual displacements, and Ritz method is followed to discretize the governing equations. The governing equations are transformed to an eigenvalue problem in state-space. The stable solutions in frequency domain are indentified by appropriately examining the nature of the complex eigenvalues. The model is validated through some reduced problems available in the literature. The non-dimensional speed-frequency behaviors are presented and discussed for different normalized nonlocal parameters, hub parameters and section aspect ratios. The spin-softening and Coriolis effects are individually illustrated and discussed. The present advanced model for rotating nano-beams is reported for the first time. The present study would help in understanding the dynamics of rotating nano-beams in a comprehensive manner.

ABSTRACT: There is significant interest in replacing conventional materials with novel, lightweight alternatives. Magnesium alloys are favorable candidates since magnesium is the lightest structural metal available. The impetus of this investigation was to examine the mechanical performance for AM30 magnesium extrusions subjected to quasi-static and dynamic progressive crushing and axial cutting with impact velocities up to 18 m/s investigated. These magnitudes replicated high speed, transportation-related impacts in a range where experimental data is crucial but absent from the literature. The collected data was compared in terms of total energy absorption, force efficiency and overall deformation stability to assess the feasibility of this novel material as a potential substitute for vehicular safety systems which are traditionally composed of steel. Axial cutting was generally outperformed in terms of energy absorption capacity when compared to crushing, except for the case of 10-bladed cutting. However, the degree of fracture observed and corresponding lack of stability under crushing was unacceptable for a safety system while every cutting test proceeded with a highly repeatable, near-constant force response which successfully mitigated fracture. The average cutting force efficiency was approximately 85%, compared to 30% for the progressively crushed specimens. A fully analytical model to predict the complete force-displacement response under a cutting deformation mode was derived and validated, based upon experimental observations, with an average error of 4% for a series of geometries, alloys, loading rates and cutting tools. Additionally, this revised model possesses a stronger theoretical basis than the original by considering the influence of strain energy release rate per unit area (J-integral) and a brittle cutting membrane rather than empirical correction factors. The influence of mechanical leverage on the axial cutting force, by radial clamping of the flared sidewalls, was also considered in the revised analytical model and validated for an expanded parametric scope.

ABSTRACT: In this paper, the stability of pipes conveying fluid with viscoelastic fractional foundation is investigated. The pipe is fixed at the beginning while the pipe end is constrained with two lateral and rotational springs. The fluid flow effect is modeled as a lateral distributed force, containing the fluid inertia, Coriolis and centrifugal forces. The pipe is modeled using the Euler-Bernoulli beam theory and a fractional Kelvin-Voigt model is employed to describe the viscoelastic foundation. The equation of motion is derived using the extended Hamilton’s principle. Presenting the derived equation in Laplace domain and applying the Galerkin method, a set of algebraic equations is extracted. Calculating the determinant of the coefficients of the extracted algebraic equations results in the stability margin of the pipe. Some run is done and effects of some physical
parameters such as stiffness and damping of fractional viscoelastic foundation, fractional order parameter and the end lateral and rotational stiffness of end springs on the stability boundary of the pipe are considered and some conclusions are drawn.


ABSTRACT: This study presents the analytical formulation and the finite element solution of a geometrically nonlinear and nonlocal plate modeled via fractional-order mathematics. The finite nonlocal strains are obtained from a frame-invariant and thermodynamically consistent fractional-order continuum formulation. The fractional-order continuum model is used to capture softening nonlocal response via both Mindlin and Kirchhoff formulations. The governing equations and the corresponding boundary conditions of the geometrically nonlinear and nonlocal plates are obtained using variational principles. Further, a 2D nonlinear finite element model for the solution of this class of fractional-order systems is developed. The fractional finite element model is used to study the geometrically nonlinear response of nonlocal plates subject to various loading and boundary conditions. It is established that irrespective of the nature of boundary conditions, the fractional-order nonlocality leads to a reduction in the plate’s stiffness thereby increasing the magnitude of the transverse displacements. More specifically, the nonlocal plate model based on fractional-order strain-displacement relations is free from boundary effects that lead to mathematical ill-posedness and inaccurate predictions typical of classical strain-driven integral approaches to nonlocal elasticity under certain loading and boundary conditions. This consistency in the predictions of the fractional-order nonlocal model is a result of the well-posed nature of the fractional-order governing equations.


ABSTRACT: This paper addresses the theoretical and experimental assessment of thin-walled hexagonal structures manufactured by laser powder bed fusion which is a layerwise powder bed based additive manufacturing process. The lightweight potential and mechanical properties of such cellular structures are governed by their relative density for which the present literature only gives approximate values. Thus, a closed-form analytical solution is given which considers the cell wall overlaps that are neglected by the current models. Effective inplane elastic properties, i.e. two moduli of elasticity and two Poisson's ratios, are treated in the framework of a new closed-form analytical method that uses a homogenization approach applied to a representative volume element and is based on Timoshenko's beam theory by using the principle of the minimum of total complimentary elastic potential in conjunction with Castigliano's 2nd theorem. The general manufacturability of such cellular structures by laser powder bed fusion is investigated by establishing overhang restrictions and by manufacturing trial specimens for the assessment of maximum cell sizes and orientations in the build space of a laser powder bed fusion system. Extensive parameter studies are performed concerning the influence of laser power, scan speed and hatch distance on the resultant hexagon geometries, the surface quality, the occurrence of imperfections and the general limits of manufacturability which enables the targeted manufacturing of cellular structures with clearly defined properties. The resultant material density is determined by Archimedeans density measurements, and the study of micrographs reveals degrees of porosity and the quality of the individual melt tracks. The closed-form analytical method for the determination of the effective elastic properties is finally validated by performing compression tests on selected specimens.


ABSTRACT: This paper presents a novel type of cylindrical cellular shell with bidirectional negative stiffness (NS) metamaterial cores. The unit cell is composed of a trapezoidal frame and four cosine-shaped curved walls, therefore showing NS effect in both the circumferential and radial directions. Numerical analyses are conducted
to investigate the mechanical properties, including the quasi-static behavior under radial compression and the sound transmission loss (STL) performance under an outward radiation wave within a wide frequency range. The acoustic performance is compared with those of cylindrical shells with annular hexagonal and re-entrant honeycomb cores. The NS-core and honeycomb-core cylindrical cellular shells are with the same outline dimensions and overall weight. Parametric studies of the STL on the thicknesses of the curved cell walls and the weight of mass inclusions are performed, followed by optimizations with the purpose of maximal averaged STL in two specified frequency ranges. It was found that the NS-core cylindrical shell yielded much higher STL than those honeycomb-core cylindrical shells for frequencies larger than about 200 Hz. Furthermore, the averaged STLs of the optimized designs increased by 123.7% and 39.5% for the two ranges, respectively. The results indicate that the proposed shell is not only able to endure large strain due to elastic instability, but also isolates sound waves under the very small sound-induced deformation. This design provides an alternative to the conventional core types in cellular structures by showing abundant designability and desirable structural and vibro-acoustic characteristics.


ABSTRACT: Based on the modified couple stress theory, an analytical approach is presented to study vibrations of thermally pre/post-buckled functionally graded (FG) tubes. The case of simply supported FG micro-tubes with uniform distributed porosity surrounded by nonlinear elastic medium in uniform temperature field is analyzed. Thermomechanical properties are functionally graded across the radius of cross-section of the tube by means of a power law function. The traction free boundary conditions on the inner and outer surfaces of the structure are satisfied. Basic formulations are constructed using the higher-order shear deformation tube theory and the von Kármán type of nonlinear strain-displacement relationships. The governing equations of motion are derived using the Hamilton principle. The dimensionless equations of motion are solved analytically by employing the two-step perturbation technique and the Galerkin procedure. An explicit closed-form solution is obtained to analyze the size-dependent linear and nonlinear free vibrations of micro-tubes in thermal environment. The numerical results are verified by comparison with the existing data in literature for tubes without couple stress effect. Novel numerical results are revealed in the parametric studies to show the large amplitude vibration responses of thermally pre/post-buckled FG porous micro-tubes. The effects of microstructural length scale parameter, functionally graded patterns, porosity distribution parameter, nonlinear elastic foundation, temperature dependence, and geometrical properties of the structure are investigated.


ABSTRACT: The metal foams are widely used in different areas of technologies due to their both, low specific weight and good stiffness. Adding nanofillers as reinforcement to metal foams makes them stiffer while keeping their lightweight. Graphene nanoplatelets (GNPs) are recently known as the best nanofillers due to their exciting features such as high Young's modulus and extremely high thermal conductivity. In the present article, bending, buckling, and free vibration analyses of micro-scaled functionally graded GNPs reinforced porous nanocomposite annular plate located on the bi-parameter elastic foundation exposed to hygro-thermo-mechanical loads are carried out. The GNPs reinforcement and also porous matrix properties are functionally graded along with the plate's thickness based on overall sixteen combination patterns. The Gaussian random field (GRF) scheme for closed-cell cellular solids is considered for the porous matrix properties, and the effective properties of the porous nanocomposite micro plate are determined via Halpin–Tsai and extended rule of mixture (ERM) micromechanics models. The modified strain gradient theory (MSGT) suggesting three material length-scale parameters is employed to cope with the size effect, and the shear deformation effects are taken into account using the first-order shear deformation theory (FSDT). The governing differential equations are derived using energy method and variational approach. The normalized, discretized equations are then solved using the generalized differential quadrature (GDQ) scheme for various boundary conditions. The reliability of the results is ensured by comparing with the previously published ones in the literature for simpler cases. The influence of the prominent parameters on the results is considered.

ABSTRACT: In this paper, we propose an effective computational approach to analyze and active control of geometrically nonlinear responses of functionally graded (FG) porous plates with graphene nanoplatelets (GPLs) reinforcement integrated with piezoelectric layers. The key concept behind this work is to utilize isogeometric analysis (IGA) based on Bézier extraction technique and C-type higher-order shear deformation theory (C-HSDT). By applying Bézier extraction, the original Non-Uniform Rational B-Spline (NURBS) control meshes can be transformed into Bézier elements which allow us to inherit the standard numerical procedure like the standard finite element method (FEM). In this scenario, the approximation of mechanical displacement field is calculated via C-HSDT whilst the electric potential field is considered as a linear function across the thickness of each piezoelectric sublayer. The FG plate includes internal pores and GPLs dispersed into metal matrix either uniformly or non-uniformly along plate’s thickness. To control responses of structures, the top and bottom surfaces of FG plate are firmly bonded with piezoelectric layers which are considered as sensor and actuator layers. The geometrically nonlinear equations are solved by Newton-Raphson iterative procedure and Newmark’s integration. The influence of porosity coefficient, weight fraction of GPLs as well as external electrical voltage on the geometrically nonlinear behaviors of plate structures with various distributions of porosity and GPLs are thoroughly investigated. A constant displacement and velocity feedback control approaches are then adopted to actively control geometrically nonlinear static and dynamic responses, where structural damping effect is taken into account, based on a closed-loop control with sensor and actuator layers.


ABSTRACT: A three-dimensional elasticity based approximate analytical solution is proposed for free vibration analysis of composite functionally graded Levy-type rectangular plates having an in-plane gradation of material properties. The density and elastic properties of the composite plates are considered to vary linearly along the x-direction. Modified Hamilton’s principle has been applied to derive the weak-form of governing equations in which all stresses and displacements consider as primary variables to ensure the exact point-wise satisfaction of all interlaminar continuity and edge support conditions. The extended Kantorovich method, in conjunction with the Fourier series and power series approach, has been used to obtain the approximate solution in analytical form. New benchmark numerical results are presented for a single-layered and multi-layered in-plane functionally graded rectangular plates. The influence of the in-plane heterogeneity, thickness ratio, and support conditions on the flexural frequencies and mode shapes of the plate are presented in detail. The present study shows that the free vibration response of the rectangular plate is affected significantly by the in-plane gradation of material properties, but the extent of influence largely depends on edge support conditions of the plate as well as on configuration. The present benchmark solution can be used to validate other 3D numerical approaches and two-dimensional (2D) plate theories.


ABSTRACT: The synergic combination of smart soft composites with kirigami/origami principles leads to self-deployable systems. To date, the development of soft deployable structures has largely been an empirical process. Focusing on the recently developed shape memory alloy (SMA)-based soft deployable structures, this paper describes an analytical model and a finite element (FE) numerical scheme to investigate deformation and deployment performance of this system. The study provides insights into the working principles of these soft deployable structures by understanding how the system deforms as a function of the SMA recovery strain for a number of geometrical parameters. The FE method was further used to simulate the fabrication and deployment process of three types of kirigami/origami reflectors. The realization of a two-step scheme, i.e., predeformation
of the deployable frame and then the concurrent deformation of both frame and kirigami/origami films, is detailed herein. This makes our simulation capable of capturing the features of SMA-based soft deployable structures observed in experiments, and also renders the prediction versatile and manufacturing-oriented. We expect the work would enhance the understanding of soft deployable structures, and may open the door for design and fabrication of soft robotics and machines.


ABSTRACT: Thin-walled tubes are one of the most popular impact absorbers. Recently, some methods have been proposed to improve crush performance parameters of the thin-walled tube such as filling by foam, modifying geometry etc. Each method has its advantages and disadvantages. It is still a challenge for crashworthy designers to design an efficient energy-absorbing system which has all the necessary requirements. Therefore, the present paper aims to introduce a new design technique which is a combination of bar extrusion and thin-walled circular tube. The crushing behavior of the new proposed energy absorber was studied both experimentally and numerically. Finite element models were developed to estimate the force-displacement curve and the folding shapes of the tube. The numerically predicted load-displacement curve and the calculated crush performance parameters were verified using experimental measurements. Moreover, a parametric study was performed to investigate the effects of different parameters on the proposed energy absorber response. According to the results, the percentage increases in energy absorption (E) capacity and specific energy absorption (SEA) for the proposed energy absorber were 39.02% and 14.37% respectively compared to the thin-walled tube. In order to determine the optimized geometric parameters of the proposed energy absorber, a multi-objective optimization technique was implemented. Based on the response surface methodology (RSM), E and SEA increased 245.5% and 246.3% for the optimum proposed energy absorber. The predictive models for E and SEA were obtained by polynomial equations.


ABSTRACT: This study aimed to investigate low-velocity impact responses and crashworthiness of different aluminum foam-core sandwich structures. Several drop-weight dynamic impact tests were first conducted on both sandwich structures and their individual components to explore the mechanism of energy absorption and interactive effect between the foam core and facesheets. Different shapes and sizes of impactors were used in the experiments. The full-field deflection distribution was acquired by a 3D optical scanner to assess the failure patterns. A full-scale finite element model was then created to simulate the low-velocity impacting response of the foam-core sandwich panels. After the finite element model was validated against the experimental results, it was used to further explore the crash behavior of multi-layered sandwiches. It was found that multi-layer sandwich structure had much better performance in the crush force efficiency than those with single-layer foam core. Based upon the energy principle, an energy-based analytical model was also derived to estimate the initial peak load. It was demonstrated that the analytical predictions were in good agreement with the experimental and numerical results. The presented experimental, numerical and analytical studies are anticipated to provide systematic understanding and new knowledge for design of multilayer sandwich configurations aiming at more desirable impact resistance and better lightweight characteristics.


ABSTRACT: Sheet metal forming processes and their simulations often require knowledge of both anisotropic yield and hardening constitutive parameters. The identification of these properties, however, involves a large number of homogeneous tests as well as various expensive testing machines. In this paper, a novel method is
proposed to enable a simultaneous identification of the multiple anisotropic yield and hardening constitutive parameters from a single test and using the simplest uniaxial testing machine, which significantly simplifies the conventional complex constitutive identification procedures. In particular, the test configuration is elaborately designed to exhibit both heterogeneous stress states and insignificant buckling under compressive loadings based on the plate buckling theory. The virtual fields method is adopted as the inverse problem solution for the selected anisotropic yield and hardening laws, namely, Hill1948 and the nonlinear kinematic hardening models. The proposed identification scheme is first validated through the simulated full-field strain and load data of the designed bridge-like test configuration. Its identification sensitivity is analyzed with respect to the influences of measurement noise, type and combination of virtual fields. The results show that using the designed test configuration it is possible to identify all the target anisotropic parameters from a single test despite a noticeable level of error. This however can be markedly improved by combining the two tests performed in the rolling and transverse directions, and with the multiple virtual fields constraints, from which accurate and robust identification results are obtained for the selected models. The validity of this method is then illustrated experimentally with the application on the wrought magnesium alloy AZ31B sheet specimens. Finally, potential improvements and applications of this method are suggested.


ABSTRACT: The objective of this study is to understand and quantify the thermo-mechanical behavior of hollow sphere (HS) steel and powder metallurgy (PM) aluminum foams over a broad range of elevated temperatures. The behavior of both the HS steel and PM aluminum foam is tested under compressive loading at ambient temperature (24°C) and elevated temperatures of 100°C, 150°C, 200°C, 300°C, 400°C, 550°C and 700°C, and results for the two foams are compared by their rates of degradation in mechanical properties. To link the cell geometry and base metal properties with the global mechanical performance, the experimental work is underpinned by a computational micro-model, consisting of an assembly of hollow spheres. The computational model shows that plastic buckling of cells with progressive plasticity of the contact area is the key local failure mechanism. As expected, due to the plastic buckling of the unit cells, thermal degradations of the tested metallic foams follow similar trends as does the yield stress of their bulk metals. The HS steel foam exhibits only minor elevated-temperature-induced degradation in stiffness and strength at or below 400°C, while still maintaining 69% of its compressive strength at 550°C. Comparatively, the PM aluminum foam begins degrading at an elevated temperature of only 150°C. Interestingly, the HS steel foam oxidized between 300°C and 400°C, resulting in corresponding increases in the quasi-elastic modulus of elasticity. Future work might explore how to take advantage of oxidation reactions at the surfaces of the cells in the design of components using HS steel foams. Our computational study also revealed a possible new regime of cellular structures made up of ultra-thin-walled spherical cells that are predicted to fall within the elastic buckling regime at the local level. Thus, their deformations would be reversible even under high strains and their thermal behavior would be only controlled by thermal deterioration in the elastic constants, rather than plasticity parameters such as the yield stress.

References listed at the end of the paper:

2 P. Vadwala, Thermal energy storage in copper foams filled with paraffin wax, Mechanical and Industrial Engineering - University of Toronto, Toronto, Canada (2011)
ABSTRACT: Functionally graded lattice structures are characterized with their varied structures and mechanical properties, which leads to better mechanical performance comparing to the uniform structures. In this paper, a series of cells with different densities and configurations were formed by changing the unidirectional size of a uniform lattice cell, and then assembled into a size-graded (SG) lattice structure with varied densities and topological configurations. Experimental samples were manufactured from PA2200 by selective laser sintering (SLS) and then tested by a quasi-static compression experiment. Based on the experiment and numerical simulation results, the compression responses and the influence of its graded orientation on the structure performance were investigated. The results show that the SG structure is connected stably and owns the merits of high modules and strong strength under small strain, and characteristics of performance enhanced layer-by-layer under large strain. Therefore, it has better support performance under small strain and superior energy absorption ability under large strain compared with other structures, which indicate its feasibility of being applied in protective devices with impact resistance properties.


ABSTRACT: This paper presents a general approach for dealing with the thermal vibration characteristics of functionally graded porous stepped cylindrical shell (FGP-SCS) by employing characteristic orthogonal polynomials. The thermal vibration characteristics including free vibration, steady-state and transient response are investigated in detail. The governing equations are derived by Rayleigh-Ritz method and the displacement admissible functions are denoted by using characteristic orthogonal polynomials. The FGP-SCS is divided into N segments with different thickness and the coupling of adjacent segment is realized by connecting springs. The boundary conditions of FGP-SCS can be determined easily by selecting the proper stiffness values of boundary springs and the boundary conditions including classical and elastic boundary conditions. Three temperature distributions including uniform, linear and nonlinear distributions and two porosity distributions including even and uneven porosity distributions are taken into account. Meantime, the influences of some key parameters including power law index, porosity volume fraction, temperature change, geometric structure on the thermal vibration behaviors of FGP-SCS are investigated in detail.


ABSTRACT: To meet the great needs for high-performance of piezoelectric nano-scaled structures, the study of their dynamic behaviour is essential in the design of stable and controllable nano-devices, such as energy harvesters, actuators and so on. Brittle wrinkled thin nanoribbons of lead zirconate titanate (Pb(Zr1-xTix)O3, abbreviated as PZT) bound to an elastomeric substrate form a wavy configuration, whose amplitude and wavelength can be designed to accommodate different deformation ranges that would suit real operating environments, including vibration. In this paper, the PZT nanoribbon is modelled as an elastic nonlinear beam with von Karman approximation, and the elastomeric substrate is modelled as a semi-infinite linear elastic
medium. Electrical-mechanical coupling is considered in the constitutive relation of the PZT nanoribbon. By utilizing the extended Lagrangian principle, the equation of motion of the PZT nanoribbon-substrate structure with damping, which can more accurately characterise the electromechanical dynamic behaviour of the structure, is derived. To evaluate the dynamic performance of the partly buckled structure, the symplectic Runge–Kutta method (SRK), which has been developed to solve linear damped ordinary differential equations, is adopted to solve the corresponding equations. Bifurcation diagrams are depicted, and the effects of the applied voltage and pre-strain to the elastomeric substrate on the static bifurcation are analysed, indicating that the pre-strain can easily induce surface wrinkling and the applied voltage can be used to more precisely control surface wrinkling. Moreover, the effect of damping on the dynamic behaviour is discussed through the results of time histories and phase portraits for different values of the applied voltage and pre-strain, confirming that as time progresses, the motion gradually vanishes around the static buckling amplitude. The conclusions of this study are useful for the wavy-design strategy of the PZT nanostructure-based stretchable electronics devices, and for the prediction and passive control of the dynamic behaviour of these devices.


ABSTRACT: This paper proposes a method to solve for closed-form analytical solutions of the free vibration problems of orthotropic rectangular thin plates with arbitrary homogeneous boundary conditions. This proposed method is called the extended separation-of-variable method, in which the mode functions are in a separation-of-variable form, and the frequencies in two spatial directions are mathematically independent of each other. The closed-form analytical eigensolutions satisfy the Rayleigh's principle exactly. Unlike the extended Kantorovich--Krylov method, the proposed method solves all eigenvalue equations of two directions simultaneously, not iteratively. Numerical experiments validate the proposed method. More importantly, the proposed method is applicable to any eigenvalue problems of plates, shells, three-dimensional plates and cubes.

References listed at the end of the paper:
1 EFF Chladni, Die akustik, Breitkopf & Härtel (1830)
7 DJ. Gorman, Accurate analytical type solutions for the free in-plane vibration of clamped and simply supported rectangular plates, J Sound Vib, 276 (2004), pp. 311-333, 10.1016/j.jsv.2003.07.037
12 R Li, B Wang, G Li, B Tian, Hamiltonian system-based analytic modeling of the free rectangular thin plates’ free vibration, Appl Math Model, 40 (2016), pp. 984-992, 10.1016/j.apm.2015.06.019
16 FA Fazzolari, M Boscolo, J.R Banerjee, An exact dynamic stiffness element using a higher order shear deformation theory for free vibration analysis of composite plate assemblies, Compos Struct, 96 (2013), pp. 262-278, 10.1016/j.compstruc.2012.08.033

20 X Liu, HI Kassem, JR Banerjee, An exact spectral dynamic stiffness theory for composite plate-like structures with arbitrary non-uniform elastic supports, mass attachments and coupling constraints, Compos Struct, 142 (2016), pp. 140-154. 10.1016/j.compstruct.2016.01.074


22 K Bhaskar, B. Kaushik, Simple and exact series solutions for flexure of orthotropic rectangular plates with any combination of clamped and simply supported edges, Compos Struct, 63 (2004), pp. 63-68. 10.1016/S0263-2223(03)00132-6

23 D Shi, Q Wang, X Shi, F Pang, A series solution for the in-plane vibration analysis of orthotropic rectangular plates with non-uniform elastic boundary constraints and internal line supports, Arch Mech Phys, 85 (2015), pp. 51-73. 10.1007/s00419-014-0899-x


28 AD. Kerr. An extension of the Kantorovich method, Q Appl Math, 26 (1968), pp. 219-229. 10.1090/qam/99857


39 YF Xing, B. Liu, New exact solutions for free vibrations of thin orthotropic rectangular plates, Compos Struct, 89 (2009), pp. 567-574. 10.1016/j.compstruct.2008.11.010


43 Y Xing, B Liu, T Xu, Exact solutions for free vibration of circular cylindrical shells with classical boundary conditions, Int J Mech Sci, 75 (2013), pp. 178-188. 10.1016/j.ijmecsci.2013.06.005


49 S Hosseini-Hashemi, M Zare, R Nazemnehzad, An exact analytical approach for free vibration of Mindlin rectangular nano-plates via nonlocal elasticity, Compos Struct, 100 (2013), pp. 290-299. 10.1016/j.compstruct.2012.11.035

58 A Pagani, M Boscolo, JR Banerjee, E Carrera, Exact dynamic stiffness elements based on one-dimensional higher-order theories for free vibration analysis of solid and thin-walled structures, J Sound Vib, 332 (2013), pp. 6104-6127, 10.1016/j.jsv.2013.06.023

ABSTRACT: This study attempts to explore the bending and free vibration response of GPL (graphene platelet) reinforced composite cylindrical panels by using Bézier extraction based IGA (isogeometric analysis) in combination with first-order shear deformation shell theory. The cylindrical panel is composed of a finite number of layers in which the GPL concentration has stepped variation across the thickness to construct layerwise FG (functionally graded) structure. The dispersion patterns of GPLs have three FG forms such as FG-O, FG-X and FG-A distributions. Uniform arrangement of GPLs is also considered for comparison. The effective elastic modulus of the nanocomposite cylindrical panel is determined from the Halpin-Tsai model, whilst the mass density and Poisson's ratio are estimated by the modified rule of mixture. The governing equations for the static and dynamic problems are derived, and Bézier extraction based isogeometric formulation is made to get the central deflections and natural frequencies of the multilayered FG GPL strengthened cylindrical panels. The validity of the present isogeometric approach incorporated with first-order shear deformation shell theory is first evidenced, followed by the illustrative parametric studies to further investigate the static and dynamic behavior of the nanocomposite cylindrical panels with various reinforcement schemes.

ABSTRACT: An efficient analytical solution is presented in this paper to model the bending vibration of plates with any numbers of cutouts and under arbitrary boundary conditions. Especially we study the efficiency of the
model while explore the influence of increasing number of cutouts and increasing area of cutouts on the
eigenpairs of the plate. In the first step, the model of the plate with cutouts is decomposed into certain amount
of primitive cells with double cutouts and solved based on the Chebyshev-Lagrangian method. The two
advantages of this modeling method lie in offering a flexible assemble strategy of primitive cell plates to form
plate in various shapes and with arbitrary numbers of cutouts while bringing substantial convenience in
calculation owing to the uniformly expanded double Chebyshev series terms for the displacement of each
primitive cell plate. Secondly, the experimental and numerical validations are performed and consequent
efficiency and convergence analysis is discussed. The results show that the current model presents potential
robust in computation efficiency. At last, the influence of several key parameters on eigenpairs of plate with
cutouts is investigated, including the boundary restraint of the plate, the number of cutouts and the size of
cutouts.

Yuan Chen, Xining Cheng, Kunkun Fu and Lin Ye, “Failure characteristics and multi-objective optimisation
of CF/EP composite sandwich panels under edgewise crushing”, International Journal of Mechanical Sciences,
ABSTRACT: In this study we design an optimal composite structure for the reinforcement of vehicle
components with enhanced energy absorption but reduced weight, based on the evaluation of damage responses
and failure modes of composite sandwich panels under edgewise crushing. A numerical model for compressive
crushing of the CF/EP composite sandwich panels is then built and validated experimentally. The results
demonstrate complete buckling and progressive failure-to-buckling mode of the panels without and with a
bevel, respectively. Considering both the bevel angle and effective height, a failure mode map associated with
the energy-absorption assessments is established. The panels in sustained progressive failure exhibit remarkably
greater specific energy absorption (SEA) than those in buckling failure. A multi-objective optimisation is then
conducted using an optimal surrogate modelling technique to ameliorate energy-absorption capability and light-
weight efficiency, with the bevel angle and effective height as variables. The resulting optimal panel with the
bevel angle of 36.5° and effective height of 27 mm is obtained and is validated experimentally, showing
sustained progressive crushing with the favourable SEA of about 50 kJ/kg. A comparative study proves the
advantages of the designed CF/EP composite sandwich structures in terms of energy absorption as compared to
other composite (sandwich) structures under edgewise crushing.

Yin Yu and Hui-Shen Shen, “A comparison of nonlinear vibration and bending of hybrid CNTRC/metal
laminated plates with positive and negative Poisson's ratios”, International Journal of Mechanical Sciences,
ABSTRACT: This paper reports a study on the large amplitude vibration and nonlinear bending behaviors of
hybrid laminated plates made of carbon nanotube-reinforced composite (CNTRC) layers bonded with metal
layer on the top surface. The hybrid CNTRC/metal laminated plates with out-of-plane negative Poisson's ratio
(NPR) are proposed. The effective material properties of CNTRC layer are graded in the thickness direction in a
piece-wise pattern. The material properties of both CNTRC layer and metal layer are temperature dependent.
The plates are placed on an elastic foundation and in thermal environments. The Reddy's third order shear
deformation plate theory is utilized to establish the motion equations of the hybrid CNTRC/metal laminated
plate. These equations include the geometric nonlinearity in the von Kármán sense, the thermal effects and the
plate-foundation interaction. By employing a two-step perturbation approach the nonlinear vibration and
bending solutions are obtained. A comparison of nonlinear responses of hybrid CNTRC/metal laminated plates
with positive and negative Poisson's ratios under different thermal environmental conditions is carried out and
discussed in details.

Qingshan Wang, Fei Xie, Tao Liu, Bin Qin and Hailiang Yu, “Free vibration analysis of moderately thick
composite materials arbitrary triangular plates under multi-points support boundary conditions”, International
Journal of Mechanical Sciences, Vol. 184, Article 105789, 15 October 2020,
https://doi.org/10.1016/j.ijmecsci.2020.105789
ABSTRACT: In this research, free vibration characteristics of moderately thick composite materials arbitrary
triangular plates under multi-points support boundary conditions are analyzed by an improved Fourier series
method. After constructing the model, the triangular region is mapped to the unit square region. The boundary

ABSTRACT: A reliable and advanced program for nonlinear inelastic analyses of steel girders and steel-concrete composite girders subjected to flexural loadings has been developed in the current article. Effects of geometric nonlinearities, material nonlinearities, and residual stresses on flexural behaviors of different steel girders and steel-concrete composite girders have been thoroughly investigated. The concrete slab and steel I-beam cross-sections are discretized into fiber elements to formulate an equivalent effective cross-section. The $P - \delta$ effect of beam-column elements is investigated by using stability functions, wherein the plasticity spreading phenomena in the element cross-section are captured at different integration points along the longitudinal direction of the element based on constitutive relations in each fiber. The local buckling phenomenon that possibly occurs in web plates of noncompact composite sections has been considered by considering its effective width formulas for the first time. The generalized displacement control method is applied to solve nonlinear equilibrium equations. The proposed program validated by experimental results shows its accuracies in capturing the structure behaviors and its efficiencies in computing time compared with finite element analyses performed in ABAQUS. Different parametric studies are conducted yielding notable observations. The proposed program might be used as an efficient tool in practical advanced analyses and designs of steel girders and steel-concrete composite girders with high nonlinearities and complexity.


ABSTRACT: This work is aimed to study the bandgap property of a thin plate structure with periodically attached bilayer membrane-type resonators. An analytical method based on the Plane Wave Expansion (PWE) method combined with the Rayleigh method, is proposed to predict the bandgap property of bilayer membrane-type metamaterials. The accuracy of the proposed method is verified by the finite element analysis, and a parametric analysis is conducted to reveal the effect of parameters on the bandgap performance. It is found that such a metamaterial can generate two separated bandgaps through the contribution of its two layers of membranes. It is observed that the increase of membrane tensile stress or the magnitude of attached mass can lead to the broadening of bandgaps, whilst the change of unit cell's periodicity has the opposite effect. In addition, if compared with the corresponding single layer membrane-type metamaterials, it is shown that the bilayer membrane-type's first bandgap is suppressed while the second one is extended. However, by applying proper membrane tensile stress and mass magnitude, the suppression of the first bandgap can be weakened whilst allowing the tuning of the bandgap location. These characteristics reveal the benefits of using bilayer membrane-type metamaterial as it possesses higher agility in bandgap tuning. The proposed method can provide an effective tool for the bilayer membrane-type metamaterial design and optimisation.
ABSTRACT: The paper deals with nonlinear buckling analysis of thin-walled members using CUFSM: conventional and constrained finite strip method, 18th International Specialty Conference on Cold-Formed Steel Structures, Orlando, Florida (2006) October 26–27

1 B.W. Schafer, S. Adany, Buckling analysis of cold-formed steel members using CUFSM: conventional and constrained finite strip method, 18th International Specialty Conference on Cold-Formed Steel Structures, Orlando, Florida (2006) October 26–27


4 A.D. Martins, A. Landesmann, D. Camotim, P.B. Dinis, Distortional failure of cold-formed steel beams under uniform bending: Behaviour, strength and DSM design, Thin-Walled Structures, 118 (2017), pp. 196-213

5 G.J. Hancock, Coupled Instabilities in Metal Structures (CIMS) – What have we learned and are we going?, Thin-Walled Structures, 128 (2018), pp. 2-11

6 S. Adany, B.W. Schafer, A full modal decomposition of thin-walled, single-branched open cross-section members via the constrained finite strip method, Journal of constructional steel research, 64 (1) (2008), pp. 12-29

7 J. Loughlan, J. Rhodes, The interactive buckling of lipped channel columns under concentric or eccentric loading, J. Rhodes, A.C. Walker (Eds.), Proc. of Int. Conf. on Thin-walled Struct., Thin-Walled Structures, Granada, London, University of Strathclyde, Glasgow (1979), pp. 40-55

8 J. Rhodes, J. Loughlan, Simple design analysis of lipped channel columns, Proc., Fifth Int. Specialty Conf. on Cold-formed Steel Struct., St. Louis, Missouri (1980), pp. 241-262


12 Szymczak Cz., Kujawa M., Buckling and Initial post-local buckling behaviour of cold-formed channel member flange, Thin-Walled Structures, 137 (2019), pp. 177-184
13 M. Abambres, D. Camotim, N. Silvestre, Modal Decomposition of Thin-Walled Member Collapse Mechanisms, Thin-Walled Structures, 74 (2014), pp. 269-291

14 R. Bebiano, D. Camotim, R. Gonçalves, GBTUL 2.0 – A second-generation code for the GBT-based buckling and vibration analysis of thin-walled members, Thin-Walled Structures, 124 (2018), pp. 235-257


17 D. Camotim, P.B. Dinis, A.D. Martins, B. Young, Review: Interactive behaviour, failure and DSM design of cold-formed steel members prone to distortional buckling, Thin-Walled Structures, 128 (2018), pp. 12-42


28 Z. Kolakowski, M. Krolak, Modal coupled instabilities of thin-walled composite plate and shell structures, Composite Structures, 76 (2006), pp. 303-313

29 Z. Kolakowski, J.R. Mania, Semi-analytical method versus the FEM for analysis of the local post-buckling, Composite Structures, 97 (2013), pp. 99-106

30 Z. Kolakowski, J. Jankowski, Interactive buckling of steel C-beams with different lengths – From short to long beams, Thin-Walled Structures, 125 (2018), pp. 203-210


32 M.R. Bambach, Photogrammetry measurements of buckling modes and interactions in channels with edge-stiffened, Thin-Walled Structures, 47 (2009), pp. 485-504

33 M.M. Pastor, F. Roure, Open cross-section beams under pure bending. I. Experimental investigations, Thin-Walled Structures, 46 (2008), pp. 476-483

34 Y.B. Kwon, B.S Kim, G.J. Hancock, Compression tests of high strength cold-formed steel channels with buckling interaction, Journal of Constructional Steel Research, 65 (2009), pp. 278-289

35 M. Obst, D. Kurpisz, P. Paczos, The experimental and analytical investigations of torsion phenomenon of thin-walled cold formed channels beams subjected to four-point bending, Thin-Walled Structures, 106 (2016), pp. 179-186

36 Biegus A., Czepiak D., Experimental investigations on combined resistance of corrugated sheets with strengthened cross-sections under bending and concentrated load, Thin-Walled Structures, 46, 2008, 303-309.

37 M. Mahendran, M. Jayaragan, Experimental investigation of the new built-up lite steel beams, Proceedings of 5th International Conference on Thin-Walled Structures (2008), pp. 433-441

38 P. Paczos, Experimental investigations of thin-walled C-beams with nonstandard flanges, Journal of Constructional Steel Research, 93 (2014), pp. 77-87

39 C. Yu, B.W. Schafer, Simulation of cold-formed steel beams in local and distortional buckling with applications to the direct strength method, Journal of Constructional Steel Research, 63 (2007), pp. 581-590


41 C. Szmyczak, M. Kujawa, Buckling of thin-walled columns accounting for initial geometrical imperfections, International Journal of Non-Linear Mechanics, 95 (2017), pp. 1-9, 10.1016/j.ijnonlinmech.2017.06.003

42 C. Szmyczak, M. Kujawa, Distortional buckling of thin-walled columns of closed quadratic cross-section, Thin-walled Structures, 13 (2017), pp. 111-121, 10.1016/j.tws.2017.01.006

43 C. Szmyczak, M. Kujawa, Torsional buckling and post-buckling of columns made of aluminium alloy, Applied Mathematical Modelling, 60 (2018), pp. 711-720, 10.1016/j.apm.2018.03.040

45 C. Szymczak, M. Kujawa, Local buckling of composite channel columns, Continuum Mechanics and Thermodynamics, 2018, 10.1007/s00161-018-0674-2
51 V. Rizov, Delamination fracture in a functionally graded multilayered beam with material nonlinearity, Archive Applied Mechanics, 87 (2017), pp. 1037-1048
56 Z. Kolakowski, M. Urbaniai, Influence of the distortional-lateral buckling mode on the interactive buckling of short channels, Thin-Walled Structures, 109 (2016), pp. 296-303
58 Z. Kolakowski, T. Kubiak, Load-carrying capacity of thin-walled composite structures, Composite Structures, 67 (4) (2005), pp. 417-426
59 T. Kubiak, Static and dynamic buckling of thin-walled plate structures, Springer (2013)

ABSTRACT: High load-bearing, high storage ratio, and lightweight structures hold great trends in the field of large-scale deployable space structures. In this paper, we present a smart reconfigurable lattice (SRL) structure with bi-directional corrugated core to meet the integrated and versatile designs. The three-point bending experimental results indicate that the load-bearing efficiency of the 3D SRL structure is 5 times more than that of 2D folded lattice structure. The 3D SRL structure performed mixed-mode bending behaviors, including struts buckling, debonding, and global bending. Analytical models are also established to predict the failure load of the SRL structure, agreeing well with the tested results. The feasibility of this reconfigurable design is verified by the folding/unfolding simulations and experiments. Moreover, the effects of geometrical parameters on the failure modes and the failure load are discussed. A competitive failure mode between shear-induced failure and compression-induced failure is found. The included angle plays a key role in influencing structural failure mode. These results clearly illustrate the advantage of the SRL design and provide guidelines for future designs of deployable space structures with high load-bearing, high storage ratio, and lightweight.

ABSTRACT: In the present work, a stabilized node-based smoothed radial point interpolation method (SNS-RPIM) is proposed for analysing the behaviour of functionally graded magneto-electro-elastic (FGMEE)
structures with holes in thermal environment. By introducing the stable item related to the gradient variance of field variables, a close-to-exact SNS-RPIM model is constructed, and the temporal instability of traditional node-based smoothed radial point interpolation method (NS-RPIM) is cured. Several numerical examples validate that SNS-RPIM performs well in efficiency and convergence than finite element method (FEM) and NS-RPIM and could solve magneto-electro-thermo-elastic (METE) multi-physics coupling problems more accurately. It is also found that the position of the holes has a greater influence on the displacement and magnetic potential of the structure and has less influence on the electric potential. This provides a reference for the design and application of FGMEE structures with holes working in thermal environment in practical engineering.


ABSTRACT: In this paper a semi-analytical approach to efficiently determine the dynamic response of an Euler-Bernoulli beam with general boundary conditions crossed by a mass-spring-damper (MSD) system is presented. Based on a dynamic substructuring technique (DST), the non-classically damped beam subsystem in modal state space representation is coupled with the interacting degrees of freedom of the MSD system by applying a generalized corresponding assumption. This assumption implies equal displacements of the beam and the MSD system at the contact points. The resulting set of coupled equations of motion in state space has time-dependent system matrices. Special attention is paid to the appropriate formulation of the arrival and departure conditions of the MSD system on the beam. In an application example, the dynamic response of a viscoelastically supported beam with a lumped mass at both ends crossed by a MSD system is analyzed, examining the effect of the speed and various parameters of the viscoelastic supports. The comparison of the results of the coupled beam-MSD system and a less expensive approach, in which the MSD system is simplified by its static axle loads, shows the importance of explicitly considering the interaction between beam and MSD system for accurate response prediction.


ABSTRACT: The vibration characteristics of irregular elastic coupled plate systems are studied by Chebyshev-Ritz method in this paper, including dynamics and power flow control. Firstly, the accurate geometric model is established, and the coupling conditions and boundary conditions are simulated by artificial virtual springs. In order to facilitate integral operations, the irregular integral area is mapped into the regular integral area by a special coordinate transformation. Then all energy equations of the coupled system are established according to the first order shear deformation theory. The Chebyshev polynomial is used as the allowable displacement functions. Finally, the unknown coefficients in the allowable displacement functions are determined by the Rayleigh-Ritz technique. On the basis of the free vibration study, the dynamic behavior is studied by applying the external load to the system surface, including the forced response, the admittance and the power flow. While deriving the method, some modal verification experiments about coupled plate systems are designed. The innovation of the study is the establishment of the vibration analysis model of irregular elastic coupled plate systems based on the elastic theory, the coordinate transformation criterion and the two-dimensional Chebyshev-Ritz principle. The mechanism and control of energy transfers of the coupled plate system are studied by the power flow intensity analysis. The numerical results show that both the coupling condition and the boundary condition are important parameters in the vibration. This study provides some new insights into the vibration characteristics and energy transfer of the irregular elastic coupled plate system.

Zhen Li, Qingshan Wang, Bin Qin, Rui Zhong and Hailiang Yu, “Vibration and acoustic radiation of magneto-electro-thermo-elastic functionally graded porous plates in the multi-physics fields”, International Journal of
ABSTRACT: This paper proposes a unified model for investigating the vibration and acoustic radiation behaviors of magneto-electro-thermo-elastic functionally graded porous plates (METE-FGPPs). The model is established by first-order shear deformation theory (FSDT) combing with the Voigt model and modified power-law distribution. For the sake of simplicity, the formulations with regard to the vibration and acoustic radiation of METE-FGPPs are deduced by using the Rayleigh-Ritz method, and many fields including mechanical, magnetic, electrical and thermal fields are taken into account. Meantime, it is worth noting that the penalty functions are introduced into this model for satisfying the mechanical and magneto-electric boundaries easily. For improving the convergence, accuracy, stability of numerical calculation, the displacement functions of METE-FGPPs are expressed by adopting Chebyshev polynomials. Based on the established unified model, the investigations of the vibration and acoustic radiation characteristics of METE-FGPPs are realized in the following discussion. Firstly, the convergence of the presented method is verified by investigating the convergence of truncated number, number of elemental radiator and penalty factor. Secondly, the accuracy, stability and versatility of the presented approach is confirmed by comparing with the results of existing literatures. Finally, the influence of some key parameters on the vibration and acoustic radiation of METE-FGPPs are discussed carefully.


ABSTRACT: The present study provides a nonlocal beam model for the stress analysis of beams bonded with modulus adhesives using Peridynamic Least Square Minimization (PDLSM) and Refined Zigzag Theory (RZT). RZT is highly useful for the efficient and accurate stress analysis of thin and thick load-bearing structures. RZT avoids the use of shear correction factors to estimate the transverse shear stresses. PDLSM introduces the local derivatives in terms of their nonlocal forms. The PDLSM is applicable for the approximation of any order derivatives. In this study, the PDLSM was employed for the solution of the equilibrium equations of RZT. The robustness of the present approach was demonstrated by considering dissimilar bonded aluminum (Al)-carbon fiber-reinforced polymer composite (CFRP) beam. Modulus graded adhesives have been successfully implemented to minimize the stress concentrations occur in the bonded structures. In order to investigate the effects of the modulus graded adhesive layers on the stress minimization at the critical locations of the bonded beam, various adhesive models were investigated in detail. Each adhesive profile experienced different deformation and stress states. The peak stress levels near the adherend-adhesive interfaces were observed to be alleviated with the use of a modulus graded adhesive layer.


ABSTRACT: Graphene platelets (GPLs) can be used to enhance mechanical and electric properties of the polymer polyvinylidene fluoride (PVDF), which efficiently controls and improves dispersion characteristics of wave motion in piezoelectric composite structures. Based on the first order shear deformation shell theory and the higher-order spectral elements, this paper proposes a semi-analytical formulation to investigate wave characteristics in the piezoelectric polymer nanocomposite cylindrical shell. The cylindrical shell is composed of PVDF reinforced with graphene platelets that are dispersed along the thickness direction, following various functionally graded patterns UD, FG-X and FG-O. Governing equation of waves in the piezoelectric composite shell is derived from Hamilton’s principle. By employing the Fourier transform, a second-order polynomial eigenvalue problem is obtained for wave analysis in frequency domain. Comparisons with other methods indicate that the present approach has the higher efficiency and accuracy on computation. Then, the study of significant parameters are conducted for analyzing the effects on wave propagation and the results show that dispersion behaviors of the piezoelectric nanocomposite shell are improved apparently by the addition of a small amount of GPLs. The increasing content of GPLs promotes the propagation of elastic waves and the richer concentration on the boundaries of the shells is beneficial to only the out-of-plane modes. Meanwhile, size parameters of GPLs provide an efficient means for the modulation of wave characteristics in
nanocomposite shells. It is envisaged that the present work can provide guidelines to develop novel smart nanocomposites and structures.


ABSTRACT: A novel approach for the vibration and buckling analysis of nanobeams with surface stress effects is presented in this paper. The material model is derived in which the bulk core of a beam is assumed to be a single crystalline material and have certain crystallographic directions. The beams are assumed to be covered by atomic layers with the same crystallographic directions on the top and bottom surfaces. A generic third order shear deformable beam theory is employed to derive the total energy functional of the beams. Minimizing the total potential energy functional by applying the p-Ritz method, the eigenvalue equations for the buckling and vibration of nanobeams with surface stress effects are obtained. The buckling and vibration behaviours of the beams considering the surface stress effects are discussed in detail and are compared with the results obtained from the first order beam theory and the Reddy's third order beam theory. It is found that in certain cases, both the first order and the Reddy's third order beam theories may not be able to capture the surface effect accurately on the vibration and buckling behaviours of the nanobeams. The effects of surface stresses on the buckling and vibration behaviours for nanobeams made of Ni single crystals obtained by the generic third order beam theory showed opposite trends to the ones obtained by the first order or the Reddy's third beam theory.


ABSTRACT: Bio-inspired conception is prevailing in structure design due to its mechanical promotion. In this study, crashworthiness analyses of twelve patterns of hexagonal prismatic tubes were numerically investigated by means of Finite Element method, including original hexagonal tube (OHT), full triangular hexagonal tube (FTHT), internal clone hexagonal tube (ICHT), double filled hexagonal tube (DFHT) and their reinforced hierarchical structures. Key crashworthiness indexes of different structures were compared with each other in detail. Corresponding formulas to predict the mechanical performance were derived representatively. As confirmed by both theoretical solutions and numerical results, the energy absorption capacities and deformation modes of the bio-inspired hexagonal prismatic tubes are superior to those of the original ones. Although they contribute substantially to the improvement of energy absorption ability, the different reinforcement ways show their different merits. Self-similar hierarchical designs can greatly increase the stability of the axial collapse process. While the lattice enhancement designs show higher SEA. All achievements in this study provide significant guidelines in the reinforcement design of lightweight structures.


ABSTRACT: Internal resonance and stress distribution of pipes conveying fluid at the supercritical flow around curves have been firstly investigated, with the goal of improving the mechanical fatigue properties of such pipes. Axial pre-pressure as a way of regulating the onset and growth of 1:3 internal resonance has been examined. Based on the direct multi-scale method and the Galerkin method, an approach has been proposed to analyze the nonlinear gyroscopic elastic system with time-dependent nonlinear perturbations. The tensile, bending, and resultant vibratory stress distributions of the pipe system have been determined in the presence of 1:3 internal resonance. Internal resonance degrading fatigue properties of the pipes has been highlighted. The numerical simulations support the analytical results. Then the analytical frequency responses are employed to identify factors that govern the internal resonance and stress distribution and to offer explanations as to why improving fatigue life is accompanied by suppression in the internal resonance. The boundary for incurring internal resonance suggests that appropriate axial pre-pressure should be modified in the presence of 1:3 internal resonance at different fluid velocities.

ABSTRACT: This paper presents an analytical approach on the nonlinear magneto-electro-elastic vibration of smart sandwich plate. The sandwich plate consists of a carbon nanotube reinforced nanocomposite (CNTRC) core integrated with two magneto-electro-elastic face sheets. For core layer, three types of carbon nanotube (CNT) distribution such as FG-O, FG-V, FG-X are considered while the volume fraction of $BaTiO_3$ − $CoFeO_3$ in each face sheet is chosen to be 0.5. It is assumed that the smart sandwich plate is rested on Pasternak-type elastic foundations and subjected to the combination of external pressure, thermal, electric and magnetic loads. The coupled constitutive relations are derived based on the Hamilton's principle in which the kinematic nonlinearity is defined using Reddy's higher order shear deformation theory. The analytical solutions which satisfy the boundary conditions are assumed to have the trigonometric form. The Galerkin method is used to obtain the closed form expressions of natural frequency, the relation between the frequency ratio and dimensionless amplitude and the dynamic response of the sandwich plate. The numerical results are conducted to illustrate the effect of geometrical parameters, CNT volume fraction, temperature and moisture increment, electric and magnetic potentials on the nonlinear vibration of smart sandwich plate. The reliability of present results is evaluated by comparing with the previous results based on different approach.


ABSTRACT: This paper presents a unified solution for free vibration analysis of thick functionally graded porous graphene platelet reinforced composite (FGP-GPLRC) cylindrical shells embedded in elastic foundations. The three-dimensional (3-D) theory of shell theory is introduced for theoretical formulation. The Rayleigh-Ritz method in conjugation with artificial spring technique are employed, where the arbitrary boundary conditions can be conveniently obtained. A unified solution which comprises of six different displacement functions is developed. The calculation performances including convergence rate and calculating efficiency with respect to different displacement functions are compared extensively. Besides, three elastic foundations (Winkler/ Pasternak/ Kerr foundations), four types of porosity distributions and three categories of GPL patterns are considered. Some benchmark results are provided for free vibration of FGP-GPLRC cylindrical shells resting on elastic foundations. At last, the effects of different boundary conditions, elastic foundations with various parameters, porosity coefficient, GPL weight fraction and geometrical parameters on the vibration are elucidated.


ABSTRACT: This paper investigates the flexural-torsional buckling behaviour of concrete-filled steel tubular circular arches under mechanical and thermal loading. A thermo-elastic pre-buckling analysis is first conducted by employing the principle of virtual work to derive the non-linear equations of equilibrium. The governing geometrical, equilibrium and constitutive material relations are numerically solved as a system of first-order differential equations with boundary conditions of pinned or fixed ends. The prebuckling analysis is then generalised to consider basic creep strain which is found to have a negligible impact on the prebuckling response under short-term heating. Subsequently, an elastic out-of-plane buckling analysis is performed using energy methods and the influence of thermal loading on buckling loads is examined. The results show that stability boundaries decrease with an increase in thermal loading, and that the rate of reduction is independent of the type of end-supports. Additionally, a Finite Element (FE) model is developed to analyse the inelastic lateral buckling strength of CFST arches under both uniform thermal and fire loading. The FE analysis is validated by comparison to the numerical method derived herein for the elastic buckling analysis.

**ABSTRACT:** In this paper, a new effective smeared stiffener method is presented for investigating the global buckling behavior of the laminated sandwich conical shells with lattice cores. Superimposing the stiffness contributions of the skins with those of the stiffeners, the total stiffness of the whole sandwich structure is obtained. Theoretical formulation is derived based on the first-order shear deformation theory. Using Galerkin method, the buckling load of sandwich conical shell is calculated. A 3-D model of the structure has been numerically analyzed by the finite element method in order to validate the accuracy of the analytical solutions. Finally, the effects of several important design parameters such as stiffener orientation angle, lamination angle, lattice core dimensions, number of the stiffeners, semi-vertex cone angle and skin thickness, have been examined on both buckling and specific buckling loads. The results indicated that at higher semi-vertex angles, an increment in the stiffener parameters such as the number, orientation angle and dimension, although increases the buckling load but decreases specific one. Moreover, the analytical approach led to high-accuracy results for higher skin thicknesses. It was found that variations of the lamination, inner and outer skin thicknesses, significantly affect the buckling load of sandwich conical shells. Results can be considered as a benchmark for the design of these structures which are extensively used in the aerospace structures.


**ABSTRACT:** The buckling characteristic of rectangular orthotropic plates under axial compression with simply supported boundary has been extensively studied. To enhance the structural efficiency, the stacking sequence of laminate should be optimized to maximize the critical buckling load. In this study, the discrete stiffness parameters are employed to yield the theoretical optimal ply orientation corresponding to the maximum critical buckling load at a layer level, and the buckling mode shapes are calculated analytically. Subsequently, the derivation is performed based on optimal ply orientation to derive the optimal stacking sequence of the laminate, in which a sign vector is adopted to minimize the bending-twisting coupling effects. As a result, two laminate optimal design problems are solved: maximizing critical buckling load with fixed thickness, as well as minimizing the thickness with buckling constraint. Two numerical examples are adopted to verify the yielded optimal solutions. Lastly, the theoretical optimal ply orientations exhibiting different load ratios and aspect ratios are presented.


**ABSTRACT:** Variable Angle Tow (VAT) composites always exhibit in-plane variable stiffness property, which provides the designer with an extended freedom in stiffness tailoring to achieve higher structural performance for lightweight composite structures. In this paper, a methodology based on a generalised Rayleigh-Ritz formulation is developed to study the thermomechanical buckling response of symmetrical VAT composite plates with general in-plane boundary constraint. It is assumed that the material is of temperature-independent and the panel is exposed to an arbitrary in-plane temperature change. In the framework of thermoelastic theory, the principle of thermoelastic complementary energy in conjunction with Airy’s stress function formulation, for the first time, is applied to solve the in-plane thermoelastic problem of the tow-steered plate. The non-uniform distribution of in-plane force resultant over the entire plate is determined by utilizing the Rayleigh-Ritz formulation enhanced by Lagrangian multiplier method. The merit of the proposed modelling strategy lies in that the application of Lagrangian multiplier method removes the restrictions inherent in conventional Rayleigh-Ritz formulation and thus provides generality to model general in-plane boundary constraint against thermal expansion or contraction. During the buckling analysis, the governing equation of thermomechanical buckling problem of the tow-steered plate under a combination of both temperature change and general in-plane boundary constraint is derived based on the third-order shear deformation theory of Reddy’s type. The accuracy
and robustness of the proposed Rayleigh-Ritz model is validated against finite element solutions and previously published results. Effects of boundary condition, fibre orientation angle and temperature change on the in-plane thermoelastico and thermomechanical buckling behaviours of VAT composite plates are studied by numerical examples. Finally, the mechanism of applying tow-steered technology to improve the thermomechanical buckling resistance of composite plates is explored.


ABSTRACT: Soft electro-active (SEA) materials can be designed and manufactured with gradients in their material properties, to modify and potentially improve their mechanical response in service. Here, we investigate the nonlinear response of, and axisymmetric wave propagation in a soft circular tube made of a functionally graded SEA material and subject to several biasing fields, including axial pre-stretch, internal/external pressure, and through-thickness electric voltage. We take the energy density function of the material to be of the Mooney-Rivlin ideal dielectric type, with material parameters changing linearly along the radial direction. We employ the general theory of nonlinear electro-elasticity to obtain explicitly the nonlinear response of the tube to the applied fields. To study wave propagation under inhomogeneous biasing fields, we formulate the incremental equations of motion within the state-space formalism. We adopt the approximate laminate technique to derive the analytical dispersion relations for the small-amplitude torsional and longitudinal waves superimposed on a finitely deformed state. Comprehensive numerical results then illustrate that the material gradients and biasing fields have significant influences on the static nonlinear response and on the axisymmetric wave propagation in the tube. This study lays the groundwork for designing SEA actuators with improved performance, for tailoring tunable SEA waveguides, and for characterizing non-destructively functionally graded tubular structures.


ABSTRACT: An overview of extended research recently pursued on unified continuous/reduced-order modeling and nonlinear dynamics of thermomechanical composite plates of interest in aerospace, mechanical and civil engineering is presented. Reduced models exhibit the fundamental features of geometrical nonlinearity and thermomechanical coupling of the underlying continua. The role of multiphysics coupling and the main features of nonlinear response obtained with variably refined minimal models is highlighted. Besides transverse mechanical excitation and mechanically or thermally-induced buckling, a variety of active thermal excitations, of body or boundary nature, are considered. Features of thermal response obtained with variably refined thermal assumptions are compared, in view of detecting cheap, yet reliable, models to be used for systematic numerical investigations. The effects of two-way thermomechanical coupling on local and global nonlinear dynamics are addressed through bifurcation diagrams, phase portraits and planar cross sections of 4D basins of attraction, highlighting the important role played by the slow transient thermal dynamics solely detectable with coupled models in the steady outcome of the swifter mechanical response. Conditions allowing to utilize partially coupled models or even the uncoupled mechanical one with prescribed steady temperature are discussed.


ABSTRACT: The preform architectures and the variability of the constituents of carbon fiber reinforced polymer (CFRP) composites materials can affect their mechanical behaviors significantly. This paper describes a systematic analysis of the low-velocity impact response and energy absorption capacity of biomimetic architected CFRP laminates. High-fidelity multiscale Finite Element (FE) models considering constituent material property uncertainties are developed to evaluate the effect of pitch angles on the impact performance of Bouligand architected composite laminates. Experimental results extracted from open literature have been used to validate the low velocity impact response of the CFRPs predicted by the numerical model. Constituent material property uncertainties are identified as parametric variables, and the peak impact load and energy absorption responses of the bio-inspired CFRPs are obtained with the verified numerical models. The main
conducted to quantify the effective nonlinear response of representative unit cells under periodic boundary conditions. Virtual characterization tests are validated against tensile and compressive experiments on a 3D printed sample lattice structure manufactured via multi-material jetting. For the development and calibration of macroscale continuum constitutive models for nonlinear elastic deformation of soft lattice structures at finite strains, virtual characterization tests are conducted to quantify the effective nonlinear response of representative unit cells under periodic boundary

ABSTRACT: Soft lattice structures and beam-metamaterials made of hyperelastic, rubbery materials undergo large elastic deformations and exhibit structural instabilities in the form of micro-buckling of struts under both compression and tension. In this work, the large-deformation nonlinear elastic behaviour of beam-lattice metamaterials is investigated by micromechanical nonlinear buckling analysis. The micromechanical 3D beam finite element model uses a primary linear buckling analysis to incorporate the effect of geometric imperfections into a subsequent nonlinear post-buckling analysis. The micromechanical computational model is validated against tensile and compressive experiments on a 3D-printed sample lattice structure manufactured via multi-material jetting. For the development and calibration of macroscale continuum constitutive models for nonlinear elastic deformation of soft lattice structures at finite strains, virtual characterization tests are conducted to quantify the effective nonlinear response of representative unit cells under periodic boundary


ABSTRACT: The flexural wave in a periodic non-uniform Euler-Bernoulli beam with arbitrarily contoured profiles is studied by utilizing the power series expansion method. The convergence criterion that makes the power series expansion method applicable is also illustrated. The validation is carried out by comparing the theoretical results with that from the finite element analysis when the beam thickness varies in different forms. For a quadratic thickness variation, the first band gap evolution versus the structural parameter is investigated, based on which a flexural-wave-based low-pass filter for frequency shunting and a rectangular lens for energy focusing are designed. It is revealed in the frequency domain analysis that the flexural wave with a lower frequency can propagate further when it travels into the wave filter. The lens designed exhibits a good focusing phenomenon with the focusing size smaller than one wavelength, and has a good performance at a certain finite frequency range. The theoretical method and design scheme can provide effective guidance for the flexural wave control.


ABSTRACT: Bonding the upper and lower faces of a nanocomposite porous plate with piezoceramics eventuates a smart multidisciplinary plate (SMP). In the current work, the deflection and stress responses of such SMPs under static electrical voltages and mechanical loads have been presented. The middle plate of SMP is assumed to have simultaneous functionally graded (FG) dispersions of pore and nanofiller along the thickness. The enhancement parts of the nanocomposite material are assumed to be carbon nanotubes (CNTs) and their agglomerations with random orientations. The mechanical properties of such three-part nanocomposites are evaluated using Eshelby-Mori-Tanaka (EMT)'s technique. The coupled electromechanical governing equation of SMP under static loads is obtained by the estimation of displacement field with Reddy's third order theory (Reddy's TSDT) of plates. The coupled equation is also treated by developing a mesh-free solution to examine the impacts of embedding nanoparticles and pores on the static electromechanical deflection and stress responses of SMPs. The results reveal that embedding pores up to around 90% of the volume of the middle plate leads to only 11.3% and 2.2% increase in mechanical and electrical deflections, respectively. Moreover, due to the formation of CNTs agglomerations, enhancing the middle plate with CNTs has a sharp positive impact on the reduction of deflections only up to some limited values of CNT volume fractions.


ABSTRACT: Soft lattice structures and beam-metamaterials made of hyperelastic, rubbery materials undergo large elastic deformations and exhibit structural instabilities in the form of micro-buckling of struts under both compression and tension. In this work, the large-deformation nonlinear elastic behaviour of beam-lattice metamaterials is investigated by micromechanical nonlinear buckling analysis. The micromechanical 3D beam finite element model uses a primary linear buckling analysis to incorporate the effect of geometric imperfections into a subsequent nonlinear post-buckling analysis. The micromechanical computational model is validated against tensile and compressive experiments on a 3D-printed sample lattice structure manufactured via multi-material jetting. For the development and calibration of macroscale continuum constitutive models for nonlinear elastic deformation of soft lattice structures at finite strains, virtual characterization tests are conducted to quantify the effective nonlinear response of representative unit cells under periodic boundary

effect sensitivity indices of the parameters are then calculated based on a variance-based global sensitivity analysis model. The presented studies clearly shows that smaller pitch angles and larger fiber longitudinal elastic modulus achieve more desirable impact resistance and better energy-absorption characteristics. This study aim to open up new possibilities for improving low velocity impact performance of CFRP composite laminates by adopting bionic design approach and considering constituent materials effect.
conditions. These standard tests, commonly used for hyperelastic material characterization, include uniaxial, biaxial, planar and volumetric tension and compression, as well as simple shear. It is observed that besides the well-known stretch- and bending-dominated behaviour of cellular structures, some lattice types are dominated by buckling and post-buckling response. For multiscale simulation based on nonlinear homogenization, the uniaxial standard test results are used to derive parametric hyperelastic constitutive relations for the effective constitutive behaviour of representative unit cells in terms of lattice aspect ratio. Finally, a comparative study for compressive deformation of a sample sandwich lattice structure simulated by both full-scale beam and continuum finite element models shows the feasibility and computational efficiency of the effective continuum model.

ABSTRACT: In this study, a multifunctional metastructure is proposed for vibration suppression by combining a honeycomb sandwich structure and a locally resonant metastructure. To localize the low-frequency bandgaps, an analytical model based on Hamilton's principle and the energy averaging technique is developed and is confirmed by a three-dimensional numerical simulation. Moreover, the effective mass density is determined analytically to give a physical insight into the wave control mechanism. Then, the dynamic behavior of the finite structure is investigated analytically. A finite element (FE) simulation and experimental measurements are performed to demonstrate the validity and accuracy of this dynamic model. Results show that the proposed metastructure exhibits an excellent vibration suppression performance, as well as a significant tunability. Furthermore, to claim multifunctionality, the out-of-plane compression behavior is analyzed experimentally. Experimental results indicate that mechanical properties of the proposed metastructure are significantly improved in comparison with a traditional square honeycomb sandwich structure. The proposed strategy is a novel multi-functional combination, which can help realize vibration control and high mechanical efficiency. This will significantly impact multiple research areas in vibration analysis and provide engineering applications.

ABSTRACT: This paper presents a simple and effective analytical method based on displacement potential functions for solving the 3D free vibration problem of the functionally graded circular plates with surface boundary conditions consisting of a transversely isotropic linearly elastic material. Material properties vary in the thickness direction according to exponential law and a special power law. Using the potential function method, the coupled governing equations are decomposed into two linear partial differential equations of fourth and second-order, and each equation solved independently by using the separation of variables with exact satisfaction of the two special boundary conditions in a pointwise manner. In addition, the analytical solutions are degenerated for two particular cases, including FG isotropic material and axisymmetric vibration. Also, the in-plane shear vibration has been discussed separately without considering the coupling of transverse and plane displacements. As an advantage of the proposed method, contrary to plate theories, all boundary conditions have been applied in a three-dimensional manner and surface-constraint form. Moreover, obtained solutions are applicable to any thickness ratio. In-plane/out of plane frequencies and mode shapes with nodal patterns are presented for different material properties and different thickness ratios. The results are compared with other analytical works as well as a 3D finite element (FE) solution obtained from the ABAQUS software, which demonstrates the effectiveness and high accuracy of the present method.

International Journal of Mechanical Sciences, Vol. 188, Article 105967, 15 December 2020,


ABSTRACT: Friction-induced vibration of a pad-on-disc frictional system is analyzed in this paper. Equations of motion are established considering the moving load simulation and using the Striebeck-type friction model. The partial differential equation of the disc vibration is reduced to the 1st-order mode by the Galerkin method, then the obtained frictional coupled ODE equations are solved by the Runge–Kutta method. The system stability is investigated by the complex eigenvalue analysis, which shows that the relative-equilibrium of the braking pad loses its stability through super-critical Hopf bifurcation in tangential direction, no matter where the contact position is. Simulations show that the pure-slip limit cycle is resulted at the initial stage of the friction-induced instability. When the rotating speed decreases to a turning point, the pure-slip vibration turns to be stick–slip one as the amplitude increases to a certain level. Then the amplitude of stick–slip type limit cycle vibration decreases with the further decreasing speed. The Hopf point and turning point are influenced by the contacting stiffness. Three types of limit-cycle vibrations are analyzed both in time- and frequency-domains, which shows the critical speeds (Hopf points) under 1:2 and 1:4 internal resonances are much higher than that under non-internal resonance The higher the critical speed is, the earlier the instability occurs. That is to say the strong dynamical coupling between the moving elements of a structure brings earlier occurrence of the frictional instability during braking procedure. As a counterpart of the pad, the disc vibrates also with large amplitude transversely. Influences of the braking initial displacement and the normal pressure between the pad and disc on the instability are also discussed.


ABSTRACT: The model of single-walled carbon nanotubes nonlinear vibrations, which is based on shell theory, is derived. The system of partial differential equations with respect to three displacements projections is obtained using the Sanders–Koiter shell theory and nonlocal elasticity. The system of nonlinear ordinary differential equations, which describes the nanotubes vibrations, is obtained by the Galerkin method. The harmonic balanced method is used to calculate free nonlinear vibrations. The bifurcation behavior of CNT vibrations owing to the Naimark–Sacker bifurcation is analyzed. Almost periodic vibrations of carbon nanotubes are investigated numerically. The nanotube periodic and almost periodic vibrations have three displacements projections u, v, w, which are commensurable. This is essential difference of the nanotube vibrations from macrosheets.


ABSTRACT: Linear and geometrically nonlinear vibrations of the three-layered functionally graded shallow shells with a complex form of the base are studied. It is assumed that outer and inner layers are made of functionally graded materials (FGM) or an isotropic material (metal or ceramic). The first-order shear deformation theory of shallow shells (FSDT) is employed. Effective material properties of layers are varied along the thickness according to a power law. To calculate different mechanical characteristics for different types of lamination schemes, analytical expressions are obtained. The linear problem is solved by combining the Ritz and the R-functions method. Linearization of the nonlinear problem is carried out by a novel original approach. Namely, the initial problem is reduced to solving a sequence of linear problems including those vibrations related to linear, special type of the elasticity problem and the nonlinear system of ordinary differential equations. Validation of the proposed method and the developed software has been examined on test problems for shallow shells with rectangular plan form and different boundary conditions. In order to demonstrate possibilities of the proposed approach, new results for laminated FGM shallow shells of the complex form of the base are presented. Effects of different material distributions, lamination schemes, curvatures, boundary conditions, and geometrical parameters on natural frequencies and backbone curves are reported and analyzed.

ABSTRACT: Deciphering the bio–chemo–mechanical mechanisms in tissue growth and deformation helps understand the morphogenesis of organs and organisms under physiological and pathological conditions. In this paper, we present a finite element method that can account for the interplay of volumetric growth, chemical transport, and mechanical deformation in soft tissues, such as tumors. The poroelastic theory and the volumetric growth model are combined to capture the essential growth and deformation traits of biological tissues. This method can not only simulate the bio–chemo–mechanical coupling processes in growing tissues, but also track their morphological instabilities and evolutions. The deformation and instability of interacting blood vessels in a growing tumor are considered as an example. The mechanisms underpinning the collapse of blood vessels observed in vascular solid tumors are revealed. This work holds promise for applications in the diagnosis and therapy of diseases such as cancer.

References listed at the end of the paper:
27 Tallinen T., Biggins J.S., Mechanics of invagination and folding: Hybridized instabilities when one soft tissue grows on another, Phys. Rev. E, 92 (2) (2015), Article 72720

ABSTRACT: This work deals with mechanical analysis of hyper-elastic lattices in the finite-strain range through multi-scale simulations and experimental testing. It describes designing appropriate unit cells (UCs) and mode-shapes to accurately predict mechanical behaviors of soft lattices in the finite-strain range. Lattices are based on three different types of repeating UCs in triangular, square and hexagonal shapes. Generic planar UCs consisting of beam-like structures are simulated to determine overall constitutive behaviors. In this respect, periodic boundary conditions are introduced in the finite-strain regime. Deformations of the unit cells and lattice are described on the basis of non-linear Green strains. Finite element (FE) solutions coupled with the Mooney–Rivlin constitutive equations are developed and solved using an iterative Newton–Raphson method and a multi-scale strategy. Then, the computational tool is applied to analyze lattice structures fabricated by three-dimensional (3D) printing technology. Samples are tested in tension and compression modes in different
directions revealing strong non-linear, directional and load-dependent responses. A detailed analysis of small-scale behavior of unit cells is presented. Large-scale and multi-scale FE models are also implemented to simulate experimental results with high accuracy and computational efficiency. Due to the absence of similar results in the literature, this paper would contribute to understanding of hyper-elastic behaviors of lattices at small-scale and be instrumental in the large-scale design and analysis of soft tissue structures.

References listed at the end of the paper:
1 Jiang X.Y., Metamaterial, InTech, Croatia (2012)
4 Ai L., Gao X.L., Metamaterials with negative Poisson’s ratio and non-positive thermal expansion, Compos. Struct., 162 (2017), pp. 70-84


https://doi.org/10.1016/j.ijnonlinmec.2018.11.006
ABSTRACT: A one-dimensional beam-like model is proposed to analyze the mechanical behavior of elastic double-layered pipes. Besides the classical kinematic descriptors of the Timoshenko beams, further terms are introduced to describe the local distortion of the cross-section, indeed able to warp, ovalize and perform longitudinal slipping of the two layers. A homogenization procedure is applied, making use of a corresponding three-dimensional model, in order to obtain the nonlinear, coupled, elastic response function of the beam-like model. Case studies for different load conditions are considered, and instability phenomena, which cause loss of the bearing capacity of the structure, are found by means of numerical integration of the relevant boundary value problems.


ABSTRACT: Nonlinear dynamics of a double-layer viscoelastic nanobeam embedded into an electromechanical system is investigated in this paper. The nanoelectromechanical system (NEMS) consists of two piezoelectric and Kelvin–Voigt viscoelastic nanobeams with visco-Pasternak medium in between. An electrostatic force which is the combination of DC and AC voltages is applied to the lower nanobeam through the fixed electrode. Taking into account both the small-scale effect and surface energy effect, the modified couple-stress theory together with Gurtin–Murdock elasticity theory is implemented. As intermolecular interactions between the fixed and lower electrodes, the influence of Casimir regime on the dynamic behavior of the NEMS device is also included in the proposed model. The differential motion’s equations are derived by means of Hamilton’s principle and discretized to a set of nonlinear ODEs through Galerkin’s decomposition procedure. In order to capture the steady-state dynamic response of the system, a combined shooting and arc-length continuation method is schemed. A comprehensive study has been carried out on the impact of viscoelasticity, size-dependency, surface effects, direct and alternating current voltages, piezoelectric voltage and visco-Pasternak parameters on the frequency-response behavior of the system near primary resonance. Furthermore, some bifurcation points in the frequency-response curves are addressed. The combined hardening–softening-type behaviors are observed in the dynamic response of the system. It has been shown that the nonlinear characteristics of the motion of the proposed NEMS device have sensitive-dependence on some of the mentioned parameters.


ABSTRACT: Concepts and tools of global dynamics play a meaningful role in enhancing the engineering design and safety of multistable structural systems in a dynamic environment. Basins of attraction topology can vary meaningfully as a function of system parameters, and the basin boundaries can be smooth or fractal. Fractal boundaries have important practical consequences as they lead to uncertainty with respect to the outcome of a given initial condition, thus reducing the system safety, which can be quantified through different dynamic integrity measures and their variation with a control parameter. In the present paper two key issues influencing the integrity measures and basins’ erosion profiles are addressed: transient escape and added random noise. Transient escape is a significant issue in many structural systems since it may lead to unwanted stresses and strains or exceed some safe design requirements in terms of maximum displacements and velocities. In turn, the random noise may increase the uncertainty of the systems, thus decreasing their practical safety and escape load. As a case study, the bistable von Mises truss is considered and the effects of transient escape and added random noise on the global dynamics of the harmonically excited truss are investigated in detail, clarifying their influence on the system safety as evaluated with different integrity measures.

ABSTRACT: This paper investigates the stability and bifurcations of periodic solutions in three-degree-of-freedom vibro-impact systems based on the explicit critical criteria and the discontinuous mapping method. Firstly, a six-dimensional Poincaré map is established by taking the impact surface as the Poincaré section. The explicit criteria including eigenvalue assignment and transversality condition are applied to determine the bifurcation point of co-dimension one pitchfork bifurcation. The stability and direction of the bifurcation solution are then studied by using center manifold reduction theory and normal form approach. Secondly, the bifurcation points of co-dimension-two Hopf–Hopf interaction bifurcation and pitchfork–Neimark–Sacker bifurcation are determined by applying the explicit critical criteria, and the local dynamic behaviors are examined in the neighborhood of these co-dimension-two bifurcation points. Finally, a six-dimensional Poincaré map formed by choosing the constant phase angle as the Poincaré section is used to investigate the existence and stability of grazing bifurcation based on the piecewise compound normal form map. The causes of the discontinuous jump and the coexistence of attractors near the grazing periodic motion are explained for the three-degree-of-freedom vibro-impact system with a moving constraint.


ABSTRACT: The objective of this paper is to use the constrained mixture theory of growth and remodeling to simulate the non-axisymmetric dilatation of a thick-walled aortic aneurysmal tissue. The primary load carrying constituents of the vascular tissue are elastin and collagen and the contribution of smooth muscle cells is secondary and therefore not included. In the homeostatic state a blood vessel is in a mechanobiologically stable regime. Hence, a loss of wall material is compensated by production of new material without a significant dilatation of the artery. Using the theory we find that a local degradation of the matrix material produces a mechanobiologically unstable regime that causes aneurysm formation. It induces an increase of mass locally achieved via production of new material that exceeds the removal of old material. The combined effects of loss of elastin, degradation of existing and deposition of new collagen as well as remodeling results in a continuous enlargement of the aneurysm bulge. Numerical results are included to verify and validate the theory.


ABSTRACT: In this research work, the nonlinear structural behavior of a non-parallel plates micro-actuator design is investigated via a reduced-order modeling. The micro-actuator is considered to be made of an initially flexible curved doubly-clamped microbeam and two evenly arranged stationary rectangular shaped out-of-plane electrodes of different lengths. The subsequent actuating attractive electrostatic force is mainly formed by the unevenness of the electric fringing-fields (non-parallel) electrodes arrangement. Results of this numerical investigation show that by increasing the actuation voltage the shallow arch behavior tend to reach a softening like behavior, mainly due to its dominant flexibility effect. With a further increase in the actuation voltage, the micro-arch starts to stretch and thus develops a hardening like behavior. Furthermore, and for certain values of the design parameters (mainly the shape and the length of the stationary electrodes), the shallow arch presented a snap-through like bi-stability behavior. Indeed, when the voltage approaches a certain critical value, the micro-arch static profile alters from a symmetrical shape to an asymmetric one, thus showing a symmetry breaking like behavior that depends a lot on the shape and length of the stationary non-parallel actuating electrodes. It is also demonstrated that by varying few of the micro-actuator design parameters, the variation of the normalized fundamental frequency showed rises and declines for certain ranges of the applied bias voltage. This approves that with such electrostatically actuated micro-actuator design, and with a smart tuning of its geometrical design parameters, one can obtain softening as well as hardening like behaviors. Modes frequency variations curves showed also that for certain actuation DC loads, it is possible to achieve a one-to-one internal resonance state involving both the first symmetric and the first antisymmetric modes of the shallow micro-arch.

ABSTRACT: A new formulation based on the classical Rayleigh–Ritz method (CRRM) is proposed in this study to conduct a geometrically nonlinear analysis for flexible multibody structures (FMSs). The proposed formulation can employ various shape functions for global discretization. This feature renders the proposed formulation straightforward and suitable for computer programming. The convergence characteristics of various shape functions for the proposed formulation were first examined with some numerical examples. Then we investigated the efficiency of the proposed formulation for obtaining converged solutions of the displacement, reaction force, maximum stress, and the location where the maximum stress occurs by comparing the degrees of freedom (DOFs) used for the proposed formulation and FEM formulation. The comparative study showed that the proposed formulation can be used to solve geometrically nonlinear FMS problems much more efficiently than the FEM formulation with the same level of accuracy.


ABSTRACT: In recent years, paper has been used as an alternative to traditional substrate materials in the development of strain sensors and accelerometers due to its flexibility, disposability due to environment low footprint and low cost. A lack of knowledge about the sources of nonlinearity in the mechanical behavior of paper makes difficult to consistently predict its performance. The characterization procedures available in the literature are based on both static and dynamic loading as a first attempt to describe the elastic behavior of paper in sensing applications. However, these procedures do not reveal the necessary information to describe the elastic behavior of paper under dynamic excitation. In this work, the nonlinear dynamic response of a harmonically excited paper-based cantilever beam is studied. A lumped model with a quadratic nonlinearity is adopted to describe the nonlinear response of paper-based cantilever beams. The obtained results show that the nonlinear resonance frequency response is dependent on the intrinsic properties of paper when discarding hygrothermal variations of paper as the main source of nonlinear behavior. It was found that the estimation of two nonlinear elastic parameters, alphap (hysteresis nonlinear parameter) and Eo (linear elastic modulus) could yield an improved description of the elastic behavior of paper subjected to vibrations. It was concluded that the existing paper characterization standards should be adapted to better predict the dynamic behavior of paper-based mechanical systems. Different types of paper materials were analyzed to study the influence of the intrinsic characteristics of paper on the nonlinear parameters.


ABSTRACT: Highly flexible laminated composite structures, prone to suffering large-deflection and post-buckling, have been successfully employed in a number of scenarios. Therefore, accurate predictions of their stress distributions in the geometrically nonlinear analysis are of paramount importance for their design and failure evaluation. In this paper, for composite beams subjected to large-deflection and post-buckling, we investigate the effectiveness of different geometrically nonlinear strain approximations for the description of their nonlinear static response and for the determination of stress distributions. For this purpose, a unified formulation of geometrically nonlinear refined beam theory based on the Carrera Unified Formulation (CUF) and a total Lagrangian approach constitutes the basis of our analysis. Accordingly, various kinematics of one-dimensional structures are formulated via an appropriate index notation and an arbitrary cross-section expansion of the generalized variables, leading to lower- to higher-order beam models with only pure displacement variables for laminated composite beams. In view of the intrinsic scalable nature of CUF and by exploiting the principle of virtual work and a finite element approximation, nonlinear governing equations corresponding to
various nonlinear strain assumptions can be straightforwardly and easily formulated in terms of fundamental nuclei, which are independent of the theory approximation order. Several numerical assessments are conducted, including large-deflection and post-buckling analyses of asymmetric and symmetric laminated beams under compression loadings. The numerical solutions are solved by using a Newton–Raphson linearization scheme along with a path-following method based on the arc-length constraint. Our numerical findings demonstrate the capabilities of the CUF model to calculate the large-deflection and post-buckling equilibrium curves as well as the stress distributions with high accuracy, which could be a basis to assess the validation ranges of various kinematics and different nonlinear strain approximations.


ABSTRACT: In this work, the nonlinear dynamic analysis of a parametrically base excited cantilever beam based piezoelectric energy harvester is carried. The system consists of a cantilever beam with piezoelectric patches in bimorph configuration and attached mass at an arbitrary position. The attached mass is placed in such a way that the system exhibits 3:1 internal resonance. The governing spatio-temporal equation of motion is discretized to its temporal form by using generalized Galerkin’s method. To obtain the steady state voltage response and stability of the system, Method of multiple scales is used to reduce the resulting equation of motion into a set of first-order differential equations. The response and stability of the system under principal parametric resonance conditions has been studied. The parametric instability regions are shown for variation in different system parameters such as excitation amplitude and frequency, damping and load resistance. Bifurcations such as turning point, pitch-fork and Hopf are observed in the multi-branched non-trivial response. By tuning the attached mass an attempt has been made to harvest the electrical energy for a wider range of frequency. Such kind of smart self-sufficient systems may find application in powering low power wireless sensor nodes or micro electromechanical systems.


ABSTRACT: A uniformly-valid plate theory, independent of the magnitudes of applied loads, is derived based on the two-dimensional plate theory obtained from series expansions about the bottom surface of a plate. For five different magnitudes of surface loads, it is shown by using asymptotic expansions that this unified plate theory recovers five well-known plate models in the literature to leading-order. This demonstrates its uniform validity. More generally, it provides a uniformly-valid plate model provided that two asymptotic conditions are satisfied, which can be checked as a posteriori. The weak formulation of the uniformly-valid plate equations is furnished, which can be used for finite element implementation.


ABSTRACT: This paper presents an isogeometric analysis (IGA) integrated with pseudo-arclength continuation technique in order to predict the elastic bifurcation behavior of geometrically nonlinear free-form curved beams under static loading. The presented formulation is based on the Timoshenko beam theory and accounts for shear deformations in the large-displacement analysis of curved beams. The full equilibrium path of the buckled structures including common types of static instabilities (e.g., the saddle–node and pitchfork bifurcations) can be tracked by the presented approach. Thanks to the exact geometry representation of the IGA framework, the objective of this paper is to extend the current literature of the nonlinear buckling analysis of curved beams to a broader range of free-form geometries with engineering applications. Some practical case studies with different loading scenarios are investigated and the results are validated against the commercial finite element software and well-established benchmark examples.

ABSTRACT: This paper focuses on the elastic structural stability analysis of the pressurized thin-walled functionally graded material (FGM) arches under temperature variation field. The material properties are temperature-dependent and thermo-elastic. The total potential energy function of the pinned–pinned arch was expressed explicitly by employing the classical thin-walled arch theories and admissible radial displacement functions. By means of the variational principle, the expressions of the critical buckling pressure were obtained analytically and verified numerically by developing a two-dimensional (2D) simulated model. The pre- and post-buckling equilibrium paths were depicted to explore the maximum pressure (buckling pressure). The comparison showed that the numerical results were in excellent agreement with the analytical solutions for different subtended angles, volume fraction exponents and temperature variations. In the end, the effects of volume fraction exponent and temperature variation were examined on the critical buckling pressure, the bending moment, the hoop force, the hoop strain and stress, the hoop and radial displacement components through the whole arch.


ABSTRACT: This paper deals with the nonlinear finite element computation of the prestressed state of structures partially filled with an incompressible inviscid liquid. The fluid is modeled by hydrostatic follower forces such that no volumetric fluid mesh is needed. Large deformations are taken into account and lead to the fluid height variation of the wetted surface to satisfy the fluid volume conservation. The main originality of this work lies on the use of a level-set approach to handle numerical integration on the fluid–structure interface. The method is developed on 3D problems considering a finite element quadratic mesh. Various numerical examples are computed using a Newton–Raphson algorithm and a quadratic convergence rate is reached by using consistent tangent stiffness operators.


ABSTRACT: A geometrically-exact non-linear beam model is developed based on conservation of momentum for application to arbitrarily-shaped beams having large deformations and large overall motions. Coordinate transformations are used to derive the non-linear inertial forces and moments and the non-linear relationships between displacements and strains, enabling rigorous consideration of kinematic and geometric nonlinearities. General non-linear equations of motion are first derived in a differential form, and then are simplified using practical engineering assumptions, including developments of a linearized model for small angles and small strains and a discretized model using finite volumes. A separation of displacements technique is proposed, which enables non-linear beam dynamics to be rigorously reduced to a series of piecewise-linear models. The proposed model is unique amongst existing geometrically-exact beam formulations in that it is formulated using dynamic quantities relative to intermediate non-inertial coordinates, allowing general Lagrangian formulations to be established in floating frames with inertial coupling effects, which is compatible with multibody models. The practical value of these theoretical developments is demonstrated through numerical implementation and convergence analyses. The piecewise-linear dynamic solver in which displacements are computed from an evolving configuration is shown to capture non-linear dynamic behaviors using linear solutions without iteration at each time-step.


ABSTRACT: We study the isometric conical deformation of an inextensible elastic sheet in response to a distributed external loading that is normal to the deformed sheet. The sheet is planar in the reference configuration and it deforms into a cone with a flower-shaped cross-section under load. These deformed configurations are distinguished by the number of lobes. We focus on the geometry and energetics of various
lobed-cones in the deformed configuration and discuss their relative stability. First, we assume that the displacements are small which leads to linear governing equations for the curvature that we solve analytically to yield sinusoidal solutions. Then, we relax this restriction on the magnitude of the displacement which leads to nonlinear governing equations, which we again solve analytically using Jacobi elliptic functions which are periodic but not sinusoidal. We show that the sinusoidal solution can be recovered in the limit that the external loads are small.


ABSTRACT: When an elastic tube reinforced with helical fibres is inflated, its ends rotate. In large deformations, the amount and chirality of rotation is highly non-trivial, as it depends on the choice of strain–energy density and the arrangements of the fibres. For anisotropic hyperelastic tubes where the material parameters are single-valued constants, the problem has been satisfactorily addressed. However, in many systems, the material parameters are not precisely known, and it is therefore more appropriate to treat them as random variables. The problem is then to understand chirality in a probabilistic framework. Here, we develop a procedure for examining the elastic responses of a hyperelastic cylindrical tube of stochastic anisotropic material, where the material parameters are spatially-independent random variables defined by probability density functions. The tube is subjected to uniform dead loading consisting of internal pressure, axial tension and torque. Assuming that the tube wall is thin and that the resulting deformation is the combined inflation, extension and torsion from the reference circular cylindrical configuration to a deformed circular cylindrical state, we derive the probabilities of radial expansion or contraction, and of right-handed or left-handed torsion. We refer to these stochastic behaviours as ‘likely inflation’ and ‘likely chirality’, respectively.


ABSTRACT: We refine a previously proposed semi-analytical method, and use it to study the effects of pre-stretch, compressibility and material constitution on the period-doubling secondary bifurcation of a uni-axially compressed film/substrate bilayer structure. It is found that compared with the case of incompressible neo-Hookean materials for which the critical strain is approximately 0.17 when the thin layer is much stiffer than the substrate, the critical strain when the Gent materials are used is a monotonically increasing function of the constant Jm that characterizes material extensibility, becoming as small as 0.12 when Jm is equal to 1, whereas for compressible neo-Hookean materials the critical strain is a monotonically decreasing function of Poisson’s ratio; the period-doubling secondary bifurcation seems to become impossible when Poisson’s ratio is approximately equal to 0.307. The latter result may indicate that when Poisson’s ratio is small enough there are other preferred secondary bifurcations — an example is given where a secondary bifurcation mode with 7/4 times the original period occurs at a lower strain value. The effect of a pre-stretch (compression or extension) in the substrate is not monotonic, giving rise to a critical strain that varies between 0.15 and 0.22.

B. Wu (1), A. Pagani (1), M. Filippi (1), W.Q. Chen (2) and E. Carrera (1)
(1) Mul Group, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, 10129 Torino, Italy
(2) Department of Engineering Mechanics, Zhejiang University, 310027 Hangzhou, China

ABSTRACT: Accurate predictions of the in-service nonlinear response of highly flexible structures in the geometrically nonlinear regime are of paramount importance for their design and failure evaluation. This paper develops a unified formulation of full geometrically nonlinear refined plate theory in a total Lagrangian approach to investigate the large-deflection and post-buckling response of isotropic rectangular plates. Based on the Carrera Unified Formulation (CUF), various kinematics of two-dimensional plate structures are consistently implemented via an index notation and an arbitrary expansion function of the generalized variables in the thickness direction, resulting in lower- to higher-order plate models with only pure displacement variables via
the Lagrange polynomial expansions. Furthermore, the principle of virtual work and a finite element approximation are exploited to straightforwardly and easily formulate the nonlinear governing equations. By taking into account the three-dimensional full Green–Lagrange strain components, the explicit forms of the secant and tangent stiffness matrices of unified plate elements are presented in terms of the fundamental nuclei, which are independent of the theory approximation order. The Newton–Raphson linearization scheme combined with a path-following method based on the arc-length constraint is utilized to solve the geometrically nonlinear problem. Numerical assessments, including the large-deflection response of square plates subjected to transverse uniform pressure and the post-buckling analysis of slender plates under compression loadings, are finally conducted to confirm the capabilities of the proposed CUF plate model to predict the large-deflection and post-buckling equilibrium curves as well as the stress distributions with high accuracy.

R. Hassani (1), R. Ansari (1) and H. Rouhi (2)  
(1) Department of Mechanical Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran  
(2) Department of Engineering Science, Faculty of Technology and Engineering, East of Guilan, University of Guilan, P.C. 44891-63157, Rudsar-Vajargah, Iran  
ABSTRACT: A numerical solution technique named as variational differential quadrature (VDQ) is adopted herein for the compressible nonlinear elasticity problems. The governing equations are obtained based on the virtual work principle by considering displacement as the unknown field. The neo-Hookean model is also considered for the hyperelastic behavior of material. In the solution method, an efficient vector–matrix formulation is developed from which the discretized governing equations are achieved from the weak form of equations in a direct approach. Simplicity in implementation and accuracy are among the features of the proposed approach. Moreover, it does not suffer from the locking problem and unphysical instabilities. Fast convergence rate and computational efficiency are other advantages of this method. A number of numerical examples are given to reveal the good performance of VDQ in the large deformation analysis of compressible and nearly-incompressible bodies.

ABSTRACT: The non-linear in-plane stability of pin-ended circular shallow arches is analytically investigated. The arches are made of functionally graded material with the material properties varying along the thickness. The external load is a radial concentrated force in the direct vicinity of the crown. The effect of the bending moment on the membrane strain is included in the one-dimensional model. The equations of the pre-buckling and buckled equilibrium are derived using the principle of minimum potential energy. Analytical solutions are found for both bifurcation and limit point buckling. Extensive parametric studies are performed to find and demonstrate the effect of various parameters on the buckling load and in-plane behaviour. It is found that most arches have multiple stable and unstable equilibria and the number of equilibria increases with the modified slenderness. When the load is applied exactly at the crown, the lowest buckling load is related to bifurcation buckling for most geometries and material compositions but when there is a small imperfection in the load position, only limit point buckling is possible. The position of the load can have quite a huge influence on the buckling load, therefore pin-ended functionally graded shallow arches are sensitive to small imperfections in the load position.

ABSTRACT: In this paper, a novel approximation method is presented for the large deformation analysis of moderately thick fiber-reinforced composite plates based on elasticity responses at asymptotic times. The displacement vector is approximated using separation of variables, by two functions of geometrical parameters
and one function of time parameter with unknown coefficients. The unknown coefficients of the time function are determined employing the least squares optimization and the Lagrange multipliers method. It is shown that the geometrically nonlinear responses of time-dependent composite plates can be obtained by finding the optimum coefficients of the time function with low computational cost and high precision.


(1) School of Mechanical Engineering, Vellore Institute of Technology, Vellore, 632 014, India
(2) Université de Lorraine, CNRS, Arts et Métiers ParisTech, LEM3, F-54000 Nancy, France
(3) LEME, UPL, Univ. Paris Nanterre, 50 rue de Sevres, 92410, Ville d’Avray, France


ABSTRACT: In this paper, the large amplitude free flexural vibration characteristics of fairly thick and thin functionally graded graphene platelets reinforced porous curved composite beams are investigated using finite element approach. The formulation includes the influence of shear deformation which is represented through trigonometric function and it accounts for in-plane and rotary inertia effects. The geometric non-linearity introducing von Karman’s assumption is considered. The non-linear governing equations obtained based on Lagrange’s equations of motion are solved employing the direct iteration technique. The variation of non-linear frequency with amplitudes is brought out considering different parameters such as slenderness ratio of the beam, curved beam included angle, distribution pattern of porosity and graphene platelets, graphene platelet geometry and boundary conditions. The present study reveals the redistribution of vibrating mode shape at certain amplitude of vibration depending on geometric and material parameters of the curved composite beam. Also, the degree of hardening behaviour increases with the weight fraction and aspect ratio of graphene platelet. The rate of change of non-linear behaviour depends on the level of amplitude of vibration, shallowness and slenderness ratio of the curved beam.

Cesare Davini (1), Antonino Favata (2) and Roberto Paroni (3)

(1) Università degli Studi di Udine, Via Parenzo 17, 33100 Udine, Italy
(2) Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy
(3) Dipartimento di Ingegneria Civile e Industriale, Università di Pisa, Pisa, Italy


ABSTRACT: We deduce a non-linear continuum model of graphene for the case of finite out-of-plane displacements and small in-plane deformations. On assuming that the lattice interactions are governed by the Brenner’s REBO potential of 2nd generation and that self-stress is present, we introduce discrete strain measures accounting for up-to-the-third neighbor interactions. The continuum limit turns out to depend on an average (macroscopic) displacement field and a relative shift displacement of the two Bravais lattices that give rise to the hexagonal periodicity. On minimizing the energy with respect to the shift variable, we formally determine a continuum model of Föppl–von Kármán type, whose constitutive coefficients are given in terms of the atomistic interactions.

Prashant Saxena (1,2), Narravula Harshavardhan Reddy (3) and Satya Prakash Pradhan (2)

(1) Glasgow Computational Engineering Centre, James Watt School of Engineering, University of Glasgow, Glasgow G12 8LT, UK
(2) Department of Mechanical & Aerospace Engineering, Indian Institute of Technology, Hyderabad, Kandi, Sangareddy 502285, Telangana, India
(3) Graduate Aerospace Laboratories, California Institute of Technology, Pasadena 91125, CA, USA


with a variational formulation, solving the resulting governing equations to determine the equilibria and checking the second variation condition for stability. Conjecture of possibility of multiple equilibria under a single coupled load, and attaining elastic and magnetic limit points made in the above two papers is confirmed in the present work for a circular membrane. Another main focus of this work is on the determination of wrinkling instability in the membrane due to magnetoelastic stresses. Wrinkles along one or both in-plane directions of membrane appear in a majority of loading scenarios due to compressive Maxwell stresses. Our computations demonstrate that wrinkles arise in the central region when dipole and inflation are in the same direction and in the annular region close to the edges when the dipole and inflation are in opposite directions.

Landon Brockmeyer (1), Elia Merzari (1), Jerome Solberg (2), Kostas Karazis (3) and Yassin Hassan (4) (1) Argonne National Laboratory, United States of America (2) Lawrence Livermore National Laboratory, United States of America (3) Framatome Inc., United States of America (4) Texas A&M University, United States of America


ABSTRACT: Flow induced vibrations can be detrimental to all manner of engineering applications with fluid flow. Heat exchangers with bundles of thin tubes experiencing a crossflow are especially susceptible to the unexpected onset of vibration. Heat-exchanger design necessarily involves extensive modeling and testing to ensure that significant vibrations cannot develop for any expected flow conditions. A properly validated numerical simulation can work in conjunction with physical experiments to identify problematic vibrations and allow for rapid iteration of design at relatively low expense. A high-fidelity fluid–structure interaction code has been developed by fully coupling CFD LES/DNS code Nek5000 and CSM code Diablo. The coupled code is used to simulate crossflow through a tube bundle in a geometry recreated after a physical experiment. Validation against this experiment involves comparing the amplitude and frequency spectrum for three different flow velocities. The velocities compared straddle the onset of large magnitude vibrations. The simulation accurately captures the onset of the vibrations with a marginally lower predicted frequency of vibration. When the onset velocity is compensated for the difference in natural frequency, the simulation results closely match the experiment. The continuous nature of the simulation measurements helps illustrate the fluid mechanics behind the pin motion and reveals the front to back propagation of the vibrations as the fluid velocity increases.

Tenghao Yin (1), Peng Wang (1), Honghui Yu (2) and Shaoxing Qu (1) (1) State Key Laboratory of Fluid Power & Mechatronic System, Key Laboratory of Soft Machines and Smart Devices of Zhejiang Province, Center for X-Mechanics, and Department of Engineering Mechanics, Zhejiang University, Hangzhou 310027, China (2) Department of Mechanical Engineering, The City College of New York, New York, NY 10031, USA


ABSTRACT: Dielectric elastomer (DE) attracts more and more attentions as soft membrane structures in engineering and biological fields, due to its lightweight and fast response under external electric field. In this paper, we study the deformation and failure of a DE membrane analytically and experimentally with a central circular hole actuated by both mechanical and electric loads. The size of the deformed hole in the experiments agrees well with the analytical prediction. The first invariant of the right Cauchy–Green deformation tensor is adopted to predict the mechanical failure of the membrane. The evolution of the hole and the failure modes of the membrane structure under different loading conditions are thoroughly investigated. We show that instead of reducing the load capacity, the applied voltage actually increases the maximum mechanical load that the membrane structure can carry. This work can help the design of the membrane structure with a hole and avoid the failure of the structure, which is very important for the membrane applications.

Renwei Mao (1), Bin Wu (2), Erasmo Carrera (2) and Weiqiu Chen (1) (1) Key Laboratory of Soft Machines and Smart Devices of Zhejiang Province and Department of Engineering Mechanics, Zhejiang University, Hangzhou 310027, PR China
ABSTRACT: Designing tunable resonators is of practical importance in active/adaptive sound generation, noise control, vibration isolation and damping. In this paper, we propose to exploit the biasing fields (induced by internal pressure and radial electric voltage) to tune the three-dimensional and small-amplitude free vibration of a thick-walled soft electro-active (SEA) spherical balloon. The incompressible isotropic SEA balloon is characterized by both neo-Hookean and Gent ideal dielectric models. The equations governing small-amplitude vibrations under inhomogeneous biasing fields can be linearized and solved in spherical coordinates using the state–space formalism, which establishes two separate transfer relations correlating the state vectors at the inner surface with those at the outer surface of the SEA balloon. By imposing the mechanical and electric boundary conditions, two separate analytical frequency equations are derived, which characterize two independent classes of vibration for torsional and spheroidal modes, respectively. Numerical examples are finally conducted to validate the theoretical derivation as well as to investigate the effects of both radial electric voltage and internal pressure on the resonant frequency of the SEA balloon. The reported analytical solution is truly and fully three-dimensional, covering from the purely radial breathing mode to torsional mode to any general spheroidal mode, and hence provides a more accurate prediction of the vibration characteristics of tunable resonant devices that incorporate the SEA spherical balloon as the tuning element.


ABSTRACT: We introduce a compact and unified shear deformation theory for plates with elasto-plastic behavior. We formulate the kinematics of the two-dimensional structure in a compact and unified manner using the Carrera Unified Formulation. This formulation allows for generalized expansions of the primary variables and through-the-thickness functions. We obtain the governing equations using the principle of virtual work and a finite element discretization. We solve the nonlinear equations using a Newton–Raphson linearization scheme, and linearize the constitutive equations using the algorithmic tangent moduli. We consider the J2 flow theory of plasticity, and use a backwards Euler scheme to update the stresses. We analyze the convergence, and compare the effectiveness of the Mixed Interpolation of Tensorial Components technique in contrasting the shear locking phenomenon in the nonlinear regime to the use of full and uniform reduced integration. We also conduct numerical assessments for plates under uniform and line loads. We compare the present results to those obtained by finite element commercial software, and demonstrate the computational efficiency of the present method.

References listed at the end of the paper:

ABSTRACT: In this theoretical work, the nonlinear dynamics of a pinned–pinned inclined functionally graded (FG) pipe conveying pulsatile hot fluid is investigated. The equation of motion of the FG pipe is derived based on the Euler–Bernoulli beam theory and plug-flow model, and that is subsequently solved using Galerkin discretization in conjunction with the incremental harmonic balance/Runge–Kutta method. First, the divergence of the FG pipe is investigated where it is mainly revealed that the inclination of the pipe with the vertical axis yields buckling at a higher temperature while the type of the associated bifurcation changes from pitchfork to saddle–node bifurcation. On the basis of this static instability, the pre- and post-buckled equilibriums of the inclined FG pipe are identified, and its nonlinear dynamics associated with each of these equilibrium states is subsequently studied based on the variations of some system parameters namely inclination angle, temperature, graded exponent of FG material, mean flow velocity, amplitude of pulsatile flow velocity and material damping. The corresponding results reveal some notable nonlinear dynamic characteristics of the inclined FG pipe like the appearance of both the principal primary and secondary parametric resonances in the pre-buckled state, exchange between softening and hardening structural behavior through period doubling/period demultiplying/fold bifurcation, movement of saddle periodic orbit with temperature leading to the unequal domains of attraction over the post-buckled equilibriums and the appearance higher order parametric resonances at low material damping.

References listed at the end of the paper:
7 Holmes P.J., Pipes supported at both ends cannot flutter, J. Appl. Mech., 45 (1978), pp. 619-622
18 Dong Li Y., Ren Yang Y., Nonlinear vibration of slightly curved pipe with conveying pulsating fluid, Nonlinear Dynam., 88 (2017), pp. 2513-2529
ABSTRACT: In this paper, a nonlinear theoretical model is developed for the dynamics of a flexible cantilevered pipe that is simultaneously subjected to internal and partially-confined external flows. The pipe under consideration discharges fluid downwards, which accumulates in a relatively large tank, and then flows upwards through a generally shorter annular region surrounding the pipe. Thus, the internal and external flows are interdependent and in opposite directions. A practical application of this system may be found in solution mining processes for brine production, and in the subsequent usage of the salt-mined caverns for hydrocarbon storage. The equation of motion is derived using the extended Hamilton’s principle to third-order accuracy with a separate derivation of the fluid-related forces associated with the internal and external flows. The equation is discretized using Galerkin’s scheme and solved via the pseudo-arclength continuation method and a direct time integration technique. Two pipes of different dimensions and materials are considered in this
study; the stability of these pipes is investigated with increasing flow velocity. Also, the influence of varying the length and tightness of the annular region on the dynamical behaviour of the pipes is explored theoretically. The predictions of the proposed model are compared to experimental observations from the literature. The results obtained are in excellent qualitative and good quantitative agreement with the experimental observations. Furthermore, this model predicts the frequencies of oscillation more accurately than linear theory.

References listed at the end of the paper:
1 Cesari F., Curioni S., Buckling instability in tubes subject to internal and external axial fluid flow, Proceedings of the 4th Conference on Dimensioning, Hungarian Academy of Science, Budapest (1971), pp. 301-311
4 Wang X., Bloom F., Dynamics of a submerged and inclined concentric pipe system with internal and external flows, J. Fluids Struct., 13 (4) (1999), pp. 443-460
5 Paidoussis M.P., Luu T.P., Prabhakar S., Dynamics of a long tubular cantilever conveying fluid downwards, which then flows upwards around the cantilever as a confined annular flow, J. Fluids Struct., 24 (1) (2008), pp. 111-128
8 Rinaldi S., Experiments on the Dynamics of Cantilevered Pipes Subjected to Internal and/or External Axial Flow, (Master of Engineering Thesis), Department of Mechanical Engineering, McGill University (2009)
12 Moditis K., Paidoussis M.P., Ratigan J., Dynamics of a partially confined, discharging, cantilever pipe with reverse external flow, J. Fluids Struct., 63 (2016), pp. 120-139
20 Benjamin T.B., Dynamics of a system of articulated pipes conveying fluid-i. theory, Phil. Trans. R. Soc. A, 261 (1307) (1962), pp. 457-486
24 Paidoussis M.P., Dynamics of cylindrical structures subjected to axial flow, J. Sound Vib., 29 (3) (1973), pp. 365-385
29 Taylor G.I., Analysis of the swimming of long and narrow animals, Phil. Trans. R. Soc. A, 214 (1117) (1952), pp. 158-183
ABSTRACT: Mathematical models of a non-linear shallow shell subjected to mechanical and temperature fields and one-sided corrosion wear are proposed. The governing equations are yielded by Hamilton’s principle. The geometric and physical non-linearity follow the Föppl–Kármán approximation and the plastic deformation theory, respectively. Dolinskii and Gutman corrosion models as well as the Duhamel–Neumann model are implemented. The governing mixed-type PDEs are derived. The algorithm to solve the PDEs is based on the method of variational iterations (MVİ) and linearization. Convergence of the developed procedure is proved. Theoretical considerations are validated by numerical results.

References listed at the end of the paper:

7 Carrera E., Brischetto S., Nali P., Plates and Shells for Smart Structures: Classical and Advanced Theories for Modeling and Analysis, John Wiley & Sons, UK (2011)
20 Ovchinnikov I.G., Pochtman Yu.M., Calculation and rational design of structures subjected to corrosive wear (review), Mater. Sci., 27 (2) (1992), pp. 105-116
36 Awrejcewicz J., Krysko A.V., Some problems of analysis and optimization of plates and shells, J. Sound Vib., 264 (2) (2003), pp. 343-376
ABSTRACT: Micro and nanoelectromechanical systems M/NEMS have been extensively investigated and exploited in the past few decades for various applications and for probing fundamental physical phenomena. Understanding the linear and nonlinear dynamical behaviors of the movable structures in these systems is crucial for their successful implementation in various novel technologies and to meet the long list of new sophisticated requirements. This paper presents a review for some of the recent topics pertaining to the dynamical behaviors, linear and nonlinear, of M/NEMS resonating structures. First, an overview is presented of the various used dynamical approaches to enhance the sensitivity of resonators for sensing applications. Then a review of some of the recent topics pertaining to the dynamical behaviors, linear and nonlinear, of M/NEMS resonating structures is presented. This paper presents a review for some of the recent topics pertaining to the dynamical behaviors, linear and nonlinear, of M/NEMS resonating structures. First, an overview is presented of the various used dynamical approaches to enhance the sensitivity of resonators for sensing applications. Then a summary is presented of the recent works on the linear and nonlinear mode coupling in M/NEMS resonator. Next, recent research is reviewed on coupled M/NEMS resonators, mechanically and electrically, leading to collective behaviors like mode localization. The final part of the paper discusses analytical approaches that have been developed to better understand and investigate the dynamical behavior of M/NEMS resonators focusing on the perturbation method the multiple time scales.

S. Sadamoto (1), M. Ozdemir (2), S. Tanaka (1), T.Q. Bui (3) and S. Okazawa (4)
(1) Graduate School of Engineering, Hiroshima University, Japan
(2) Department of Naval Architecture and Marine Engineering, Ordu University, Turkey
(3) Department of Civil and Environmental Engineering, Tokyo Institute of Technology, Japan
(4) Division of Mechanical Engineering, Faculty of Engineering, University of Yamanashi, Japan

ABSTRACT: Geometrically nonlinear analysis of flat, curved and folded shells under finite rotations is performed by enhanced six degrees of freedom (6-DOFs) meshfree formulation. Curvilinear surfaces are dealt with the concept of convected coordinates. Equilibrium equations are derived by total Lagrangian formulation with Green–Lagrange strain and Second Piola–Kirchhoff stress. Both shell geometry and its deformation are approximated by Reproducing Kernels (RKs). Transverse shear strains are considered by Mindlin–Reissner theory. Numerical integration of the stiffness matrix is estimated by using the Stabilized Conforming Nodal Integration (SCNI) method. To show accuracy and effectiveness of the proposed formulation and discretization, benchmark problems from the literatures are considered. Apart from reference solutions available in the literature, additional reference results based on finite element method (FEM) conducted by the present authors are also presented.

Kautuk Sinha (1), Niels K. Singh (1), Mostafa M. Abdalla (2), Roeland De Breuker (1) and Farbod Alijani (3)
(1) Department of Aerospace Structures and Materials, Faculty of Aerospace Engineering, Delft University of Technology, Kruiverweg 1, 2629 HS, Delft, the Netherlands
(2) Zewail City of Science and Technology, Sheikh Zayed District, 12588, Giza, Egypt
(3) LEME, UPL, Univ. Paris Nanterre, 50 rue de Sevres, 92410, Ville d’Avray, France


ABSTRACT: The article proposes a method developed for model order reduction in a Finite Element (FE) framework that is capable of computing higher order stiffness tensors. In the method, a truncated third order asymptotic expansion is used for transformation of an FE model to a reduced system. The basis matrix in the formulation of the reduced-order model (ROM) is derived from linear mode shapes of the structure. The governing equations are derived using Hamilton’s principle and the method is applied to geometrically nonlinear vibration problems to test its effectiveness. An initial validation of the numerical formulation is obtained by comparison of results from time domain nonlinear vibration analyses of a rectangular plate using Abaqus. Subsequently, a stiffened plate is modeled to test a more complex structure and a continuation algorithm is used in combination with the ROM to compute nonlinear frequency response curves. The validation of the stiffened plate has been performed through comparisons with the results of nonlinear vibration experiments. The experiments are conducted with Polytec Laser Doppler Vibrometer and PAK MK-II measurement systems for large amplitude vibrations to validate the nonlinear vibration analyses.

B. Anirudh (1), T. Ben Zineb (2), O. Polit (3), M. Ganapathi (4) and G. Prateek (4)
(1) Faculty of Aerospace Engineering, Technische Universiteit Delft, 2629 HS Delft, The Netherlands
(2) Université de Lorraine, CNRS, Arts et Métiers ParisTech, LEM3, F-54000 Nancy, France
(3) LEME, UPL, Univ. Paris Nanterre, 50 rue de Sevres, 92410, Ville d’Avray, France
(4) School of Mechanical Engineering, Vellore Institute of Technology, Vellore, 632 014, India


ABSTRACT: In the present study, the nonlinear flexural bending of thick and thin porous curved composite beams reinforced and functionally graded by graphene platelets is carried out using a three-noded C_0 continuous curved beam finite element developed introducing an efficient shear deformation theory based on trigonometric function. The nonlinearity through the strain–displacement relationship by introducing von Karman’s assumptions is considered. The nonlinear equilibrium equations resulting from minimum potential energy principle are numerically solved based on the direct iteration technique. The bending nonlinear features through the load–deflection relationship are presented by selecting various design parameters like long and short beams, shallow and deep curved cases, support conditions, the variation of graphene platelets in the metal foam and the existence of porosity. This investigation reveals that the level of nonlinearity gets noticeably affected by the depth coupled with the curved beam slenderness ratio.

A. Amor, A. Fernandes and J. Pouget (Sorbonne Université, CNRS, Institut Jean le Rond d’Alembert, UMR 7190, F-75005 Paris, France), “Snap-through of elastic bistable beam under contactless magnetic actuation”,

https://doi.org/10.1016/j.ijnonlinmec.2019.103346
ABSTRACT: We propose the modeling of contactless switching of a bistable slender beam using Laplace force actuation. The model beam is based on the elastica approach which allows large amplitudes of the cross-section rotation and large elastic transformations. Furthermore, the extensibility of the elastic beam is accounted for and it plays a crucial role in the switching process. The study is devoted particularly to the actuation mechanism of the bistable beam uniformly loaded by a density of lineic force which is permanently perpendicular to the beam deformation. Such actuation can be produced by the Laplace force due to an electric current traveling along the beam placed in a magnetic induction. The mechanism of the bistable switching is analyzed in detail using a variational formulation and stable and unstable equilibria are described. We investigate numerically the post-buckling behavior to capture the exact buckling modes that follow the path in the unstable region. The numerical simulations are also used to obtain the bistable response in terms of actuating force (or electric current amplitude), beam end-shortening and mid-point displacement of the beam. We also perform a finite element computation and provide a validation of the results obtained by solving the set of equations of the boundary value problem. The second part of the work is focused on the experimental validation of the switching mechanism of the bistable beam presented in the analytical part. We design an experimental set-up for the fine measurement of the mid-point displacement of the bistable beam as a function of the electric current traveling the beam. The region of bistable instability is revealed by experimental adjustment of the bifurcation point associated with the actuating force. All the results extracted from experimental tests are compared to those coming from the modeling investigations, which ascertains with good accuracy the approach of the proposed model for bistable beam.

Lei Li (1,2), Wenming Zhang (1), Jing Wang (3), Kaiming Hu (1), Bo Peng (1) and Mingyu Shao (2)
(1) State Key Laboratory of Mechanical System and Vibration, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
(2) School of Transportation and Vehicle Engineering, Shandong University of Technology, Zibo 255049, China
(3) Library, Tianjin University, Tianjin, 300350, China
“Bifurcation behavior for mass detection in nonlinear electrostatically coupled resonators”, International Journal of Non-Linear Mechanics, Vol. 119, Article 103366, March 2020,
https://doi.org/10.1016/j.ijnonlinmec.2019.103366

ABSTRACT: The nonlinear coupled vibrations widely exist in coupled resonant structures, which can lead to complex dynamic bifurcation behavior and expand the research scope of fundamental physics. A new micro-mass detection method is proposed by using bifurcation jumping phenomenon in nonlinear electrostatically coupled resonators in this article. Considering the fundamental frequency excitation, the one-to-one internal resonance equations to describe electrostatically coupled resonant sensor are obtained by using Hamilton’s principle and Galerkin method. Then, the perturbation analysis method is introduced to study the response and stability of the system for small amplitude vibration. Through bifurcation analysis, it is found that the isolated response branches appear in nonlinear electrostatically coupled resonators and present the physical conditions of this phenomenon. Typically, we demonstrate the exploitation of the bifurcation jump phenomena of two electrostatically coupled microbeam resonators to realize the mass quantitative detection and threshold detection, which overcomes the detection inaccuracy caused by frequency drift in the nonlinear vibration. Finally, the numerical experiments verify the validity of the method. The results of this paper can be potentially useful in micro-mass detection.

Ping Du (1), Hui-Hui Dai (2), Jiong Wang (1) and Qiongyu Wang (1)
(1) School of Civil Engineering and Transportation, South China University of Technology, 510640 Guangzhou, Guangdong, China
(2) Department of Mathematics, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon Tong, Hong Kong
https://doi.org/10.1016/j.ijnonlinmec.2019.103370
ABSTRACT: In this work, we study the growth-induced bending deformations of multi-layered hyperelastic plates. First, under the assumption of plane strain, we formulate the 3D governing system for a multi-layered hyperelastic (neo-Hookean) plate, which incorporates the growth parameters in the different layers. Based on the governing system and by adopting a series expansion–truncation approach, we derive a plate equation system. In the case of traction-free boundary conditions, we solve the plate equation system explicitly and obtain some simple analytical results, which can be used to describe the deformations of the multi-layered plates induced by growth. We verify the accuracy and efficiency of the analytical results through comparisons with some numerical and experimental results. We also provide a comparison between the analytical results obtained for single- and multi-layered hyperelastic plates. Furthermore, we analyze the properties of residual stresses in the multi-layered plates. The plate equation system and the analytical results obtained here have wide potential applications in the design of intelligent soft devices.


ABSTRACT: A homogeneous continuous visco-elastic shear-beam, describing the dynamics of base-isolated tall buildings exposed to a uniformly distributed steady wind flow, is studied. The shear beam is constrained at the bottom end by a nonlinear visco-elastic device and free at the top end. The aeroelastic effects, responsible for self-excitation, are evaluated via the quasi-static theory. The occurrence of Hopf bifurcation is detected. Critical and post-critical behavior is analyzed by applying a perturbation scheme. The critical wind velocity and the associated complex galloping mode are found. The steady value of the oscillation amplitude on the stable limit-cycle and its stability are evaluated as function of the mean wind velocity. The mechanical performances of the structure are investigated in accord with the effectiveness of the visco-elastic isolation system. A passive controller is proposed to increase the galloping wind velocity and to reduce the amplitude of the limit-cycle.

Ehab E. Basta (1), Mehdi Ghommem (1) and Samir A. Emam (2,1)
(1) Department of Mechanical Engineering, American University of Sharjah, P.O. Box 26666, Sharjah, United Arab Emirates
(2) Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt

ABSTRACT: In this paper, we investigate the nonlinear vibrations of a metamaterial structure that consists of a host Euler–Bernoulli beam attached to a periodic array of spring–mass–damper subsystems deployed for vibration absorption. The main objective is to demonstrate that the capability of the metastructure to suppress vibrations can be significantly enhanced when the absorbers are tuned to the optimal frequency. A MATLAB-based optimization algorithm is used to minimize a given objective function for the optimal tuning frequency. A mathematical model is first utilized to perform the linear free and forced vibration analyses. The effect of the local resonators (absorbers) on the suppression of the oscillations of the host beam is studied. The ability to mitigate the vibration of the host structure at a desired resonant frequency is achieved by tuning the resonant frequencies of the local absorbers. More interestingly, the results show that the simultaneous suppression of several modes is possible by tuning and properly placing each absorber along the host structure. Furthermore, the impact of the resonators on the nonlinear behavior of the main structure when subjected to external forcing over an extended frequency range is investigated. The numerical study reveals that proper tuning of the local resonators allows significant vibration suppression of the metamaterial beam when being excited in the neighborhood of the natural frequencies. We demonstrate the capability of the metamaterial structure to withstand external loadings even when operating near resonance. Finally, we combine the nonlinear mathematical model with an optimizer to identify the number and tuning frequencies of the absorbers that maximize the vibration suppression. The optimization results show that significant mitigation can be achieved by tuning properly the absorbers in the vicinity of the host structure’s natural frequencies.

M.R. Delfani (1) and H.M. Shodja (2)
(1) Faculty of Civil Engineering, K. N. Toosi University of Technology, Tehran, Iran
(2) Institute for Nanoscience and Nanotechnology, Sharif University of Technology, Tehran, Iran

ABSTRACT: By considering a single-walled carbon nanotube (SWCNT) as a two-dimensional elasica obtained from the roll-up of a graphene sheet into a circular tube, the present paper develops a precise well-posed continuum theory for describing the entire torsional behavior of SWCNTs from an initial unloaded state through their ultimate levels of loading. In addition, the proposed approach can capture the dual ideal shear strengths as well as the asymmetrical behavior of chiral tubes with respect to the direction of the applied torsional loading. The theory incorporates a highly nonlinear constitutive equation which provides information about the nanoscopic morphological parameters of the tubes. As it will be shown, the longitudinal and twist deformations are coupled. Accordingly, a parameter referred to as the torsion-induced extension will be defined.

Matteo Strozzi (1), Valeri V. Smirnov (2), Leonid I. Manevitch (2) and Francesco Pellicano (3)
(1) Department of Sciences and Methods for Engineering, University of Modena and Reggio Emilia, Via Giovanni Amendola 2, 42122 Reggio Emilia, Italy
(2) N.N. Semenov Institute of Chemical Physics, Russian Academy of Sciences RAS, 4 Kosygina street, 119991 Moscow, Russia
(3) Department of Engineering “Enzo Ferrari”, University of Modena and Reggio Emilia, Via Pietro Vivarelli 10/1, 41125 Modena, Italy


ABSTRACT: The nonlinear resonance interaction and energy exchange between bending and circumferential flexure modes in single-walled carbon nanotubes is studied. First, the results of an analytical model of the resonance interaction between the considered nonlinear normal modes previously developed are reported. This approach was based on a reduced form of the Sanders–Koiter thin shell theory obtained by using simplifying hypotheses on the shell deformations. The analytical model predicted that the nonlinear resonance interaction leads to energy localization in a certain coherence domain over the carbon nanotube surface within a specific range of the initial oscillation amplitude. Then, a numerical model of the resonance interaction between the analysed nonlinear normal modes in the framework of the complete Sanders–Koiter thin shell theory is reported. Numerical simulations are performed to verify the energy localization phenomenon over the carbon nanotube surface and to compute the threshold values of the initial oscillation amplitude giving rise to energy localization. Finally, from the comparison between the two different approaches, it is obtained that the results of the numerical model for the threshold values of the nonlinear energy localization confirm with very good accuracy the predictions of the analytical model.

V.A. Krysko (1), J. Awrejcewicz (1), M.V. Zhigalov (2) and V.A. Krysko (2)
(1) Department of Automation, Biomechanics and Mechatronics, Lodz University of Technology, 1/15 Stefanowskiego St., 90-924 Lodz, Poland
(2) Department of Mathematics and Modeling, Saratov State Technical University, 77 Politehnicheskaya Str., 410054 Saratov, Russian Federation


ABSTRACT: In this paper, a mathematical model of multilayer orthotropic shells is developed on the basis of the third-order approximation of the Sheremetev–Pelekh–Reddy theory, taking into account geometric non-linearity. Conservative difference schemes of the considered model are derived and validated based on the variation-difference method. The influence of the number of layers on the stability of shells is considered. In addition, the stability of symmetric/asymmetric packages of multilayer shells is also discussed.

References listed at the end of the paper:

ABSTRACT: Natural frequencies and mode shapes are functions of the equilibrium state. In the large displacement regime, pre-stresses may modify significantly the modal behaviour of structures. In this work, a geometrical nonlinear total Lagrangian formulation that includes cross-sectional deformations is developed to analyse the vibration modes of composite beams structures in the nonlinear regime. Equations of motion are solved around nonlinear static equilibrium states, which are identified using a Newton–Raphson algorithm along with a path-following method of arc-length type. Different boundary conditions and stacking sequences are analysed. It is shown that vibration modes are strongly modified by nonlinear phenomena. Moreover, models that do not describe those effects accurately may result in misleading results, especially if compression is dominant. In fact, results show a crossing phenomenon in the post-buckling regime of an asymmetric cross-section, whereas it is completely unforeseen by the linearized analysis.


ABSTRACT: The work presented here alludes to the application of a semi-analytical method for ultimate strength predictions of square composite plates with geometric imperfections that are subjected to uniaxial in-plane compressive load. The Ritz method is developed with the assumptions of large deflections and higher-order shear deformation theory that accounts for through-the-thickness deformation. Therefore, some thick and relatively thick simply-supported square laminates are analyzed in this study. To obtain the ultimate strength of the plates, we consider two geometric degradation models to assess the degradation zone around the failed location. To predict the first ply failure load and also nonlinear response in the progressive damage analysis, we use the Hashin–Rotem failure criteria. We present results with respect to the number of plies, thickness of the laminates and different magnitudes of imperfection for some symmetric lay-ups.

E. Ruocco (1) and J.N. Reddy (2)
(1) Department of Engineering, University of Campania L. Vanvitelli, Aversa (Ce), Italy
(2) Department of Mechanical Engineering, Texas A&M University, College Station, TX, 77843-3123, USA

ABSTRACT: The paper analyzes the elastic–plastic buckling behavior of thick, rectangular nanoplates embedded in a Winkler–Pasternak foundation, adopting the Reddy third-order plate theory in nonlocal elasticity. Elasto-plasticity is accounted for by considering two alternative plasticity theories, namely the J2 flow incremental and the J2 deformation theory, with material properties defined by a Ramberg–Osgood relation. An iterative procedure is proposed to obtain the critical load, and the corresponding critical mode, of plates simply supported on two opposite edges under applied uniaxial and biaxial loading conditions. Extensive analysis investigates the effects of geometrical, constitutive, and nonlocal parameters on the critical behavior of plates with different boundary conditions. To the best of the authors’ knowledge, there are no findings about elastoplastic buckling of nanoplates in the existing literature. It is therefore hoped that the results obtained may provide a helpful basis for comparison for future investigations.

Andrey Melnikov (1), Luis Dorfmann (2) and Ray W. Ogden (3)
(1) Department of Earth Sciences, Memorial University of Newfoundland, St. John’s, Canada
(2) Department of Civil and Environmental Engineering, Tufts University, Medford, MA 02155, USA
(3) School of Mathematics and Statistics, University of Glasgow, Glasgow G12 8SQ, UK
ABSTRACT: This paper is concerned with the bifurcation analysis of a pressurized electroelastic spherical shell with compliant electrodes on its inner and outer boundaries. The theory of small incremental electroelastic deformations superimposed on a radially finitely deformed electroelastic thick-walled spherical shell is used to determine those underlying configurations for which the superimposed deformations do not maintain the perfect spherical shape of the shell. Specifically, axisymmetric bifurcations are analyzed, and results are obtained for three different electroelastic energy functions, namely electroelastic counterparts of the neo-Hookean, Gent and Ogden elastic energy functions. For the neo-Hookean energy function it was reported previously that for the purely mechanical case axisymmetric bifurcations are possible under external pressure only, no bifurcation solutions being possible for internally pressurized spherical shells. In the case of an electroelastic neo-Hookean model bifurcation under internal pressure becomes possible when the potential difference between the electrodes exceeds a certain value, which depends on the ratio of inner to outer undeformed radii. Results obtained for the three classes of model are significantly different and are illustrated for a range of fixed values of the potential difference. Although of less practical significance, results are also shown for fixed charges, and these are both different between the models and different from the case of fixed potential difference.


ABSTRACT: A displacement-based, geometrically nonlinear finite element model is developed for lattice core sandwich panels modeled as 2-D equivalent single-layer (ESL), first-order shear deformation theory (FSDT) micropolar plates. The nonlinearity is due to the moderate macrorotations of the plate which are modeled by including the von Kármán nonlinear strains in the micropolar strain measures. Weak-form Galerkin formulation with linear Lagrange interpolations is used to develop the displacement finite element model. Selective reduced integration is used to eliminate shear locking and membrane locking. The novel finite element model is used to study the nonlinear bending and linear free vibrations of web-core and pyramid core sandwich panels. Clamped and free edge boundary conditions are considered for the first time for the 2-D micropolar ESL-FSDT plate theory. The present 2-D finite element results are in good agreement with the corresponding detailed 3-D FE results for the lattice core sandwich panels. The 2-D element provides computationally cost-effective solutions; in a nonlinear bending example, the number of elements required for the 2-D micropolar plate is of the order 1000, whereas for the corresponding 3-D model the order is 100000.


ABSTRACT: The nonlinear mechanical response of highly flexible plates and shells has always been of primary importance due to the widespread applications of these structural elements in many advanced engineering fields. In this study, the Carrera Unified Formulation (CUF) is used in a total Lagrangian framework to analyze the large-deflection and post-buckling behavior of isotropic rectangular plates based on different nonlinear strain assumptions. The scalable nature of the CUF provides us with the ability to tune the structural theory approximation order and the strain–displacement assumptions opportunely. In this work, the Newton–Raphson linearization scheme with a path-following constraint is used in the framework of the 2-D CUF to solve the geometrically nonlinear problems to draw important conclusions about the consistency of many assumptions made in the literature on the kinematics of highly flexible plates. In this regard, the effectiveness of the well-known von Kármán theory for nonlinear deformations of plates is investigated with different modifications such as the thickness stretching and shear deformations due to transverse deflection. The post-buckling curves and the related stress distributions for each case are presented and discussed. According to the results, the full Green–Lagrange nonlinear model could predict the nonlinear behavior of plates efficiently and accurately, whereas other approximations produce considerable inaccuracies in the case of thick plates subjected to large rotations and deflections.

Yifan Lu (1), Qi Shao (1), Marco Amabili (2), Honghao Yue (1) and Hongwei Guo (1)
ABSTRACT: In recent years, with the increasing use of membrane structures in space applications, the problems of large-amplitude (compared to the thickness) vibrations arise; leading to the degradation of their working performance. It is challenging to control the large-amplitude vibrations of membranes due to the high flexibility, low damping, and strong geometrical nonlinearity. In this study, polyvinylidene fluoride (PVDF) actuators are considered to develop the active vibration control of a pre-tensioned Kapton membrane. The governing equations are established based on the geometrically nonlinear theory of plates, taking into account the modal control force induced by the actuators. To analyze the nonlinear dynamic characteristics of the membrane, the theoretical and approximate solutions of nonlinear frequencies of the membrane are obtained, and the discrepancies between the two solutions under different vibration amplitudes are discussed. Control performance for both free vibration and harmonic forced vibration of the membrane is numerically studied. A comprehensive parametric study is carried out to investigate the influences of different system parameters, including the pretension and the size of the membrane, and the position and number of the actuators, on the control performance. Analytical results indicate that the vibration of the membrane can be effectively suppressed with the appropriately laminated PVDF actuators. The results of this research can be extended to the active control of different gossamer space structures.


ABSTRACT: As a basic structure and a fundamental vibration issue, the vibration of cantilever structures has been thoroughly studied, and there are some generally accepted conclusions, for example, internal resonance does not take place in the transverse vibration of a basic cantilever beam. In this study, by including 3:1 internal resonance caused by gravity, mode interactions of hanging cantilever beams are firstly presented in the primary and secondary external resonance. The second mode can be easily and remarkably stimulated in the primary resonance, while the first mode response can also be generated in the secondary resonance. Besides, internal resonance complicates the dynamic characteristics of mode responses, such as ring-like and other strange response shapes, and further influences the mode interactions in the primary resonance. Furthermore, with non-strict internal resonance and large excitation amplitude, the chaotic motion can be achieved in the secondary resonance, which may not occur in the primary resonance. In summary, the research in this paper shows that, although it is a fundamental subject of vibration, there are still some unknown phenomena in the vibration of cantilever beams. Understanding these phenomena will undoubtedly help design engineering systems and control structural vibration.

Emilio Turco (1), Emilio Barchiesi (2), Ivan Giorgio (3) and Francesco dell’Isola (4)
(1) Department of Architecture, Design and Urban planning (DADU), University of Sassari, Italy
(2) MEMOCS, International Research Center for Mathematics and Mechanics of Complex Systems, University of L’Aquila, Italy
(3) Department of Civil, Construction-Architectural and Environmental Engineering, University of L’Aquila, Italy
(4) Department of Structural and Geotechnical Engineering, University of Rome “La Sapienza”, Italy

ABSTRACT: Among the most studied models in mathematical physics, Timoshenko beam is outstanding for its importance in technological applications. Therefore it has been extensively studied and many discretizations have been proposed to allow its use in the most disparate contexts. However, it seems to us that available discretization schemes present some drawbacks when considering large deformation regimes. We believe these
drawbacks to be mainly related to the fact that they are formulated without keeping in mind the mechanical phenomena for describing which Timoshenko continuum model has been proposed. Therefore, aiming to analyze the deformation of complex plane frames and arches in elastic large displacements and deformation regimes, a novel intrinsically discrete Lagrangian model is here introduced whose phenomenological application range is similar to that for which Timoshenko beam has been conceived. While being largely inspired by the ideas outlined by Hencky in his renowned doctoral dissertation, the presented approach overcomes some specific limitations concerning the stretch and shear deformation effects. The proposed model is applied to get the solutions for some relevant benchmark tests, both in the case of arch and frame structures. It is proved that, also when shear deformation effects are of relevance, the enriched, yet simple, model and numerical computation scheme herein proposed can be profitably used for efficient structural analyses of nonlinear mechanical systems in rather nonstandard situations.

https://doi.org/10.1016/j.ijnonlinmec.2020.103513

ABSTRACT: The von-Kármán effect on the free torsional vibrations of carbon nanotube made of functionally graded materials (FGMs) is inspected in this research using the theory of nonlocal elasticity. The material properties are assumed to change continuously through the radius of the FGM carbon nanotube (FGM-CNT) according to a power-law distribution. Using Hamilton’s principle, the equations of nonlinear torsional vibrations is obtained. The torsional frequencies and mode shapes of FGM-CNT are derived for two boundary conditions, namely, clamped–clamped and clamped–free. The approximate-analytical solution for the nonlocal nonlinear natural frequencies is extracted using multiple scales method (MSM). Next, the effects of the FG index, the length, the outer radius, the amplitude of vibration and the mode number on the vibrational characteristics of the FGM-CNT are studied. The obtained results in this paper can be used as a key tool for efficient and exact design of devices comprising of torsional nanotubes.


ABSTRACT: A numerical approach is presented to find the equilibrium solutions of a soap film spanning a flexible but inextensible boundary (Giomi and Mahadevan 2012). Various shapes of the soap films are quantified in terms of a dimensionless parameter. Numerical stability and bifurcation analysis is performed. Specifically, estimates of two critical values of the bifurcation parameter responsible for the onset of non-planar shape and first self contact in plane are provided. These two critical values are not known analytically.

https://doi.org/10.1016/j.ijnonlinmec.2020.103510

ABSTRACT: A variety of methods have been proposed to improve the performance of dielectric elastomer transducers, which lead to the anisotropic electromechanical behavior of the material. This paper theoretically analyzes the effect of material anisotropy on the diffuse modes of instability in dielectric elastomer plates. As a first step, a transversely isotropic material is considered in the present study. The linearized incremental theory is used and the plate thickness is considered in the stability analysis. The bifurcation equations are solved with Wolfram Mathematica (Wolfram Research, Inc., 2019) [1] to obtain the critical stretches under different electric field. It is found that, compared to the isotropic material, material anisotropy results in larger unstable regions and higher critical stretches above which the plate is stable. It is also shown that material anisotropy has a stronger influence on a thinner plate. As the plate thickness increases, the influence decreases.

ABSTRACT: Investigated herein are the nonlinear vibration characteristics of a rectangular microsheet comprising micro fiber composite with graphene (GP) skin under coupled excitations. Owing to the good thermal conductivity of GP, the heat sink performance of the GP skin is also considered. In this study, the constitutive relation for the microsheet is established by applying the Eringen theory and the governing equations for nonlinear dynamics of the microsheet are obtained from the principle of conservation of energy. The Green and Naghdi’s generalized thermo-elasticity theory and the Galerkin weighted residual method are employed to describe the thermo-elasticity-coupling effect of the MFC-GP microsheet. The positive piezoelectric effects of graphene and MFC are also taken into consideration. Next, the coupled ordinary differential equations of thermo-elasticity-electricity are obtained by the Galerkin discrete method. Finally, the nonlinear frequency response equations of the microsheet are derived through the multi-scale method. By using the global residual harmonic balance method, nonlinear vibration characteristic of the MFC-GP microsheet are discussed with respect to nonlocal parameters, volume fraction of graphene, and aspect ratio, which have a significant impact on the dynamic behaviors of the microsheet. The findings will provide a theoretical guidance for engineering design of such microsheets.


ABSTRACT: The phenomenon of mode localization is explored theoretically and experimentally on two mechanically or electrostatically coupled beam resonators. Lumped parameter models are used to simulate the response of the systems. The eigenvalue problems are solved for both case studies under different stiffness perturbations and coupling strengths. The influence of the side electrode bias on the veering points is also explored. The dynamics of the systems are studied and compared using their frequency response curves under different perturbation and damping scenarios. The effect of damping for different elements of the coupled system is studied and proposed to improve sensitivity in high damping environments. It is observed that the exploitation of mode localization depends primarily on the choice of the resonator of the coupled system to be under direct excitation, its stiffness to be perturbed, and its response to be monitored. The revealed dynamic behaviors show great potential for applications in sensing and mechanical computing. The theoretical findings are validated using experimental case studies of two silicon doubly-clamped mechanically coupled microbeams and two electrostatically coupled microcantilevers. Electrothermal voltage is applied to the mechanically coupled resonators to introduce the stiffness perturbation in order to investigate mode localization. The theoretical and experimental results show good qualitative agreement.


ABSTRACT: The time-dependent deflection responses of the mechanically excited layered skew sandwich shell panels are computed numerically via a generic model developed mathematically using the higher-order shear deformation theory including the effects of the large displacement. The model includes the large displacements associated with the structural distortion under the small strain regime through Green–Lagrange nonlinear strain kinematics. The derived nonlinear system governing equation is converted to a set of algebraic form with the help of finite element steps. Subsequently, the time-dependent displacement values are computed numerically through the direct iterative technique including Newmark’s integration scheme. The dynamic deflections of the sandwich structural component under the influence of the externally excited mechanical loading are obtained through a generic computer code (developed in MATLAB) via the nonlinear higher-order finite element model. Before the implementation of the proposed model for the sandwich analysis, the solution stability and accuracy have been established by solving different kinds of numerical example from the published domain. Additionally, a few layered sandwich plates of different face sheet layers have been fabricated and the experimental dynamic data are recorded for the comparison purpose with the help of available modal test rig. Finally, the influences of the different structure-dependent design parameters on the nonlinear dynamic responses are investigated using the presently developed numerical model of skew sandwich shell panel, which also reveals that the present results give more accurate results.

ABSTRACT: This paper investigates the dynamic snap-through buckling of classical and non-classical curved beams subjected to a suddenly applied step load. The small scale effect prevalent in non-classical beams, viz, micro and nanobeams, is modeled using the nonlocal elasticity approach. The formulation accounts for moderately large deflection and rotation. The governing equilibrium equations are derived using the dynamic version of the principle of virtual work and are subsequently simplified in terms of the generalized displacements for the development of a nonlocal nonlinear finite element model. The spatial domain comprises of 3-noded higher-order curved beam elements based on shear flexible theory associated with sine function. The non-linear governing equations are solved using the incremental stiffness matrices and by adopting direct time integration method. The critical dynamic buckling load is identified by the smallest load at which there is a sudden rise in the amplitude of vibration. The efficacy of model here is compared against the available analytical studies for the local and nonlocal beams. A detailed study is made to highlight the effects of the geometric parameter, initial condition, nonlocal parameter, load duration, and boundary conditions on the dynamic stability of both classical and non-classical curved beams. The nature and degree of participation of various eigen modes accountable for the dynamic snap-through behavior are examined a posteriori using the modal expansion approach. Some interesting observations made here are valuable for the optimal design of such structural members against fatigue and instability.


ABSTRACT: The mechanical response of a hollow circular cylinder to internal pressure represents an important theoretical model which can be helpful in the design of tubular structures, and in the biomechanical research of tissues like arteries. It has been shown that arteries in vivo, in addition to pressure loading, sustain significant axial extension. It is manifested as a retraction that is observed when they are excised from a body. Previous research has shown that the axial prestretch ensures that the longitudinal motion of arteries is negligible under physiological conditions. The magnitude of the axial prestretch at which a tube does not change its length during pressurization, is referred to as the inversion point, because at this point mechanical response changes from pressure-induced elongation to pressure-induced shortening. In the present paper, another property observed when a nonlinear elastic tube is inflated at a constant axial load is studied. It is shown that at axial prestretching corresponding to the inversion point, when a tube exhibits no axial movement, the maximum internal volume of the pressurized tube is attained. This property is shown for thin-walled tubes made from material that is characterized with Mooney–Rivlin and Gent strain energy density function. Differences in the inflation–extension response obtained for Gent’s material, and for the human abdominal aorta that is considered to be anisotropic and is described with exponential strain energy density, are studied in the paper. To the best of our knowledge, our study is the first showing that the maximum internal volume of the inflated tube is intimately linked with its axial prestretch.


ABSTRACT: Aerospace vehicle structures in the supersonic regime flight have their outer skin subjected to unsteady aerodynamic and thermal loading, which may lead to aeroelastic instability. Typical aerospace structures are built as multiple adjacent panels, the so-called multi-bay configuration, but early efforts to predict the supersonic flutter were based on a single panel arrangement. This work evaluates the aeroelastic behavior of supersonic multi-bay fluttering panels under thermal effects, aiming to improve the understanding of adjacent panels interaction in the nonlinear regime. The aeroelastic model is established by using the first-order quasi-steady piston theory in conjunction with isotropic panel model using the von Kármán’s assumptions to account
for geometrical nonlinearities. The Newmark time-integration method is used to evaluate the resulting equations of motion. The Hopf bifurcation behavior that determines the flutter onset, thermo-buckling loading, phase portrait plots, and bifurcation diagrams for two adjacent panels are presented. The numerical results show the detrimental aspect of thermal loading in the aeroelastic behavior of fluttering panels, and the new findings corroborate with some recent studies that highlight the difference in the nonlinear flutter behavior between a single panel and multi-bay panels. Moreover, the existence of limit cycle oscillations amplitude jumps from a certain level of flow dynamic pressure is also observed. The multi-bay panels configuration also shows the anticipation of the buckled to the limit cycle oscillation solutions, when compared with a single panel analysis. Results indicate that simplified single bay panel assumptions can underestimate the post-flutter oscillations amplitudes of the adjacent bay. Such dynamic behavior may lead to a negative impact on aircraft structural design and fatigue life estimation.


ABSTRACT: The nonlinear panel flutter behaviour of two-dimensional porous curved panel reinforced by graphene platelets exposed to a supersonic flow is investigated. A curved beam element developed based on the trigonometric shear deformation theory is employed. The formulation integrates the geometric nonlinearity with von Karman’s approximation. The effort to model the fluid–structure interaction is reduced by implementing the first-order form of piston theory aerodynamics to describe the flow and accounting for the influence of static aerodynamic load due to the inherent geometric curvature of the panel. The nonlinear governing equations are formulated adopting the Lagrangian formulation. The panel deflection under the static aerodynamic load is evaluated using the Newton–Raphson iteration method. The flutter behaviour is analysed with reference to the large deflection equilibrium state through an eigenvalue analysis and by tracing the complex eigenvalues and identifying the first coalescence of any two vibratory modes. The flutter dynamic pressure is also predicted iteratively using the eigenvalue approach for the selected range of limit cycle amplitudes. The influence of static aerodynamic load and vibration amplitude on the flutter characteristics is brought out for both isotropic and graphene reinforced composite panels with different boundary conditions. The pre-flutter static deflection shape of the panel is also examined. The material parameters such as porosity level in the metal foam and the graphene platelet content are assessed on the nonlinear flutter features of 2D panels.


ABSTRACT: Since Euler’s elastica, buckling of straight columns under axial compression has been studied for more than 260 years. A low width-to-length ratio column typically buckles at a critical compressive strain on the order of 1%, after which the compressive load continuously increases with the displacement. Here using a general continuum mechanics-based asymptotic post-buckling analysis in the framework of finite elasticity, we show that a straight hyperelastic column under axial compression exhibits complex buckling behavior. As its width-to-length ratio increases, the column can undergo transitions from continuous buckling, like the Euler buckling, to snapping-through buckling, and eventually to snapping-back buckling. The critical width-to-length ratios for the transitions of buckling modes are determined analytically. The effect of material compressibility on the buckling modes and their transitions is further investigated. Our study provides new insights into column buckling.


ABSTRACT: The symmetric snap-through response of a bistable structure, composed from two beams, coupled via a rigid truss at their midpoint, is studied when subjected to a distributed electrostatic load. Both beams are double clamped and initially curved. The analysis is based on a reduced order (RO) model, resulting from Galerkin’s decomposition. For the base functions, symmetric buckling modes are used for either beam. The
results of the RO model are compared with results obtained via finite differences (FD) solutions, to validate the approximation to the original differential formulation, and a finite element (FE) model. Specifically, FE analysis was used as a reference under “mechanical” displacement-independent load, facilitating the usage of solutions extracted via FD for validation of the model under electrostatic, displacement-dependent, load. All solutions employed the usage of the arc-length “Riks” method to accommodate swerving equilibrium paths. To enable a broader approach, the two beams may have different initial elevations. The study indicates that a model with at least three degrees of freedom (DOF) is needed to depict an equilibrium path, for either load. For reliably quantitative equilibrium curves, a model with a minimum of five DOF was found to be necessary. The presented results also indicate that a double curved beam structure can attain actuation of several modes simultaneously, while demonstrating snap-through at reasonable voltages. In so doing, the model suggests that such a construct can be feasible for usage in various applications.


ABSTRACT: In this paper, an efficient numerical strategy is used to study the geometrically nonlinear static bending of functionally graded graphene platelet-reinforced composite (FG-GPLRC) porous plates with arbitrary shape. Porous nanocomposite plates including cutout with various shapes can be modeled by the present approach. Four types of porous distribution scheme and four GPL dispersion patterns are selected, and the material properties are calculated based on the closed-cell Gaussian random field scheme, the Halpin–Tsai micromechanical model together with the rule of mixture. First, the variational statement of governing equations based on the virtual work principle and higher-order shear deformation theory (HSDT) is derived and presented in vector–matrix form for computational aims. Then, using the ideas of variational differential quadrature and finite element methods (VDQ and FEM), a numerical approach called as VDQ-FEM is used to address the considered problem. In VDQ-FEM, the domain of problem is first transformed into a number of finite elements. In the next step, the VDQ discretization technique is implemented within each element. Then, the assemblage procedure is performed to obtain the set of Studying effects of porosity and GPL distributions and porosity coefficient matricized governing equations which is finally solved by means of the pseudo arc-length continuation algorithm. One of the main novelties of the present work in implementing VDQ-FEM is proposing an efficient way based on mixed-formulation to guarantee the continuity condition of first-order derivatives in entire domain for the used HSDT model. A detailed parametric study is conducted to investigate the nonlinear bending of FG-GPLRC porous plates with different shapes. In the numerical results, the effects of porosity coefficient, porosity distribution pattern, GPL distribution pattern and boundary conditions on the nonlinear bending response of plates are analyzed.


ABSTRACT: In this paper, the three-dimensional (3D) stress analysis of plate-type structures in instability conditions is presented. The displacement-based and hybrid-mixed four-node quadrilateral elements are developed taking the advantages of the sampling surfaces (SaS) method. The SaS formulation is based on considering inside the plate not equally spaced SaS parallel to the middle surface to specify the displacements of these surfaces as primary plate unknowns. The displacements, strains and stresses are assumed to be distributed through the thickness using Lagrange polynomials of degree N–1 that lead to a well-set higher-order plate theory. The locations of SaS are based on the use of Chebyshev polynomial nodes that allow us to minimize uniformly the error due to Lagrange interpolation. To circumvent shear locking and have no spurious zero energy modes, the assumed transverse shear strains are employed. The nonlinear equilibrium equations are solved by the Newton–Raphson iterative method combined with the Crisfield arc-length algorithm. The accuracy and efficiency of both elements in different conditions such as coarse and distorted meshes are investigated. The developed assumed-natural strain (ANS) elements can be useful for the 3D stress analysis of thin and thick plates in whole states of equilibrium path involving bifurcation, snap-through, and/or snap-back phenomena.

ABSTRACT: This paper presents a kinematic assumption free and thermodynamically consistent non-linear formulation incorporating finite strain and finite deformation for thermoviscoelastic plates/shells based on the conservation and balance laws of the classical continuum mechanics (CCM) in [math] (see Surana and Mathi, (2020) for linear theory). The conservation and balance laws in Lagrangian description with finite strain measure and the conjugate stress measure in [math] are considered. The conjugate pairs in the second law of thermodynamics (SLT), the consideration of additional physics and the principle of equipresence are utilized to determine the constitutive variables and their argument tensors. The constitutive theory for the contravariant second Piola–Kirchhoff stress tensor is derived using Green’s strain tensor and its convected time derivatives of up to order n as its argument tensors using representation theorem with complete basis (i.e. using integrity). The convected time derivatives of the Green’s strain tensor up to order n provide ordered rate constitutive theory for the dissipation mechanism that is naturally non-linear due to Green’s strain measure. The constitutive theory for heat vector derived using representation theorem and integrity is also a non-linear constitutive theory. Simplified linear forms of these constitutive theories are also presented. The solution methods for the mathematical model for the BVPs as well as the IVPs using -version hierarchical higher degree and higher order finite element method are presented. Due to dissipation, the energy equation is integral part of the mathematical model that accounts for rate of mechanical work resulting in rate of entropy production, hence heat. [Please do not introduce math expressions into your abstracts.]


ABSTRACT: Robotic Automated Fiber Placement (RAFP) has revolutionized manufacturing of large aerostructures in recent years. From producing lower costing parts to reducing scrap, RAFP has also helped in manufacturing large parts with contours precisely, with repeatable production once the RAFP machine is programmed. RAFP manufacturing allows a designer to utilize curvilinear fiber paths specifically designed to optimize structural performance, for example, maximizing buckling loads, minimizing stress concentrations etc. At the same time, RAFP introduces unintended manufacturing imperfections. These, which can include overlaps and gaps, lead to thickness non-homogeneities in structural panels. In this paper, steered fiber paths for maximizing the buckling loads of RAFP panels while explicitly accounting for manufacturing imperfections is considered. A novel method to model fiber paths is introduced where each course of the lay-up can be explicitly modeled, including manufacturing artifacts of course width, admissible tow curvature, and control on unintended manufacturing deviations that can lead to gaps and overlaps. A machine learning based surrogate modeling technique in conjunction with Genetic Algorithm is used to derive the optimal solutions.

Bhavesh Shrimali (1), William J. Parnell (2) and Oscar Lopez-Pamies (1)
(1) Department of Civil and Environmental Engineering, University of Illinois, Urbana-Champaign, IL 61801, USA
(2) Department of Mathematics, University of Manchester, Oxford Rd, Manchester M13 9PL, UK


ABSTRACT: This paper introduces a homogenization-based constitutive model for the large-strain mechanical response of elastomeric syntactic foams subject to arbitrary quasistatic loading and unloading conditions. Based on direct observations from experiments, this class of emerging foams are considered to be made of a nonlinear elastic matrix filled with a random isotropic distribution of hollow thin-walled spherical shells – commonly termed microspheres or microballoons – each having the same mean diameter that are made of an elastic brittle material that is much stiffer than the elastomeric matrix, typically, either glass or a hard polymer. Accordingly,
such underlying microballoons behave effectively as rigid particles initially. Along a given loading path, however, they may fracture (in the case of glass microballoons) or buckle (in the case of polymer microballoons) at which point they abruptly transition to behave effectively as vacuous pores. On that account, the proposed constitutive model corresponds to a homogenization solution for the nonlinear elastic response of particle-filled porous elastomers – precisely, elastomers embedding both rigid spherical particles and vacuous spherical pores of equal monodisperse size – wherein the volume fraction of pores corresponds to the volume fraction of fractured or buckled microballoons and hence is not a fixed parameter but rather an internal variable of state that evolves as a function of the loading history. After the general presentation of the model, where its theoretical and practical features are discussed, its descriptive and predictive capabilities are showcased via comparisons with experimental data for silicone syntactic foams filled with glass microballoons.

ABSTRACT: A finitely deformed elastic half-space subject to compressive stresses will experience a geometric instability at a critical level and exhibit bifurcation. While the bifurcation of an incompressible elastic half-space is commonly studied, the bifurcation behavior of a compressible elastic half-space remains elusive and poorly understood to date. The main objective of this manuscript is to study the bifurcation of a neo-Hookean compressible elastic half-space against the well-established incompressible case. The formulation of the problem requires a novel description for a non-linear Poisson’s ratio, since the commonly accepted definitions prove insufficient for the current analysis. To investigate the stability of the domain and the possibility of bifurcation, an incremental analysis is carried out. The incremental analysis describes a small departure from an equilibrium configuration at a finite deformation. It is shown that at the incompressibility limit, our results obtained for a compressible elastic half-space recover their incompressible counterparts. Another key feature of this contribution is that we verify the analytical solution of this problem with computational simulations using the finite element method via an eigenvalue analysis. The main outcome of this work is an analytical expression for the critical stretch where bifurcation arises. We demonstrate the utility of our model and its excellent agreement with the numerical results ranging from fully compressible to incompressible elasticity. Moving forward, this approach can be used to comprehend and harness the instabilities in bilayer systems, particularly for compressible ones.

ABSTRACT: Ridge-cracked blisters form when ridge cracking occurs in a biaxially compressed film on a relatively rigid substrate during buckle-delamination. The observation of telephone-cord (TC) blister with wavy ridge crack indicates that the ridge-cracked blister is not straight-sided as it used to be. How ridge cracking influences the profile of buckle-delamination remains unclear. Based on Föppl–von Kármán (FvK) nonlinear plate theory, we derive an improved analytical solution for a better description of the cross-sectional profile of the straight-sided blister with straight-sided ridge crack through considering the effect of hinge position caused by the ridge crack. Following a similar procedure in the case of the straight-sided ridge-cracked blister, an approximate solution of FvK plate in curvilinear coordinates is further obtained for the cross-sectional profile of the TC ridge-cracked blister. The results show that the position of the ridge crack significantly modifies the asymmetry, the shape, and the maximum deflection of the cross-sectional profile of the resulting blister.

ABSTRACT: We consider a variant of the classical Biot problem concerning the wrinkling of a compressed hyperelastic half-space. The traction-free surface is no longer flat but has a localized ridge or trench that is invariant in the x1-direction along which the wrinkling pattern is assumed to be periodic. With the x2-axis aligned with the depth direction, the localized imperfection is assumed to be slowly varying and localized in the
x3-direction, and an asymptotic analysis is conducted to assess the effect of the imperfection on the critical stretch for wrinkling. The imperfection introduces a length scale so that the critical stretch is now weakly dependent on the wave number. It is shown that the imperfection increases the critical stretch (and hence reduces the critical strain) whether the imperfection is a ridge or trench, and the amount of increase is proportional to the square of the maximum gradient of the surface profile.


ABSTRACT: The present work deals with the progressive damage analysis of composite laminates subjected to low-velocity impact. We develop a numerical model using higher-order structural theories based on the Carrera Unified Formulation (CUF) with Lagrange polynomials and resulting in a 2D refined layer-wise model. To model damage, we use a combination of the continuum damage-based CODAM2 intralaminar damage model to account for fibre and matrix damage within the ply, and cohesive elements to account for delamination between successive composite plies. We carry out numerical assessments for the case of a linear elastic composite plate subjected to impact, to compare the current framework with standard approaches based on 3D finite element (FE) analysis. We, then, consider the elastoplastic analysis of a bimetallic laminated plate to compare the performance of the proposed layer-wise model and 3D-FE approaches, for the case of nonlinear impact analysis. The final assessment considers progressive damage due to low-velocity impact, and the results are compared with available literature data. The numerical predictions show a good correlation with reference experimental and simulation results, thus validating the current framework for impact analysis of composite structures. Comparisons of the proposed layer-wise structural models with those based on 3D finite elements demonstrate the improved computational efficiency of the CUF models in terms of model size and analysis time.


ABSTRACT: This paper presents a derivation of a hinged–hinged Euler–Bernoulli beam including cubic and quintic nonlinearities. Then, a three-mode Galerkin discretization technique has been utilized to generate a system of ordinary differential equations governing the temporal deflections of the first three modes of the studied beam. The pioneering work of Nayfeh and Mook (1995) has shown the absence of internal resonances among the modes of a hinged–hinged beam with cubic nonlinearities despite there are commensurable linear natural frequencies. In this work, extra quintic nonlinearities are involved to show the presence of internal resonances among such modes. Approximate solutions of the resulted system have been approached by the method multiple scales to get the modulations governing the amplitudes and phases of the first three modal temporal deflections. Their stability is investigated via Routh–Hurwitz criterion and a shaded region of unstable solutions has been plotted to conclude picture where the stable solutions are. Different response curves are plotted to explore the effects of beam parameters on the nonlinear dynamical behavior of such beam. Finally, a simulated response of the modal temporal deflections and the overall spatial–temporal deflection are portrayed to show the accurate behavior of the beam at different initial conditions.


ABSTRACT: In this paper, geometrically nonlinear analysis of functionally graded beams using the dual mesh finite domain method (DMFDM) and the finite element method is presented. The DMFDM makes use of a primal mesh of finite elements and associated approximation for the variables of the formulation and a dual mesh of control domains, which does not overlap the primal mesh, for the satisfaction of the governing equations. The dual variables can be postcomputed uniquely and accurately at the control domain interfaces. The method is used to obtain nonlinear (due to the von Kármán nonlinear strains) bending solutions of straight, through-thickness functionally graded beams using the Euler–Bernoulli and the Timoshenko beam theories. Mixed models, which contain displacements and the bending moment as degrees of freedom, and displacement models are developed. Numerical results of linear and nonlinear analyses are presented to illustrate the
methodology and a comparison of the generalized displacements and bending moments obtained with the DMFDM and FEM models while bringing out certain interesting features of functionally graded beams.


ABSTRACT: Buckling instabilities of layered materials are an important phenomenon that has been analyzed both analytically and numerically, but generally only in the absence of surface pressure. In this study, we present a linear stability analysis of the wrinkling of an inhomogeneous bilayer made up of dissimilar neo-Hookean elastic materials, under uniaxial compression with pressure applied to the top surface. Using a variational method, we investigate the effects of stiffness ratio and pressure boundary condition on buckling instabilities. In all cases, the addition of surface pressure decreases the stability of the system to some extent. For softer films, the pressure is the dominant influence on the instability of the system. In stiffer films, however, pressure loading and stiffness ratio interact to affect the unstable state of the bilayer system. Our results indicate that for a sufficiently high value of stiffness ratio $\mu_{f}/\mu_{s}$ greater than or about equal to 10, the instability of the system does not depend on pressure.

ABSTRACT: Soft functionally graded materials have attracted intensive attention owing to their special material inhomogeneity and are realized as various applications. In this paper, we theoretically investigate the finite deformation and superimposed bifurcation behaviors of an incompressible functionally graded dielectric tube subject to a combination of axial stretch and radial voltage. The theoretical framework of nonlinear electroelasticity and the related linearized incremental version is employed. We assume that the modulus and permittivity of the elastomer vary linearly along the thickness of the tube. The surface impedance matrix method is adopted to obtain the bifurcation equation for buckling of the tube. We present numerical calculation for the ideal neo-Hookean dielectric elastomer to study the effects of the applied voltage, geometrical size and material grading parameters on the nonlinear response and the incremental buckling behavior of the tube. We validate our results through comparison with those of the elastic problem. The results can provide solid guidance for the design and realization of dielectric actuators.

ABSTRACT: Many biological tissues and organisms are in a state of residual stress, which should be considered rather than ignored as in many previous studies. In this work, we establish a theoretical model to study the growth and patterns of a residually stressed core–shell soft sphere. The effect of the initial residual stress is considered by employing a modified multiplicative decomposition growth model. Numerical solution of the marginal instability relies on gaining a critical differential growth ratio which depends on the initial residual stress, geometry, and material elasticity. Results show that the initial residual stress can not only well regulate the growth procedure but also affect the critical pattern of the growing instability. Compared with the way of changing material elasticity or geometrical size, it is more effective in practice. This work may help understand the morphological transition of residually stressed soft matters, and provide insights into the growth self-assembly and biomedical engineering.

ABSTRACT: The complex buckling behavior of one of the simplest structures, an elastic thin strip under combined stretch and twist loading represents a fascinating example for structural stability analysis. For stretched-twisted strips, in contrast to solely stretched strips, not just the computation of the post-buckling process but also the simulation of the pre-buckling behavior and the determination of the bifurcation loading state requires nonlinearities to be taken into account. Under twist, not only shear stresses but also membrane normal stresses, with buckling relevant compressive stress contributions, develop. These compressive membrane stresses have components in the longitudinal and – maybe surprisingly – also in the transversal direction, i.e., normal to the long axis of the strip. Depending on the length to width ratio of the strip and on the ratio of the intensity of torque to tension loading, it is either the longitudinal or the transversal compression stress distribution, which is predominantly responsible for the loss of stability of the trivial equilibrium state. This is the reason for the transition from one characteristic of buckling mode shapes to a completely different characteristic of buckling modes in dependence of the loading conditions. Of course, within each of these two characteristics, the buckling modes vary in terms of wave numbers in dependence of the mentioned parameters. While these kinds of mode transitions has been studied recently elsewhere, the focus of the present paper is, in addition, laid on further mode transitions appearing in the post-buckling domain due to instabilities of equilibrium states either in the form of further bifurcations or snap-through jumps. Capturing all these effects by numerical simulations requires a well thought out model and a careful control of the computational analysis.

References listed at the end of the paper:
1 Friedl N., Rammerstorfer F.G., Fischer F.D., Buckling of stretched strips, Comput. Struct., 78 (2000), pp. 185-190, 10.1016/S0045-7949(00)00072-9
11 Chopin J., Demery V., Davidovitch B., Roadmap to the morphological instabilities of a stretched twisted ribbon, J. Elasticity, 119 (2015), pp. 137-189, 10.1007/s10659-014-9498-x
18 Rammerstorfer F.G., Fischer F.D., Friedl N., Buckling of free infinite strips under residual stresses and global tension, J. Appl. Mech., 68 (2001), pp. 399-404, 10.1115/1.1357519
ABSTRACT: A two-dimensional plate theory is derived for incompressible transversely isotropic fiber-reinforced materials with wavy fibers. Single-layer plates and two-layer laminates are considered. Numerical simulations of axially loaded rectangular sheets in the post-buckling regime illustrate the marked effect fiber waviness has on both the wrinkling patterns and the effective axial stiffness. For fibers oriented along the loading axis, increased waviness tends to decrease the axial stiffness. Conversely, for fibers oriented transverse to the loading direction, increased waviness tends to increase stiffness.


ABSTRACT: Growth-induced pattern formation in tubular tissues is intimately correlated to normal physiological functions. Moreover, either the microstructure or certain diseases can give rise to material inhomogeneity, which can lead to a change of shape in the tissue. Therefore, it is of fundamental importance to understand surface instabilities and pattern transitions of graded tubular tissues. In this paper we perform such analysis by the use of a mechanical model of a graded tube which grows with a fixed outer boundary by focusing on a plane-strain problem within the framework of nonlinear elasticity. A theoretical model is established to determine the uniform growth state, the critical growth factor, and the critical wavenumber for a general material model and for a general material gradient. For a case study, the material is specified by the neo-Hookean model, and the shear modulus is assumed to decay linearly or exponentially from the inner surface. Then, a parametric study is carried out to unravel the effects of material and geometrical parameters on the bifurcation threshold and the associated wrinkled pattern. In addition, a finite element model, which is validated by the theoretical one, is developed to trace the post-buckling evolution. It is found that wrinkled pattern will evolve into an arch mode and then into a creasing mode if the modulus decays linearly. However, the typical creasing mode may give way to a period-doubling mode when applying an exponentially decaying modulus, and there is a co-existence of the creasing mode and the wrinkling mode. As a result, different modulus gradients can generate diverse pattern formations. The obtained results are useful to supply insight into the effects of material inhomogeneity and different modulus gradients on surface instabilities and morphology evolutions in graded tubular tissues.


ABSTRACT: Four nonlinear computational models for the surface wrinkling of curved shell-core systems under external pressure are presented. Three of the considered finite element models neglect the displacements tangential to the shell surface. Two of the models are static formulations and the other two are derived in the dynamic framework. For the latter, the energy-decaying time-stepping algorithm is applied, which is suitable for numerically stiff problems, such as shell-core systems, characterized by stiff membrane and soft wrinkling deformation modes. In all cases the core is modeled by elastic springs. As a comparative problem we choose the surface wrinkling of pressurized shell-core spheres. In particular, five systems with different material and geometric properties are computed, which have different wrinkle patterns. A good agreement is found between the results of the models as well as with the relevant references, which provide numerical and experimental results. However, it has been observed that our reduced-order models are blind to the prediction of the secondary transformation – from the dimple-like pattern to the labyrinthine pattern. Another conclusion is that a
non-tailored (i.e. standard) shell finite element on an elastic foundation combined with the energy-decaying scheme, provides excellent predictions of the surface wrinkle patterns.


ABSTRACT: This work proposes an alternative approach for the nonlinear analysis of 2D, thin-walled lattice structures. The method makes use of the well-established Carrera Unified Formulation (CUF) for the implementation of high order 1D finite elements, which lay along the thickness direction. In this manner, the accuracy of the mathematical model does not depend on the finite element discretization and can be tuned by increasing the theory approximation order. In fact, the governing equations are invariant of the order of the structural model in CUF. Another advantage is that complex curved geometries can be considered with ease and without altering the nonlinear strain–displacement relations. After a preliminary assessment, attention is focussed on the nonlinear equilibrium analyses of U-shaped 2D lattice structures both in traction and compression. Also, a sensitivity analysis against the effect of various geometrical nonlinear terms is conducted. The results demonstrate the accuracy of the present method, as well as its computationally efficiency, giving confidence for future research in this direction.

References listed at the end of the paper:

1 Euler L., Methodus inveniendi lineas curvas maximis minimive proprietate gaudentes sive soluto problematis isoperimetrici latissimo sensu accepti, Vol. 1, Springer Science & Business Media (1952)
3 De Saint-Venant M., Mémoire sur la flexion des prismes: sur les glissements transversaux et longitudinaux qui l’accompagnent lorsqu’elle ne s’opère pas uniformément ou en arc de cercle, et sur la forme courbe affectée alors par leurs sections transversales primitivement planes, Gauthier-Villars (1836)
13 Li Z., Qiao P., Buckling and postbuckling behavior of shear deformable anisotropic laminated beams with initial geometric imperfections subjected to axial compression, Eng. Struct., 85 (2015), pp. 277-292
14 Li Z., Yang D., Thermal postbuckling analysis of anisotropic laminated beams with tubular cross-section based on higher-order theory, Ocean Eng., 115 (2016), pp. 93-106
ABSTRACT: Flexural tensegrity is a structural principle for which the integrity under flexure of a beam formed by a chain of segments in unilateral contact is provided by an unbonded prestressing tendon anchored to the end segments, with the possible interposition of linear springs and linear dashpots. These are activated by the inflexion of the beam as a consequence of the particular shape of the contact surfaces of adjacent segments, so to induce a nonlinear dependence of the bending stiffness and structural damping on the amplitude of the inflexion. Under simplifying hypotheses, these nonlinear effects are analyzed for the nonlinear vibrations under harmonic excitation, also considering the effects of an initial camber. A variation of the tensile force in the tendon, via an actuator, can likewise modify the bending stiffness of the beam. A harmonic variation can provoke phenomena of parametric resonance, whereas an active control permits to annihilate pre-existing vibrations. The possibility of taking advantage of the nonlinear character of the damping through the optimization of the dissipated energy is also explored.

ABSTRACT: The excess geometrical deformation due to the in-plane hygrothermal and transverse mechanical loading are computationally (through a customized MATLAB code) obtained for the weakly bonded structure using the different kinematic theories in combination with the finite element steps. To evaluate the nonlinear deflection data a macro mechanical model is prepared mathematically considering the stretching effect (through the thickness), as well as the constant functions of displacement. The model includes the variation of composite properties due to the change in environmental temperature and moisture content including the necessary continuity assumptions between the separated layers for the weak bonding. The role of delamination i.e. location, position and size on the nonlinear deflection parameters are also computed under the combined loading (Hygral/Thermal/Mechanical/Hygro-Thermo-Mechanical). The solution accuracy and the elemental sensitivity have been computed for the proposed macro mechanical finite element model. Moreover, a set of numerical examples are solved to show the environmental effect on the flexural strength of a weakly bonded composite panel including the design-dependent parameters. The final results are indicating the necessity of the various kinematic model for the analysis of laminated structure with/without hygrothermal loading as well as the debonding.

References listed at the end of the paper:
3 Joshi P., Kondo A., Watanabe N., Progressive failure analysis of carbon-fibre/epoxy composites laminates to study the effect of stitch densities under in-plane tensile loading, Plast. Rubber Compos., 46 (2017), pp. 147-154
7 Baseri V., Jafari G.S., Kolahchi R., Analytical solution for buckling of embedded laminated plates based on higher order shear deformation plate theory, Steel Compos. Struct., 21 (2016), pp. 883-919
8 Carrera E., Pagani A., Valvano S., Plane fibre waviness and plane tensile loading (Hygral/Thermal/Mechanical/Hygro-Thermal), A review of the present and future utilisation of FRP composites in the civil infrastructure with reference to their important in-service properties, Constr. Build. Mater., 24 (2010), pp. 2419-2445

Babu Ranjan Thakur, Surendra Verma, B.N. Singh and D.K. Maiti, “Geometrically nonlinear dynamic analysis of laminated composite plate using a nonpolynomial shear deformation theory”

ABSTRACT: A computationally efficient C0 finite element model in conjunction with the nonpolynomial shear deformation theory (NPSDT) is extended to examine the free and forced vibration behavior of laminated composite plates. The employed NPSDT assumes the nonlinear distribution of in-plane displacements which qualify the requirement of traction free boundary conditions at the top and bottom surfaces. The present formulation utilizes both von Kármán and Green–Lagrangian type of strain–displacement relations to model the geometric nonlinearity. Using Hamilton’s principle, the nonlinear governing equation of motion is derived and then discretized based on the nine-noded Lagrange element. The obtained equations are solved by utilizing unconditionally stable Newmark’s scheme in conjunction with Newton–Raphson method. A damping effect in the transient analysis has been introduced in the framework of the Rayleigh damping model. The steady state forced vibration analysis has also been carried out by employing harmonic force with excitation frequency around the natural frequency. The arc-length continuation method is applied to obtained the frequency response. The present model has been validated for a wide range of problems and a detailed numerical study has been carried out for several types of boundary conditions under various types of loading with different magnitude of the load.

References listed at the end of the paper:
2 Reissner E., The effect of transverse shear deformation on the bending of elastic plates (1945)
ABSTRACT: This work aims to investigate the dynamics of Micro-electro-mechanical systems (MEMS) straight multi-stepped micro-beams. An analytical model is presented based on the Euler–Bernoulli beam theory and the Galerkin discretization. The effect of various parameters on the natural frequencies of micro-beams is examined, including the effects of varying the geometry (number of steps and their ratios), the axial force (including those from electrothermal actuation), and the nonlinear electrostatic forces. The analytical results are validated and compared with the simulation results of a Multiphysics Finite-Element (FE) model. Good agreement is found among all the results. The variations of the pull-in and buckling instabilities due to the various parameters are also reported. The results highlight the capability of both passive (geometry) and active (electrostatic and electrothermal/axial) methods to tune the natural frequencies of the structures, which can be useful in applications, such as tunable filters, switches, as well as for creating/avoiding internal resonance and energy exchanges among the various modes.

References listed at the end of the paper:
3 Alcheikh N., Hajjaj A.Z., Younis M.I., Highly sensitive and wide-range resonant pressure sensor based on the veering phenomenon, Sensors Actuators A, 300 (2019), Article 111652
7 Moory-Shirbani M., Sedighi H.M., Ouakad H.M., Najar F., Experimental and mathematical analysis of a piezoelectrically actuated multilayered imperfect microbeam subjected to applied electric potential, Compos. Struct., 184 (2018), pp. 950-960
9 Haryanto I., Widodo A., Prabasto T., Satrijo D., Pradiptya I., Ouakad H., Simulation and analysis of the aeroelastic-galloping-based piezoelectric energy harvester utilizing FEM and CFD, MATEC Web of Conferences (Vol. 159, 01052), EDP Sciences (2018)
15 Ouakad H.M., AlQasimi J.E., Reliability of MEMS shallow arches based actuator under the combined effect of mechanical shock and electric loads, Microelectron. Reliab., 79 (2017), pp. 352-359
17 Zhang C., Siegel S.H., Yenuganti S., Zhang H., Sensitivity analysis of piezo-driven stepped cantilever beams for simultaneous viscosity and density measurement, Smart Mater. Struct., 28 (2019), Article 065012
18 Tsukazan T., The use of a dynamical basis for computing the modes of a beam system with a discontinuous cross-section, J. Sound Vib., 281 (2005), pp. 1175-1185


ABSTRACT: This work investigates the primary sinusoidal bifurcation wrinkling response of single- and multi-layered magnetorheological elastomer (MRE) film–substrate systems subjected to combined transverse applied magnetic fields and in-plane biaxial pre-compression. A recently proposed continuum model that includes the volume fraction of soft-magnetic particles is employed to analyze the effect of the magnetic properties upon the...
bifurcation response of the system. The analysis is built in a highly versatile manner using a finite-element discretization approach along the direction of the applied magnetic field and Fourier expansions along the infinite in-plane layer directions. This allows for a seamless investigation of various multi-layered structures. First, we analyze the effect of biaxial pre-compression upon the critical magnetic field for a film–substrate system and for various mechanical stiffness ratios. We observe a kink in the critical magnetic curves and a reflection in the corresponding wave numbers as they cross the equi-biaxial pre-compression regime. Subsequently, we consider a MRE film bonded to a MRE substrate and study the effect of the particle volume fraction ratios in those two parts. As a result, we obtain sharp pattern transitions, i.e., long-to-short wavelength changes with only minor perturbations of the applied pre-compression. The presence of a magnetic substrate changes qualitatively and quantitatively the bifurcation response of the film–substrate system. Finally, we carry out a data-mining exercise to minimize the critical magnetic field at bifurcation by using three different topologies, i.e., a monolayer, a bilayer and a sandwich film. We find that the topologies resembling closely the monolayer one lead to the lowest critical magnetic fields for a given biaxial pre-compression.

References listed at the end of the paper:
URL: http://www.sciencedirect.com/science/article/pii/S0022509619301978
URL: http://www.sciencedirect.com/science/article/pii/S0022509619301978
22 Xu F., Potier-Ferry M., Belouettar S., Cong Y., 3D finite element modeling for instabilities in thin films on soft substrates, Int. J. Solids Struct., 51 (21) (2014), pp. 3619-3632, 10.1016/j.ijsolstr.2014.06.023

ABSTRACT: Some nuclear power plants in Japan experienced severe seismic ground motions that exceed their structural design specifications. Therefore, it is important to assess the margin of structural design against failure of piping systems under the severe seismic loading. The purpose of this study is to establish an analytical approach by which the failure behavior of piping systems can be simulated under severe dynamic seismic loading considering plastic effects. A series of dynamic-elastic-plastic analyses was performed focusing on a dynamic excitation test of a three dimensional piping system. The analytical results agree with the experimental data in terms of natural frequency, natural vibration mode, response accelerations, elbow opening-closing displacements, strain histories, failure position and low-cycle fatigue failure life.


ABSTRACT: An accurate assessment of the bending resistance of thick cylindrical metal tubes is necessary for the safe and efficient design of pipelines, piles, pressure vessels, circular hollow sections and other common tubular structures. Bending tests continue to be widely performed as part of many engineering research programmes, but despite their ubiquity they often generate results that are difficult to interpret. Discrepancies from the attainment of the classical full plastic moment are common and often attributed to a mixture of ovalisation, local buckling, imperfections and strain hardening. However, the effects of these phenomena are yet to be quantified in isolation, even for a system as classical as a cylinder under uniform bending. The goal of this computational study is to quantify the extent to which geometrically nonlinear effects, specifically ovalisation and bifurcation buckling, may depress the resistance of a thick perfect cylinder under uniform bending that would otherwise be expected to attain the full plastic moment. Simulations are performed using two- and three-dimensional finite element models with a simple ideal elastic-plastic material law that excludes the influence of strain hardening. The study aims to arm designers of test programmes on the bending of tubulars with ‘rules of thumb’ to approximately quantify the likely influence of tube length on their results, recently shown to be an important parameter controlling geometric nonlinearity. For thick tubes, ovalisation at the plastic limit state under bending is found to be almost negligible.

References listed at the end of the paper:


ABSTRACT: This paper presents an isogeometric finite element method based on Lagrange extraction in combination with a primal-dual algorithm for estimating limit and shakedown loads of pressure vessel components. The primal-dual algorithm is used to determine simultaneously both upper and quasi-lower bounds of the limit load multiplier. The Lagrange extraction is integrated into isogeometric analysis. This way, which directly connects a Co Lagrange basis with smooth NURBS basis and offers an alternative implementation of isogeometric analysis in the standard finite element method code, allows computations in the same manner as the standard finite element, but the present approach possesses the distinguishing advantages of using higher-order basis approximations. Numerical results of plane and axisymmetric problems are compared with analytical or other available solutions to prove the reliability and efficiency of the present approach. The application of shakedown analysis in pressure vessel engineering is illustrated by some examples.

References listed at the end of the paper:
3 W. Prager, P.G.J. Hodge, Theory of Perfectly Plastic Solids, Wiley, New York, USA (1951)
ABSTRACT: In the present research, effects of the hygrothermal degradation of the material properties on rates of the creep strains and stresses and stress redistributions of thick-walled FGM spheres subjected to internal and external pressures, temperature rises, and diffusions are investigated. In this regard, the non-linear time-dependent governing equations of the sphere are derived based on the theory of elasticity, Prandtl-Reuss flow rule, and Norton's creep law and solved using a special iterative solution scheme. The main novelties of the present research are: (i) analyzing the FGM sphere as it is; without dividing it into isotropic homogeneous sub-spheres, (ii) considering the temperature and moisture dependencies of the elastic modulus of the FGM material, (iii) proposing a more general numerical procedure instead of the traditional successive elastic or Taylor's expansion procedures, and (iv) successively updating of the inner and outer radii of the vessel to consider the resulting inelastic creep deformations. Results reveal that the moisture absorption generally increases the maximum values of both the elastic and creep portions of the stresses, strains, and stress and strain rates. The creep process reduces the circumferential stresses in the interior regions and increases them in the outer regions, but even in presence of moisture absorption, the area beneath the radial distribution curve of the circumferential stress remains unchanged.

References listed at the end of the paper:


27 M.H. Mansouri, M. Shariyat, Biaxial thermo-mechanical buckling of orthotropic auxetic FGM plates with temperature and moisture dependent material properties on elastic foundations, Compos. Part B, 83 (2015), pp. 88-104


**ABSTRACT:** Z2CND18.12N austenitic stainless steel elbow pipes were studied experimentally under reversed in-plane load of 20 kN and constant pressure of 17.5 MPa after thermal aged 1000 h and 2000 h respectively at the same thermal aging temperature of 500 centigrade degrees (°C). The ratcheting behaviors of pressurized elbow pipes were analyzed compared with original elbow pipe. The results indicate that the ratcheting behavior of pressurized elbow pipe is prominently affected by thermal aging. The uniaxial tensile properties of Z2CND18.12N austenitic stainless steel were also studied under the same condition of thermal aging. It is
shown that yield stress of material decreases obviously with the increase of thermal aging period. Chen-Jia-Kim (CJK) kinematic hardening model was used to evaluate the ratcheting behaviors of pressurized elbow pipes under different thermal aging periods. Simulation results are perfectly agreement with experimental data. Ratcheting shakedown boundaries of thermal aged elbow pipes were determined by CJK model.

References listed at the end of the paper:
6 KTA, Ageing Management in Nuclear Power Plants, Kerntechnischer Ausschuß (2017), Standard No. 1403
7 ASME, ASME Boiler and Pressure Vessel Code, Section III (Div. 1) & VIII (Div. 2), The American Society of Mechanical Engineer, New York (2010)

ABSTRACT: Polymethyl methacrylate (PMMA) has recently been used to build the pressure vessels for application in neutrino detectors. For thin-wall vessels under external pressure, they may undergo buckling failure. Taking the creep behavior of PMMA into consideration, buckling analysis of PMMA pressure vessels has not yet been studied. In this paper, creep tests of PMMA immersed into liquid scintillator were performed. Creep damage constitutive model for PMMA under multi-axial stress state was derived and incorporated into ABAQUS by developing a CREEP subroutine. Then creep buckling analysis of spherical pressure vessels for neutrino detector was conducted. Double failure criteria were proposed to judge whether the creep buckling occurred or not. Finally, the relationship between the maximum stress on the vessel and the creep buckling time was revealed. The research results can be used to predict the service lifetime and guide the stability design of PMMA pressure vessels in neutrino detectors.

References listed at the end of the paper:
17 J. Blachut, Buckling of shallow spherical caps subjected to external pressure, J. Appl. Mech., 72 (5) (2005), pp. 803-806
32 Yucai Zhang, Study on Creep Damage and Crack Propagation of Brazing Head under Multi-axial Stress State, Ph.D. thesis, East China University of Science and Technology, China (2016)


ABSTRACT: The reliability of pipes, tubes and liquid tanks (cylinders) is of paramount significance to our life. The typical way to examine the ability of those structures to undergo plastic deformation is to apply a flattening test. In this paper, we used the Gurson-Tvergaard-Needleman damage model and finite element simulations to capture the flattening of a tube made of typical pipe materials. We demonstrated how the tube thickness, radius, and length would affect the critical displacement where tube failure initiates. For flattening with platens, the failure displacement first increases with tube length and reaches a peak value, and it then decreases and converges to a constant value for a particular geometry. The failure initiates at the two edges of short tubes, but shifts to the center in intermediate tubes where the failure displacement maximizes. Failure then always starts from the middle in even longer tubes. In contrast, flattening with indenters exhibits two peaks in the
compressible displacement vs. tube length curve. In the end, we proposed effective experimental strategies to obtain the intrinsic ability of tubes under plastic deformation. The results reported here could be employed to characterize the mechanical properties of materials for pipes, tubes and tanks, and they could also be applied to guide the engineering design of such structures.


ABSTRACT: Free vibration of layered circular cylindrical shell filled with fluid with cross-ply walls including first order shear deformation theory is presented. The fluid is assumed to be quiescent and inviscid. The governing equations are obtained in terms of displacement and rotational functions and the normal displacement is coupled with fluid equation. These functions are assumed in a separable form, resulting in a system of differential equations. By applying Bickley-type splines of order three to approximate the functions, along with the boundary conditions, an eigenvalue problem is obtained. The eigenvalue is solved numerically for frequency parameters with an associated eigenvectors of the spline coefficients from which the mode shapes are constructed. Parametric studies with respect to thickness to radius ratio and length to radius ratio under different boundary conditions are carried out to analyse the frequency of the shell. The effects of material properties, number of layers and angle orientations are also studied.


ABSTRACT: In this paper, the improved resonance reliability and global sensitivity analysis of multi-span pipes conveying fluid is proposed via active learning Kriging model. The natural frequency of multi-span functionally graded materials pipes conveying fluid is calculated using the dynamic stiffness method. A new improved resonance performance function is proposed which is suitable for both broadband and multi-frequency resonance failure. This paper extends resonance reliability to the global sensitivity analysis, and proposes a moment-independent global sensitivity index based on the resonance failure probability. An importance ranking of random variables is obtained, which provides vital guidance and advice for the optimal design of pipe anti-resonance. A new resonance reliability analysis method via the active learning Kriging model is established, which greatly improves the application of pipelines resonance reliability analysis in engineering practice. Based on active learning Kriging model, the effects of fluid velocity, pressure and volume fraction of functionally graded material on resonance reliability are analyzed. The results demonstrate that the proposed method has high performance for the anti-resonance analysis of multi-span functionally graded materials pipes conveying fluid.


ABSTRACT: A striking correlation of control aims with temperature variation and mechanical deflections promotes the use of smart materials in structural health monitoring applications of laminated structures. To maintain the whole structure in a consistent situation, performing its desired function, and to remove the thermal stresses and degradation associated with the operational circumstances, the assembled smart counterparts should be considered. In this study we explore the transient characteristics of laminated spherical vessels made of functionally graded materials (FGMs) with piezoelectric substrates exposed to mechanical, electrical, and thermal shocks. The material properties of the pyroelectric media are constant, and the host shell is made of isotropic and FGMs, of which the material properties, encompassing thermal and mechanical agents, are assumed to be graded through the thickness. In light of the energy balance among different sub-layers, it is plausible to reconsider the design of the system aiming at extension of the operational life of the constituent materials. In the context of transient analysis, the direct and converse piezoelectric effects and the operational
evaluation of the FG vessels are semi-analytically scrutinized in order to present the dynamic perturbations in the corresponding elements. Qualitative patterns of stresses, electric potential, and temperature graphs for different material parameters are calculated and presented graphically in order to clarify the effect of the grading index of material properties, electric and thermal motivations, and geometry of the laminated shell. The data acquired from the proposed concept not only display the behavior of the FG host shell subjected to judiciously varied working conditions, but also can skillfully predict the sensory and actuatorial outputs of the embedded smart layers, presenting a highly efficient tool for structural health monitoring and damage detection.


ABSTRACT: Marine un-bonded flexible pipes wrapped with fiber-reinforced polymer are essential in offshore oil and gas exploration because of their high flexibility and reliability. These flexible pipes may be subjected to tensile loads, compressive loads, and torsional loads, causing the armor wires to undergo large displacements that may result in failure. This study develops a nonlinear simplified finite element model to investigate the mechanical behavior of flexible pipe armor wires under various types of load. The stiffness change rule of flexible pipe armor wires is obtained from numerical simulations of the flexible pipe tensile armor layer under combined loads. The results reveal that the flexible pipe stiffness under combined loads varies significantly from that under single loads, and the combination of different load types can either increase or decrease the stiffness. This study provides essential reference data for the further design, fabrication, and application of flexible pipes.


ABSTRACT: Three steel pipes longitudinally welded by a high-frequency induction process are developed. A post weld heat treatment is performed, and its effect on the microstructure, mechanical properties, and collapse resistance is analysed. The influence of the length/diameter ratios on the collapse resistance, and a method to improve the metallographic analysis of the weld lines are studied. The post weld heat treatment resulted in a homogeneous microstructure and uniform mechanical properties, and the etchant for the weld line analysis revealed the flowlines and the localised decarburisation with excellent contrast. An increase in the length/diameter ratio leads to a decrease in the collapse resistance; however, the tensile strength proved to be a significant influence on this phenomenon. Collapse resistance is a characteristic of the component itself in which several aspects such as manufacturing, mechanical properties, and dimensions shall be considered, and it is not an intrinsic property of the alloy.


ABSTRACT: The present research focuses on generating interaction diagrams (i.e. limit moment boundaries vs steady internal pressure spectra) of pressurized miter and smooth bends. One-, two-, three-, and four-weld miter bends are modelled and analyzed. Additionally, smooth bends (SBs) bearing the miter bends’ same material and major geometric parameters are analyzed thus providing broader range of comparisons concerning structural responses to external applied loadings. All bends analyzed are subjected to steady internal pressure spectra and monotonic in-plane closing, in-plane opening, and out-of-plane bending moment modes discretely. The finite element (FE) method is utilized for solution and analyzes. Limit load FE validation studies are initially conducted against experimental test outcomes of both miter and smooth bends subjected to different bending modes. Outcomes of conducted FE validation studies illustrated excellent correlation as compared to the experimental tests recordings. Interaction diagrams are successfully generated for pressurized miter and SBs possessing nominal pipe size (NPS) of 10 in. Schedule (SCH) 40 Standard (STD) and NPS 10 in. SCH 20
subjected to the three bending modes. The American Society of Mechanical Engineers (ASME) Twice-Elastic-Slope (TES) Method is adopted for computing limit moments. It is generally observed that the combined load carrying capabilities (moments-pressures) increase as the number of miter welds increases; however, SBs recorded considerably higher limit moments and broader internal pressure spectra. Finally, all generated limit moment boundaries are expressed in mathematical equations.

ABSTRACT: The pipe support and restraint design by analysis buckling criteria for linear and plate-and-shell-type (P&S) supports given within the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF is investigated to determine if it should be refined to include a basis upon instability criterion. If a Class 1 support is considered linear-type or plate-and-shell-type (P&S), the allowable buckling load is limited to two-thirds or one-half of the calculated critical buckling load, respectively. Five types of analyses are performed to demonstrate finite element and closed form solutions including linear Euler method, nonlinear second order large deformation method, nonlinear large deformation method with nonlinear elastic-plastic material, energy method, and Euler-Bernoulli beam theory. The techniques are compared with explanations of the considerations taken and their impact on the final solution. The structural components chosen to conduct the buckling analyses are rigid struts which are an integral part of commercial nuclear power plants.

ABSTRACT: In this study, nonlinear thermo-elastic vibration characteristics of shear deformable functionally graded (FG) curved porous panels have been analyzed using the finite element method. The present formulation is based on the higher-order shear deformation nonlinear shell theory. The FG panels' material properties are varied continuously in the thickness direction by a simple power law distribution in terms of the constituents’ volume fractions. The distribution of the porosity along the thickness direction is considered as even and uneven distribution. Comparison and convergence studies have been performed to validate the present nonlinear formulation. Parametric studies have been performed to study the effect of different influencing parameters on the frequency ratio of the curved FG panels, i.e., porosity, temperature rise, volume fraction indices, and side-to-thickness ratios. The benchmark solutions for the problems of large amplitude vibration characteristics have been accomplished with the present model.

Jian Zhang, Yuewen Zhang, Fang Wang, YongMei Zhu, WeiCheng Cui, Yun Chen and Zhe Jiang (The first author is from: School of Mechanical Engineering, Jiangsu University of Science and Technology, Zhenjiang, China), “Experimental and numerical studies on the buckling of the hemispherical shells made of maraging steel subjected to extremely high external pressure”, International Journal of Pressure Vessels and Piping, Vol. 172, pp 56-64, May 2019, https://doi.org/10.1016/j.ijpvp.2019.03.016
ABSTRACT: This work is devoted to the nonlinear buckling of the hemispherical shells subjected to extremely high external pressure. The shells are made of maraging steel with yield strength of 2100 MPa. The experiment on a tentatively devised laboratory-scale hemispherical shell is conducted in high pressure chamber, after precisely fabricated, optically and ultrasonically measured. Numerical predictions are carried out and proved to have a good agreement with experimental results. The laboratory-scale hemispherical shell can borne the pressure as high as about 139 MPa and demonstrates an unstable post-buckling character and a local dimple post-buckling mode near the base. Based on the study, a segmented hemispherical configuration is conceived and evaluated numerically, which can provide a reference for the deep-sea pressure hull design made of maraging steel.

James C. Hastie, Igor A. Guz and Maria Kashtalyan (School of Engineering, University of Aberdeen, Scotland, UK), “Effects of thermal gradient on failure of a thermoplastic composite pipe (TCP) riser leg”, International
ABSTRACT: Thermoplastic composite pipe (TCP), consisting of a fibre-reinforced thermoplastic laminate fully bonded between homogeneous thermoplastic liners, is an ideal candidate to replace traditional steel riser pipes in deepwater where high specific strengths and moduli and corrosion resistance are advantageous. During operation, risers are subjected to combined mechanical and thermal loads. In the present paper, a 3D finite element (FE) model is developed to analyse stress state in a section of TCP under combined pressure, axial tension and thermal gradient, illustrative of a single-leg hybrid riser (SLHR) application. From the obtained stresses, thickness failure coefficient is evaluated based on appropriate failure criteria. The effects of increasing the internal-to-external thermal gradient are investigated considering temperature dependent material properties. The influence of varying the thickness of the isotropic liners with respect to the laminate is examined.


ABSTRACT: Shakedown assessment is an important task in determining the load-bearing capacity of structures and evaluating their safety. The traditional shakedown analyses, which are based on the upper or lower bound shakedown theorem to establish the mathematical programming formulation and solve an optimisation problem, are difficult to apply in engineering practice owing to limitations of the computing scale and computational efficiency. In this study, a numerical shakedown analysis using the recently developed stress compensation method (SCM) is performed for a torispherical head with a piping nozzle, which is a typical structural component of pressure vessel equipment. The loads applied to the structural component include an internal pressure, axial force, twisting moment, out-of-plane and in-plane bending moments, and thermal loading, all of which vary independently of each other. Two- and three-dimensional strict shakedown boundaries for the torispherical head under different combinations of these loads are presented and analysed. In addition, the effect of a temperature-dependent yield strength on the shakedown domain is also investigated. These investigations demonstrate that the proposed SCM is capable of solving the practical shakedown problem for structures under complicated combined loads in industrial applications. The obtained results can provide guidance for the safe structural design of torispherical heads with piping nozzles.


ABSTRACT: A pipeline usually extends thousands of meters or more, and, in order to test the pipeline in the lab accurately, it is expected to develop a reasonable method to simplify the length of the model and simulate the small deformation section of the pipeline for a practical lab test. In this research, the scale model with consideration of the strengthening stage after the pipeline yielding is given to study the mechanical performance of the pipeline under fault displacement. Based on the mechanical model of the elastic foundation beam, a new analytical method of strain and deformation of pipeline is developed in which an equivalent spring model is established to simulate the small deformation section of the pipeline far away from the fault. The similarity ratio of the model is designed, and the results of the shell model with fixed boundary at both ends are compared by using ABAQUS software. On this basis, the soil-box test model with equivalent spring boundary is made. The elastic coefficients of springs at both ends are determined by \( N-\Delta L \) curve (\( N \) and \( \Delta L \) represents the interaction force and the relative displacement of pipeline-soil, respectively), and the influences of pipeline diameter, buried depth, soil and spring with different elastic coefficients on the mechanical properties of pipelines are analyzed. The results show that the two-end spring device can better control the size of the test model and enhance the reliability of the test results. The strain and deformation responses of the pipeline can be reduced by choosing larger pipeline diameter, smaller buried depth, non-cohesive backfill soil and spring with smaller elastic coefficient.

ABSTRACT: An analytical procedure has been proposed for buckling analysis of elastic cylindrical shells with varying thickness under combined axial and radial loads by considering the first-order shear deformation theory as the displacement filed. The kinematics of the problem is defined by the von-Karman relations, and the constitutive equation obeys Hooke's law. The equilibrium equations are a system of nonlinear coupled differential equations with variable coefficients and the corresponding stability equations which are a linear system with varying coefficients are solved to find the eigenvalues of the system. The results are compared with the finite element method and some other references.


ABSTRACT: This paper presents an investigation of the large displacement analysis of ellipsoidal pressure vessel heads, based on the membrane shell theory. The strain components of deformed shell configurations could be obtained by using the fundamental knowledge of differential geometry. Energy functional of the ellipsoidal shell was derived from the principle of virtual work, which is expressed in the appropriate forms. Based on the nonlinear finite element procedures, the nodal displacements of the shell configuration were numerically obtained. Analytical method for the small displacement was derived in order to validate the numerical results obtained from the FEM. Interesting features from parametric study of normal and tangential displacements for arbitrary shapes of ellipsoidal shells are presented and discussed. It is revealed that the point of zero normal displacement for arbitrary shapes of ellipsoidal shells is always the same point which is independent of the applied internal pressure and thickness of shell. Furthermore, there exists the maximum point of tangential displacement and it is always at the same points of the radial distance when the internal pressure and thickness of shells are varied.


ABSTRACT: In this paper, the previous research on the limit load of the pipe is summarized, and the methodology on the limit load of the pipe, including theoretical calculation, finite element analysis (FEA), and experimental validation. Besides, to present the factors of limit load, case studies are showed herein. Currently, several 90° elbows with straight pipe with local defect as the research object. According to the Elastic-plasticity theory, pipes with the same boundary conditions under various defect positions, sizes, were calculated and analyzed by means of finite element (FE) simulation to obtain the limit load to compare the results from FEA and theoretical calculations. Furthermore, a series of complete hydrostatic pressure blasting test and pre-experimental test plans were proposed. The agreement is achieved between test and FEA. The results can point out the direction of research on the limit load carrying capacity of pipes, find the main factors affecting the carrying capacity of pipes, and provide scientific guidance for the safe operation of pipes.


ABSTRACT: The current study proposes a new vertical seismic isolation of an aboveground liquid storage tank (AST) and theoretically and numerically evaluates its effectiveness for a comprehensive practical range of tank geometries. In the proposed system, the forces in the vertical direction caused by the overturning moment are isolated as an alternative to the common horizontal system used for shear base isolation of ASTs. The equations of motion for a liquid tank equipped in the proposed system were extracted using the mass-spring simplified
model of contained liquid. A parametric study was performed by employing the non-linear solution of the governing equations and the effectiveness of the proposed system for all AST aspect ratios is discussed. The numerical results show that the overturning moment of the tanks equipped with the proposed isolation system decreased significantly with respect to the corresponding fully anchored tanks. The results of the parametric study on the tank aspect ratio and liquid height indicate that the proposed system is more efficient for slender tanks than for broad tanks.


ABSTRACT: The dynamic load in tubes due to detonation has a number of applications, such as in oil pipeline systems and pulse detonation engines. Various experimental, analytical, and numerical investigations have been conducted to study the mechanical, thermo-mechanical, and fracture behavior of tubes under internal detonation loads. Regarding numerical analysis, different approaches such as interface cohesive element, mesh-free, and extended finite element methods have been used to model the propagation of crack(s) in a tube. This paper presents a review of relevant literature pertaining to numerical and experimental analyses of detonation-driven deformation and fracture, and of studies based on the analytical investigation of moving loads in detonation tubes. The corresponding findings are discussed in detail, and possible avenues for future research are highlighted.


ABSTRACT: The fabrication of pipe bends by rotary bending results in geometrical imperfections as manifested by cross-sectional ovality and wall thickness variations which affect their load carrying capacity and hence their performance during service. Previous studies ignored the exact distribution of these imperfections and adopted either ideal pipe bend shape (IB) or assumed the distribution these imperfections in their analysis by a simplified assumed shape model (AS). The objective of the present work is to investigate the effect of the presence of the inherited geometrical imperfections as obtained from the rotary pipe bending process of 90° pipe bends including the presence of residual stresses on their load carrying capacities as compared with the IB and AS models. The present work is conducted by means of non-linear finite element modeling considering both material and geometrical non-linearities. Rotary pipe bending process is simulated with basic tooling configuration to obtain the as-fabricated 90° pipe bend after accounting for springback. Results of this step were verified against published experimental results and analytical solutions. The pipe bend was then subjected to different combinations of in-plane moment and internal pressure in order to construct a comparative limit load diagram. The IB model for the pipe bend results in non-conservative results, while AS model results in acceptable results compared to results of the as-fabricated shape. Results have also shown that presence of residual stresses improves the pipe performance under in-plane closing bending moment.


ABSTRACT: The present investigation is devoted to the nonlinear elastic collapse properties of externally pressurized egg-shaped shells under local geometrical imperfections. The shells have nominal major axis, nominal minor axis, and nominal wall thickness of 256mm, 180mm, and 2mm, respectively. Nine resin egg-shaped shells are manufactured, measured accurately, tested hydrostatically, and analysed numerically. Of these, three each have nominally identical perfect geometries, nominally identical geometries with local flat imperfections, and local dimple imperfections. Furthermore, the effect of local and eigenmode imperfection depths on the collapse pressures of egg-shaped shells are studied numerically using nonlinear elastic buckling analysis. Both experimental and numerical data are presented and compared through graphs and tables. References listed at the end of the paper:


10 W.T. Koiter, Over de stabiliteit van het elastisch evenwicht, Delft University of Technology, Delft (The Netherlands) (1945) [On the stability of elastic equilibrium]


17 J. Blachut, Buckling of composite domes with localised imperfections and subjected to external pressure, Compos. Struct., 153 (2016), pp. 746-754, https://doi.org/10.1016/j.compstruct.2016.07.007

18 J. Blachut, Locally flattened or dented domes under external pressure, Thin-Walled Struct., 97 (2015), pp. 44-52, https://doi.org/10.1016/j.tws.2015.08.022


ABSTRACT: Plain and reinforced torispheres were manufactured and subjected to external pressure. Under single incremental pressure they were loaded up to buckling level. Experimental values of buckling pressure were compared with numerical predictions based on the FE analyses. Some domes were reinforced by stringers attached to external surface, and running along meridians. In each case they were evenly spread in hoop direction. For a ‘threshold-number’ of stringers buckling pressure was smaller than that for the case of plain (non-reinforced), torisphere. It only begun to increase once the number of stringers was larger than the ‘threshold value’. The intricate role of the number of stringers on bifurcation buckling is discussed. Performance of domes with smeared reinforcements is discussed together with stringers which do not cover the full length of meridians.

References listed at the end of the paper:


ABSTRACT: On the basis of the moment theory of orthotropic shells of revolution and the theory of the boundary effect, analytical expressions have been obtained for deflections, stresses and the necessary thickness of orthotropic cylindrical pressure cylinders with bottoms. This analytical expressions are convenient for practical use.


ABSTRACT: Uni-directional functionally graded materials (FGMs) providing a relative change in terms of material properties have been implemented in many high-tech engineering applications, including shells and plates. As a new concept, multi-directional FGMs highlight the emergence of modern materials design in the development of multi-functional materials. Pressure vessels made of materials varying in the radial direction have been comprehensively studied. In some practical instances, however, tailored grading of material properties is required in other directions. Shells with bi-dimensional FGM properties can present practical problems arising from excessive temperature gradients and extreme deflections. In this work, asymmetric deformations of two-directional FG pressure vessels under the effect of thermo-mechanical loads are studied numerically, taking advantage of Fourier and polynomial quadrature methods. Unlike most published research on this topic, we assume that the material properties of the shell are graded in the radial and axial directions obeying an exponential formulation, leading to a more accurate simulation of the real work condition. Governing equations are formulated based on three-dimensional elasticity theory, discretised into the series form, and then the resulting equations are solved. To evaluate the accuracy and superiority of this approach, numerical results are obtained and compared with exact solutions for material properties defined by the power law and are found to be in good agreement. In the results section, it is shown that variations of the grading parameter, temperature shock, geometry profile and boundary conditions play important roles in the distribution of stress, displacement and temperature fields. In the context of the thermoelastic theory of shells and plates, the results of this work will provide a reliable database for design engineers to choose a desirable material property function, changing throughout different directions of the geometry, to mitigate thermal stresses, which should be as small and uniform as possible.


ABSTRACT: This study determines the plastic, shakedown and elastic limit loads and the corresponding regimes of 90° pressurized pipe bends with shape imperfections subjected to cyclic in-plane closing bending moment. Three dimensional FE analyses with small strain formulation was performed. The induced shape imperfections are ovality and thinning, which were varied from 0% to 20% with a 5% increment at every step. Plastic limit load was determined from the moment rotation curve while shakedown and elastic limit loads were determined by using Abdalla's simplified technique (ST). The analysis indicates that the presence of ovality produces considerable effect on plastic limit loads. Thinning alters plastic limit loads only for long bend radius models with no ovality when normalised internal pressure ratio is unity and in other cases its effect is minimal. Presence of ovality and thinning has a remarkable effect on shakedown and elastic limit loads and their regimes though the thinning effect is insignificant at higher ovality (10%–20%). Bree diagram was constructed for the reference pipe bend models. It was observed that the failure of pipe bends is due to either reversed plasticity or ratcheting. Mathematical equations are proposed to express the generated plastic, shakedown and elastic limit moment boundaries for the analyzed pipe bend models.

ABSTRACT: The as-welded 1/8 sector of vacuum vessel (VV) is a necessary component in Chinese Fusion Engineering Testing Reactor (CFETR), and it needs to be within a very tight tolerance. However, it is a challenge to find an effective way to predict and reduce the welding stress and distortion on a full scale prototype of the 1/8 VV due to its large size and complex structure. In this paper, a full size finite element model of the 1/8 VV was built using ABAQUS, and three different tungsten inert gas (TIG) welding sequences were simulated on the 1/8 VV to study the effect of welding sequences on the welding stress and distortion. The results showed that the main welding stress occurred around the welding joints and the inboard segment of 1/8 VV. Meanwhile, the shells near the top and bottom windows distorted perpendicularly to outside of the shells, while the shells around the middle window and the inboard segment distorted perpendicularly to inside of the shells. It was also noted that in three different welding sequences, the maximum distortion all occurred on the shells near the transition structures, the notable difference of the welding stress and distortion was all observed on the shells around windows. Based on the simulation results, an optimized welding sequence was obtained to control the welding stress and distortion in the actual assembly of 1/8 VV.


ABSTRACT: The reinforced S-shaped bellows, which can withstand high pressure, is a kind of typical metal bellows. A mathematical description of the structural configuration of bellows and reinforced hoop was put forward in the present study. Mechanical characteristics of the reinforced S-shaped bellows under internal pressure, forced axial and bending displacement were discussed. The ultimate pressure bearing capability of the bellows decreases slightly with the increase of the number of layers, but the decrease is limited. Axial tensile rigidity of the reinforced S-shaped bellows tends to have weak nonlinear characteristics. It can be demarcated two states by whether the stress reaches yield strength, defined as high and low rigidity respectively. Bending characteristics of the reinforced S-shaped bellows shall be analyzed based on theoretical and numerical simulation analysis, respectively. The bending rigidity is affected by material nonlinearity and fitting extent of local wave. It is directly related to the mechanical characteristics of axial torsion and compression.

Yongmei Zhu (1), Wanwan Liang (1), Xilu Zhao (2), Xiaorong Wang (1) and Jing Xia (1)
(1) School of Mechanical Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
(2) College of Mechanical Engineering, Saitama Institute of Technology, Saitama, 369-0293, Japan

ABSTRACT: This paper focuses on three viewport structures of a deep-sea spherical pressure hull. By employing the rule design method, the plane disk, conical frustum, and spherical sector viewport structures were designed, and its basic dimensions were determined. The strength and stability of pressure hulls with three different viewports were examined by employing theoretical and numerical methods under the condition that D-sub-i and t were consistent. To satisfy the strength requirement, the effects of the structural parameters of the conical frustum viewport on the stress and deformation of the contact surface were studied, and the reasons for failure, in addition to the design criterion, of acrylic plastic viewports were investigated. Additionally, equally proportioned models of pressure hulls with three different viewports were manufactured and tested. The geometrical and buckling properties of these spherical hull specimens were demonstrated via a series of tests. The results of theoretical, numerical, and experimental investigations were compared by constructing tables and figures.

Pengfei Wang (1,2), Wensheng Zhao (1,2), Jin Jiang (1,2), Xiaochuan Wang (1,2), Shunyang Li (2) and Xiangyu Luo (2)


ABSTRACT: The reinforced S-shaped bellows, which can withstand high pressure, is a kind of typical metal bellows. A mathematical description of the structural configuration of bellows and reinforced hoop was put forward in the present study. Mechanical characteristics of the reinforced S-shaped bellows under internal pressure, forced axial and bending displacement were discussed. The ultimate pressure bearing capability of the bellows decreases slightly with the increase of the number of layers, but the decrease is limited. Axial tensile rigidity of the reinforced S-shaped bellows tends to have weak nonlinear characteristics. It can be demarcated two states by whether the stress reaches yield strength, defined as high and low rigidity respectively. Bending characteristics of the reinforced S-shaped bellows shall be analyzed based on theoretical and numerical simulation analysis, respectively. The bending rigidity is affected by material nonlinearity and fitting extent of local wave. It is directly related to the mechanical characteristics of axial torsion and compression.

Yongmei Zhu (1), Wanwan Liang (1), Xilu Zhao (2), Xiaorong Wang (1) and Jing Xia (1)
(1) School of Mechanical Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
(2) College of Mechanical Engineering, Saitama Institute of Technology, Saitama, 369-0293, Japan

ABSTRACT: This paper focuses on three viewport structures of a deep-sea spherical pressure hull. By employing the rule design method, the plane disk, conical frustum, and spherical sector viewport structures were designed, and its basic dimensions were determined. The strength and stability of pressure hulls with three different viewports were examined by employing theoretical and numerical methods under the condition that D-sub-i and t were consistent. To satisfy the strength requirement, the effects of the structural parameters of the conical frustum viewport on the stress and deformation of the contact surface were studied, and the reasons for failure, in addition to the design criterion, of acrylic plastic viewports were investigated. Additionally, equally proportioned models of pressure hulls with three different viewports were manufactured and tested. The geometrical and buckling properties of these spherical hull specimens were demonstrated via a series of tests. The results of theoretical, numerical, and experimental investigations were compared by constructing tables and figures.

Pengfei Wang (1,2), Wensheng Zhao (1,2), Jin Jiang (1,2), Xiaochuan Wang (1,2), Shunyang Li (2) and Xiangyu Luo (2)
ABSTRACT: Flow-induced vibration of tube array structures is a major concern in nuclear engineering. In this paper, the dynamical behavior of flexible tubes in cross flow is studied. A computational fluid dynamics (CFD) model is developed to investigate the interaction between flow perturbations and tube oscillations. The Large Eddy Simulation (LES) is validated and adopted in the simulations. The motion of tubes in different tube configurations (i.e., single tube, three in line tubes, normal square tube array, and normal triangle tube array with different pitch to diameter ratios) under different flow conditions are analyzed and compared by time trace, power spectral density (PSD), phase plane plot and Poincaré map. Experiments have been conducted using a flexible tube in a closed-loop piping system to compare with the CFD model predictions. It is found that tube undergoes vortex-induced vibration and then fluid elastic instability, limit-cycle oscillation occurs when the inlet flow velocity exceeds a critical point. The central tube in normal square tube array is the most stable among the three configurations. The critical pitch to diameter ratio of tube array under reduced velocity $Ur = 6$ is about 5.5. The experimental observations are in good agreement with the CFD predictions.


ABSTRACT: The effect of two-parameter of Pasternak foundations on the oscillations of composite pipelines conveying a two-phase slug flow is studied in the paper. To analyze the oscillations of the pipelines conveying gas-containing fluid, a viscoelastic model of the theory of beams and a model of Pasternak foundation are used. The Boltzmann-Volterra hereditary theory of the viscoelasticity is used to describe the viscoelastic properties of the pipeline material and earth foundation. A computational algorithm has been developed for solving problems of calculating the oscillatory processes in the pipelines conveying a two-phase gas-containing flow. On the basis of the computational algorithm developed, a set of applied computer programs has been created, which makes it possible to carry out numerical studies of pipeline oscillations. The effect of the flow rate of gas and liquid phases, the effect of tensile forces in the longitudinal direction of the pipeline, Pasternak foundations parameters, the parameters of singularity in the heredity kernels on the oscillations of the pipeline made of composite materials are numerically investigated. It is found that an increase in the length of the gas bubble zone leads to a decrease in the critical velocity of a two-phase slug flow.


ABSTRACT: The present study aimed to study ratcheting strains of pressurized stainless steel (UNS S32750) pipes with cyclic axial loading conditions. To this aim, some experiments were performed for the tubes involving cyclic axial loading under internal pressure. All specimens were analyzed with a finite element code. Ohno-Wang hardening model was employed in numerical analysis to calculate the ratcheting of the tubes. By using this hardening model, all predicted ratcheting results were consistent with those of the experimental ones. In this study, the effect of pre-compressed strain, internal pressure and stress amplitude were evaluated experimentally and the numerical results were compared with the results. Finally, the tubes collapsed at about the same strain level as it did under monotonic loading. The number of cycles to collapse and the ratcheting strain rate of the pressurized pipelines depend on the different parameters such as cyclic loading parameters, pre-strain and internal pressure. The results show that an increase of pre-strain, internal pressure and cyclic loading parameters leads to increase ratcheting strain rate of pipelines in both axial and circumferential directions.
Guo-jun Tong (1), Yong-shou Liu (1), Qian Cheng (1), Jia-yin Dai (1), Yu-zhen Zhao (1) and Ying-chao Wang (2)
(1) School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, Xi’an 710129, China
(2) College of Information Science and Engineering, Ocean University of China, Qingdao 266100, China


ABSTRACT: In this paper, the dynamic stiffness method is used to research the dynamic stability characteristics of multi-span aluminum-based functionally graded material (FGM) fluid-conveying pipe enhanced by carbon nanotube. The influence of the different volume fraction on natural frequency, critical pressure and critical velocity of the FGM pipe is discussed. The influence of different radiuses on the natural frequency of the pipe and the influence of different span-ratios on the stability characteristics of the pipe are also discussed. It can be concluded that change of material component has significant influence on natural frequencies, critical velocity and critical pressure of the FGM pipe. The instability caused by flow velocity variation is different from that caused by pressure change. If the total length of the pipe remains unchanged, different span-ratios will have a great impact on the stability of the pipe. Increasing outside diameter of the pipe will cause the increase of the natural frequency.


ABSTRACT: Long-distance pipelines play an important role in oil and gas transportation. It is of great significance to study the dynamic responses of pipelines under impact loads. In this paper, based on the theories of unit impulse function and Fourier series, a Euler-Bernoulli foundation beam model is established to obtain the responses of the pipelines under impact loads. Meanwhile, embedded and surface-bonded piezoceramic transducers are used to monitor the impact force and the acceleration of the pipelines under impact loads respectively. Based on the signal received by piezoceramic transducers, the impact force is obtained and the effect of wall thickness, diameter, buried depth, impact energy and other parameters on the acceleration of pipelines are analyzed. Nonlinear finite element simulation of the impact process was carried out and the results are basically consistent with experimental and theoretical. The experimental results show that the maximum acceleration increased with an increase in the impact energy. The acceleration of large diameter and thin wall pipelines are larger at the same impact energy. The deeper the pipelines buried, the smaller the acceleration is. The effectiveness of the piezoceramic transducers are verified by the test results in monitoring dynamic responses of the buried pipelines, which provide reference for seismic design and safety evaluation of pipeline engineering.

Shunfeng Gong (1), Xipeng Wang (1), Lin Yuan (2) and Chengbin Liu (1)
(1) Department of Civil Engineering, Zhejiang University, Hangzhou 310058, China
(2) Key Laboratory of Mechanism and Equipment Design of Ministry of Education, Tianjin University, Tianjin 300072, China


ABSTRACT: Integral buckle arrestor, which consists of welded stiff rings, has proved to be very effective to arrest the propagating buckle and can be applied in sandwich pipe systems. This paper examines the propagating buckle experiments on small-scale sandwich pipes with integral arrestors under different interface bonding conditions. In addition, a numerical framework was developed to reproduce the phenomenon of buckling propagation and crossover under external pressure, and good consistency was observed between the measured and predicted results. Then, the crossover pressure was studied parametrically covering the interface bonding conditions, key material properties, as well as geometries. An empirical expression was established based upon extensive numerical analysis to predict the crossover pressure of integral arrestors for sandwich
pipes. The analysis further demonstrated that its arresting performance can be reasonably evaluated with the established empirical expression and lower bound envelope line.

Jian Zhang (1), Jiawei Tan (1), Wenxian Tang (1), Fang Wang (2) and Xilu Zhao (3)  
(1) School of Mechanical Engineering, Jiangsu University of Science and Technology, Zhenjiang 212003, China  
(2) Shanghai Engineering Research Center of Hadal Science and Technology, Shanghai Ocean University, Shanghai, 201306, China  
(3) College of Mechanical Engineering, Saitama Institute of Technology, Saitama 369-0293, Japan  
“Collapse performance of externally pressurized resin egg-shaped shells with corrosion thinning”, International Journal of Pressure Vessels and Piping, Vol. 177, Article 103993, November 2019,  
https://doi.org/10.1016/j.ijpvp.2019.103993  
ABSTRACT: In this article, we discuss the collapse performances of externally pressurized egg-shaped shells with corrosion thinning. Shells consist of photosensitive resin, with major and minor axes of 256 and 180mm, respectively. Corrosion begins at the critical location with the lowest principal meridional curvature. The circumferential corrosion values were set to 2.5°, 5°, 10°, 20°, 60°, and 360°, and the meridional corrosion values were defined as 20, 30, 40, and 50mm. The corrosion depth was assumed to be 10%, 20%, 30%, and 40% of the wall thickness, respectively. A total of 96 partially corroded egg-shaped shells were numerically analyzed with regards to nonlinear collapse modes and ultimate strengths, in addition to one noncorroded shell and four fully corroded shells. On this basis, representative egg-shaped samples, including one noncorroded, four partially corroded, and one fully corroded case, were tentatively fabricated, carefully measured, and hydrostatically tested for further experimentation. The numerical and experimental data are provided in figures and tables.

A. Ravi Kiran (1), G.R. Reddy (1), M.K. Agrawal (1), Mohan Raj (2) and S.D. Sajish (2)  
(1) Structural & Seismic Engineering Section, Bhabha Atomic Research Centre, Trombay, Mumbai, 400 085, India  
(2) Structural & Seismic Engineering Section, Bhabha Atomic Research Centre, Trombay, Mumbai, 400 085, India  
https://doi.org/10.1016/j.ijpvp.2019.103995  
ABSTRACT: Shake table tests and numerical simulations are carried out to study ratcheting based seismic performance assessment of a piping system. A carbon steel piping loop is pressurized with water and subjected to shake table excitation of increasing amplitude until failure. The resulting strain accumulation at critical location of the loop is studied with an emphasis of characterizing the ratcheting based performance levels. These test results along with codal guidance are used to propose suitable limits of these strains. Wavelet transforms are applied to study change of free vibration characteristics of the loop. Later, a numerical simulation of the loop is carried out using an experimentally validated numerical tool. The simulated strains are compared with test results.

James C. Hastie, Maria Kashtalyan and Igor A. Guz (School of Engineering, University of Aberdeen, Scotland, UK), “Failure analysis of thermoplastic composite pipe (TCP) under combined pressure, tension and thermal gradient for an offshore riser application”, International Journal of Pressure Vessels and Piping, Vol. 178, Article 103998, December 2019,  
https://doi.org/10.1016/j.ijpvp.2019.103998  
ABSTRACT: Useful characteristics of fibre-reinforced thermoplastics, including high specific strengths and moduli and excellent corrosion resistance, make them ideal candidates for offshore riser pipe applications. When in operation, risers are subjected to combined mechanical and thermal loading. In the present paper, a 3D finite element (FE) model is used to analyse stress state in a section of thermoplastic composite pipe (TCP), consisting of a fibre-reinforced thermoplastic laminate fully bonded between inner and outer thermoplastic liners, under conditions illustrative of a deepwater riser application. The effects of varying combinations of pressure and thermal differentials on the distribution of stress-based failure coefficient are examined. Failure responses under different axial tensions at low/high pressures and temperatures are assessed for configurations
with different laminate ply stacking sequences. Temperature-dependent material properties are considered in the thermomechanical analysis.

H.N.R. Wagner (1), C. Hühne (1,2), J. Zhang (3) and W. Tang (3)
(1) Institute of Adaptronic and Functional Integration, Langer Kamp 6, 38106, Braunschweig, Germany
(2) Institute for Composite Structures and Adaptive Systems, German Aerospace Center (DLR), Lilienthalplatz 7, 38108, Braunschweig, Germany
(3) School of Mechanical Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China

“On the imperfection sensitivity and design of spherical domes under external pressure”, International Journal of Pressure Vessels and Piping, Vol. 179, Article 104015, January 2020,
https://doi.org/10.1016/j.ijpvp.2019.104015

ABSTRACT: Deep spherical shells are often used as pressure vessels in ocean and aerospace engineering. When subjected to external pressure, these thin-walled shells are prone to buckling. The corresponding critical buckling pressure heavily depends on deviations from the ideal shell shape. In general, these deviations are defined as geometric imperfections, and although imperfections exhibit comparatively low amplitudes, they can significantly reduce the critical load. Considering the influence of geometric imperfections adequately into the design process of thin-walled shells poses major challenges for structural design. The most common procedure to take into account the influence of imperfections is based on the classical buckling pressure obtained by a linear analysis which are then corrected by a knockdown factor. The knockdown factor represents a statistical lower-bound with respect to data obtained experimentally for different types of thin-walled shells. This article presents a versatile and simple numerical design approach for deep spherical shells under external pressure. The new design procedure leads to significantly improved critical load estimations in comparison to lower-bounds obtained empirically. Different design example are given and validated with experimental results.

References listed at the end of the paper:

1 R. Zoelly, Über ein Knickungsproblem an der Kugelschale, Zürich (1915)
2 A. van der Neut, De Elastische Stabilität Van Den Dunwandigen bol, Dissertation, Delft. (1932)
5 H. Karimi, I. Kani, Finding the worst imperfection pattern in shallow lattice domes using genetic algorithms, J. Build Eng., 23 (May) (2019), pp. 107-113
12 A. Zingoni, Liquid-containment shells of revolution: a review of recent studies on strength, stability and dynamics, Thin-Walled Struct., 87 (2015), pp. 102-114
18 K. Klopl, O. Jungbluth, Beitrag zum durchschlag-problem duennwandiger kugelschalen, Stahlbau, 22 (1953), pp. 121-130
35. L. Berke, R. Carlson, Experimental studies of the post buckling behaviour of complete spherical shells, Exp. Mech., 8 (1968), pp. 548-553, 10.1007/BF02327517
41. H. Wagner, C. Hühne, S. Niemann, Constant Single-Buckle Imperfection Principle to determine a lower bound for the buckling load of unstiffened composite cylinders under axial compression, Compos. Struct., 139 (2016), pp. 120-129
42. H. Wagner, C. Hühne, K. Rohwer, S. Niemann, M. Wiedemann, Stimulating the realistic worst case buckling scenario of axially compressed cylindrical composite shells, Compos. Struct., 160 (2017), pp. 1095-1104
44. H. Wagner, C. Hühne, S. Niemann, K. Tian, B. Wang, P. Hao, Robust knockdown factors for the design of cylindrical shells under axial compression: analysis and modeling of stiffened and unstiffened cylinders, Thin-Walled Struct., 127 (June 2018), pp. 629-645
57 A. Evkin, Composite Spherical Shells at Large Deflections. Asymptotic Analysis and Applications, Composite Structures (2020) (accepted manuscript)
64 J. Croll, Towards simple estimates of shell buckling loads, Stahlbau, 1 & 2 (1975)
69 C. Bach, Die widerstandfähigkeit kugelförmiger wandungen gegenüber äusserem druck, Zeitschrift des Vereins deutscher Ingenieure, 46 (1902), pp. 333-341
72 R. Belinfante, Buckling of Spherical Caps under Uniform External Pressure, (1962), Douglas Aircraft company report No. SM-38938
74 C.W. Radtke, Buckling of Hemispherical Shells under External Pressures, Douglas Aircraft Company (1962), Missile Division Rept. SM-3815
76 R.R. Parmeter, The Buckling of Clamped Shallow Spherical Shells under Uniform Pressure, California Institute of Technology (1963), Tech. Rept. AFOSR 5362
77 W.A. Little, Reliability of Shell Buckling Predictions Based on Experimental Analysis of Plastic Models, Sc.D. Thesis, Massachusetts Institute of Technology (1963)
81 M. Sunakawa, I. Kazuo, A High Precision Experiment on the Buckling of Spherical Caps Subjected to External Pressure, Institute of Space and Aeronautical Science, University of Tokyo (March 1974)
82 S. Yamada, Theory and Application of Shell Buckling Mechanics, Techn. Report, Department of Architecture and Civil Engineering, Toyoohasi University of Technology (1983)
M. Javani (1), Y. Kiani (2) and M.R. Eslami (1)

(1) Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran
(2) Faculty of Engineering, Shahrekord University, Shahrekord, Iran


Abstract: Present study deals with the dynamic snap-through phenomenon of an isotropic shallow spherical cap under transient type of thermal loading. The inner surface of the shell is subjected to sudden temperature elevation, whereas the outer surface is kept at reference temperature. Transient thermal shock is applied uniformly and shell thickness is assumed to be thin enough. Therefore, transient heat conduction equation is analytically solved across the thickness direction (one dimensional). Immovable simply-supported boundary conditions are assumed for the shell. Since the boundary conditions and the applied thermal shock are axisymmetric, the governing motion equations of the shell are restricted to the case of axisymmetric. First order shear deformation theory of shells is utilized to approximate the displacement field. The von Kármán type of geometrical non-linearity is used in strain-displacement relations. With the establishment of the associated Hamilton principle, differential equations of motion are extracted. Motion equations are discretized within the shell domain by means of the harmonic differential quadrature method (HDQM). The Newmark time marching scheme based on the constant average acceleration method is applied to turn the motion differential equations into a system of algebraic equations at each time step. Highly coupled equations are solved implementing the well-known Newton-Raphson iterative technique. By means of the Budiansky criterion, critical thermal shock parameters are distinguished. Critical dynamic snap-through temperatures are also verified using the phase-plane presentation. Comparison study is performed to validate the formulation and solution method of the present research with simple cases. Also, parametric investigations are performed to demonstrate the geometrical effects on the dynamic critical buckling temperatures of the shallow spherical shells subjected to thermal shock.

References listed at the end of the paper:


14 R. Zoelly, Ueber ein Krichungstr Problem und der Kugelschale, (1915), Thesis, Switzerland


33 C.C. Chao, I.S. Lin, Static and dynamic snap-through of orthotropic spherical caps, Compos. Struct., 14 (4) (1990), pp. 281-301


Numerical analyses were carried out for the containment under diverse postulated aircraft collision conditions. Stress and strain criteria was estimated at this region under 200 m/s of speed regardless of impact angles. Moreover, effects of key parameters such as crash angles, locations, and velocities were investigated. As results, central part of the concrete wall was determined to be the most vulnerable and failure based on the conservative strain criteria. Next, effects of key parameters such as crash angles, locations, and velocities were investigated. As results, central part of the concrete wall was determined to be the most vulnerable and failure based on the conservative strain criteria.
References listed at the end of the paper:

natural frequency, they are less damageable than displacement frequency than natural frequency, they become closer to displacement controlled. When higher than twice of understood. They act like load controlled when frequency is lower than natural freq

dynamic loads and their frequencies. Furthermore, frequency dependent characteristics of seismic loads were evaluated by the Bree diagram, where main parameters are constant gravity force and alternate loads. The frequency of seismic loads was also introduced as an additional parameter.

seismic alternate loads. The frequency of seismic loads can be evaluated by the Bree diagram, where main parameters are constant gravity force and alternate loads. Ratc

ABSTRACT: Evaluation for BDBE (Beyond Design Basis Event) requires best estimation based on realistic failure phenomena. However failure modes of piping under seismic loads are not clear, because seismic load is alternate one and has both load- and displacement-controlled characteristics. For design and seismic PRA (probabilistic risk assessment), the failure mode is assumed to be collapse under PGA (peak ground acceleration). However, this conservative assumption is not appropriate for risk assessment with best estimation and uncertainty. The objective of this study is the clarification of realistic failure modes of piping under seismic loads. Previous experimental studies showed ratcheting deformation and fatigue as the most probable piping failure modes. Collapse cases were seldom. Authors pay attention to the analogy of failure modes between thermal alternate loads and seismic alternate loads. Ratcheting and collapse under thermal loads can be evaluated by the famous Bree diagram, where main parameters are constant pressure and alternate thermal loads. The Bree diagram was extensively applied to piping ratchet and collapse with such parameters as constant gravity force and alternate seismic loads. The frequency of seismic loads was also introduced as an additional parameter. As the results of experimental and analytical studies, ratcheting and collapse under seismic loads can be evaluated by the Bree-like diagram, where main parameters are constant gravity force, dynamic loads and their frequencies. Furthermore, frequency dependent characteristics of seismic loads were understood. They act like load controlled when frequency is lower than natural frequency. In the case of higher frequency than natural frequency, they become closer to displacement controlled. When higher than twice of natural frequency, they are less damageable than displacement-controlled.

References listed at the end of the paper:

Naoto Kasahara (1), Md Abdullah Al Bari (2) and Ryota Sakemi (1)

1 Nuclear Engineering and Management, The University of Tokyo, Japan
2 The University of Tokyo, Japan

“Failure modes of piping under seismic loads which have both load and displacement controlled characteristics”, International Journal of Pressure Vessels and Piping, Vol. 179, Article 103938, January 2020,

https://doi.org/10.1016/j.ijpvp.2019.103938

ABSTRACT: Evaluation for BDBE (Beyond Design Basis Event) requires best estimation based on realistic failure phenomena. However failure modes of piping under seismic loads are not clear, because seismic load is alternate one and has both load- and displacement-controlled characteristics. For design and seismic PRA (probabilistic risk assessment), the failure mode is assumed to be collapse under PGA (peak ground acceleration). However, this conservative assumption is not appropriate for risk assessment with best estimation and uncertainty. The objective of this study is the clarification of realistic failure modes of piping under seismic loads. Previous experimental studies showed ratcheting deformation and fatigue as the most probable piping failure modes. Collapse cases were seldom. Authors pay attention to the analogy of failure modes between thermal alternate loads and seismic alternate loads. Ratcheting and collapse under thermal loads can be evaluated by the famous Bree diagram, where main parameters are constant pressure and alternate thermal loads. The Bree diagram was extensively applied to piping ratchet and collapse with such parameters as constant gravity force and alternate seismic loads. The frequency of seismic loads was also introduced as an additional parameter. As the results of experimental and analytical studies, ratcheting and collapse under seismic loads can be evaluated by the Bree-like diagram, where main parameters are constant gravity force, dynamic loads and their frequencies. Furthermore, frequency dependent characteristics of seismic loads were understood. They act like load controlled when frequency is lower than natural frequency. In the case of higher frequency than natural frequency, they become closer to displacement controlled. When higher than twice of natural frequency, they are less damageable than displacement-controlled.

References listed at the end of the paper:


ABSTRACT: The research reported here sought to obtain the optimal winding angle ($\phi$) in laminated carbon fiber reinforced polymer (CFRP) composite pipes under patch loading. To observe the sole effect of winding angle on the pipe's mechanical strength, the stacking sequence of the composite laminates ($[0]_n$) was kept constant. An analytical investigation based on linear membrane shell theory was adapted to obtain the radial displacements ($w$) along the radial direction ($z$). A double Fourier series expansion was used during the analytical investigation. Two crucial factors were considered when selecting the optimal winding angle: (1) the minimum difference between the inward (compression) and outward (tensile) radial displacements, and (2) the minimum radial deflection at the circumference where patch loading is applied ($\theta = 0^\circ$). The optimal winding angle, $\phi = 55^\circ$, was obtained using a classical trial and error technique. The analytical results for $\phi = 55^\circ$ were demonstrated to be reasonable for simplifying large-scale complex piping systems when conducting shock resistance research.

Ebrahim Sharifi Tashnizi (1), Soheil Gohari (2), S. Sharifi (2) and Colin Burvill (2)
(1) Department of Mechanical Engineering, Tafresh University, Iran
(2) Department of Mechanical Engineering, The University of Melbourne, Parkville, VIC, 3010, Australia

"An analytical investigation based on linear membrane shell theory was adapted to obtain the radial displacements ($w$) along the radial direction ($z$). A double Fourier series expansion was used during the analytical investigation. Two crucial factors were considered when selecting the optimal winding angle: (1) the minimum difference between the inward (compression) and outward (tensile) radial displacements, and (2) the minimum radial deflection at the circumference where patch loading is applied ($\theta = 0^\circ$). The optimal winding angle, $\phi = 55^\circ$, was obtained using a classical trial and error technique. The analytical results for $\phi = 55^\circ$ were demonstrated to be reasonable for simplifying large-scale complex piping systems when conducting shock resistance research."

Jun Guo (1), Xun Zhao (1), Yin Zhang (1), Chen Ji (2) and N.A. Taranukha (1)
(1) College of Shipbuilding Engineering, Harbin Engineering University, Harbin, 150001, China
(2) Naval Research Academy, Beijing, 100000, China


ABSTRACT: The shock resistance of ship piping systems is very difficult to study owing to the large scales of such systems, and the high level and variability of the impact loading involved. To address these issues, the present work establishes a numerical model of pipe systems based on multi-span beam bending moment theory. An analysis of the bending moments of different multi-span continuous beams under static loading demonstrates that the simplified model employing just five spans provides a bending moment for target equal diameter straight tube (EDST) segments that deviates from theoretical calculations by less than 1%. Moreover, the bending moments obtained by the five-span model for a target EDST segment deviate by only about 4% from corresponding results obtained by the finite element (FE) method under both uniformly distributed static loading and complex static loading. The proposed simplified five-span model is then employed to calculate the stress responses obtained at individual critical points in a complex piping system under impact loading. The results obtained deviate at most by less than 15% from corresponding results obtained from the FE method based on the overall piping system model. Moreover, the average deviation for all critical points considered was only 5.87%. The results show that the shock response obtained using the simplified five-span model is essentially equivalent to that of the complex model. The proposed simplified five-span method is thereby demonstrated to be reasonable for simplifying large-scale complex piping systems when conducting shock resistance research.
then validated by an experimental investigation. Due to a lack of prior reported experimental investigations into radial deformation analysis of laminated composite pipes under patch loading, the manufacturing and test procedures have been discussed comprehensively in this paper. The pipe with optimal stacking sequence $[55^\circ/-55^\circ/55^\circ/-55^\circ/55^\circ]$ was first manufactured using the filament winding machine and then subjected to patch loading using the INSTRON machine. The experimental tests were conducted on three arbitrarily selected circumferential angles $\theta = (0^\circ, 48^\circ, 77^\circ)$. The radial displacement at $\theta = 0^\circ$ was measured using a tensile testing (INSTRON) machine. The radial displacements at $\theta = (48^\circ, 77^\circ)$ were simultaneously measured using a laser displacement sensor (model: ANR 1150) and a dial indicator (model: 0.01–30 mm Mitutoyo), respectively. Ultimately, the radial displacements for a loading range of $F = [0 - 800]$ (N) were obtained. There was good agreement between the analytical and experimental results, which offers a useful guideline for future design and manufacture of laminated composite pipes with elevated section.


ABSTRACT: This paper is concerned with the failure analysis of elasto-plastic thin-walled pipes under combined internal pressure and axial loading (monotonic or alternating). Depending on the loading history (pressure and axial loading histories) the pipe may exhibit a different mechanical behavior due to the progressive accumulation of plastic deformation. The study, performed under different loading histories, is adequate to identify the history dependent failure pressure. The analysis of the results allows obtaining a very simple safety criterion for the plastic collapse. The main result is that, regardless the load history, a safe region can be defined analytically in the space of circumferential and axial stresses. A comparison of the theoretical predictions with experiments shows coherent preliminary results. The simplified methodology proposed in this study provides a safe and reliable preliminary tool for designers and engineers that can be used to help to plan inspection and preventive maintenance.

Alexandros I. Valsamis (2), George D. Bouckovalas (1) and Charis J. Gantes (2)
(1) School of Civil Engineering, Department of Geotechnical Engineering, National Technical University of Athens, 15780 Zografou, Greece
(2) School of Civil Engineering, Department of Structural Engineering, National Technical University of Athens, 15780 Zografou, Greece

ABSTRACT: The use of “flexible joints” in buried high-pressure pipelines is examined herein as an effective design technique for the mitigation of Permanent Ground Displacement (PGD) effects due to fault activation. Pipeline joints that are available in the industry today are considered in connection with the needs of high-pressure pipelines in areas of seismic faults. The efficiency of this novel technique is examined through a series of parametric numerical analyses for both strike-slip and normal faults, while its applicability in common engineering problems is examined through an economic-technical comparison with more conventional techniques. It is concluded that the use of flexible joints provides a cost-efficient design method, that can drastically reduce pipeline strains for medium to large fault displacements.


ABSTRACT: A theoretical model of the fluidelastic instability of tube bundles in two-phase cross flow is proposed. The model considers the interaction between fluid force and cylinder motion. Through theoretical
investigation, the mechanism of fluidelastic instability induced by two-phase flow was revealed, and an experiment was conducted to verify the approach. The effects of the time delay parameter and the tube natural frequency on the critical velocity of fluidelastic instability were also investigated, and the results indicate that both are important factors in this respect. The influence of the time delay parameter on critical velocity is significant, particularly when the void fraction is low. A linear relationship between critical velocity and tube frequency was observed under all tested void fraction conditions. By comparison with previously reported test data, it is demonstrated that the model proposed herein is able to provide an accurate prediction of the fluidelastic instability of a tube array in two-phase flow.

P. Karimi Zeverdejani (1) and Y. Kiani (2)
(1) Mechanical Engineering Department, Shahrekord University, Shahrekord, Iran
(2) Faculty of Engineering, Shahrekord University, Shahrekord, Iran


ABSTRACT: In the present research, the coupled and non-linear thermo-mechanical response of a functionally graded material (FGM) hollow sphere under thermal shock is investigated. It is assumed that all of the properties of the sphere except for the thermal relaxation time are graded through the radial direction using an exponential representation. The formulation is based on the Lord and Shulman theory which contains a single relaxation time parameter to avoid the infinite speed of temperature wave propagation. Two coupled equations namely energy and motion equations are obtained. These two equations are written in terms of temperature change and radial displacement. The energy equation is kept in its non-linear form and the assumption of small temperature change in comparison to reference temperature is not established in this research. The obtained equations are provided in a dimensionless presentation. After that using the generalised differential quadrature (GDQ) method, nonlinear algebraic presentation of the governing equations is established. Using the successive Picard algorithm and the Newmark time marching scheme, the temporal evolution of the temperature and displacement are obtained. Numerical results are validated for the case of homogeneous sphere with the available data in the open literature. After that, novel numerical results are given to explore the effect of relaxation time, coupling parameter, exponential index and non-linearity of the energy equation.


ABSTRACT: The well-established benefits of compressive residual stresses over the fatigue lifetime constantly motivate engineers to scrutinize these trapped stresses in mechanical/civil structures. This research deals with characterization of thermal residual stresses in fiber reinforced polymer (FRP) tubes. Three important thermo-mechanical parameters, namely “cooling temperature”, “CNT reinforcement” and “tube size” are taken into account with the aim of achieving optimum design in manufacturing of FRP tubes. The work includes experimental evaluation of residual stresses coupled with developing a MATLAB programming code and performing a thorough finite element (FE) analysis. After fabricating several hybrid FRP tubes with respect to the mentioned parameters, we measured residual stresses conducting “slitting” semi-destructive method. The impact of either of parameters is then examined and some key points are suggested regarding controlling residual stress in FRP structures. The outcomes of this work suggest that slitting method can practically provide access to the in-depth distribution and through thickness of trapped stresses in the FRP laminates with a good accuracy. It is also underscored that studied parameters could play a crucial role in creation of thermal residual stresses.

Jian Li (1,2), Chang-Yu Zhou (3,4) and Jian-Guo Zhu (1,2)
(1) Institute of Structural Health Monitoring, Faculty of Civil Engineering and Mechanics, Jiangsu University, Zhenjiang, 212013, China
(2) National Center for International Research on Structural Health Management of Critical Components, Jiangsu University, Zhenjiang, 212013, China
ABSTRACT: This paper is dedicated to providing a detailed limit load analysis for 180° pipe bends under bending moment using three dimensional finite element (FE) method considering geometric nonlinearity. Results show that FE results for 180° pipe bends are all lower compared to those for 90° pipe bends, especially for pipe bends with thin wall and small bend radius ($R/r = 1.5$, $t/r = 50$). However, for pipe bends with thick wall and large bend radius ($R/r = 4$, $t/r = 5$), results seem very close. New predicted equations are proposed based on the FE results. If the geometric nonlinearity effect is considered, when the material parameters of yield strain $\varepsilon_y = 0$, results still obey the estimating solutions without geometric nonlinearity considered. But the geometry change should have some significant influence on the failure with the material's behavior changing. With the applied bending load increasing, the ovalization parameter $C$ will also continue to increase. The change of the parameter $C$ is significant for the thin pipe bends ($t/r = 50$), while is not obvious for thick pipe bends ($t/r = 5$). The influence of the bend radius on the parameter $C$ is not significant. Geometric effect is significant for a high yield strain value that the pipes will have enough ability to be deformed.

Qichen Tang (1,2), Nan Jiang (1,2), Yinkang Yao (2,3), Chuanbo Zhou (1) and Tingyao Wu (1)
(1) Faculty of Engineering, China University of Geosciences, No.388, Lumo Road, Wuhan, 430074, Hubei, China
(2) Hubei Key Laboratory of Blasting Engineering, No.6, Boxue Road, Wuhan, 430000, Hubei, China
(3) Wuhan Explosion & BlastingCo., Ltd., No.6, Boxue Road, Wuhan, 430000, Hubei, China

ABSTRACT: In order to study the impact of surface explosion load such as terrorist attacks and disasters on buried pipelines, the field experimental study of the dynamic response characteristics of buried pipelines under surface explosion load was carried out by means of explosion experiment of on-site pre-buried pipelines and explosives, combined with blasting vibration and dynamic strain monitoring. The attenuation law of the ground surface peak particle velocity (PPV) above the pipeline was analyzed under explosion load with varied explosive charge and different blasting distances, meanwhile, the PPV and the peak particle strain (PPS) distribution characteristics of buried pipelines under surface explosion load are studied. The function expression of the relationship between ground surface's PPV, pipeline's PPV and pipeline's PPS is established on the basis of field experiment results. Integrated with the maximum allowable strain theory of pipelines, the safety evaluation of buried pipelines under blasting load is carried out. Then, the “safety area” of explosion parameters for preventing pipeline damage is proposed.

Nosakhare Enoma (1) and Alphose Zingoni (2)
(1) Department of Mechanical Engineering, University of Benin, Ugbowo, 300283, Benin City, Nigeria
(2) Department of Civil Engineering, University of Cape Town, Rondebosch, 7701, Cape Town, South Africa

ABSTRACT: As part of recent work on the structural behaviour of toroidal shells, this paper presents results of a numerical study on the buckling resistance of a closed toroidal vessel with a doubly-symmetric parabolic-ogival cross-section, subjected to uniform external pressure. The analysis was carried out on both geometrically perfect and imperfect elastic steel shells, and boundary conditions resulting in the lowest buckling pressure were adopted. A range of shell geometries and possible imperfections of the geometry were considered. The study shows that buckling initiates as non-axisymmetric deformations in the weakest zones near the top and bottom edges of the outer segment of the vessel. The buckling strength of the vessel is found to be strongly dependent on the geometrical parameters of the cross-section, and parameters giving the largest buckling resistance of the vessel, and parameters giving the largest buckling resistance of the vessel.
vessel are identified. While the buckling behaviour is sensitive to initial geometric imperfections in the form of eigenmodes, the vessel is generally stable after bifurcation.


ABSTRACT: The concept of sandwich pipes for subsea applications has been studied independently of an available connection to joint the pipe segments. Therefore, it is necessary to propose and study the design of a pipe segment connection to build a continuous sandwich pipeline. The reported research work suggests using threaded connections of integral type with square teeth and metal-to-metal sealing. The threaded connector is analyzed by a two-dimensional numerical model using nonlinear finite elements to obtain both contact stress and maximum tension under make-up torque, external pressure, and axial loads. The make-up torque is applied through radial interference for different tightening torques. The results indicate that the threaded connector is a feasible solution for the sandwich pipe joint, especially for the watertight requirement under combined loads.


ABSTRACT: Polypropylene (PP) plastic pipes have recently gained widespread application in non-pressurized gravity pipes used for seawater intake lines in the petrochemical industry. These pipes consist of a solid wall base pipe, on which an outer reinforcement called the omega-profile is spirally wound and hot fusion bonded. The omega-profile is usually filled with grout to provide on-bottom stability for subsea installation. It is of high importance that the bond between the omega-profile and the base pipe has sufficient strength to provide resistance against buckling of the pipeline system. The objective of this study is to investigate the collapse behaviour of such large-diameter PP pipes subjected to a negative internal pressure. The bond is modelled with cohesive zone modelling technique with the aim to determine the failure mode that governs the collapse behaviour of the pipe, e.g. buckling or delamination. Experiments where conducted on single cantilever beam (SCB) specimens cut from the pipe to determine the cohesive bond strength between the omega-profile and base pipe. The findings from the experiments are implemented in a full pipe model, where the surface between the omega-profile and base pipe is assigned bond strength characteristics in accordance with the experimental results. The FEA results of the non-linear collapse analysis of the full pipe model show that for the range of grout stiffness values considered (0 ≤ E ≤ 30 GPa), the governing failure mode of the pipe is initiated by buckling and proceeded by delamination. For delamination to govern the failure mode, a grout stiffness greater than 36 GPa in combination with a weaker bond strength than the experimentally measured would be required. The methodology presented in this study gives a rather accurate tool for the design and analysis of this type of structures, and can reliably assess the bond strength level required in view of the governing failure modes, e.g. buckling and delamination.


ABSTRACT: This paper presents an analytical study on the buckling of cylindrical shells under arbitrarily distributed axial loads. It has three main innovation points. First, different from the previous studies, the axial loads need not be assumed to be specific forms beforehand and be simple ones such as cosine type, which are arbitrary in this paper (including continuous and discontinuous distributions). Second, combining the separation of variables and perturbation methods, it develops a novel general method to solve the fourth-order partial differential equations with unknown variable coefficients for cylindrical shells under distributed axial loads. Last, it derives the asymptotic formula of buckling loads with respect to shell geometry sizes and load functions for the first time. Using the presented formula, two continuous axial load distributions are analyzed first and the results show a good agreement with previous studies and those by the Bubnov-Galerkin method. Furthermore, one discontinuous axial load distribution is investigated. Comparative study on effects of load distribution
parameters and types is also performed. The study has sufficient accuracy and significant engineering application value.


ABSTRACT: The paper presents a result of the numerical investigation into the buckling behaviour of geometrically imperfect cone-cylinder transition subjected to external pressure. The models are assumed to be made from the Hiduminium alloy (HE-15). Various initial geometric imperfections such as eigenmode imperfection and Single Load Indentation (SLI) imperfections were superimposed on the perfect cone-cylinder shell. The reduction of the buckling strength was then quantified numerically. As expected, the buckling strength of cone-cylinder shells were strongly affected by initial geometric imperfection and the reduction in buckling strength was seen to be strongly dependent on the choice and location of imperfection. Overall, the lowest SLI imperfection curve produces the worst sensitivity as compared to the eigenmode imperfection curve. Conservative knockdown factors that can be implemented for the design of cone-cylinder transition have been proposed for both eigenmode imperfection and SLI imperfection. Finally, a simple empirical solution based on several case studies has been proposed that could reasonably be used to estimate the buckling of externally pressurized cone-cylinder shell transition under Geometrical and Materially Non-linear Analysis (GMNA) and Geometrical and Materiaally Non-linear Imperfection Analysis (GMNIA) cases. A good correlation with the ultimate strength is observed with the application of the proposed empirical formula.


ABSTRACT: Subsea steel pipes are often used to form extensive networks for transporting oil and gas over large distances. Such pipes can be subjected to actions characterised by high loading rates and intensities stemming from high-mass low-velocity collisions. To ensure that such networks continue to operate, even after being subjected to impact loads, it is essential that the behaviour of the pipes is characterised by a certain level of resilience. Considering that most of the available data obtained from drop-weight tests on steel pipe specimens does not provide a detailed description of the behaviour exhibited throughout the loading process, the work herein aims at investigating numerically, via dynamic nonlinear finite element analysis, the problem at hand. After validating the predictions obtained against the available test data, the numerical investigation focuses on studying the effect of a range of parameters on the exhibited behaviour. The latter parameters are associated with the shape and mass of the impacting object, the geometry and the support conditions of the pipe, the level of axial loading (applied along the axis of the pipe) as well as the level of internal and/or external pressures imposed onto the pipe walls. The numerical predictions reveal that the above parameters, most of which are associated with the in-situ conditions imposed onto subsea pipes throughout their operational life, can influence, potentially detrimentally, the exhibited behaviour. The numerical predictions obtained reveal that this effect is not accurately captured by the existing assessment methods employed in practice for predicting the level of damage suffered by pipes during impact.


ABSTRACT: The structural reliability of a pipe-in-pipe system operating in deep-waters under high internal pressure and high temperature is assessed. First, the major failure modes are identified and the respective limit state functions are formulated. In particular, the collapse of the outer and inner pipes, the local buckling of the inner and outer pipes under combined loading, the burst of the inner pipe and the buckle propagation are addressed. Additionally, a serviceability limit state function is formulated for the lateral buckling response due to excessive axial force on the outer pipe. Appropriate resistance and load models for the pipe-in-pipe configuration are included in the limit state functions. Uncertainties in the structure, operating and environmental conditions are incorporated in the limit state functions through probabilistic modelling. First-Order and Second-Order, reliability methods and Monte Carlo Simulation techniques are used to assess the
structural reliability and the effect of limit state variables on the probability of the PiP failure modes. System reliability bounds for combined failure modes are estimated through a second-order series bounds approach. The importance of basic variables of the limit states is evaluated through sensitivity analysis. Several parametric studies are conducted to show the influence of the limit state variables on the reliability of each failure mode and on the bounds of the system reliability.


ABSTRACT: It has recently been contemplated to use spherical caps as outer space energy concentrators. Adding toroidal segment to a cap gives a component known as torisphere which offers the necessary, space-relevant reinforcement of cap's rim. The current study addresses a range of issues related to the above shell. Buckling, affected by shape imperfections, being one of them, is studied numerically. Possible forms of reinforcement by stringers and/or rings are also discussed. Analysed domes can be impacted by debris, creating dimples, leading in turn to the loss of buckling strength. Results of this aspect, together with possible repair scenario are provided.


ABSTRACT: Boiler tubes used in power plants and manufacturing industries are prone to failure due to the harsh environment they operate in, usually involving high temperature, pressure, and some erosive-corrosive mechanisms. Among the wide range of failures associated with the tubes, localized external erosion continues to be a leading cause of tube leakages and unscheduled boiler outages in power plants and other utilities. This paper lays the foundation to develop a rapid decision-making tool to help prioritize the maintenance, repair, or replacement of these tubes. A failure assessment methodology is proposed, based on the analysis of failed localized thinned tubes from a power plant. Minimal geometric measurements are available for each failed tube (width of flaw, length and flaw and minimal remaining thickness). Finite element models of idealized flaws are created that match the measured data for all the failed tubes. Finite element models with higher remaining wall thickness than the measured values are also constructed. Using two material models, comprehensive nonlinear finite element analyses are conducted on the 160 modeled flawed tubes. The flawed tubes are assessed using the API-ASME fitness-for-service assessment protocol to demonstrate how these flawed tubes would be ranked from most severe to least severe. Allowable wall loss for some of the considered flawed tubes ranges from 44% to 81% of the original wall thickness, indicating that fitness-for-service assessments can establish safe operation even for substantially eroded boiler tubes.


ABSTRACT: The main purpose of the present research is the investigation of the stress and displacement distributions of the internally pressurized thick-walled hyperelastic cylindrical vessels or pressure pipes. The governing equations are derived by incorporation of the incompressible neo-Hookean and Mooney-Rivlin hyperelastic constitutive models into the direct hyperelasticity theory in the von Karman framework of large deformations. In contrast to the available researches, no simplifications or linearization are made. The nonlinear governing equations are solved by utilizing a second-order point-collocation procedure and implementation of details of the proposed incremental iterative solution scheme in the Matlab code written by the authors. Another novelty of the present research is experimentally identifying the employed polymeric hyperelastic material and verification of the results through experiments conducted by the authors. Due to using both nonlinear constitutive laws and nonlinear stress-displacement relations, through-thickness distributions of the radial displacement and radial and circumferential stresses are extracted for various pressures. The experimental results reveal that while the neo-Hookean hyperelastic model cannot be used for materials with stress-softening, the Mooney-Rivlin model reproduces the experimental results with excellent accuracy. In
addition to the experimental verification, the results are verified by the Abaqus finite element analysis code as well.


ABSTRACT: The stratum settlement caused by underground mining is one of the main geological disasters that threaten and damage buried pipelines. Therefore, the mechanical behavior of buried pipe under stratum settlement is investigated in this paper. Effects of pipeline parameters, mining area parameters and inclination directions of mining area on mechanical behavior of the buried pipeline are discussed. The results show that the maximum Von Mises stress and the maximum vertical displacement of pipeline are located in the middle of the pipeline during the mining process. As the excavation length increases, the Von Mises stress, the circumferential strain and vertical displacement increase. However, there is only stress concentration in the pipeline, and does not appear yield deformation. The vertical displacement of the pipeline is much greater than the horizontal displacement. The maximum stratum displacement appears on the upper surface of the mining area and it is stratum settlement. In addition, as the diameter-thickness ratio, buried depth, surrounding soil thickness of the pipeline and the height and the width of mining area increase, the maximum Von Mises stress, the circumferential strain and maximum vertical displacement of the pipeline increase, but they decrease with the increase of the buried depth of mining area. Whether the mining area is horizontal inclination or longitudinal inclination, the maximum Von Mises stress and maximum vertical displacement of pipeline are located in the middle of the pipeline. The maximum Von Mises stress, the circumferential strain and vertical displacement of pipeline decrease with the increase of the inclination angle. However, for the mining area of longitudinal inclination, the pipeline would produce horizontal displacement, the horizontal displacement of the pipeline increases with the increase of longitudinal inclination angle, and the position of the maximum strain of the pipe appears to shift. For the mining area of horizontal inclination, with the increase of horizontal inclination angle, the right side of vertical displacement curves approximately overlap, but the left side separates from each other.


ABSTRACT: Accurate assessment of the burst pressure of corroded pipes is pivotal for pipelines integrity management and adequate decision-making and thus, meticulous selection of an appropriate prediction model is vital. Several burst strength models have been developed based on analytical, numerical and empirical analyses, often validated by full or small-scale experiments. This paper provides a comprehensive review, calibration and model uncertainty evaluation of a wide range of burst strength models available in the literature relative to a large sample of more than 240 tests of burst pressure covering a variety of steel grades. First, the most appropriate strength model for corrosion free pipes is calibrated by comparing it with extensive test data and the inherent model uncertainty factor is derived. Then, 25 burst strength models for corroded pipelines are categorically analysed in three classes of steel pipe grades, i.e., low (X42 or less to X56), medium (X60 to X70) and high strength (X80 to X120). Statistical parameters such as the mean and absolute mean errors and standard deviation are adopted to analyse and compare the models’ performance against test results. The burst strength models of corroded pipelines in the three categories are then calibrated by model uncertainty factors derived from the experimental data. Then, the top 10 models are comparatively analysed in each category to check their performance and uncertainty. Monte Carlo simulation is used to assess the uncertainties with increasing defect depth. The paper concludes exploring the extent of applicability and best utilization of the models for assessing the burst pressure of corroded pipelines. The present study also provides guidance on the calibrated models, which can be used to assess probabilistically the safety of intact and corroded pipelines against burst failure.


ABSTRACT: This study focused on the buckling of corroded spherical shells with wall-thickness reduction in local regions under a uniform external pressure. For spherical shells whose wall thickness was reduced owing to
local corrosion on the outer surface, the effects of the shape, area, depth, and location of the reduction on the buckling properties were evaluated to identify the most dangerous case. Accordingly, the load-carrying capacity of corroded spherical shells with local reduction was predicted. Moreover, by verifying the five buckling prediction formulas of the spherical shells, reasonable prediction formulas for the compressive capacity of the spherical shells under the condition of corrosion defects were obtained. Four scale models were fabricated using resin material for testing. The geometric shape and wall thickness of each spherical shell model were measured and compared with those of the ideal model. Then, the buckling load and ultimate collapse mode were determined through a hydrostatic test. The experimental and numerical analysis results were compared to verify the numerical analysis.


ABSTRACT: The purpose of this article is to study the large amplitude vibration behavior of functionally graded orthotropic double-curved shallow shells (FGODCSSs), such as the shallow spherical and hyperbolic paraboloidal shells. After mathematical modeling of the properties of the FG orthotropic material, von-Karman type non-linear basic relations are created, and at the next stage the non-linear equations of motion for double-curved shallow shells are derived. The non-linear basic partial differential equations of FGODCSSs are converted to non-linear ordinary differential equations using the principle of superposition and the Galerkin method. Then non-linear equations are solved by applying the method proposed by Grigolyuk [46] and get the expressions for the frequency-amplitude relationship and the ratio of the nonlinear frequency to the linear frequency for FGODCSSs. Using these expressions, the results are compared with the results in the literature, and after checking the reliability and accuracy of the proposed formulation, specific numerical calculations are performed. For specific analyzes, the homogenous and FG orthotropic shallow spherical and hyperbolic paraboloidal shells are used, and their large amplitude vibration behaviors are discussed in comparison with each other, and various examples reveal that the influence of heterogeneity is noticeable.


ABSTRACT: Return mapping algorithms are popular procedures for evaluating elasto-plastic material behaviour. This paper presents a dedicated return mapping algorithm for thin walled pipes and vessels with Von Mises plasticity and isotropic hardening, for which it can be assumed that the hoop stress is constant. This applies for example to pipe line sections during offshore laying operations. In the algorithm a nonlinear scalar equation is solved iteratively. A general 3D radial return mapping algorithm with an iteration loop to fulfil the assumptions on hoop and radial stress is used to verify results obtained with the dedicated algorithm. Results of both algorithms are identical, while the new algorithm is more efficient.


ABSTRACT: The present study uses advanced numerical tools to examine the mechanical behavior of steel pipe bends (elbows), subjected to strong cyclic loading, associated with repeated plastic deformations of alternate sign. The elbows are modeled with finite elements, accounting for the measured elbow geometry and the actual properties of steel elbow material. The main feature of the present work is the simulation of material response using an advanced cyclic-elasticity model, based on the bounding-surface concept, implemented through an in-house material subroutine. Upon appropriate calibration with material tests in strip specimens, extracted from the bends under consideration, the constitutive model is employed for predicting the mechanical response of large-scale physical laboratory experiments. Very good predictions are obtained in terms of global load-displacement response, as well as in terms of local strains and their accumulation over the loading cycles (ratcheting) at specific elbow locations. This indicates that the bounding-surface model can be an efficient tool for predicting accurately the mechanical response of piping components under severe cyclic loading conditions. Finally, using the validated numerical models, extensive results are obtained, focusing on the effects of internal pressure on strain accumulation at specific locations of the elbow, for three values of pipe thickness.
ABSTRACT: In this paper, the blast responses of fiber metal laminates (FMLs) and gradient aluminum honeycomb sandwich panels with FML as skins were experimentally investigated. The woven basalt fabric was chosen as the composite reinforcement in FMLs due to its excellent mechanical and eco-friendly properties. Five different core layer arrangements were considered for sandwich panels in the experiments by arranging honeycomb core layers with different cell geometric dimensions. The deformation/failure modes of sandwich panels were obtained in the experiments, in terms of FML face-sheets and gradient honeycomb cores. The energy absorption of gradient honeycomb cores was quantitatively analyzed by digitizing the deformation/failure region of cores. The results showed that the use of basalt FMLs as face sheets can greatly enhance the blast resistance of sandwich panels compared with that with aluminum sheets as skins. The blast resistance of gradient sandwich panels not only depends on the geometric dimensions and arrangements of core layers, but also related to the intensity of target load which will cause different deformation/failure mechanism of panels. Thus, in order to obtain the best blast resistance, a well-design gradient sandwich panel should have suitable core layer arrangements and geometry to satisfy the intensity of target blast load. The results obtained from current study can give valuable reference to the using of sandwich panels in engineering protection field.

References listed at the end of the paper:
3 CJ Shen, G Lu, TX Yu, Dynamic behavior of graded honeycombs – A finite element study, Compos Struct, 98 (2013), pp. 282-293
5 X Xu, Y Wang, Z Yin, H Zhang, Effect of temperature and strain rate on mechanical characteristics and constitutive model of frozen Helin loess, Cold Reg Sci Technol, 136 (2017), pp. 44-51
6 Z Xue, JW Hutchinson, Preliminary assessments of sandwich plates subject to blast loads, Int J Mec Sci, 45 (2003), pp. 687-705
8 JW Hutchinson, Z Xue, Metal sandwich plates optimized for pressure impulses, Int J Mech Sci, 47 (2005), pp. 545-569
12 GN Nurick, GS Langdon, Y Chi, N Jacob, Behaviour of sandwich panels subjected to intense air blast – Part 1: experiments, Compos Struct, 91 (2009), pp. 433-441
15 X Li, P Zhang, Z Wang, G Wu, L Zhao, Dynamic behavior of aluminum honeycomb sandwich panels under air blast: experiment and numerical analysis, Compos Struct, 108 (2014), pp. 1001-1008
17 L Cui, S Kiernan, MD Gilchrist, Designing the energy absorption capacity of functionally graded foam materials, Mat Sci Eng A-Struct, 507 (1) (2009), pp. 215-225
18 X Liu, X Tian, TJ Lu, B Liang, Blast resistance of sandwich-walled hollow cylinders with graded metallic foam cores, Compos Struct, 94 (8) (2012), pp. 2485-2493
19 S Li, Z Wang, G Wu, L Zhao, X Li, Dynamic response of sandwich spherical shell with graded metallic foam cores subjected to blast loading, Compos Part A-Apppl, 56 (2014), pp. 262-271
20 S Li, X Li, Z Wang, G Wu, G Lu, L Zhao, Sandwich panels with layered graded aluminum honeycomb cores under blast loading, Compos Struct, 173 (2017), pp. 242-254
influence on the impact resistant properties of the laminated glass. The impact results indicated that both the type of the interlayer materials and testing temperature have great performance of laminated glass.

ABSTRACT: This paper investigates the influence of the interlayer material on the low velocity impact response of laminated glass with different types of interlayer material on the low velocity impact resistance of high-performance aluminium foam sandwich structures, J Reinf Plast Comp, 24 (10) (2005), pp. 1057-1072.


ABSTRACT: The article presents the outcome of research concerning the energy absorption of thin-walled structures made of AZ31B magnesium alloy. Tested material cracks brittle during bending at ambient temperature. This well-known problem makes plastic forming of magnesium alloys very difficult. It also causes less frequent use of this material in the production of energy-absorbing elements. Following study demonstrates that the use of proper geometric shape allows to control the process of dynamic crushing and activates a new mechanism of energy absorption that is progressive crushing.


ABSTRACT: This paper investigates the influence of the interlayer material on the low velocity impact performance of laminated glass. The effect of temperature (50°C, 23°C, 0°C and −30°C) has been explored to observe damage mechanisms and the associated impact resistant properties of the laminated glass. The four interlayer materials investigated were: SGP – ionoplast as employed in Sentry Glas’ Plus, TPU – thermo-plastic polyurethane, PVB – polyvinyl butyral and a TPU/SGP/TPU hybrid interlayer. The impact resistance was measured in terms of load peak, absorbed energy, ultimate deformation and crack patterns. The low velocity impact results indicated that both the type of the interlayer materials and testing temperature have great influence on the impact resistant properties of the laminated glass. The laminated glass with SGP interlayer
exhibited best impact resistant properties amongst the four structures at room temperature. However, as the temperature was varied, the TPU/SGP/TPU hybrid interlayer performed the best over the entire range of temperatures tested, which can better ensure the safety of the occupants in the vehicle. This is because the elastic and viscous properties of the interlayer materials greatly changes with the temperature caused by the different glass transition temperatures of the interlayer materials.


ABSTRACT: This paper presents a series of experimental, numerical and theoretical analyses of cylindrical tubes subjected to lateral external air blast loading. The cylindrical tubes are laterally loaded in the mid span using cylindrical TNT with a charge mass of 20, 25, 30, and 40 g detonated at a stand-off distance of 50, 100, and 150 mm. The resultant impulses produce failures ranging from large inelastic deformation of the cylindrical tube to tearing of the structure. The results are compared with a modal solution and numerical simulations carried out in ABAQUS 6.12-1, where good correlations with the numerical simulations are observed. The experimentally obtained deformed cross-section can be divided into three parts: a flat top section, two arcs near the flat top and an undeformed circular arc at the bottom. The axial deformation section can also be divided into three parts: the first part is a large plastic deformation region at the center of the structure that divides two outward moving plastic hinges from the second part, which can be defined as a rigid section moving around the plastic hinge at the support, and the third part is the undeformed boundary region. The above deformation patterns were used to develop a theoretical model based on a rigid-plastic analysis. Since the experimental pressure of the cylindrical explosive was more localized than the theoretically defined pressure distribution, the modal solution together with the upper bound yield condition of the tube used in the analysis, overestimated the resistance of the tube.

References listed at the end of the paper:
ABSTRACT: A series of twenty experimental tests were first carried out to assess the large transverse deformation of double-layered rectangular plates subjected to gas mixture detonation load. Specimens were made from a combination of an aluminum alloy front layer (the impulse-receiving face) and a mild steel back layer. Four different types of thickness configurations, namely, 1 mm + 1 mm, 2 mm + 1 mm, 1 mm + 2 mm, and 2 mm + 2 mm were selected to bring an insight into the influence of back and front layer thicknesses on the deformation resistance of double-layered plates. Each specimen group was subjected to five different pre-detonation pressures of acetylene and oxygen mixture. Quantitative experimental results were obtained and discussed in detail. The experimental results showed that the back layer deflection was approximately equal to the front layer deflection when there was no gap between the layers and the front layer had a lower strength and density than the back layer. A closed-form analytical model based on energy method was developed for double-layered plates subjected to the uniform impulsive loading. Furthermore, empirical design formulae were derived based on new dimensionless numbers to predict the maximum permanent deflection of back and front layers. The influence of strain rate sensitivity of materials was considered in both analytical and empirical models. An encouraging agreement between the experimental, analytical and empirical results in terms of the normalized deflection was achieved.


ABSTRACT: Hierarchical materials born of variable natural cellular and intricate architecture are demonstrated to have the potential to achieve outstanding mechanical properties, thus make them excellent constituents for impact protection. Inspired by the unique microstructure of pomelo peel, this study constructed a novel hierarchical honeycomb and investigated the crushing resistance along with energy absorption capabilities of such structural materials. An integrated analytical-numerical approach was developed to fully elucidate the underlying quantitative structure-property relations by parametric studies on the evaluation of different hierarchical orders and equivalent thickness. It is revealed that the deformation modes of pomelo peel inspired honeycomb are governed by the geometric parameter-equivalent thickness, where three deformation modes (hexagonal mode, transitional mode and coin mode) and two localized band (“V” mode and “I” mode) can be observed under out-of-plane and in-plane crushing, respectively. Additionally, in conjunction with theoretical and numerical studies, improved crushing resistance and energy absorption properties of the pomelo peel inspired honeycomb can be obtained via increase of structural hierarchy and variation of geometric dimensions. The crushing resistance criteria, SEA (specific energy absorption) and equivalent plateau stress of hierarchical honeycomb, can be enhanced up to 1.5 and 2.5 times than its counterpart for traditional honeycomb under out-
of-plane and in-plane crushing, respectively. The promising results of pomelo peel inspired honeycomb may exhibit a novel perspective on providing the superior mechanical properties of natural cellular materials and offer insights for applications of bio-inspired engineering materials.


ABSTRACT: Localised blast loads due to proximal charges are encountered in a variety of circumstances. This paper proposes an analytical solution for the dynamic plastic response of a rigid-perfectly plastic thick square plate subject to a localised explosion. The proposed model is an extension of the analytical model proposed by Micallef et al [1] to study circular plates which is adopted and modified in order to study impulsively loaded square plates where the effect of shear deformation is included. A piecewise continuous blast load function was assumed with axisymmetric spatial distribution of constant pressure in the central zone and exponentially decaying beyond it. Using the constitutive framework of limit analysis and incorporating the interactions between bending moment and transverse shear forces in the analyses, transverse displacement and response duration were examined on three classes of plates, classified according to the length to thickness ratio parameter \( \nu \). The results were furnished in terms of the impulsive velocity, which is a function of the localised blast load parameters. A theoretical solution for plates with \( \nu > 2 \) was sought for the non-impulsive blast loads. Parametric studies were performed to elucidate the effect of loading parameters and plate thickness on the permanent deformation. The theoretical solutions have been found generic and can predict, by the correct choice of the load parameters, the dynamic response of most blast load scenarios brought about by proximal or distal charges. It was found that, for proximal impulsive blasts, the effect of transverse shear becomes irrelevant for even moderate values of \( \nu \), which effect is inconsequential on both central and endpoint displacements at discontinuous interface in the range of \( \nu > 5 \). Since the short duration pulse is of concern, localised pressure loads affect only a small area of the plated structures. Thus, whilst the theoretical treatments also examine the fully clamped plates, the boundary conditions in such loads do not influence the overall response of the structure compared to the static or global blast loads.


ABSTRACT: To study the aeroengine containment capability at high temperatures, experimental and numerical investigations have been carried out to determine the ballistic performance and energy absorption characteristics of GH4169 alloy thin plates at temperatures ranging from 25–600 °C. First, experiments were conducted using a gas gun. Target plates were impacted by projectiles with various initial velocities. The effects of the temperature and initial velocity on the deformation, failure pattern and energy absorption of the plate were correspondingly obtained. The experimental results showed that at higher temperature, the deformation of the target plates is greater, the energy absorbed by the target plates is smaller and the ballistic limit velocities are lower. The petal deformation of the target plate caused by bending is severe at the temperature of 600°C. Second, numerical simulations of the impact were conducted by an implicit dynamics FE code (LS-DYNA). The Johnson-Cook constitutive model with parameters obtained from split Hopkinson pressure bar (SHPB) experiments was used to describe the materials properties of the plates at various temperatures and strain rates. It was found that the numerical results are consistent with those obtained by the ballistic experiments. In addition, the results of the numerical simulations also showed that the ballistic limit velocity of the target plate exhibits an approximately linear relationship with the temperature of the target plate. The energy absorbed by the target plate is decreased by 18% and 9% at 600 °C and 300 °C, respectively, compared with that at 25 °C.

ABSTRACT: Plate impact tests on IM7/8552 composite laminates with different projectile incident angles and velocities were carried out. Numerical simulations were conducted to predict the impact damage, with both Puck and LaRC failure criteria having been employed in this study. The dynamic failure performance of IM7/8552 lamina was reviewed first, by referring to data obtained from experiments conducted at a range of strain rates. The performance of the assessed modelling approaches was evaluated by comparing the results of simulations against experimentally (quantitatively and qualitatively) acquired projectile velocity, impact load and the failure modes of the plates. It proved to be challenging to model the macroscopic damage of the laminate at elevated projectile velocities; further improvement can be made through enriching the dynamic material data and mitigating the mismatch between the complex fibre architecture and its numerical representation.


ABSTRACT: A new type of self-locking multi-cell structure fabricated by assembling four C-shaped open sections is proposed in this paper. Quasi-static and dynamic experimental tests are performed to investigate the axial crush resistance and energy absorption characteristics of this type of structures. The experiment results show that the SEA of the assembled multi-cell sections is 35–40% and 40–50% higher than that of the constituent C-shaped elements for quasi-static and dynamic loading, respectively. Numerical analyses are carried out to simulate the experiment and perform the parametric study on the influences of geometric parameters, boundary condition and load speed on the crush resistance of structures. The behavior and performance of single C-shaped open sections are also studied, and the interaction effects originated from the self-locking features are investigated quantitatively. In addition, theoretical expressions are derived to predict the crush resistance of the assembled self-locking multi-cell sections. Comparisons show that the theoretical expressions can predict the static and dynamic mean crushing forces of the self-locking multi-cell structures with errors below 5% in most cases.


ABSTRACT: This article presents experimental and numerical results following blast tests on a polyether grade thermoplastic polyurethane (TPU). Aluminium alloy (AA) 2024-T3 skins were used as facings to enhance the blast resistance of sandwich structures with TPU cores and varying thicknesses. The experimental results highlighted an improvement in blast resistance with the addition of skins to the TPU core. Increasing the thickness of the TPU core in the sandwich panels served to increase the blast resistance of the structure. For example a 20 mm core offered a blast resistance that was 50.2% higher than an equivalent 5 mm core and 71.2% higher than a plain (i.e. no skin) 5 mm TPU core. Numerical simulations of the blast response of the TPU panels were conducted by converting the explosive loading regime applied to the panels to a simplified pressure pulse loading. Good agreement was obtained between the numerical and experimental results for the back face deflection profiles through the central cross-sections of the panels.


ABSTRACT: A combined experimental and numerical investigation was conducted into evaluating the influence of the geometry of a water-filled container on maximising the reduction in deformation it provides to a high-strength steel plate subject to localised blast loading. Experiments were conducted with a range of novel container shapes including a cone, inverted cone, diamond and mushroom. In addition to these container shapes, an array of water bottles known as a kinetic energy defeat device (KEDD) and a high performing quadrangular container design were also evaluated. The performance of each container was evaluated in terms of both the
reduction in deformation of a steel target plate and the efficiency of the mitigation in terms of the reduction per unit mass of water. The numerical simulations were found to provide adequate predictions for the novel container shapes. They were then used to isolate the differences in target loading for each container type. Further numerical simulations were then performed to identify improvements in the design of the best performing containers. The best performing novel geometries were the mushroom and inverted cone shaped containers, which are more effective at radially spreading the water. However, the mushroom shaped container was the only container found to outperform the most efficient quadrangular container on a mass efficiency basis. The results of this investigation can be used to assist in the design of water-filled containers that are used as part of a near-field blast protection system on an armoured vehicle or other protected structure.


ABSTRACT: In this study, lightweight armoured panels were designed using ultra high performance fibre reinforced concrete (UHPFRC) and experimental testing was conducted. Panels were cast with the dimensions of 1040 mm × 535 mm × 38 mm to limit their mass to approximately 50 kg and allow them to be carried by two individuals. These panels were designed to be a part of a modular protective system that could be used to protect key infrastructure and assets in a deployed military environment. Experimental quasi-static and dynamic tests were conducted. Quasi-static tests were done to determine a baseline loading capacity of the panels using three-point flexural bending. Dynamic testing was conducted using a pendulum-type impact hammer that could vary the amount of impact energy by altering the drop height of the hammer. Residual panel strength was determined after each panel was tested dynamically by using the same three-point flexural bending test that was used for quasi-static testing. All tests were conducted with panels at ambient laboratory temperatures and extreme cold temperatures to simulate Arctic conditions. Panels were tested at Arctic temperatures to determine their feasibility protecting critical infrastructure in Canada's Arctic. The testing demonstrated that the UHPFRC panels could resist impact loads with energies up to 2000 J without complete failure. Panels were not adversely affected by the extreme cold temperatures and in fact displayed increased effectiveness at cold temperatures. Single degree of freedom (SDOF) modelling was used to predict panel deflections based on various impact energies. The model developed can accurately predict peak displacements based on impact loading data.


ABSTRACT: In this study, lightweight armoured panels were designed using ultra high performance fibre reinforced concrete (UHPFRC) and experimental testing was conducted. Panels were cast with the dimensions of 1040 mm × 535 mm × 38 mm to limit their mass to approximately 50 kg and allow them to be carried by two individuals. These panels were designed to be a part of a modular protective system that could be used to protect key infrastructure and assets in a deployed military environment. Experimental quasi-static and dynamic tests were conducted. Quasi-static tests were done to determine a baseline loading capacity of the panels using three-point flexural bending. Dynamic testing was conducted using a pendulum-type impact hammer that could vary the amount of impact energy by altering the drop height of the hammer. Residual panel strength was determined after each panel was tested dynamically by using the same three-point flexural bending test that was used for quasi-static testing. All tests were conducted with panels at ambient laboratory temperatures and extreme cold temperatures to simulate Arctic conditions. Panels were tested at Arctic temperatures to determine their feasibility protecting critical infrastructure in Canada's Arctic. The testing demonstrated that the UHPFRC panels could resist impact loads with energies up to 2000 J without complete failure. Panels were not adversely affected by the extreme cold temperatures and in fact displayed increased effectiveness at cold temperatures. Single degree of freedom (SDOF) modelling was used to predict panel deflections based on various impact energies. The model developed can accurately predict peak displacements based on impact loading data.


ABSTRACT: In this study, the performance of glass fiber-reinforced epoxy resin (GFRP) reinforced circular steel tubes under low-velocity transverse impact loads was examined using both numerical and experimental methods. In the tests, the energy dissipation capacity and bearing capacity of steel and GFRP reinforced steel tubes were compared. Furthermore, failure modes of the specimen and the effects of steel thickness and winding angle (the angle between the axis of the tube and tangential direction of the winding fiber) were discussed. The impact process was simulated through finite element simulation. Additionally, the influence of steel tube thickness and outer diameter, GFRP thickness and winding angle, specimen length, and the mass of the drop hammer and impact velocity was analyzed.
ABSTRACT: Recent experimental work by the current authors has provided highly spatially and temporally resolved measurements of the loading imparted to, and the subsequent dynamic response of, structures subjected to near-field explosive loading [1]. In this article we validate finite element models of plates subjected to near-field blast loads and perform a parametric study into the relationship between imparted load and peak and residual plate deformation. The energy equivalent impulse is derived, based on the theory of upper bound kinetic energy uptake introduced herein, which accounts for the additional energy imparted to a structure from a spatially non-uniform blast load. Whilst plate deflection is weakly correlated to total impulse, there is shown to be a strong positive correlation between deflection and energy equivalent impulse. The strength of this correlation is insensitive to loading distribution and mode of response. The method developed in this article has clear applications for the generation of fast-running engineering tools for the prediction of structural response to near-field explosions.


ABSTRACT: The responses of Miura-ori patterned metamaterials to in-plane dynamic compression are studied for several scenarios, namely: compression of uniform density metamaterials at a constant velocity and impulsive loading modelled as an impact with initial velocity, and a mass impact of a metamaterial with graded density. Analytical models of the dynamic strength enhancement, impact velocity attenuation and energy absorption are proposed for materials with uniform initial density and materials with positive density gradient. Attention is paid to the influence of the material topology governed by the initial dihedral angle \( \gamma \) on the dynamic response of origami-based stationary blocks with equal densities. The propagation of disturbances—velocity and nominal strains—along the samples is analysed and it is shown that the localisation is more pronounced for small values of \( \gamma \). Different from other open cell materials (e.g. foam and honeycomb), the propagation speed of the yield stress, which corresponds to the quasi-static strength, is not related to the elastic properties of the metamaterial in the form of precursor elastic wave as it is governed by the inertial properties of the cells due to the local structural softening. Therefore, the in-plane dynamic compression of Miura-ori patterned metamaterials cannot be directly interpreted by means of the shock wave theory commonly used for cellular materials with different topologies. Nonetheless it is shown that, similarly to other cellular materials, the Miura-ori patterned metamaterials exhibit increased energy absorption capacity when increasing the loading rate. However, the dynamic energy absorption capacity of the analysed metamaterials in not uniquely defined by their relative density and is strongly dependent on their topology. The analytical models are verified by numerical simulations.

References listed at the end of the paper:
ABSTRACT: Explosion tests were performed underwater to study the blast resistance of water-backed sandwich panels. Effects on the structural response of face-sheet and core configurations, including face-sheet thickness, cell wall thickness of the honeycomb, core thickness and charge mass, were investigated by a large number of experiments. Quantitative results were obtained in the tests with corresponding sensors and further processing. Further results characterized the permanent deformation of sandwich panels. A failure mode map was adopted to identify the effect of design parameters on the structural failure mechanism at this blast magnitude. Finally, a comparison between sandwich panels and monolithic plates was performed. The comparative study provided further experimental evidence for the benefits of sandwich in water-backed configuration. Present study led to the apprehension of blast resistance of water-backed sandwich structure to underwater blast load, thereby developed useful guidelines for the design of blast-resistant structural systems.

ABSTRACT: Small-scale experimentation is recognised to play an important role in the investigation of the behaviour of large-scale structures. Presently however, there exists no known procedure for analysing structures involving damage or failure by means of scaled experiments when high-rate impact loading is involved. The principal problem impeding the scaled approach is that similarity seldom exists for high-rate dissipative problems and consequently dimensional analysis provides an ineffective framework for experimental design and analysis.

This paper is concerned with the application of the finite similitude theory which scales experiments by means of space distortion. Although finite similitude suffers many of the limitations of dimensional analysis it has one principal advantage, i.e. it is able to cater for inexact similitude where sources and effects of mismatch can be quantified. This feature is exploited in the work to answer the open question whether it is possible to determine the failure response of structures subjected to high rate loading by performing experimental tests on scaled structures manufactured with different materials.

The efficacy of the proposed methodology for scaled experimentation is tested by means of numerical analysis on a number of well-known test cases, which are supported by experimental evidence. In particular the perforation of circular plates and the Taylor bar impacting on a rigid wall are analysed using the commercial finite element software package Abaqus. The Johnson–Cook thermo-viscoplastic constitutive equation together with the Johnson–Cook damage model are used to describe yielding, strain hardening, strain rate effects, thermal softening and material failure. It is revealed in the paper that although exact similitude is not achievable the results of the full-scale model can be predicted to good accuracy by means of scaled experimentation founded on finite similitude theory.


ABSTRACT: The effects of inter-ply stacking sequences on the ballistic and structural performance of ultra-high molecular weight polyethylene (UHMwPE) fiber/carbon fiber hybrid composite hard ballistic panels have been studied. Unexpected effects were observed simply by varying the positions of small amounts of carbon layers at the front, middle, back and front-back of the UHMwPE-based panels. The most dramatic positive hybrid effect was observed for a front-facing hybrid configuration resulting in a significant 30% reduction in back-face signature (BFS) with a more than two times improvement in flexural yield strength. Interesting secondary hybrid effects such as the mitigation of bulging and buckling of the UHMwPE component of the panel as well as bullet deformation upon ballistic impact by the carbon layer was observed. These results indicate that strategic positioning of the carbon layer in UHMwPE panels can boost the ballistic performance of applications where low BFS and structural performances are key.


ABSTRACT: The compressive large deformation response of tubes, comprising walls made of rhombic dodecahedron unit cells, under quasi-static and dynamic loadings is investigated. Six types of tubes with cellular walls that vary with respect to cell density, tube cross-section and cellular tube wall thickness are manufactured by selective laser melting (SLM). The quasi-static and dynamic compression tests are conducted by using a universal testing machine, a drop hammer device and direct-impact Hopkinson pressure bar (DHPB), respectively, to determine the force-deformation responses of the different structures. In addition, the deformation modes and energy absorption capacity of the tubes are identified. The influence of the cross-sectional shape and cellular-walled density gradient on the energy absorption capacity of the various tube configurations is examined. The results indicate that the Ti-6Al-4V lattice-walled tubes with a density gradient exhibit the best absorption efficiency among the tubes studied. The collapse strength of the square cross section tube tested is more significant than that of its cylindrical counterparts.

Hamdi Kuleyin and Recep Guemruek (Department of Mechanical Engineering, Karadeniz Technical University, 61080 Trabzon, Turkey), “Pressure wave propagation in pressurized thin-walled circular tubes
ABSTRACT: The pressurized thin-walled tubes are called as a member of adaptive energy absorbers of which energy absorbing performance can be controlled by variation of internal pressure. In this context, this study numerically investigates the axial impact performance of pressurized thin-walled circular tubes. For the realistic modeling of the compressed air, the ALE model was developed in LS-DYNA, which enabled an opportunity to investigate both pressure wave propagation in pressurized air and fluid-structure interaction effects between tube-wall and air. In addition, the models were run by taking into account both states, whether pressure regulator, which is an adjustable valve to control internal pressure value, was active. To validate the numerical models, the axial impact tests on Aluminum Aerosol cans were carried out using a light gas gun set-up. The results showed that at the onset of impact, a radial pressure wave, as well as an axial pressure one, simultaneously emerged. Whereas a radial pressure wave propagated towards the center from the tube-wall, the other one propagated along the centerline of the tube. Therefore, a complex pressure distribution and wave propagation occurred in the pressurized tubes. The pressure distribution obtained in the model with a pressure regulator revealed different behavior from the corresponding one obtained without pressure regulator. Also, the results showed that there is no distinct interaction between strain energy absorbed by tube-wall and pressure wave propagation although the total absorbed energy of pressurized tubes increases to some extent with the effects of wave propagation in the pressurized medium.


ABSTRACT: Dynamic response of fully clamped sandwich beams with a metal foam core under low-velocity impact is investigated experimentally and theoretically. Failure modes of metal sandwich beams are identified and competing initial failure mechanism map depending on the geometries and material properties is constructed to characterize the initial failure mechanism. A fracture criterion of the maximum allowed deflection is proposed based on the maximum tensile strain of face sheets to evaluate the fracture-resistance of sandwich beams. Effects of loading location, geometries, and material properties are also considered for both initial failure and final fracture. Good agreement is achieved between the experimental results and theoretical predictions. It is shown that the loading location, geometries, and material properties have significant effects on low-velocity impact response of sandwich beams.


ABSTRACT: A dynamic loading facility is developed to investigate the underwater shock response of polyvinyl chloride foams of varying densities. The shock loading facility consists of a water filled hollow cylindrical structure, with one end fully closed and the other end fitted with a nylon piston. A rigid striker is used to impact the piston, which creates an underwater shockwave. The facility is comprised of four separate sections, where the middle section is an optically clear acrylic window, and the other three sections are aluminum. The optically clear acrylic window is utilized for the employment of three-dimensional Digital Image Correlation in conjunction with high-speed photography (90,000–100,000 frames per second) to obtain full-field deformation data of the foams during shock loading. Pressure data is recorded using piezoelectric pressure sensors at different locations along the underwater shock tube. Peak pressures in the range of 1–10 MPa with exponential decays are generated by changing the striker velocity. Furthermore, quasi-static hydrostatic response of pre-shocked foams is evaluated using a previously developed underwater loading facility. Strain rate of $10^{-3}$ s$^{-1}$ is obtained in foam specimens during the experiments. Findings showed substantial delay between the underwater shock loading and material response. Polyvinyl chloride foams recovered 80–90% of their original shape after underwater shock loading and also retained much of their energy absorption capacity.

ABSTRACT: Tetra-chiral (TC) honeycombs are a type of auxetic materials showing negative Poisson's ratio (NPR), which are promising for impact energy absorption. This study aims to analyze the in-plane crushing response of the TC honeycombs under both quasi-static and dynamic loading conditions through numerical simulations and theoretical analyses. The numerical modeling techniques in LS-DYNA were validated using the quasi-static crush test data of TC honeycomb specimens obtained with a 3D-printer. Numerical simulations revealed the “Z” mode deformation and the “bulge effect” under quasi-static crushing, and the row-by-row “I” mode deformation under dynamic crushing of the TC honeycombs. By referring to the simulation results, theoretical models were derived based on the representative unit for predicting the TC honeycomb's crushing strength, i.e. plateau stress, under both quasi-static and dynamic loads. Good agreement was found between the theoretical and the numerical predictions with a maximum relative error of 7%. Parametric analyses showed that the unit cell configuration has a great effect on the crushing strength of TC honeycomb under in-plane crushing. The dynamic sensitivity index was defined to quantitatively evaluate the sensitivity of the TC honeycomb's crushing strength to the loading speed, and was found to depend on the unit cell geometry. The TC honeycomb was found to present a varied effective Poisson's ratio (EPR) with strain under both quasi-static and dynamic in-plane crushing; smaller radius ratio and lower crushing speed were found to yield more obvious NPR effect. Moreover, relative dimension of the TC honeycomb represented by the orthogonal array ratio do not affect its plateau stress under either quasi-static or dynamic crushing, while large orthogonal array ratio results in more obvious “bulge” and NPR effects under quasi-static crushing.


ABSTRACT: Steel-tube-confined concrete (STCC) targets show better anti-penetration performance than semi-infinite concrete targets as the steel tube imposes constraint on the in-filled concrete to enhance its strength and toughness. Cellular structural system for in-plane and multi-layer overlay extension is an effective way to promote the application of STCC targets to practical protective structures. In this paper, penetration tests of cellular STCC targets (single-layer and double-layer 7-cell hexagonal STCC targets) impacted by 12.7mm Armor Piercing Projectile (APP) were conducted, and side length and thickness of steel tube, steel ratio, impact point and velocity, and repeated impacts were considered. Moreover, single-cell STCC targets and semi-infinite concrete targets were also designed and tested for comparison with the cellular STCC targets. The typical damage modes and parameters of the tested cellular STCC targets including the range, depth and volume of funneled crater and depth of penetration (DOP), were obtained and discussed. It is shown that the 7-cell hexagonal STCC targets show improved anti-penetration performance in comparison to the single-cell STCC targets under the same conditions; the anti-penetration performance of the double-layer 7-cell hexagonal STCC targets was weakened due to the free surfaces between the layers; the side length and thickness of steel tube, steel ratio and impact velocity have significant influence on the DOP of the 7-cell hexagonal STCC targets; optimizing the side length and thickness of steel tube could greatly improve the anti-penetration performance of the cellular STCC protective structures. Moreover, the 7-cell hexagonal STCC targets also show excellent anti-penetration performance under the repeated impacts of 12.7mm APP.


ABSTRACT: Dynamic crushing responses of multi-layer folded truncated sandwich structures are investigated experimentally in this study. The proposed structures are folded from aluminium thin sheets, forming open-top truncated pyramids with square and triangular base shapes. The folded structures are then stacked into a multi-layer sandwich panel by implementing 3mm thick plate in-between foldcores with thread rods used as guide of movement during deformation. No bonding is applied between any parts of the sandwich structure, which allows the easy replacement of deformed core after crushing. Two shapes of folded structures, i.e. Truncated
Square Pyramid (TSP) and Truncated Triangular Pyramid (TTP) are used as the foldcores to form sandwich panels. Specimens are crushed under different velocities. The testing data are compared to those obtained under quasi-static loading condition. Uniform load-displacement response with very low initial crushing peak force is observed for TSP foldcore under different loading rates, where the initial peak crushing force of TTP foldcore is slightly more sensitive to crushing velocity. Different damage modes of TSP are observed with the change of crushing velocity which is consistent with the previous numerical results of this folded structure. Multi-layer TSP foldcore with lower volumetric density is also studied under dynamic loading condition.


ABSTRACT: The increasing use of improvised explosive devices in terrorist attacks against civil targets has challenged the scientific community to find new strengthening or protective solutions, able to mitigate the effects of the blast loads. As a response to this demand, the present study investigates the nonlinear response of 3D printed PLA honeycomb structures in order to analyse their energy absorption capacity when used as the crushable core of a sacrificial cladding solution. The dynamic response of the proposed sacrificial solution is experimentally obtained by means of an explosive driven shock tube, while the corresponding numerical simulations are performed using the commercial finite element software LS-DYNA. Both the experimental and numerical data are in good agreement and clearly show that, as expected, the dynamic force plateau and the specific energy absorption is directly proportional to the considered relative density, which controls the crushing of the top and bottom layers of the PLA honeycomb and the buckling of its interior cell walls. When compared with other available materials, the analysed sacrificial cladding solutions exhibit promising values of energy dissipation and encourage future research in this area.


ABSTRACT: Steel-concrete composite (SC) panels consist of two steel faceplates and a concrete core. The past studies have shown that the SC panels are effective against impact loadings. This paper presents a method for evaluating the displacement response of SC panels subjected to impact loadings using the equivalent single-degree-of-freedom (SDOF) model. The resistance and stiffness of the SC panels are theoretically derived and validated to develop an idealized trilinear resistance function model. The validations against the past experimental results show that the proposed model provides a basis for the dynamic response analysis of SC panels and lays a foundation for further design methods.


ABSTRACT: The energy absorption capability of carbon fiber-epoxy tubular specimens having closed circular and open C-shape cross-sections was investigated using experimental tests when focusing on the effect of the layup configuration. Specimens were subjected to a wide range of loading rates ranging from axial quasi-static compression to axial impact loading in order to reveal the deformation mechanism of CFRP samples. Several different combinations of mass and velocity of the striker were selected to study the possible effects on the crushing behavior of composite specimens. C-section specimens were used to investigate the effects of the cross-section shape on the crushing performance of carbon fiber material and to provide a better step-by-step visual understanding of the damage initiation and propagation in each layer due to quasi-static compression. It was observed that, in general, the different stacking sequences and loading conditions had minor effects on the SEA value of full-tube specimens while a significant difference between SEA values of C-section specimens with different layups was found. The calculated SEA value of C-section cross-plied specimens was lower than the SEA value of the full circular tubes having the same stacking sequence while an insignificant difference between the SEA values of C-section and full circular tube specimens of angle-ply layup configuration was observed. It was established experimentally that the removal of the outer layer with fibers oriented along the tube axis has no significant effect on the crushing force value under quasi-static compression. As a sequence, the SEA value increased due to the decrease of the total absorber weight.
ABSTRACT: A new Rotatable Hopkinson bar is proposed for investigating the impact shear-compressive behavior of cellular materials with separated normal and shear responses. Validating works by numerical simulations on the whole loading process indicates that this dynamic shear-compression method provides a quite accurate measurement on the specimen forces and deformation in both shear and normal directions. With this new design, the impact shear-compression responses of a 5052 honeycomb in TW plane are investigated at different loading angles and compared with the corresponding quasi-static results. Good reproducibility is achieved for most of the loading cases in terms of normal stress/normal displacement and shear stress/shear displacement curves, except the ones in which different deformation modes co-exist. The experiment results from both quasi-static and dynamic loadings reveal that the normal strength of the honeycomb will be weakened, but the shear strength becomes more important with an increasing shear deformation component. A crush envelope in elliptical shape is found to describe the average shear and compressive strengths of honeycomb for both quasi-static and dynamic loadings. The deformation modes of honeycombs under combined shear-compression are examined for all the testing results and some influencing factors, such as specimen dimensions, contact conditions and specimen geometric imperfections are confirmed.

ABSTRACT: The effects of the relative density and loading rate on the compressive response, deformation pattern and energy absorption of 3D printed polymeric Kelvin foams are investigated experimentally and computationally. A high-speed camera is used to record the loading processes of different cubic specimens, and the deformation distribution is calculated using the digital imaging correlation (DIC) method. Experimental results show that the elastic modulus and plateau stress increase with increasing relative density, which obeys the Gibson-Ashby polynomial scaling law. Four different deformation modes are observed in experiments for the specimens with different relative densities and at different loading rates. Further numerical results indicate the presence of a critical relative density, below which the Kelvin foams deform primarily by cell edges bending, and beyond which the cell membranes stretching dominates. It is also found that the position of the deformation bands is dominated by the loading rate. These findings can be used to explain the existing of four deformation modes observed in experiments. In conclusion, a mode classification map is proposed to clarify the effects of the relative density and loading rate on the deformation modes of Kelvin foams based on the experimental and numerical results.

ABSTRACT: Energy absorbing systems are extensively used in the automotive industry to ensure crashworthiness. Such crash components could typically consist of a sandwich structure with thin ductile plates as skins and a cellular foam as core to dissipate the kinetic energy. In a previous study, the quasi-static behaviour of two polymeric foam types with different densities, namely extruded polystyrene (XPS) and expanded polypropylene (EPP), used as core material in typical crash components was examined. The investigation involved a large number of compression tests of the core materials loaded in different material directions and indentation tests on sandwich structures in different configurations. In the present study, low-velocity impact tests are conducted in a drop tower on the same target configurations consisting of 0.8mm thick skins of Docol 600DL steel and the various foams as core. During testing, the dropped mass was kept constant at approximately 15kg, while the impact velocity varied between 5 and 10m/s. The impact force was registered by the instrumented striker of the drop tower, and these measurements were used to obtain the displacement of the striker and the energy absorption of the different crash components. In addition, high-speed cameras and 3D-DIC were used to measure the out-of-plane displacement of the back skin. The presented results indicate that to minimise the weight and at the same time maximize the energy absorption of the crash component, a low
density foam should be used as core material. It is also shown that by proper design, it is possible to optimize the protection level of such components, at least within a given velocity range.

Ye Yuan, P.J. Tan, “On large deformation, damage and failure of ductile plates to blast loading”, International Journal of Impact Engineering, Vol. 132, Article 103330, October 2019, 
https://doi.org/10.1016/j.ijimpeng.2019.103330
ABSTRACT: This paper concerns the irreversible deformation and failure of metal plates to brief, but intense, dynamic (impulsive) load encountered in an air-blast. Hitherto, nearly all of the dynamic structural plasticity models of ‘fully-clamped’ plate only calculates its inelastic (mode I) deformation but have largely ignored damage and failure – exemplified by the partial and/or complete detachment (modes II*, II and III) of a plate from its support through material rupture – that occurs when the blast load is sufficiently intense. An analytical model that captures all three modes of the plate deformation is developed in this paper where emphasis shall be on providing the simplest formulation that contains all the essence of a material and deformation effect needed to quantify the problem. The proposed model adopts an energy density failure criterion of Shen and Jones [19] to delineate the various inelastic failure modes; employs the constitutive framework of limit analysis for simplicity; accounts for the simultaneous influence of bending, membrane stretch and transverse shear through an interaction yield criterion; and, include the effects of strain rate on the material flow stress through the Cowper–Symonds relation. Accuracy of model predictions for square mild-steel plates are assessed through comparison with results from finite element analysis, and experimental data compiled from the literature for a range of impulsive load intensities – they will be shown to be in good general agreement. Design maps delineating the different deformation regimes for different combinations of blast impulse and length versus thickness ratio are constructed for plates of equal mass.

https://doi.org/10.1016/j.ijimpeng.2019.06.002
ABSTRACT: The present study aimed at understanding the influences of structural parameters on the mechanical properties of Pyramidal Kagome (PK) lattice material under impact loading. Seven different PK structures varying height-width ratio and rod diameter were manufactured by selective laser melting (SLM). In this study, both experiments and simulation were conducted to understand the influences of rod diameter, height-width ratio, number of units and layers on the mechanical properties of PK lattice material. The failure characteristics and the deformation process were recorded by using the digital photography technique. All the specimens were observed to have a clear rupture along 45° in the quasi-static test, while broke along the direction of the vertical panel in the SHPB test with a strain rate of about 2000s⁻¹. The results showed that the initial deformation zone of the PK switched from the intermediate layer to the lower and upper layer with the increase of rod diameter. Moreover, the strength, modulus and energy absorption capacity of the PK were proportional to the square of its relative density. As the height-width ratio increases, the modulus of the PK gradually increased. In addition, increasing the number of lateral units and reducing the number of layers contributed to the improvement on the mechanical properties of the PK.

https://doi.org/10.1016/j.ijimpeng.2019.05.020
ABSTRACT: This study investigates the structural response of blast-loaded aluminium plates with pre-cut slits. The 1.5mm thick plates were tested after three different heat-treatments and with four different pre-cut slit geometries at two different blast intensities in a shock tube facility. By varying the number and orientations of the pre-cut slits, different crack patterns and failure modes were obtained in the plates, and it was found that the blast resistance of the plate was markedly affected by the design of the defects. The heat-treatments of the aluminium plates resulted in materials with different strength, work-hardening capacity and ductility, which made it possible to study the influence of these material characteristics on the structural behaviour. It was found that the heat-treatment affected the crack propagation and thus the blast resistance of the plates, whereas the failure mode was not significantly altered. High-speed cameras synchronised with pressure sensors recorded the blast event, and were together with 3D-DIC measurements and 3D-scans used to reveal the dynamic response of
the plates. Quasi-static tensile tests were conducted to calibrate the parameters of the modified Johnson-Cook constitutive model and the Cockcroft–Latham failure criterion. Finite element models of the plates were made in Abaqus/Explicit and used in a sensitivity study to investigate the influence of element size and meshing technique on the predictions of crack propagation. Based on the sensitivity study, simulations of the blast experiments were performed using a randomly generated mesh of hexahedral solid elements with a characteristic element size of 0.5mm. The finite element simulations were able to predict the initiation of failure correctly, even though the subsequent crack propagation was not accurately predicted in all cases.


ABSTRACT: Bird strikes represent a major hazard in the lifecycle of composite aircraft components, due to the low impact resistance of composites. The research presented in this paper investigates soft body impact performance of composite sandwich panels with corrugated and tubular core reinforcements. This type of panel with augmented strength and stiffness in one direction is of high importance for specific aerospace applications. The panels were subjected to high velocity impact with soft gelatine projectile as used in bird strike tests. In addition, the experimental part included non-destructive inspections of the sandwich panel samples. Panel performance was also analysed with the non-linear transient analysis software LS-DYNA with finite element and SPH capability. The panel with corrugated reinforcement showed good impact resistance with damage restricted to the impacted face sheet, foam core and corrugated reinforcement. The panel with tubular reinforcement, of the same thickness, did not suffer any damage at the same impact velocity of 115m/s, but was damaged at a higher impact velocity of 235m/s. The numerical studies helped to understand the experimental data, enabling comparison of impact performance of the reinforced sandwich panels and a benchmark conventional sandwich panel. The proposed reinforced sandwich panels, with the desired augmented strength and stiffness in one direction, showed improved impact resistance in comparison to conventional sandwich panels and therefore have potential for application in aerospace structures where these properties are desirable.


ABSTRACT: This study investigates the behavior of ultra-high performance fiber-reinforced concrete (UHPFRC) filled steel tubular (UHPFRCFST) members under lateral impact loading. A total of five specimens were prepared and tested under lateral impact loading. All specimens were 168mm in diameter and 2000mm in length. In addition to UHPFRCFST members, normal strength concrete (NSC) filled steel tubular (NSCFST) members were also tested for comparison purpose. Other investigated parameters in this study include the impact energy and the presence of an inner void. The test results show that as compared to the NSCFST members, the UHPFRCFST members exhibit higher lateral impact resistance with higher peak and plateau impact forces, smaller deflection, and less local indentation. With the increase of impact energy, the peak impact force, the impact duration, and the deflection of the UHPFRCFST members are increased, while the plateau impact force is almost kept constant. Moreover, the presence of an inner void does not deteriorate the lateral impact resistance of the UHPFRCFST members. Finite element (FE) model was then developed and validated by the test results in this study. Afterwards, full-range analysis was performed to investigate the damage evolution, sectional bending moment distribution, and the interactions between the steel tube and the concrete during the impact process. Finally, detailed parametric analyses were carried out to investigate the influences of different parameters on the lateral impact behavior of UHPFRCFST members.


ABSTRACT: In this study, we use the explicit finite element method in combination with higher order elements and 3D node splitting to simulate fracture and fragmentation of blast-loaded laminated glass. Node splitting is a modelling technique where elements are separated instead of being eroded when a fracture criterion is reached.
The resulting FE simulations are thus capable of describing behaviours such as fragmentation without loss of mass or momentum, fine cracking of the glass plates, and delamination and separation between the glass and the polymer interlayer. The simulations are compared to blast experiments conducted in a shock tube. In total, 15 laminated glass specimens (consisting of annealed float glass plates and PVB) were tested at five different pressure levels. The time and position of fracture initiation in the glass plates varied, which in turn resulted in varying post-fracture behaviour within the different pressure levels. The simulations were in good agreement with the blast tests, revealing the potential of the selected numerical method. Additional simulations of monolithic (i.e., non-laminated) glass plates were conducted and compared to experiments that were presented in an earlier study. Again, these simulations displayed a highly comparable response to the experiments, and were able to describe crack branching, formation of large glass splinters and free-flying fragments.

References listed at the end of the paper:
3 X. Zhang, H. Hao, Experimental and numerical study of boundary and anchorage effect on laminated glass windows under blast loading, Eng Struct, 90 (2015), pp. 96-116
10 J. Franz, J. Schneider, Through-cracked-tensile tests with polyvinylbutyral (PVB) and different adhesion grades, Engineered transparency, international conference at glass tec, Düsseldorf, Germany (2014), pp. 135-142
22 P. Hooper, B. Blackman, J. Dear, The mechanical behaviour of poly (vinyl butyral) at different strain magnitudes and strain rates, J Mater Sci, 47 (8) (2012), pp. 3564-3576
30 J. Bergrström, M. Boyce, Constitutive modeling of the time-dependent and cyclic loading of elastomers and application to soft biological tissues, Mech Mater, 33 (9) (2001), pp. 523-530
Impact protection structures are required to efficiently use material and provide maximum energy absorbing capability. When using plate structures against out-of-plane impact, most impact energy is dissipated near the impact area, resulting in low use efficiency of material. In this study, material distribution is analyzed to reveal its influence on intrusion in the out-of-plane direction and dynamic response in the transverse direction in plate structures. First, partitioning a plate into two plates along the thickness direction, mechanisms of dynamic response in the out-of-plane direction are studied. The upper plate takes impact from intruding object and the lower plate serves as delayed defense when the two plates contact and interact to each other. There exists optimal configuration range of the thickness partition and the gap between the plates for minimizing intrusion. The configuration determines contribution to energy absorption by membrane deformation. Second, mechanisms of diverting out-of-plane impact to energy dissipation in the transverse direction are studied. The material distribution determines the area on plate where most energy is dissipated. It has been found that energy dissipation can spread transversely to a larger range on plate when the strength is lower, demonstrating competing effects between deformation capability and activation of inertia. By adding non-structural mass on plate, it has been found that it can influence range of plastic deformation as the result of the inertial effect. The
mechanism has been verified by using a mass-spring model. These mechanisms revealed offer insights to diverting out-of-plane impact transversely on protection plate by using non-uniformly distributed mass and material properties to increase energy absorbing efficiency.


ABSTRACT: Crushing behaviours of foam filled multi-layer truncated square pyramid (TSP) kirigami structures are studied experimentally and numerically in this study. Each layer of this TSP foldcore is folded using a single aluminium sheet with pre-cuts. Light weight foams are inserted into each unit cell of the TSP foldcore to enhance its loading and energy absorption capacity. The effects of the foam material, density and shapes of foam material on crushing resistance of the multi-layer folded structure are studied. Two foam materials, i.e. expanded polystyrene (EPS) foam with density of 13.5, 19 and 28kg/m³; rigid polyurethane (PU) foam with density of 35kg/m³ are used as foam infill for this multi-layer foldcore. Two shapes of PU foam infill are studied as well. Single layered TSP foldcores with foam infill are firstly studied under quasi-static crushing condition, then foam filled multi-layer TSP foldcores are crushed under dynamic loading conditions. Numerical models are verified with the experimental results, followed by intensive numerical simulations. Key parameters such as peak and average crushing resistance, densification strain and specific energy absorption are compared among the foldcores with different foam configurations. Comparing with other cellular structures, uniform collapsing of the proposed foldcore is observed under both quasi-static and dynamic loading conditions with the uniformity ratio ranging between 1.1 and 2.0. Significant increases in average crushing resistances ranging from 36.6% to 82% are also observed by adding foam fillers, while the mass only increases by 3.2% to 20.4%.


ABSTRACT: The response of a submerged structure to an underwater explosion (UNDEX) involves complex interactions between the structure and surrounding fluid. This study describes a numerical modelling methodology for calculating the structural response of an internally stiffened submerged aluminum cylinder to a close-proximity UNDEX. The simulations account for the effects of both the shock wave and bubble jetting on the deformation of the cylinder. The accuracy of the simulations is demonstrated by comparison of calculated pressure, bubble motion, structural displacement and strain with experimental measurements. The simulated migration and jetting of the gas bubble agrees well with experimental observations. The magnitude of calculated strains is consistent with measurements and the calculated depth of permanent deformation in the shell plating is within 3% of the experimental value.

Yuexin Jiang (1), Boyi Zhang (1), Jianshu Wei (2) and Wei Wang (1)
(1) School of Civil Engineering, Harbin Institute of Technology, No. 73, Huanghe Road, Nan'gang District, Harbin, Heilongjiang Province, China
(2) Shanghai Dragon Industrial Engineering Co. Ltd., Shanghai 200122, China

ABSTRACT: Experimental and numerical studies on the response of polyurea coated steel plates to low velocity impact of a cylindrical hammer are presented in this paper. Low carbon steel plates were made and coated with polyurea layers to enhance their impact resistances. The polyurea-steel composite plates were constrained by a test rig and impacted by a blunt cylinder hammer using a drop weight machine. Numerical simulations of the impact processes were performed using the finite element code LS-DYNA. The numerical simulation method was validated by comparing its results with the experiments’. The experimental results showed that the polyurea coatings can effectively improve the ultimate energy absorption capacity of the steel plates. The decreasing order of the ultimate energy absorption capacity of the composite plates when coated with same thickness of polyurea layers was: the upper-side-coated plates, the double-side coated plates and the
lower-side-coated plates. In order to quantify the energy absorption efficiency of the composite plates, a parameter $E$ was proposed, and it was found that the composite plate coated with 4mm polyurea on its upper side had the greatest value of $E$ among all the plates.


ABSTRACT: Polyurea coating provides a new method to improve the underwater shock resistance of ships. In this study, high-strength shock wave was loaded on the polyurea coated 6061 aluminum target plate through impact-type underwater shock wave loading device, and the dynamic deformation process was recorded by three-dimensional digital imaging correlation (DIC) method. Then, the influences of the shock wave peak, polyurea coating thickness and coating method were investigated. The experimental results confirmed that the underwater shock resistance performance of polyurea coated aluminum plate was improved as the peak of initial loading pulse and the polyurea coating thickness increased. In the meanwhile, it was found that under the same polyurea content, the underwater shock resistance of the aluminum plate with polyurea coated on the front surface was basically the same as that of the aluminum plate with polyurea coated on the rear surface, both of which were better than that of the aluminum plate with polyurea coated on both surfaces. Finally, the quantitative relationships of the residual deformation of the polyurea coated aluminum plate with the peak of initial loading pulse and the polyurea coating thickness were concluded.

J Jefferson Andrew (1), Jabir Ubaid (1), Farrukh Hafeez (2), Andreas Schiffer (3) and S Kumar (1)
(1) Department of Mechanical Engineering, Khalifa University of Science and Technology, Masdar Campus, Masdar City, Abu Dhabi 54224, UAE
(2) Department of Mechanical Engineering, University of Birmingham-Dubai, Dubai 341799, UAE
(3) Department of Mechanical Engineering, Khalifa University of Science and Technology, Abu Dhabi Campus, Abu Dhabi 127788, UAE


ABSTRACT: We report the enhanced low-velocity impact performance of geometrically tailored honeycomb structures enabled via stereolithography additive manufacturing. Geometrical tailoring of the honeycomb structures was realized by linearly varying the cell wall thickness along the through-thickness direction, while retaining the overall mass of the structures. We examine the effects of cell wall thickness gradient, impact energy, cell topology, geometric scaling and impact direction on the energy absorption capacity and damage mechanisms of tailored honeycombs. For the geometrical and material properties of honeycomb structures considered here, experimental results indicate that, at low impact energy levels ($\leq 30J$), the effect of geometrical tailoring has no significant advantage. Nevertheless, at higher impact energy levels ($>30J$), geometrically tailored honeycombs outperform non-tailored counterparts, exhibiting over 60% increase in energy absorption capacity. Experimental observations further reveal that geometrical tailoring results in a change of failure mode from brittle fracture to progressive damage of the cell walls from thinner sections at which the structures were subjected to low-velocity impact, offering superior energy absorption characteristics. The results of this study suggest that the concept of geometrical tailoring in conjunction with additive manufacturing offers new opportunities for the development of high performance architected lattices.


ABSTRACT: Solitary wave propagation behavior within a granular crystal chain is fundamentally important for impact wave mitigation. Here, we study the propagation behavior of traveling waves in a one-dimensional (1D) mixed chain of stainless-steel and polytetrafluoroethylene dimer hollow spherical particles. The formation and propagation of a unique, highly nonlinear, solitary wave is observed. To have an in-depth understanding of the
wave propagation behavior, we establish numerical theoretical models to describe the wave behavior and agree well with the experiment. We also discover that different configurations of dimer wall thicknesses largely influence not only the nonlinear contact interaction between neighboring spheres but also the physical relation of wave velocity $V$ and dynamic force $F$. The influence of different ratios of elastic moduli and densities in a dimer is also studied. Results may shed light on the design and evaluation of the 1D chain for supporting specific wave propagation for possible engineering application.

Junhua Zhang (1), Xiufang Zhu (1), Xiaodong Yang (2) and Wei Zhang (2)
(1) College of Mechanical Engineering, Beijing Information Science and Technology University, Beijing, 100192, PR China
(2) College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, PR China

https://doi.org/10.1016/j.ijimpeng.2019.103383

ABSTRACT: In this paper, we study the nonlinear transient responses of an auxetic (negative Poisson's ratio) honeycomb sandwich plate under impact dynamic loads. The partial differential equations of the honeycomb sandwich plate based on Reddy's higher shear deformation theory and Hamilton's principle are obtained. The nonlinear ordinary differential equations are then derived by Galerkin truncation method. The dynamic responses of the honeycomb sandwich plate subjected to different loads, such as step loading, air-blast loading, sinusoidal loading, triangular loading and incremental loading, respectively, have been investigated. The contributions of total thickness, core thickness ratio, Poisson’s ratio, cell inclination angle and blast types to transient responses of the plate are discussed in detail by numerical simulations. The effect of geometrical parameters on the dynamics of the plate and the effect of different blast loads on the plate are obtained. It is found that the honeycomb sandwich plate with negative Poisson’s ratio would be a better choice compared with the positive one for some structures under dynamic loads.

Sina Sinaie (1), Tuan Duc Ngo (1), Alireza Kashani (1) and Andrew S. Whittaker (2)
(1) Department of Infrastructure Engineering, The University of Melbourne, VIC 3010, Australia
(2) Department of Civil, Structural and Environmental Engineering, State University of New York at Buffalo, New York 14260, United States

“Simulation of cellular structures under large deformations using the material point method”, International Journal of Impact Engineering, Vol. 134, Article 103385, December 2019,
https://doi.org/10.1016/j.ijimpeng.2019.103385

ABSTRACT: Cellular materials and structures have been shown to be highly effective in the context of energy absorption systems. However, accurate simulation of the response of these materials and structures is rather complex. As a simulation tool, the material point method (MPM) simplifies the creation of intricate geometries. At the same time, being a particle-based approach, it is also well-suited for problems involving large deformations and contact. These features make MPM attractive for the simulation of cellular structures under large deformations. This study evaluates the performance of MPM for such simulations. An in-house computer code is developed for this purpose. Experimental data in the literature is used, from which geometric and material properties of cellular systems (in the form of stacked tubes) are extracted and used to validate the numerical model. The performance of the numeric models is evaluated using experimental measurements of the force-deformation curve and energy-absorption capacity. Validation involves a comprehensive evaluation of different simulation parameters, namely; model refinement, rate of loading and boundary conditions. Results indicate that MPM is capable of predicting the large deformation response and energy absorption properties of cellular structures.

Guangyong Sun (1,2), Erdong Wang (1), Jingtao Zhang (1), Shiqiang Li (1), Yong Zhang (3) and Qing Li (2)
(1) State Key Laboratory of Advanced Design and Manufacture for Vehicle Body, Hunan University, Changsha 410082, China
(2) School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Sydney, New South Wales 2006, Australia
(3) College of Mechanical Engineering and Automation, Huaqiao University, Xiamen 361021, China
ABSTRACT: Sandwich panels with an energy-absorbing core material have exhibited great potential in lightweight structures for blast protection. In this study, the deformation/failure modes of sandwich panels against blast impulse were investigated experimentally. The blast tests were conducted on the aluminum foam-core sandwich panels with different facesheet materials, namely aluminum alloy, steel, and carbon fiber reinforced plastics (CFRP); and the cores involve uniform foam and graded foam. The deformation modes of the whole sandwich panels as well as the front facesheet, foam core, and back facesheet were analyzed systematically. It is shown that the deformation patterns are fairly sensitive to the impulse intensity, facesheet material, and foam core gradient. Based upon the measurements, the back facesheet deflection increases linearly with the impulse, apart from the petal-tearing failure of front facesheet. When considering the specific impulse and the same metallic back facesheets, the blast resistance of the sandwich specimen with CFRP front facesheet is superior to those of the metallic front facesheet specimens. Interestingly, the sandwich panels with the aluminum front and steel back facesheet perform better in blast resistance than those with the steel front and aluminum back facesheet. The blast resistance of sandwich panels with a positive gradient of core density (i.e. core density linearly decreased along the blast direction) is superior to those with a negative gradient of core density; and the performance increases with increasing density difference. Compared with the uniform core, the positively-graded foam core with a larger density difference exhibits a stronger blast resistance, while those with a smaller density difference present a weaker blast resistance. The study is expected to provide some fundamental data and design guide for a more efficient sandwich structure with lighter weight and higher capacity of blast protection.

References listed at the end of the paper:

1 H Xi, L. Tang, S Luo, Y Liu, Z Jiang, Z Liu, A numerical study of temperature effect on the penetration of aluminum foam sandwich panels under impact, Compos Part B-Eng, 130 (2017), pp. 217-229
3 G Sun, D Chen, X Huo, G Zheng, Q Li, Experimental and numerical studies on indentation and perforation characteristics of honeycomb sandwich panels, Compos Struct, 184 (2018), pp. 110-124
4 G Sun, X Huo, D Chen, Q Li, Experimental and numerical study on honeycomb sandwich panels under bending and in-panel compression, Mater Des, 133 (2017), pp. 154-168
7 Z Xiao, J Fang, G Sun, Q Li, Crashworthiness design for functionally graded foam-filled bumper beam, Adv Eng Softw, 85 (2015), pp. 81-95
8 Y Xia, C Wu, Z Liu, Y Yuan, Protective effect of graded density aluminium foam on RC slab under blast loading – An experimental study, Construct Build Mater, 111 (2016), pp. 209-222
12 X Li, P Zhang, Z Wang, G Wu, L Zhao, Dynamic behavior of aluminum honeycomb sandwich panels under air blast: experiment and numerical analysis, Compos Struct, 108 (2014), pp. 1001-1008
13 G.N. Nurick, G.S. Langdon, Y. Chi, N. Jacob, Behaviour of sandwich panels subjected to intense air blast – Part 1: experiments, Compos Struct, 91 (2009), pp. 433-441
16 W Huang, W Zhang, D Li, N Ye, W Xie, P Ren, Dynamic failure of honeycomb-core sandwich structures subjected to underwater impulsive loads, Eur J Mech, 60 (2016), pp. 39-51
18 L Jing, Z Wang, L Zhao, The dynamic response of sandwich panels with cellular metal cores to localized impulsive loading, Compos Part B-Eng, 94 (2016), pp. 52-63
undertakes dynamic loading. Both the localized tearing and the entrapped air affect the deformation pattern and uniform large deformation, and influence of the entrapped air proves honeycombs, tearing in the thin:

ABSTRACT: For the de


ABSTRACT: For the deformable barrier often used in full-car crash tests, which mainly consists of aluminum honeycombs, tearing in the thin-walled structure of honeycomb is a common phenomenon induced by non-uniform large deformation, and influence of the entrapped air proves non-negligible when the honeycomb undertakes dynamic loading. Both the localized tearing and the entrapped air affect the deformation pattern and
the global mechanical response of the honeycomb in crash scenarios. The present paper documents development of an equivalent finite element model (FEM) for the aluminum honeycomb focusing on these two effects as well as the relevant experimental study. Four tests of the honeycomb block with out-of-plane loading, i.e., uniform compression, compression-shear along two orthogonal cross-sections and indentation, are performed at quasi-static and dynamic loading speeds to quantitatively address the tearing effect and the air effect on the entire mechanical response. It is also found that the honeycomb exhibits different tearing mechanisms along the two orthogonal cross-sections. In developing the solid-element based equivalent model for the honeycomb, airbags are introduced to characterize the air effect, and beam elements with failure criteria are embedded to simulate the tearing effect. Parameters of the airbags and the beam elements in the equivalent FEM are determined based on different combinations of the honeycomb tests. Simulations of all the loading cases in the present study achieve good agreement with the test results in terms of the global mechanical response and overall deformation pattern, reflecting feasibility of the equivalent FEM.

References listed at the end of the paper:


7 S. Xu, J.H. Beynon, D. Ruan, G. Lu, Experimental study of the out-of-plane dynamic compression of hexagonal honeycombs, Compos Struct, 94 (8) (2012), pp. 2326-2336


9 A. Ashab, D. Ruan, G. Lu, S. Xu, C. Wen, Experimental investigation of the mechanical behavior of aluminum honeycombs under quasi-static and dynamic indentation, Mater Des, 74 (2015), pp. 138-149, 10.1016/j.matdes.2015.03.004


14 D. Asprone, F. Auricchio, C. Menza, S. Morganti, Statistical finite element analysis of the buckling behavior of honeycomb structures, Compos Struct, 105 (2013), pp. 240-255, 10.1016/j.compstruct.2013.05.014


22 Y. Xia, G.H. Chen, Q. Zhou, X.N. Shi, F.Y. Shi, Failure behaviours of 100% SOC lithium-ion battery modules under different impact loading conditions, Eng Fail Anal, 82 (2017), pp. 149-160, 10.1016/j.engfailanal.2017.09.003


https://doi.org/10.4271/2005-01-1352
ABSTRACT: Underwater explosion shock loadings can seriously damage the vitality and fighting capacity of warships. Plastering a layer of sacrificial coating on the ship hull is one of effective strategies to isolate shock impulses and absorb shock energy. In this paper, the shock mitigation effects of sacrificial coatings plastered on a stiffened double cylindrical shell are analyzed numerically. The numerical models are validated by conducting a series of physical experiments of a stiffened double cylindrical shell under noncontact underwater explosion. Three different configurations are considered: both the pressure and thin hulls are plastered with sacrificial coatings; only the thin hull is plastered with sacrificial coatings; and only the pressure hull is plastered with sacrificial coatings. The total pressure field in water and the dynamic response of the stiffened double cylindrical shell are obtained. The results indicate that the deformation and motion of the sacrificial coatings can more easily generate rarefaction wave, which can decrease the total shock impulse acting on the structure. Among three configurations, the configuration of the coating plastered on the thin hull has a better capability of isolating the shock impulse and reducing the shock loadings transmitted to the pressure hull. The dynamic stress and velocity responses of the shell are effectively decreased. Comparisons between different configurations suggest that the coating on the thin hull plays a key role in mitigating shock loadings, while the coating on the pressure hull has limited effects. Moreover, comparison results between the bare hull and the equivalent model which increases the thickness of the thin or pressure hulls under the same mass conditions indicate that the method of using a sacrificial coating is more effective in improving the blast resistance of the structure. The research results are useful in guiding the shock resistance design of stiffened double cylindrical shells.

ABSTRACT: Experimental and numerical results of a novel polymeric laminate consisting of poly(methyl methacrylate) (PMMA) and thermoplastic polyurethane (TPU) are presented. The laminate was subjected to low-velocity impact loadings using clamped three-point bending and dart impact tests at different temperatures and velocities in order to investigate the highly strain-rate and temperature dependent characteristics of a purely polymeric laminate. An investigation of the adiabatic heating of the highly strained interlayer in the post-breakage phase was performed with high-speed infrared thermography. A significant temperature rise of the interlayer in the impacted area and in the vicinity of cracks of the broken PMMA was observed, which facilitates temperature-based alteration of material properties during the test. Material and Finite Element modelling techniques are proposed and discussed, which are able to represent the mechanical and thermal behaviour of the laminate qualitatively and quantitatively.
ABSTRACT: A novel fibre composite sandwich core has been introduced in this study. Trapezoidal corrugated core glass-fibre sandwich structures were hybridised using Kevlar and Zylon fibres to improve the dynamic impact performance. The composite cores were fabricated with four layers of glass fibre and one of the layers was replaced either by Kevlar or Zylon fibre to create hybrid composite core (Glass-to-Kevlar or Glass-to-Zylon ratio 75:25). The impact behaviour, damage mode, specific absorbed energy, and residual strength after the impact of the composite sandwiches were investigated using a low-velocity impact test with 30J, 40J and 50J kinetic energy level. The experimental results revealed that the hybridised sandwiches with high-performance fibre are performing extremely well when subjected to impact energy above the threshold limit. The observations during the experimental work and numerical simulation have confirmed that Glass-Kevlar and Glass-Zylon hybridisation can eliminate severe core rupture by minimising stress concentration and provide high specific energy without increasing structural weight. Moreover, the loss of strength and stiffness of trapezoidal corrugated core sandwich structures after an impact event can be minimised up to 56% and 69%, respectively using Glass-Zylon hybridisation technique. Furthermore, an empirical relationship for predicting the residual strength of the composite core sandwich is proposed.

Ying Li (1,2), Zihao Chen (2), Dengbao Xiao (1,2), Wenwang Wu (1) and Daining Fang (1,2)
(1) Beijing Key Laboratory of Lightweight Multi-functional Composite Materials and Structures, Institute of Advanced Structure Technology, Beijing Institute of Technology, Beijing 100081, China
(2) State Key Laboratory of Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, China

ABSTRACT: In recent years, auxetic metallic cellular material such as auxetic reentrant honeycomb is one of the research hotspot in metallic cellular materials due to its attractively negative Poisson's ratio. In this manuscript, the dynamic response of the end-clamped shallow sandwich arch with aluminum face sheets and auxetic reentrant hexagonal aluminum honeycomb core subjected to foam projectile with high-velocity impact was experimentally and numerically investigated. The reentrant honeycomb cores with different cell-wall thicknesses were fabricated by selective laser melting (SLM). The deformation processes of honeycomb core were captured by a high-speed camera. And deflection history of back face sheet was obtained using three-dimensional digital imaging correlation method (DIC) analysis system. Failure modes and deformation mechanisms of the sandwich arch were investigated. According to experiment results, the local negative Poisson's ratio deformation was found in honeycomb core. Then, a finite element (FE) model was established to study the dynamic deformation evolution of two face sheets and auxetic reentrant honeycomb core. The results showed that the honeycomb cells were not always undergoing shrinkage deformation and flowing into the loading center, while the local expand deformations of honeycomb core were also found.


ABSTRACT: The design of modern military and naval platforms against weapon threats is often assisted by a combination of experimental, analytical and computational simulations. These tools provide relevant insights about material reliability, mechanical performance and platform design vulnerability to support the determination of safety critical aspects, such as response to blast and fragmentation loading. Analytical models are inherently simplified, limiting their ability to accurately model scenarios with complicated geometries and material properties, or highly non-linear loadings. Appropriate experimental and
numerical modelling can overcome the limitations of analytical models but also require long lead times and high associated costs. These issues can be a point of concern for projects with strict development schedules, short time-to-solution, and limited resources.

Machine learning techniques have proven viable in the development of fast-running models for highly non-linear problems. The present work explores four models based on the Multilayer Perceptron (MLP), a type of Artificial Neural Network (ANN), for assessing the mechanical response of mild steel plates subjected to localised blast loading. Experiments combined with validated Finite Element Analysis (FEA) models provide a hybrid dataset for training ANNs. The resultant dataset is a combination of sparsely populated experimental data with a denser dataset of validated FEA simulations. The final results demonstrate the potential of ANNs to incorporate high strain-rate material response behaviour, such as that from blast loading, into optimised models that can yield timely predictions of structural response.

J. Vila-Ortega (1), A. Ridruejo (1) and F. Martínez-Hergueta (2)
(1) Department of Materials Science, Universidad Politécnica de Madrid, E. T. S. de Ingenieros de Caminos Madrid, 28040, Spain
(2) School of Engineering, Institute for Infrastructure and Environment, University of Edinburgh, William Rankine Building, EH9 3FG Edinburgh, UK


ABSTRACT: This research presents a detailed numerical study of the ballistic performance of lightweight hybrid metal/nonwoven shields for automotive applications. Several configurations, including different number of nonwoven fabrics, were analysed to find the optimal design. Impact response of the nonwoven fabric was predicted by a multiscale numerical constitutive model able to capture its complex deformation and failure mechanisms: fibre straightening, realignment and disentanglement. Special attention was paid to the interaction between layers for different air gaps in the final energy absorption capacity of the shield, and detailed analysis of the different sequences of triggered failure modes was provided. The hybrid shield outperformed the previous configurations, resulting in an absorption capacity about twice the sum of the energies dissipated by the steel plates and the nonwovens individually. Furthermore, the hybrid shield increased the energy absorption capacity of the baseline steel plates by a factor over 8, with an almost negligible increment of areal weight of 5.5%, giving the possibility to improve the ballistic performance of conventional automotive components without penalising the fuel consumption.


ABSTRACT: The air blast responses of sandwich panels with multi-layered aluminum foam/UHMWPE laminate cores were analyzed experimentally and numerically. The focus was placed on the effects of foam core gradation and the locations of UHMWPE laminates. Multiple failure modes were exhibited by the panels, including local indentation and global bending deformation of face sheets, crushing and fragmentation of foam core, debonding of adhesive, and delamination and fracture failure of UHMWPE laminate. Experimental results showed that the ascending density foam core was beneficial to decrease the face sheet deformations and to alleviate the shear-induced collapse of foam core. Incorporating the UHMWPE laminates would induce a lower front face deformation and a higher back face deformation. The phenomenon would be more evident with the UHMWPE laminates placed close to the front face. Numerical results demonstrated that deploying the UHMWPE laminate as a first layer core significantly lowered the center velocity of front face. The existence of UHMWPE laminate would change the response modes of the panels. Most of the blast energy was dissipated by the multi-layered cores. The UHMWPE laminates exhibited less efficient in absorbing energy than the aluminum foam. Generally, the findings revealed the undesirable performance of the panels with multi-layered aluminum foam/UHMWPE laminate core under air blast loading.

M.A. Kader (1,2), A.D. Brown (1), P.J. Hazell (1), V. Robins (2), J.P. Escobedo (1) and M. Saadatfar (2)
ABSTRACT: The mechanical properties of closed-cell aluminium foams are governed by their geometrical and topological evolution during impact. Here we non-destructively investigate the deformation mechanisms of a closed-cell aluminium foam sample at the cell scale. The sample has been compressed with 21 interrupted drop-weight impacts at a nominal strain rate of 40 s$^{-1}$ and the post-impacted sample has been imaged at four pertinent strain states with high-resolution X-ray micro-computed tomography (XCT). Moreover, a number of qualitative and quantitative structural analyses are carried out using advanced 3D image analyses to understand the effect of foam geometry/topology on its mechanical response. Our results show that the deforming microstructure creates strong correlations across a range of geometrical, topological and shape characteristics. Quantitative image analyses of the sample at four different strain states reveal that the regions with large void fractions predominantly undergo collapse and subsequently reduces the structural heterogeneity. Further, we show that the deformation mechanism leaves topological signatures in the evolving microstructure, which can be used to better understand the mechanical response of the sample at various stages of impact-deformation. We demonstrate here, for the first time, how the topological quantities can be used to explore the foam deformation mechanisms and to correlate the deformation with mechanical response during impact.


ABSTRACT: This study aims to investigate the dynamic response of foam core sandwich panel with composite facesheets, particularly considering the penetration processes under low-velocity impact. An analytical model based on energy approach is developed to predict contact force, contact time, impactor displacement, energy absorption and failure modes. Contribution of the structural components in energy absorption is further analyzed. The predictions are compared with experimental and numerical results and reasonable agreement is achieved. The present work provides an analytical method to study the mechanisms of impact damage and energy absorption for the composite sandwich panels with closed-cell foam core.


ABSTRACT: This work focused on a numerical modeling of innovative non-conventional energy dissipating systems developed and tested experimentally in [1] to enhance their energy absorption capacity. The basic concept utilized the axial plastic buckling of right-circular mild steel like-composite tubes with various case-hardened patterns. Such a heat treatment has been applied on 15% of the outer surface with a depth of 0.5 mm. In this work, a nonlinear finite element modeling was conducted describing the response of such tubes targeting particularly their behavior along the tube thickness. The S4R shell element of 1 mm size was used looking for an accurate mesh convergence. A contact with a dry friction penalty was highlighted by the contact between the tube surface-to-surface and the tube-to-rigid bodies. The mass scaling technique was also considered to increase the stability time. Four case-hardened patterns of 2, 3, 4 and 5 rings and two other vertical strip patterns of 2 and 3 strips were modeled, simulated and compared with the experimental data. Moreover, a numerical design platform with several new case-hardened patterns was proposed. Among the latter, two patterns (12C and 3R3V) showed better energy absorption capacities than the others even for those observed experimentally. Actually, they offered a gain in the energy absorption capacity of 42% compared to the conventional case.

Xiaqiang Yang (1,2), Hua Yang (1,3) and Sumei Zhang (4)
ABSTRACT: High strength materials and dynamic loadings are two important research topics for building structures. In this study, high-strength concrete filled square steel tube columns (HSCFST) using S690 along with Q355 structural steel subjected to transverse impact loadings were experimentally tested by a drop hammer tester, and the impact force, deformation, and energy absorption of such specimens were obtained. Results showed that HSCFST has great impact resistance, showing high impact force plateau value and small deflection. The influence of steel strength, concrete strength, steel ratio, and impact energy on impact resistance was deeply analyzed. Compared with normal-strength materials, using high strength steel can improve its impact resistance but the contribution is not as great as the increment of yield stress, whilst using the high-strength concrete has limited effect. Besides, a refined finite element (FE) method by ABAQUS/Explicit employing the rate-dependent constitutive model for S690 was adopted to simulate the dynamic responses of HSCFST under impact loadings, performing a good agreement with tests. This study provides the basic experimental data of HSCFST subjected to transverse impact and develops a reasonable FE model to predict its impact resistant performance, contributing to the related studies of HSCFST components.

Xin Wang (1,3), Run-Pei Yu (1,3), Qian-Cheng Zhang (1,4), Lang Li (1,3), Xue Li (2,3), Zhen-Yu Zhao (2,3), Bin Han (5), Si-Yuan He (6) and Tian Jian Lu (2,3)
(1) State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an 710049, PR China
(2) State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China
(3) Nanjing Center for Multifunctional Lightweight Materials and Structures (MLMS), Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China
(4) Key Laboratory of Intense Dynamic Loading and Effect, Northwest Institute of Nuclear Technology, Xi'an, 710024, China
(5) School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China
(6) School of Biological Science & Medical Engineering, Southeast University, Nanjing 210016, PR China

ABSTRACT: The effect of fluid filling on the dynamic response of corrugated sandwich beams under simulated blast loading with close-celled metallic foam projectile was systematically investigated. Deformation and failure modes as well as displacement/contact force/energy absorption histories of water-filled sandwich beams were obtained at different impact levels and compared with those of empty sandwich beams. Subsequently, a combined smoothed particle hydrodynamics-finite element (SPH-FE) model was employed to simulate the dynamic responses of water-filled sandwich beams, explore the underlying mechanisms, and assess the influence of fluid-filling and sealing material on permanent beam deflection. Good agreement was achieved between numerical simulations and experimental measurements. Under impact loading, the filled liquid provides strong interaction between fluid and sandwich components owing to its inertia and incompressibility. Fluid-filling led to not only significantly reduced permanent deflection of both face sheets but also considerably enhanced resistance of the corrugated core against plastic buckling and progressive folding.

Guowei Zhou (1), Qingping Sun (2), Joel Fenner (3), Dayong Li (4), Danielle Zeng (5), Xuming Su (5) and Yinghong Peng (4)
(1) College of Engineering, The Ohio State University, Columbus, OH 43212, USA

ABSTRACT: The dynamic crushing characteristics of unidirectional carbon fiber reinforced plastic composites under two loading types, dynamic three-point bending and axial crushing, are investigated by experiment and finite element simulation. Hat section samples with two different layup orientations are tested at various impact velocities to investigate its effects. The experiment results show that delamination plays a critical role in dynamic bending deformation. Different layup orientations lead to similar crushing bending behaviors, but remarkable variations in delamination pattern evolutions. In contrast, layup orientation exerts more significant effects on failure modes and energy absorption in axial crushing. A finite element model with multiple layers of thick shell element and cohesive element is established, and simulations are performed for both dynamic three-point bending and axial crushing. The model can capture the crushing behaviors in the two loading types reasonably well. The damage evolution and energy absorption through various mechanisms at different loading conditions are discussed.


ABSTRACT: Designing and manufacturing high strength, low weight parts with enhanced impact resistance is highly sought after in the transportation industry. The most common methods to improve strength-to-weight ratios of impact targets is a composite material composition or a favorable geometric design. An alternative method to improve impact performance is functionally gradient mechanical properties in a single material by hybrid additive stacking. In this study, low velocity impact tests were conducted on hybrid stacked 1070 steel plates where individual layers were subjected to shot peening (SP) to functionally grade mechanical properties. Hybrid additive stacking refers to secondarily processing preferential layers within a stacked build volume by cold working to achieve favorable compressive residual stresses and localized work hardening. Incorporating SP on preferential layer intervals during stacking is a radically different approach to increase the strength-to-weight ratio and impact performance of metals. Cold working individual layers by peening achieves functionally gradient mechanical properties in a single material without the need for multi-material composite manufacturing. The objective of this work was to investigate the impact strength and energy absorption from stacking shot peened and non-shot peened layers to form a hybrid target. Identifying favorable stacking sequences provides insight on how to design a hybrid structure that incorporates a mechanical surface treatment (e.g., shot peening) to outperform conventional and composite targets. Results showed energy absorption improved by incorporating stacked shot peened layers and was dependent on the sequence. The improvement in impact performance was attributed to the shot peening induced compressive residual stresses and increased friction incorporated within predefined layers.

ABSTRACT: Thin plates will experience large deformation under intense pulse loading, which may result in serious consequences. Numerous research work has been conducted since 1950s and some theoretical methods have been developed to predict the large deformation of plates based on Rigid-Plastic Idealization of material behavior. However, even with this idealization, it is often difficult to obtain complete solutions. Membrane Factor Method (MFM) has proved a powerful method to solve this problem, resulting in solutions taking into account of the effects of the transient phase and the interaction between membrane force and bending moment through a relatively simple procedure. On the other hand, Saturation Analysis (SA) based on the saturation phenomenon is more rational and accurate than the traditional analyses using total impulse of pulse loading. This paper combines these two approaches to study the dynamic plastic response of square plates under rectangular pressure pulse and linear decay pressure pulse loading, and then the results are compared with modal solutions and FE simulations. Meanwhile, the solutions of this combined method, which merely considers the modal phase are also provided to identify the effect of the transient phase. Finally, two sets of simple calculation formulae are proposed for the permanent deformation of plates so as to facilitate engineering applications.

Nejc Novak (1), Matej Vesenjak (1), Shigeru Tanaka (2), Kazuyuki Hokamoto (2) and Zoran Ren (1)
(1) Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia
(2) Institute of Pulsed Power Science, Kumamoto University, Kumamoto, Japan
ABSTRACT: The quasi-static and high strain rate response of chiral auxetic cellular structures were evaluated in this work. Samples of the chiral auxetic structures were fabricated with the Selective Electron Beam Melting (SEBM) technique from copper powder. Uniaxial quasi-static and low-speed dynamic compression tests were performed on a universal testing machine, while high strain rate tests up to 5000 s⁻¹ were performed using the one-stage powder gun. The experimental measurements together with infrared thermography and high-speed camera images were used to study the deformation mechanism of chiral auxetic structures. A significant effect of the shock enhancement observed in experiments at higher loading velocities was characterised by evaluating the specific energy absorption and specific strength. This phenomenon was further analysed in more detail by using parametric computational simulations, which offered more detailed analysis of mechanical behaviour at different strain rates. The computational results indicate that the plateau stress of chiral auxetic structure increases exponentially with increasing loading velocity. An empirical polynomial approximation was extracted from the computational results, which enables estimation of the plateau stress of auxetic cellular structures at arbitrary loading velocity in between the analyses velocity limits.

Guohua Zhu (1,2), Jiapeng Liao (3), Guangyong Sun (2,4) and Qing Li (4)
(1) School of Automobile, Chang'an University, Xi'an 710064, China
(2) Advanced Design and Manufacture for Vehicle Body, Hunan University, Changsha, 410082, China
(3) CRRC Zhuzhou Locomotive Co., Ltd., Zhuzhou, 412001, China
(4) School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Sydney, NSW 2006, Australia
ABSTRACT: This study aims to explore the crushing behavior of aluminum (AL) - carbon fiber reinforced plastic (CFRP) tubes with different hybrid configurations subjected to quasi-static and dynamic loading conditions. First, a series of experimental tests are carried out to explore the crushing behaviors of hybrid tubes in comparison with the corresponding individual tubes made of single material. The experimental results indicate that the H-II hybrid tube, made of an outer aluminum circular tube and internally adhered CFRP layers, generates a unique deformation pattern; whose outer aluminum tube inverses externally and inner CFRP layers crush progressively. With these distinctive deformation features, the H-II hybrid tubes are considered to be ideal with superior crashworthiness and energy-absorbing capacity. It is also found that loading rate has little influence on deformation pattern of hybrid tubes and single material tubes, while energy-absorbing capacity of hybrid tubes and individual CFRP tubes under dynamic loading are substantially lower than those under quasi-static loading. Second, numerical simulations are performed for the H-II hybrid tubes to provide further insights
into their underlying energy-absorbing mechanisms. It is found that the external inversion mode of the outer aluminum tube is the major energy-absorbing mechanism, in which the contribution of the outer aluminum tube to total energy absorption decreases with increase in thickness of CFRP layers. The internal energy of the externally inverted aluminum tube is considerably higher than internal energy of typical progressively-folded AL tube (sole aluminum tube). Third, a parametric study is further conducted, which indicates that with increasing aluminum wall thickness, the specific energy absorption (SEA) increases. Besides, it is found that varying fiber orientation of inner CFRP layers leads to no evident change in the deformation mode and SEA of the H-II hybrid tubes. When the interfacial strength in between aluminum and CFPR reaches a certain level, there is no evident increase in the total energy absorption with further increase of the interface strength, but the initial peak crushing force increases notably. These results are expected to deepen the understanding of crushing behavior of the H-II hybrid tubes, thereby providing guidance for the crashworthiness design.


ABSTRACT: In this study, transverse low-velocity impact response and residual axial compression behavior of braided composite tube with different ply number was investigated by experimental and numerical methods. The transverse low-velocity impact tests with 5.6 J energy were conducted on the composite tubes. The quasi-static axial compression performance of intact and pre-impacted tubes was compared to evaluate the effect of impact damage. A two-step finite element (FE) model was also established to reveal damage mechanisms of braided tube under impact loading and following axial compression. It was found that the wall thickness had a significant influence on the impact response. Obvious structural deformation occurred in 2-ply tube when subjected to impact loading, resulting in a large projected delamination area. In following axial compression process, the delamination failure significantly reduced the local compression stiffness and caused a structural instability, which led to a buckling failure mode. In contrast, increasing bending stiffness of 3 or 4-ply tube suppressed its structural deformation during impact, leading to a confined projected delamination area and therefore the buckling of tube wall was prevented effectively when subjected to axial compression. For all impacted tubes, the transition of failure mode from progressive folding mode in intact tube led to a lower energy absorption capacity per composite ply, especially for 2-ply tube.


ABSTRACT: Polar ships and offshore platforms frequently experience floating ice impacts or iceberg collisions in Arctic region, which may cause permanent deformations of plates, resulting in negative effects on their work performance. The modeling of ice material is critical and difficult point to study the ice-structure interaction. This paper proposes a new ice material model based on a soil and concrete material model (MAT 78) with some user-defined ice material curves applied, to simulate the ice mechanical behavior in an ice-plate impact scenario. Calibration of the proposed ice material model is performed by comparing the pressure-area relationship recommended by the International Organization for Standardization (ISO) rules. Using this proposed ice model, numerical simulations are conducted to study the dynamic behavior of plates under ice impact by using LS-DYNA finite element program. The related model tests were also performed to verify the accuracy of the results calculated by numerical method. Besides, a series of numerical simulations are conducted to investigate the influences of initial ice impact kinetic energy and ice impact momentum on ice-plate impact. The maximum plastic deformations of plate, energy absorption of plate and energy dissipation of ice damage during the ice impact process are studied in these numerical simulations.

ABSTRACT: Glass curtain walls are widely used in modern architectural design, the majority of which are built using laminated glass. Shattering of these glass walls during natural gas explosions caused by accidental leakages create hazardous glass shards. This work therefore experimentally investigates the dynamic response of laminated glass during a gas explosion by varying the methane concentration, vent closure material, glass layer thickness, and PVB interlayer thickness. The results indicate that the closer the gas concentration is to 9.5%. The use of a stiffer venting material venting also caused a greater displacement of the glass, thus decreasing its resiliency. The PVB interlayer can bond the glass fragments together to restrain the flying effect. Furthermore, increasing the thickness of the glass, and PVB clamp layers improved the ability of the specimen to resist the gas explosion loads. These test results provide a reference for the design of explosion-resistant laminated glass design and accident prevention.


ABSTRACT: Introducing graded cellular materials into energy absorber may improve the crashworthiness of protective structures. In order to meet the crashworthiness requirement that the impact force does not exceed the value that the protected object can afford, a backward strategy guiding the design of relative density distribution of cellular material is improved by considering the loading rate sensitivity in a shock model. Asymptotic solutions of the relative density distribution are obtained for the cases with or without considering the loading rate sensitivity, when a constant impact force is required. It is found that the second-order approximate solutions of the relative density distribution are good enough to approximate the exact solutions calculated by the fourth-order Runge-Kutta scheme. The validity of the design method is further verified by the cell-based finite element method, and the results indicate that the deformation localization at the proximal end is caused by both the density gradient and inertial effect. It is shown that the average impact force from the design without considering loading rate sensitivity exceeds the affordable value of the protected object, but that considering loading rate sensitivity can well meet the crashworthiness requirement. Therefore, the asymptotic solution of the relative density distribution from the design strategy considering loading rate sensitivity is suitable and convenient to guide the crashworthiness design in practical engineering.


ABSTRACT: In this work, the dynamic response and failure modes of carbon/epoxy sandwich structures with PVC foam cores subjected to underwater impulsive loading are experimentally investigated. The 3D digital image correlation technique with high speed photography is used to capture the dynamic response of the structures. The effects of loading intensity, core density, fluid-structure interaction and ply orientation of face sheets on the deformation and damage of the clamped sandwich structures are assessed. The results showed that the compression of PVC foam can effectively reduce the deformation and damage of the sandwich structures. The maximum deflection of rear face sheets increases with PVC core density increasing. The total deflection of sandwich plates including front sheets, cores and rear sheets increases with the decreasing of core density and fluid-structure interaction parameters. Additionally, the influence of ply orientation of carbon/epoxy face sheets on the blast resistance of the sandwich structures can be ignored in the range of normalized impulse intensity (0.08-0.29) used in the tests. With the loading intensity increasing, the failure modes of the sandwich plates present permanent deflection, fiber breakage at boundary and matrix crack of carbon/epoxy at front face-sheets, core compression and debonding between cores and face sheets including front and rear sheets. The results obtained from those tests can provide valuable reference to design the lightweight protective structures.

ABSTRACT: To safely operate subsea pipelines, protective measures must be taken against external forces such as dropped ship anchors. The responses to problems that occur while dropping anchors influence pipelines reinforced with rock berms and limit the prediction of pipe–soil interactions. In this study, laboratory experiments and finite element analysis (FEA) were used to analyze three interactions (pipe–soil–rock) simultaneously, under the scenario of anchor impact. Froude's scaling method was used in the experiments to examine the strain of the pipelines resulting from variations in the mechanical properties of the seabed, anchor weights (drop heights), burial depth of the pipeline in the seabed, and rock berm heights. Under the same conditions, FEA was performed using smooth particle hydrodynamics. Comparison of the pipeline strain results from experiments and FEA showed that the maximum error rate was 12%. The results indicated that the reduction in stress due to increases in rock berm height varied with two seabed properties. On average, this reduction was 20% effective, which is similar to an increase in the depth of seabed burial. Thus, additional protection measures using rock berms may significantly reduce the impact of dropped anchors on pipeline strain.


ABSTRACT: The compressive behaviour of sandwich panels with lattice truss core filled by shear thickening fluid (SPLTC-STF) at high strain-rates is performed analytically and numerically. Firstly, a hydrodynamic constitutive model for the shear thickening fluid (STF) involving shear thinning, shear thickening, and hydrostatic compressibility is undertaken to describe the dynamic behaviour of the STF. Then an analytical model based on the squeezing flow of viscous fluids is proposed. The squeezing resistance of the STF between the two panels of the SPLTC under various loading velocities is analysed using a fluid-structure interaction (FSI) simulation, by which the constitutive parameters of the STF are obtained. Finally, the dynamic response of the SPLTC-STF involving buckling and post-buckling of core struts in the STF is investigated using the FSI method. The enhanced energy absorption capacity of the SPLTC-STF observed in Ref [1] is numerically interpreted. The effects of shear thickening behaviour of STF on the dynamic response of SPLTC-STF are predicted, providing a method of optimal design for STF filled sandwich panels over a wide range of impulse loadings for dynamic energy absorption.


ABSTRACT: In this paper, the nonlinear dynamic behavior of a laminated composite plate with sandwich stiffener subjected to the non-uniform blast load is investigated. The main plate examined has four layers carbon/epoxy and the stiffeners composed of carbon/epoxy face sheets and polypropylene honeycomb core. The experimental and theoretical studies are carried out in order to investigate the effect of sandwich stiffeners on the dynamic response of laminated composite plates under the blast load. In the theoretical study, the equations of motion of the stiffened laminated composite plate are derived by the use of virtual work principle. Geometric nonlinearities are modelled by taking von Kármán Large Deformation Theory into account for the sandwich plate. The clamped boundary conditions are considered for all edges of the plate. The equations of motion are discretized into the time domain by using Galerkin's method. The nonlinear coupled equations system is solved by NDSOLVE function of Mathematica Software and the displacements, strains and stresses are calculated in order to investigate the stiffened laminated composite plate's response to the blast load. The experimental, theoretical and numerical analysis results are compared.


ABSTRACT: Failure analyses of reinforced concrete slabs under impact loading are essential to evaluate the impact resistance of structures accurately; further, these analyses help reasonably design and construct engineering structures. In this paper, we propose a novel three-dimensional (3D) coupled Eulerian-Lagrangian
method to simulate projectile penetration into the reinforced concrete slab. In this method, the entire computational domain is covered with Eulerian cells. The reinforcing bar is also covered with Lagrangian particles to avoid numerical oscillations. The physical quantities of the Eulerian cells and Lagrangian particles are mapped to each other by their topological relationships. Different materials do not embed owing to the combination of the fixed cells and single-valued mapping. Numerical simulations of projectile penetration into the concrete slab are compared with the corresponding experimental data and previous numerical results to verify the effectiveness of the coupled Eulerian-Lagrangian method. Then, the deformation history of the reinforcing bar, and the influence of initial penetration velocity, reinforcing bar, and the uniaxial compressive strength and thickness of concrete on the penetration performance are conducted. Numerical results demonstrate that the 3D Eulerian-Lagrangian method can effectively simulate projectile penetration into the reinforced concrete slab.

ABSTRACT: In this study, the deformation and damage behaviors of sandwich plates with composite foam core subjected to high velocity impact of metallic foam projectile are investigated. A series of experiments was conducted to address the dynamic response, failure modes and energy absorption characteristics of the sandwich plates with different configurations. The dynamic behavior of the sandwich plates was analyzed by using 3D-DIC technique with high speed cameras. The failure modes of the sandwich plates as well as front face sheet, foam core and rear face sheet were identified and discussed. The results indicate that the symmetric deformation of rear face sheet increased with the impact loading increasing, and the core with greater thickness lengthen the responding time of the structures effectively. Compared with the thickness of core, core density played the more important role on improving the impact resistance of the sandwich plates at same areal mass. The effect of sequence of core layers on the impact resistance can be neglected in this study. Additionally, the energy absorption analysis of the six different configurations exhibited that the plates with high density core provided more stable and superior energy absorption efficiency. The study could provide a valuable reference for designing more efficient light weight protective structures.

ABSTRACT: To reveal the effect and necessity of introducing the Lode angle into a fracture criterion in ballistic performance simulations of metallic Plates, experimental and numerical work were carried out on 6061-T651 aluminum alloy (AA6061-T651) thick Plates. Firstly, a series of ballistic tests were conducted via a one-stage gas gun test facility that blunt-nosed projectiles of φ12.68 mm penetrated onto 20 mm thick AA6061-T651 Plates at impact velocities ranging from 280.0 m/s to 400.0 m/s. Subsequently, experimental results in terms of initial versus residual velocities of the projectiles and the failure characteristics of the Plates were reported. Experimental results showed that shear plugging was the dominating failure mode of the perforated Plates. Meanwhile, numerical results corresponding to the ballistic tests were obtained using finite element (FE) simulations via the commercial software ABAQUS/Explicit. Specially, we compared the results between simulations using a Lode dependent fracture criterion and a Lode independent. Finally, the FE simulations indicated that using a Lode dependent fracture criterion better predicts the ballistic behavior of the thick AA6061-T651 Plates under impact of blunt-nosed projectiles. It is also found that the Lode angle affects the fracture behaviour of the AA6061-T651 significantly. And this effect decreases with the increase of the materials’ ductility.

M. Marvi-Mashhadi and J.A. Rodríguez-Martínez, “Multiple necking patterns in elasto-plastic rings subjected to rapid radial expansion: The effect of random distributions of geometric imperfections”, International Journal
ABSTRACT: In this paper we have investigated, using finite element calculations performed in ABAQUS/Explicit [1], the effect of \textit{ab initio} geometric imperfections in the development of multiple necking patterns in ductile rings subjected to dynamic expansion. Specifically, we have extended the work of Rodríguez-Martínez et al. [2], who studied the formation of necks in rings with sinusoidal spatial perturbations of predefined amplitude and constant wavelength, by considering specimens with random distributions of perturbations of varying amplitude and wavelength. The idea, which is based on the work of El Maï et al. [3], is to provide an idealized modeling of the surface defects and initial roughness of the rings and explore their effect on the collective behavior and spacing of the necks. The material behavior has been modeled with von Mises plasticity and constant yield stress, and the finite element simulations have been performed for expanding velocities ranging from 10 m/s to 1000 m/s, as in ref. [2]. For each speed, we have performed calculations varying the number of imperfections in the ring from 5 to 150. In order to obtain statistically significant results, for each number of imperfections, the computations have been run with five random distributions of imperfection wavelengths. For a small number of imperfections, the variability in the wavelengths distribution is large, which makes the imperfections play a major role in the necking pattern, largely controlling the spacing and growth rate of the necks. As the number of imperfections increases, the variability in the wavelengths distribution decreases, giving rise to an array of more regularly spaced necks which grow at more similar speed. A key outcome is to show that, for a large number of imperfections, the number of necks formed in the ring comes closer to the number of necks obtained in the absence of \textit{ab initio} geometric imperfections.

ABSTRACT: Critical instruments and buildings demand enhanced blast protection under the environments of increased local conflicts and terrorist attacks. There are currently two widely researched measures for blast protection: blast energy absorption by cellular materials and energy dispersion by V-shaped plates. Although several studies have focused on these individual protection measures, their combination has rarely been reported. Therefore, in the present study, these two measures were combined. The resulting aluminum foam sandwich panel with a double V-shaped face plate, along with its anti-blast performance, was numerically analyzed. The numerical model was validated, and then the blast responses of different structural designs of the proposed sandwich panel were examined. Finally, parametric analyses of the protection performance of the double V-shaped face plated sandwich panel were conducted. The results indicated that the designed sandwich panel could not only disperse the blast impulse but also maintain the energy-absorption property of the foam core. Gaps in the sandwich panel should be avoided to prevent acceleration of the face plate. Owing to the relatively large local energy absorption, eccentric loading did not significantly affect the performance of the V-shaped face-plated sandwich panel. The stiffness of the front and back face plates of the proposed sandwich panel must be matched properly to balance the effects of energy dispersion and energy absorption for achieving the optimal protection performance. This study provides a valuable reference for designing new protective structures and enhancing blast and impact protection.

ABSTRACT: Hierarchical structures have the potential advantage of enhancing their energy absorption capabilities. Honeycomb-like hierarchical structures are developed and manufactured by perforating on the cell walls consisting of single thickness inclined walls and double thickness vertical walls. The out-of-plane dynamic crushing experiments on metal honeycomb-like hierarchical structures with perforated walls are carried out to explore the failure modes and energy absorption mechanism. The impact failure modes of honeycomb-like hierarchical structures under different impact velocities are obtained. The corresponding numerical simulations are also performed. It is shown that the numerical results are in good agreement with
experimental data. The dynamic mean crushing stress of the honeycomb-like hierarchical structures is larger than the quasi-static mean crushing stress. The mean crushing stress, total energy absorption, specific energy absorption of honeycomb-like hierarchical structures of perforations on double walls are larger than those of perforations on single walls with the same mass. Results from parametric study of factors that influence the dynamic crushing response of honeycomb-like hierarchical structures are presented. Compared with the uniform perforation design, the perforation gradient designs increase the mean crushing stress.

ABSTRACT: A combined numerical and experimental investigation is carried out on the quasi-static and high strain rate response of additively manufactured stainless steel 316L obtained through selective laser melting. The experimental program comprises experiments on uniaxial tension, shear, notched tension and mini-Nakazima specimens, covering a wide range of stress states and strain rates (from $10^3$ to $10^4$/s). An anisotropic quadratic plasticity model with Swift-Voce hardening and Johnson-Cook rate- and temperature-dependence is identified to describe the behavior of the constituent base material under different stress-states and strain rates. Compression experiments at low and high loading speeds are conducted on elastically-isotropic shell-lattice structures to further validate the identified plasticity model in a structural application. It is found that the chosen plasticity model can describe the reaction force and deformation patterns of the smooth shell lattice loaded at different speeds and orientations with good accuracy. The experiments reveal that the additively-manufactured shell-lattices are capable of sustaining macroscopic compressive strains of more than 60% without visible fracture of the cell walls regardless of the loading speed. The comparison with the results for plate-lattice structures of the same mass elucidate the great energy absorption potential of shell-lattices.

ABSTRACT: The response of a plane, air-backed plate attached to a rigid baffle when subjected to an underwater plane shock wave is investigated numerically and analytically. The numerical simulation takes into account a full three-dimensional fluid model involving water cavitation effects. Different numerical models are employed and validated by comparing against various experimental results from the literature. The validated numerical setup is then used to simulate the underwater shock response of simply-supported, air-backed, carbon-fiber/epoxy rectangular plates attached to a rigid baffle. Simplified analytical solution is developed based on two-step approach. The two stages considered are early-time phase that adapts Taylor’s fluid-structure theory to calculate an impulsive velocity for the plate and long-time phase that involves determining its free oscillation response within linear elastic domain, taking into account the water-added mass effect. Finally, the applicability of the proposed method is investigated by performing different numerical simulations regarding various combinations of peak pressures and decay times, change of aspect ratios, change of materials as well as ply orientations.

ABSTRACT: A blastworthy structure is defined as a structure that has the ability to deform with a controlled force and preserve sufficient residual space around the occupants to limit bodily injury during a blast impact incident. In this research, a blastworthy aluminum foam sandwich (AFS) structure that consisted of an occupant side plate (OSP), a struck side plate (SSP), and an aluminum foam (Al-foam) core were numerically and experimentally subjected to blast-fragmented loading. The explosion with high-pressure shock waves was produced by steel-covered TNT, creating a synergistic blast and fragment loading. The interaction between the blast-fragment loading and the AFS created a unique perforation pattern due to Monroe's effect. The measured blastworthiness characteristics included structural integrity, acceleration, and reaction force. A numerical
modeling strategy to analyze the blastworthiness performance of the AFS structure was developed to capture the dynamic responses and the damage mechanism. Two types of blast loading, namely load blast enhanced (LBE) and smooth particle hydrodynamic (SPH) blast loading, were utilized along with the Cockcroft-Latham damage modeling on the AFS. A blast experimental setup with a fix-clamped method was used to evaluate the blastworthy characteristics of the panel to acquire the central acceleration and reaction force histories. A two-step process of experimental validation was carried out. First, a pre-test system validation with a very low explosive blast using 60 gram of TNT was conducted on the sandwich specimen to ensure the data acquisition system's functionality and to obtain comparable data for system validation. Second, a blast impact test using 8 kg of steel-covered TNT was carried out to validate the numerical modeling results. The results of the numerical analysis showed that the LBE model had good agreement with the test data for the small deformation blast impact loading with 60 gram TNT. For the large deformation blast impact loading with 8 kg TNT, the SPH models provided excellent agreement with the damage mode and dynamic responses, where the acceleration and the reaction force performances were both within 6.1% and 6.4% of the experimental validation, respectively. As for the structural performance of the AFS construction, it was observed that the sandwich panel met the structural integrity requirements. There were no cracks or fractures in the OSP. The SSP and Al-foam absorbed more than 98.3% of the blast impact energy, providing extra protection for the OSP. This research contributes to the dynamic structural-response and damage investigation of AFS subjected to fragmented 8 kg TNT blast loading.

ABSTRACT: This paper conducts a combined compression-shear test on honeycombs and Kelvin foams to compare their yield envelopes. The honeycomb and foam specimens with a similar relative density are fabricated by using the additive manufacturing technique. The quasi-static and dynamic crushing behaviors under combined shear-compression are investigated by employing a universal testing machine and a rotatable Hopkinson bar system, respectively. Five loading angles ranging from 0° to 50° are considered. Results reveal that the normal strengths of both honeycomb and Kelvin foam decrease while the shear strengths increase with the loading angle increasing. Moreover, honeycombs change the deformation mode from the progressive folding mode to the global rotation mode while Kelvin foams maintain the layered folding mode as the loading angle increases. Therefore, honeycombs show the normal strength decreasing more sharply than Kelvin foams. As a result, although honeycombs possess higher normal strengths than Kelvin foams under pure compression, the difference becomes smaller with the increase of loading angle. There is a cross point on the macroscopic yield envelopes of honeycomb and Kelvin foam. At this point, honeycomb and Kelvin foam possess the same normal and shear strengths. Moreover, the dynamic yield envelopes of both honeycombs and Kelvin foams possess an almost isotropic expansion of quasi-static envelopes due to the loading rate effect. These yield envelopes provide design criteria for cellular materials to withstand any applied shear and compressive stress state.

ABSTRACT: This work aims to study the uniaxial dynamic compression response of hexagonal honeycombs with different cell morphologies in the presence of an entrapped gas. A theoretical model is proposed to estimate the dynamic crushing strength of non-auxetic honeycombs while including the effect of the entrapped gas on the crushing process. The theoretical predictions are shown to agree well with the finite element (FE) simulations. From the numerical simulations, Hugoniot relations between the shock velocity and the impact velocity are obtained for various honeycomb geometries. It has been observed that shock velocity varies almost linearly with impact velocity. Using this fundamental relation, we derive the stress-impact velocity Hugoniot from the conservation law of momentum. The dynamic stress-strain states of a regular hexagonal honeycomb obtained from the FE simulations show a good agreement with the Hugoniot predictions. It is shown that the dynamic stress-strain states for various impact velocities lie on a unique curve, which is different from the
quasi-static stress-strain response. The local strains behind the shock front are significantly lowered in the presence of an entrapped gas, and the stresses behind the shock front are higher as compared to the case where there is no entrapped gas. The variation of the plateau stresses with the cell morphology has been explained, and correlated to the energy absorption capacity of the honeycombs. A new method to characterize the energy absorption capacity of honeycombs is proposed, and the performance of various honeycombs has been compared through the dissipation performance parameter.


ABSTRACT: In this study, the description of energy absorption capacity in different deformation modes in the perforation of thin metallic aluminum 1100-H12 targets is presented. The targets were impacted with 19 mm diameter hard steel cylindrical projectiles of varying nose profiles, viz. ogive, blunt, conical and hemispherical shape. Effect of oblique impact on the perforation behavior of 255 mm diameter circular plate targets was studied at 0 (normal), 15 and 30° angles from the incidence line. The ballistic performance of two different configurations of plate targets, viz. monolithic target of 2 mm thickness and in-contact double layered target of equivalent thickness (2 x 1 mm) was also investigated and compared. The numerical simulations were executed using Johnson-Cook elasto-viscoplastic material model for the targets in ABAQUS/Explicit solver and the results were corroborated with the experimental observations. The ballistic performance of the targets against different nose shaped projectiles, was evaluated and compared in terms of ballistic limit velocities, local and global deformations in the target, failure mechanisms and plastic work done in various deformation modes involved in the impact process. It was observed that the ballistic limit for all targets was increased with obliquity, except for targets impacted with blunt nose projectile. The energy absorbed in different deformation modes corroborated with the failure mechanisms involved in the target during perforation. Both target configurations showed the highest ballistic resistance for hemispherical nosed projectile.


ABSTRACT: In this paper, the energy absorption capability of hybridized carbon fiber-reinforced polymer (CFRP) composites with Kevlar and glass layers subjected to high-velocity impact loading was studied. The developed methodology was based on meso-macro scale finite element modeling, experimental testing and utilizing a predictive algorithm relying on artificial neural network. The induced damage mechanisms were considered in the numerical model by employing appropriate failure criteria for the yarns and matrix of the composite laminates and the results were validated against experimental results. An artificial neural network-based algorithm was used to optimize the energy absorption capability of the hybridized CFRP composites. It was found out that a considerably higher improvement in the energy absorption can be achieved by considering an appropriate laminate layup without a considerable increase in the laminate mass. The optimum hybridization of CFRP laminates resulted in 135% improvement in the absorbed energy with only 9% increase in the mass of the laminate. This study can provide a reliable and cost-effective method for designing and analyzing hybrid composite laminates under high velocity-impact loading.


ABSTRACT: Repeated drop weight impact tests have been performed on mild steel beams and aluminum alloy beams. The experimental results related to impact force, velocity of the indenter, displacement, absorbed energy process are presented and analyzed. The impact process between the indenter and the specimen is described. Pseudo-shakedown phenomenon was observed during the repeated impacts. When a pseudo-shakedown state is reached, the maximum contact force, maximum displacement of the beam, rebound velocity of the striker, contact time, all of them reach a constant value respectively and the permanent displacement of beam will not increase further more under identical repeated impacts.
ABSTRACT: Cellular materials are attractive for applications in structural protection and impact energy absorption. Progressive buckling of cell walls during compression delivers good specific strength and energy absorption. In a cellular solid, the arrangement of the cell wall material with respect to the direction of loading has a key influence on its mechanical response. This is especially true for cellular materials loaded in dynamic compression, where dynamic buckling and inertial stabilisation effects can also be sensitive to the alignment of cell walls with the loading direction. Origami-based geometries provide one route to designing cellular materials to achieve controllable collapse modes and, in some cases, auxeticity. The stacked Miura-ori geometry has been proposed recently as a strategy for constructing a volume of periodic cellular solid from an origami-inspired unit cell. However, these have been previously difficult to manufacture. Using selective laser melting, an additive manufacturing process, stainless steel stacked origami materials were produced in a periodic cellular arrangement for the first impact tests on such a cellular material. The origami specimens were tested with a gas gun and direct impact Hopkinson bar apparatus, at impact speeds of 50 m/s and 100 m/s. The auxetic behaviour of the origami fold was observed to diminish at the higher impact speeds, due to the localisation of deformation to individual fold layers. Different fold configurations were studied through simulations, with clear trends observed between fold angle and specific energy absorption and strength. Lastly, the influence of material strain rate sensitivity was investigated numerically.

References listed at the end of the paper:

1 M.F. Ashby, L. Gibson, Cellular solids: structure and properties, Cambridge University Press (1999)
22 A. Pydah, R.C. Batra, Crush dynamics and transient deformations of elastic-plastic miura-ori core sandwich plates, Thin-Walled Struct, 115 (2017), pp. 311-322
undergo dynamic tests under a drop weight tower (5.7 m/s). This configuration presents significant energy absorption performance in static (31.6 J / g) and in dynamic (28.5 J / g) crushing for a material that is natural, ecological (low carbon footprint), recyclable, and low cost in comparison with other materials such as composite materials. As with composites, the position, number, and orientation of the plies directly affect the amount of energy absorbed. The use of poplar, one of the weakest woods in mechanical terms, shows the possibilities of wood for this use.

Steven Linforth (1), Tuan Ngo (1), Phuong Tran (2), Dong Ruan (3) and Rami Odish(4)
(1) Department of Infrastructure Engineering, The University of Melbourne, VIC 3010, Australia
(2) Civil and Infrastructure Engineering, RMIT, VIC 3001, Australia
(3) Faculty of Science, Engineering and Technology, Swinburne University of Technology, VIC 3122, Australia
(4) Protected Vehicles, Land & Air Systems, Thales, VIC 3350, Australia


ABSTRACT: Auxetics are structures and materials with a negative Poisson's ratio, meaning they contract in the direction perpendicular to the applied force under a compressive load. This phenomenon can lead to increased energy absorption, among other favourable parameters to protect against impulsive loadings. In this research, a structure with alternating oval perforations was investigated which gives rise to an auxetic geometry, referred to as an 'auxetic oval' design within this paper. Quasi-static (strain rate = 0.001/s) and dynamic (strain rate = 100/s) experiments have been conducted on small-scale specimens, manufactured using subtractive fabrication (laser cutting). Different design criteria were examined to understand the mechanisms behind the energy absorption of the auxetic structures. A modified version of the energy efficiency method was developed to determine the densification strain of the auxetics. A shift from strain-softening to strain-hardening behaviour is seen as the number of cell layers increases, with the perfectly-plastic response ideal for energy absorbing structures. Inertia effects are present in the dynamic tests, showing an increase in plateau stress for several of the designs. The quasi-static and dynamic responses are fundamentally identical, meaning that the performance of the auxetics do not change under the range of strain rates examined. Digital image correlation has been successfully utilised in the analysis process. This includes confirmation of the mechanism giving rise to the auxetic behaviour (rigid rotating squares) and the calculation of the negative Poisson's ratio. Strain fields have been examined showing the regions of energy dissipation. Based on these results the auxetic oval design experiences bending dominated behaviour. Finally, a unique design has been developed, dubbed the ‘Hybrid Auxetic Oval’, which shows favourable behaviour compared to the equivalent base auxetic oval design by mitigating the effects of fracture.

References listed at the end of the paper:
2 R. Lakes, Foam structures with a negative Poisson's ratio, Science (1987), pp. 1038-1040
6 X. Ren, R. Das, P. Tran, T.D. Ngo, Y.M. Xie, Auxetic metamaterials and structures: a review, Smart Mater Struct, 27 (2) (2018), Article 023001
8 J.N. Grima, A. Alderson, K. Evans, Auxetic behaviour from rotating rigid units, Phys Status Solidi (B), 242 (3) (2005), pp. 561-575
11 K. Bertoldi, P.M. Reis, S. Willshaw, T. Mullin, Negative Poisson's ratio behavior induced by an elastic instability, Adv Mater, 22 (3) (2010), pp. 361-366
ABSTRACT: This paper aims to study the blast-resistant behavior of one-way simply-supported reinforced ultra-high performance concrete (UHPC) panels through field tests and numerical simulations. Firstly, by designing a box-like blast loading apparatus, both three reinforced UHPC panels and three reinforced normal strength concrete (NSC) control panels were fabricated and tested under medium-range explosions from end-detonated cylindrical charges with different scaled distances (0.5−1.0 m/kg). The valuable data including the explosion-induced incident and reflected overpressure-time histories, deflection- and acceleration-time histories, as well as the post-blast damage of panels were obtained and assessed experimentally. The superiority of UHPC as a blast-resistant material was proved quantitatively by comparison with NSC. Then, the corresponding 3D finite element (FE) model was established by adopting the program LS-DYNA, both the blast loadings induced by the medium-range explosions and the constitutive model parameters of UHPC were mainly concerned. The applicability of the CONWEP method in predicting the blast overpressures was verified, but the prediction precision declines with the decrease of scaled distance since the influences of charge shape and detonation point enhanced accordingly. Moreover, based on the systematic static and dynamic mechanical tests data, the parameters of Karagozian & Case concrete (KCC) model describing the strength surface, equation of state (EOS), damage evolution, and strain rate effect of UHPC were calibrated. Finally, the present FE model, numerical algorithm and the calibrated model parameters were fully verified by comparing the numerical results with the test data, which could provide reference for the evaluation and design of UHPC structures under blast loadings.

ABSTRACT: Explosions due to terrorist attacks or accidents can cause severe damage to critical infrastructure. To protect important facilities from explosion damage, they can be constructed below ground. Further, an explosion mitigation layer can be used to provide additional protection. In this study, an expanded polystyrene (EPS) plate has been incorporated into the soil layer for blast mitigation, and the performance of the system has been investigated experimentally. The results indicate that there is an optimum ratio of sand layer thickness and EPS plate thickness for decreasing and dispersing blast pressures. Formulas describing the peak pressure and scaled impulse on the bottom of the mitigation system as functions of a scaled distance from directly under the explosion source and scaled layer thickness have been derived.

ABSTRACT: Direct impact testing with a Hopkinson bar is, nowadays, a very popular experimental technique for investigating the behavior of cellular materials, e.g., lattice metamaterials, at high strain-rates as it overcomes several limitations of the conventional Split Hopkinson Pressure Bar (SHPB). However, standard direct impact Hopkinson bars (DIHB) have only single-sided instrumentation complicating the analysis. In this paper, a DIHB apparatus instrumented with conventional strain-gauges on both bars (a so called Open Hopkinson Pressure Bar - OHPB) is used for dynamic impact experiments of cellular materials. Digital image correlation (DIC) is used as a tool for investigating the displacements and velocities at the faces of the bars. A straight-forward wave separation technique combining the data from the strain-gauges with the DIC is adopted to increase the experiment time window multiple times. The experimental method is successfully tested at impact velocities in a range of 5−30m/s with both linear elastic and visco-elastic bars of a medium diameter. It is
shown that, under certain circumstances, a simple linear elastic model is sufficient for the evaluation of the measurements with the visco-elastic bars, while no additional attenuation and phase-shift corrections are necessary. The applicability of the experimental method is demonstrated on various experiments with conventional metal foams, hybrid foams, and additively manufactured auxetic lattices subjected to dynamic compression.

International Journal of Impact Engineering, Vol. 148, Article 103767, February 2021,


ABSTRACT: The structure of a foam-filled corrugated core sandwich panel is optimized. Failure modes under consideration are the overall and local instability of the panel. Models of plates resting on an elastic foundation are used to take into account the foam’s reinforcement effect. Additional constraint related to the effective thermal conductivity of the panel is incorporated.

ABSTRACT: In the current study, the vibration behavior of axially functionally graded nanobeams is investigated in the framework of Eringen's two-phase local-nonlocal model which considers both local and nonlocal phases in modelling nano-scale structures. Material properties are varied through the length using power-law functions. By employing the Hamilton's principle and a conversion between integral-differential, higher order equation of motion with two additional higher order non-classical boundary conditions are achieved. A modified differential quadrature method is used to solve the problem and the accuracy of the current methodology is approved by comparing the results with previous studies for simplified models. In order to indicate the influence of different parameters such as nonlocal term, phase coefficients, material varying function, etc., a comprehensive parametric study is presented and nanobeam with different boundary conditions are discussed. For different boundary conditions, variation of frequency terms is presented especially for cantilever axially functionally graded nanobeams in which differential form of Eringen's nonlocal theory is unable to model accurately. It is shown that the two-phase nonlocal model has the capability to model the axially functionally graded nanobeams with different boundary conditions and material varying terms.

ABSTRACT: In the present article, an effort is made to analyse the coupled global dynamics of nanoscale fluid-conveying tubes. The influences of geometric nonlinearity are captured through the nonlinear Euler–Bernoulli strain relation of beams. Moreover, the size influences related to the nanoscale tube are captured via developing a nonlocal strain gradient model of beams. The Beskok–Karniadakis theory is also used for capturing the size influences related to the nanofluid. In addition to size influences, Coriolis acceleration effects together with the influences of the centrifugal acceleration are taken into account. Hamilton's principle gives two coupled equations of motions, which are discretised utilising Galerkin's technique. A time integration scheme is used for
extracting the global dynamic characteristics of the nanotube containing nanofluid flow. The non-dimensional critical speed associated with buckling is also determined. It is found that the nanofluid speed plays a crucial role in the global dynamics in both the subcritical and supercritical regimes.


ABSTRACT: For the first time, the nonlinear bending behavior of porous functionally graded (FG) curved nanotubes is studied in this paper. The stiffness enhancement and stiffness reduction effects are described by the nonlocal strain gradient theory. The FG curved nanotubes have uniformly distributed pores in the radial direction. The material properties of the nanotubes corresponds to a modified power-law function. The asymptotic solutions of the curved nanotubes is obtained by using the two-step perturbation method. It shows that the nonlinear bending behavior of the curved nanotubes is influenced by the size effects, power law index, porosity distribution, temperature variation, boundary conditions, and physical dimension. Furthermore, the jump changes as well as snap-through buckling can take place when the FG curved nanotubes are under the influence of normal bending loads.


ABSTRACT: A viscoelastic axially functionally graded (FG) imperfect microbeam is considered and the complex nonlinear dynamics is analysed for the first time. The distribution of the material properties from beam's left end to the right one is of an exponential form. The small nature of the system is incorporated using the couple stress theory (CST) in a modified form. The viscosity between microbeam's infinitesimal elements is incorporated through the Kelvin-Voigt scheme. The elastic part of the energy is formulated via the elastic component of the stress and its couple; the viscous parts are incorporated via a negative work. The energy of kinetic type is also formulated. Without ignoring the axial displacement/inertia, Hamilton's principle of energy is used to formulate the viscoelastic mechanical model of the microsystem. A high-dimensional truncation/discretisation is conducted and numerical simulations are performed based upon it. The complex nonlinear dynamics of the axially FG imperfect beam is analysed in the presence/absence of viscosity.


ABSTRACT: Wrinkles are commonly observed in uniaxially stretched rectangular sheets with clamped-clamped boundaries, and can disappear upon excess stretching. Here we explore this wrinkling and restabilization behavior both analytically and numerically. We find that Poisson's ratio plays a crucial role in the wrinkling and restabilization behavior. Smaller Poisson's ratio makes later onset of wrinkling, lower amplitude and earlier disappearance of wrinkles. In particular, when Poisson's ratio is below a threshold, no wrinkles occur, which can be explained by the decreasing transverse compressive stresses with respect to the reducing Poisson's ratio. Furthermore, based on the Koiter stability theory, we have semi-analytically predicted isola-center bifurcation points, through looking into the sign change of the quadratic terms of potential energy. Both theoretical buckling and restabilization points are in agreement with finite element results. Lastly, a 3D phase diagram on stability boundaries is provided and we find that when the aspect ratio is beyond a threshold, wrinkles may not occur in the center but are split into two packets near the stretching ends.


ABSTRACT: In the current work, free vibration of porous nanotubes is studied using Timoshenko beam model. The stiffness enhancement and stiffness reduction mechanisms of nanostructure systems are described by the nonlocal strain gradient theory. The thickness and material terms are varying along the length where an even distribution of porosity is considered using a modified power-law rule. The governing equations and boundary
conditions are achieved via a virtual work of Hamilton's principle. The equations of motion are solved using the generalized differential quadrature method (G-DQM) and also the accuracy and convergency of the present methodology are studied. It shows that the dynamic characteristics of porous nanotubes are influenced by size effects, geometry, material composition, porosity, and various boundary conditions. Furthermore, for all boundary conditions except for the first mode in the case of nano-cantilever porous tubes, the rising of the nonlocal and strain gradient parameters lead to decreasing and increasing the natural frequencies, respectively.


ABSTRACT: This article reviews, for the first time, the mechanical behaviour of functionally graded structures at small-scale levels. Functionally graded nanoscale and microscale structures are an advanced class of small-scale structures with promising applications in nanotechnology and microtechnology. Recent advancements in fabrication techniques such as the advent of powder metallurgy, made it possible to tailor the mechanical properties of structures at small-scale levels by fabricating them out of functionally layerwise mixture of two or more materials; this class of structures, called functionally graded (FG), can be used to improve the performance of many microelectromechanical and nanoelectromechanical systems due to their spatially varying mechanical and electrical properties. The increasing number of published papers on the mechanical behaviours of FG nanoscale and microscale structures, such as their buckling, vibration and static deformation, employing scale-dependent continuum-based models, has proved their importance in academia and industry. Generally, the nonlocal elasticity-based models have been used for FG nanostructures whereas modified versions of couple stress and strain gradient theories have been utilised for FG microstructures. In this review paper, first, various scale-dependent theories of elasticity for FG small-scale structures are explained. Then, available studies on the mechanical behaviours of FG nanostructures such as FG nanobeams and nanoplates are described. Moreover, available investigations on the mechanics of microstructures made of FG materials are reviewed. In addition, in each case, the most important findings of available studies are reviewed. Finally, further possible applications of advanced continuum mechanics to FG small-scale structures are inspired.


ABSTRACT: This research presents an analytical approach for nonlinear static responses and stability analysis of functionally graded porous (FGP) arches with graphene platelets (GPLs) reinforcements (i.e., FGP-GPLRC arches). The constitutive material composition of the FGP-GPLRC arch varies along the radial direction of the cross section specifically, so that the mechanical performance of the arch such as buckling strength and weight can be well controlled for various engineering design purposes. The effective Young's modulus of the FGP-GPLRC arch is determined by the volume fraction distribution of materials. Based on the Euler-Bernoulli hypothesis, the structural responses of the arch considering the geometric nonlinearity are derived by using the virtual work method. Two boundary conditions are considered which are including the pinned-pinned and the fixed-fixed supports. The loading condition is defined as uniformly distributed load in the radial direction of the arch. Different buckling modes are discussed by the illustration of the equilibrium paths. By adopting the developed analytical solution, the relationship between the structural response, buckling load, self-weight, porosity level and the percentage of content of the GPLs can be investigated efficiently. The applicability and effectiveness of the proposed analytical approach for the geometric nonlinear analysis of FGP-GPLRC arch structures are demonstrated through numerical examples.

ABSTRACT: Mechanical properties of hierarchical lattice structures depend not only on their overall shapes and topologies, but also on their microstructural configurations. This paper proposes a new method for concurrent topology optimization of structures composed of layer-wise graded lattice microstructures. Both macroscale design variables representing the distribution of different lattice materials and microscale design variables defining the topologies of the microstructural unit cells are to be simultaneously optimized. This formulation thus integrates the microstructure design into the structural design, instead of pursuing a grey macroscale design and then interpreting the intermediate densities into certain microstructures. The proposed method also enlarges the design space by allowing for graded microstructures. Two new design constraints, namely the structural coverage constraint and the average porosity constraint, are introduced into the proposed optimization formulation to reduce the complexity of the constraints in the layer-wise graded design. The macroscale and microscale designs are linked by using the Asymptotic homogenization method to compute the effective elastic properties of the microstructured materials. Numerical examples show validity of the proposed method. It is also found that layer-wise graded lattice structures outperform those with uniform lattice microstructures in terms of structural stiffness. Finite element simulations of constructed models of the optimized designs suggest that graded lattice structures exhibit higher buckling resistance and ultimate load bearing capacity than single-scale solid material structures or uniform lattice structures under the same material usage.


ABSTRACT: The nonlocal strain gradient elasticity theory is being widely used to address structural problems at the micro- and nano-scale, in which size effects cannot be disregarded. The application of this approach to bounded solids shows the necessity to fulfil boundary conditions, derived from an energy variational principle, to achieve equilibrium, as well as constitutive boundary conditions inherent to the formulation of the constitutive equation through convolution integrals. In this paper we uncover that, in general, is not possible to accomplish simultaneously the boundary conditions, which are all mandatory in the framework of the nonlocal strain gradient elasticity, and therefore, the problems formulated through this theory have no solution. The model is specifically applied to the case of static axial and bending behaviour of Bernoulli-Euler beams. The corresponding governing equation in terms of displacements results in a fourth-order ODE with six boundary conditions for the axial case, and in a sixth-order ODE with eight boundary conditions for the bending case. Therefore, the problems become overconstrained. Three study cases will be presented to reveal that all the boundary conditions cannot be simultaneously satisfied. Although the ill-posedness has been pointed out for an elastostatic 1D problem, this characteristic holds for other structural problems. The conclusion is that the nonlocal strain gradient theory is not consistent when applied to finite structures and leads to problems with no solution in a general case.

References listed at the end of the paper:


ABSTRACT: In this paper, the theory of thermo-acoustic wave emission and propagation is further generalized to consider media viscosity effects. The fully coupled thermo-acoustic field theory and solution for a free-standing nano-thin film in viscous fluid are further developed where fluid viscosity was usually ignored in many early works on thermo-acoustic interaction. The effects of heat loss, heat capacity and heat exchange are also considered in this investigation. In addition to examining the double frequency effect when a sinusoidal alternating current acts on the nano thin film, we have successfully decoupled the thermal wave propagation from the acoustic effect by reformulating the governing differential equations. With appropriate simplification, an analytical prediction for near-field and far-field acoustic pressure response with viscosity effect is derived. We illustrate in some practical examples that the analytical predictions are in excellent agreement with experiments. Further referring to some past works, an analytical solution of higher-order accuracy with respect to the wavenumber omitted in the previous studies is obtained. Although the viscous effect may have limited influence in the vicinity of the thermo-acoustic source, it is vital for the subsequent propagation of acoustic waves. This work may have shown great potentials for the design of thermo-acoustic projectors for new underwater sonars as compared with the electro-acoustic traditional designs that are induced by membrane vibrations.


ABSTRACT: This paper aims to propose an efficient and accurate framework for the post-buckling analysis of sandwich structures with elastic-plastic material behaviors. Correspondingly, efforts are made in two aspects, i.e., the model and the nonlinear solver. A new one-dimensional sandwich model is firstly established, in which the skins are described by Euler–Bernoulli beam theory, while the core layer is approximated by high-order functions. The Ramberg–Osgood elastic-plastic material behavior is considered for the core and the linear elastic for the skins. Green–Lagrange strains are used for accurately describing large deformations in both skins and core layer. The resulting nonlinear equations are then solved by an efficient and robust path-following technique, i.e., the Asymptotic Numerical Method (ANM), in which the bifurcation indicator is introduced to precisely detect bifurcation points and the corresponding instability patterns. Several typical instability phenomena (global buckling, local-global-coupling instability and shear crimping) are investigated and numerical results demonstrate that the proposed approach is able to accurately characterize the post-buckling behaviors of sandwich structures with few computational cost.


ABSTRACT: In the present study, thorough research on bending analysis of the fullerene structures (such as $C_6$, $C_{10}$, $C_{18}$, and $C_{29}$) resting on the Winkler-Pasternak elastic foundation and under external loading is conducted. Small-scale effects on the results are taken into consideration via nonlocal elasticity theory. The
geometry of fullerene structures is assumed as a sphere and doubly-curved structure. The static governing
equations for fullerene structures are derived by implementing the principle of minimum potential energy on the
basis of the nonlocal first-order shear deformation theory. Various types of boundary conditions including the
free edges are considered. The elastic foundation is applied locally on the particular area of the structure, on the
contrary of the most available researches that have considered it on the whole of problem geometry. For this
aim, an innovative formulation is presented in which simulates the elastic foundation locally. The resulting
equations are solved by using the semi-analytical polynomial method (SAPM). Since no similar research has
been done before, the bending results of a spherical structure (whereas the fullerene structure can be
approximated by a sphere) are compared and validated with the results of ABAQUS software. Also, the effects
of several important parameters such as the type of fullerene structure, the nonlocal parameter, and the elastic
foundation constants on the results are investigated in detail.

Ali Farajpour, Mergen H. Ghayesh, Hamed Farokhi, “Nonlocal nonlinear mechanics of imperfect carbon
https://doi.org/10.1016/j.ijengsci.2019.03.003
ABSTRACT: In this article, for the first time, a coupled nonlinear model incorporating scale influences is
presented to simultaneously investigate the influences of viscoelasticity and geometrical imperfections on the
nonlocal coupled mechanics of carbon nanotubes; large deformations, stress nonlocality and strain gradients are
captured in the model. The Kelvin-Voigt model is also applied in order to ascertain the viscoelasticity effects on
the mechanics of the initially imperfect nanoscale system. The modified coupled equations of motion are then
derived via the Hamilton principle. A solution approach for the derived coupled equations is finally developed
applying a decomposition-based procedure in conjunction with a continuation-based scheme. The significance
of many parameters such as size parameters, initial imperfections, excitation parameters and linear and
nonlinear damping effects in the nonlinear mechanical response of the initially imperfect viscoelastic carbon
nanotube is assessed. The present results can be useful for nanoscale devices using carbon nanotubes since the
viscoelasticity and geometrical imperfection are simultaneously included in the proposed model.

nanotubes reinforced materials and on influence of carbon nanotubes spatial distribution on mechanical
ABSTRACT: A recently developed approximate approach for modeling of carbon nanotubes and for evaluation
of the effective properties of carbon nanotubes reinforced materials is applied to analysis of square plate with
hole under uniaxial tension. It is assumed, that the plate is made of polymer with randomly distributed and
randomly oriented carbon nanotubes. Distributions of carbon nanotubes volume fraction is varied over the
surface of the plate, with the constraint that the total volume of nanotubes in the structure is the same, and the
effects of that on stress concentration is evaluated. Such special variation volume fraction makes the carbon
nanotubes reinforced polymer a functionally graded material.
In evaluation of the local effective properties the Gutrin–Murdoch material surface model is applied to a hollow
cylinder of finite thickness and combined with the notion of energy equivalence to replace carbon nanotube
with an equivalent solid cylinder. The interphase, if any, can be modeled as a spring layer and subsequently
added to obtain another equivalent solid cylinder. The material reinforced with such solid cylinders is then
evaluated using the method of conditional moments, a stochastic homogenization approach proposed earlier for
determination of the effective properties of random materials.

M.H. Jalaei, Ő. Civalek, “On dynamic instability of magnetically embedded viscoelastic porous FG nanobeam”,
International Journal of Engineering Science, Vol. 143, pp 14-32, October 2019,
https://doi.org/10.1016/j.ijengsci.2019.06.013
ABSTRACT: Dynamic instability of viscoelastic porous functionally graded (FG) nanobeam embedded on
visco-Pasternak medium subjected to an axially oscillating loading as well as magnetic field is presented in this
research. Porosity-dependent material properties of the porous nanobeam are described via a modified power-
law function. Viscoelasticity of the nanostructure is considered based on the Kelvin–Voigt model. Employing
Eringen's differential law in conjunction with Timoshenko beam theory (TBT), the motion equations are
derived via Hamilton's variational principle. Navier's solution as well as Bolotin's approach are utilized to
obtain the dynamic instability region of viscoelastic porous FG nanobeam. Some benchmark results related to the effects of structural damping, length to thickness ratio, foundation type, nonlocal parameter (NP), static load factor, power-law index, porosity volume index and magnetic field on the instability region of porous FG nanobeam are evaluated. The results reveal that with increasing power-law index and structural damping, the pulsation frequency decreases and so, instability region shifts to left side while as magnetic field magnifies, the dynamic instability moves to right side. Also, it is represented that the porosity effect on the dynamic stability of FG nanobeam depends significantly on the values of power-low index and magnetic field.

ABSTRACT: This work deals with free vibration analysis of doubly-curved nanoshells in which the material properties are temperature and porosity dependent, and varying along the thickness direction. The size-dependent effects of nanostructure systems are captured using the nonlocal strain gradient theory. A modified power law rule and the Hamiltonian principle are adopted, respectively, to obtain the material properties and governing equations of motion. An analytical technique based on Navier series is utilized to solve the eigenvalue problem and satisfied the boundary condition for simply-supported edges. The numerical results show that the vibration characteristics of the nanoshells are influenced by small scale parameters, geometry conditions, material compositions, porosities and thermal environment. Presented numerical results can serve as benchmarks for future analyses of doubly-curved nanoshells with porosity phases.

ABSTRACT: This contribution addresses the multiscale computational modelling of closed cell metallic foams by means of an integrated Representative Volume Element (RVE) generation and computation strategy. The microstructural geometry is computationally generated by controlling relevant fine scale features such as the distribution of cell sizes, the spatial organization of cell sizes and that of cell wall thicknesses and curvatures. The number of faces per cell and of edges per face are also set to comply with the experimentally observed values. The computational generation of the RVE is built on three ingredients: (i) a random close inclusions packing algorithm based on random sequential addition assisted by neighbour distance control, (ii) a distance field-based shape tessellation (morphing) that allows reproducing cell wall curvatures and varying cell wall thicknesses from the inclusions packing, (iii) a close control of the shape of the cells. The RVE geometry is thus described using implicit functions, thereby allowing a seamless transition towards a recently developed mesh generation technique for heterogeneous microstructures represented by such implicit functions, enabling simulations in standard softwares. This controlled generation methodology is illustrated based on experimental data available in literature for morphological indicators relevant to the foam mechanical behaviour. A qualitative and quantitative agreement between FE results and experimental data is obtained for the mechanical response of a commercially available ALPORAS foam. The individual contribution of each microstructural feature (size distributions, wall thickness and curvatures) to the average behaviour of closed cell foams is assessed through FE computations on increasingly complex geometries.

Ahmad Almagableh (1), Mohammad A. Omari (2) and Igor Sevostianov (3)
(1) Mechanical Engineering Department, Faculty of Engineering, The Hashemite University, 13133, Zarqa, Jordan
(2) Department of Mechanical Engineering, Jordan University of Science and Technology, Irbid, Jordan
(3) Mechanical and Aerospace Engineering Department, New Mexico State University, Las Cruces, NM, USA
ABSTRACT: Non-linear three dimensional finite element model of double wall carbon nanotube has been developed to evaluate its anisotropic elastic properties. Carbon nanotube was modeled as a frame-like structure and its elastic properties have been considered in the sense of the average over volume (effective) response on the axial and radial loadings. The principal bonds between two adjacent atoms were simulated using equivalent
The von Neumann analysis of partial differential equations for both the pipe and fluid are taken into account. The equations of motion of the system in the form of pseudo-rectangular beam elements which exhibit different flexural rigidity along the two principal centroid axes of the cross-section. The simulation of the interlayer van der Waals force with intrinsic nonlinearity and complicated applying region has been performed. Resulting Young's moduli of double walled carbon nanotube of diameter of 0.7–2 nm was found to vary from 0.2 to 0.5 TPa in axial direction and from 1.4 to 43.3 GPa in radial direction. The radial Young's modulus exponentially decays with the tube diameter.

Behrouz Karami (1), Davood Shahsavari (1), Maziar Janghorban (1) and Li Li (2)
(1) Department of Mechanical Engineering, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran
(2) State Key Lab of Digital Manufacturing Equipment and Technology, School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China


ABSTRACT: Up to now, there is no a unified model for the force resonance problem of a three-directional functionally graded material (3D-FGM). This contribution tries to present an investigation on the resonance behavior of Kirchhoff nanoplates. To capture the small-scale effects on the resonance deflection of nanoplates, the bi-Helmholtz nonlocal strain gradient theory incorporating three small-scale parameters is adopted. Governing equations of the 3D-FGM nanoplate are derived using the variational approach. Afterwards, an analytical method based on Navier series is utilized to obtain the closed-form solution of the resonance deflection of nanoplates whose properties vary along the thickness direction. The effects of some parameters such as constant material parameters, aspect ratio, and small-scale parameters are investigated in detail. Both low- and high-order nonlocal parameters exhibit a “stiffness-softening” effect; the resonance deflection will move to the lower load frequencies as either low- or high-order nonlocal parameter increases. The strain gradient parameter has, however, a “stiffness-hardening” effect, and the resonance deflection will move to the higher load frequencies if considering an increase in the strain gradient parameter. To the best of the authors’ knowledge, it is for the first time that the governing equations of 3D-FGM nanoplates using bi-Helmholtz nonlocal strain gradient theory are derived, and the resonance phenomena is investigated for the bi-Helmholtz nonlocal strain gradient nanoplates.

M. Taylor (1), M. Shirani (2), Y. Dabiri (3), J.M. Guccione (3) and D.J. Steigmann (2)
(1) Department of Mechanical Engineering, Santa Clara University, Santa Clara, CA 95053 USA
(2) Department of Mechanical Engineering, University of California, Berkeley, CA 94720 USA
(3) Department of Surgery, University of California, San Francisco, CA 94143 USA


ABSTRACT: A two-dimensional plate theory, valid for finite elastic deformations with small strains, is derived for incompressible, fiber-reinforced materials. Single-layer plates and two-layer laminates are considered. Numerical simulations illustrate the substantial effect that fiber reinforcement has on wrinkling patterns in the sheet.

Amir Mehdi Dehrouyeh-Semnani (1), Esmaeil Dehdashti (2), Mohammad Reza Hairi Yazdi (1) and Mansour Nikkhah-Bahrami (1)
(1) School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran
(2) Department of Mechanical Engineering – Engineering Mechanics, Michigan Technological University, 1400 Townsend Drive, Houghton, MI, USA


ABSTRACT: In the current paper, an attempt is made to analyze the moderately large oscillations of a geometrically nonlinear functionally graded pipe conveying hot fluid subjected to a harmonic lateral excitation. The material properties of functionally graded pipe are presumed to vary continuously and smoothly through its radial direction according to a power law function. In addition, the temperature-dependency of material properties for both the pipe and fluid are taken into account. The equations of motion of the system in the form of partial differential equations (PDEs) are derived by implementing the Euler-Bernoulli beam hypothesis and the von-Karman geometric nonlinearity. The achieved PDEs are discretized to a set of nonlinearly coupled
ordinary differential equations via the Galerkin technique. In order to assess the nonlinear thermo-resonant characteristics of the system, the method of harmonic balance is employed. Furthermore, the temperature distribution in the radial direction of pipe is calculated by use of the one-dimensional steady state heat conduction model in conjunction with the Galerkin technique. The nonlinear thermo-resonant behavior of the system accompanied by bifurcations is examined via constructing the frequency-amplitude, force-amplitude, and backbone curves. In addition, the role of gyroscopic damping in the nonlinear resonant responses of system is explored. Eventually, the comparative studies for a homogeneous isotropic pipe conveying fluid in the reference temperature are conducted by employing numerical results available in the scientific literature.


ABSTRACT: Molecular mechanics models like the molecular structural mechanics (MSM) model have been proven to be a valuable tool for the investigation of carbon nanotubes. This class of models is based on a chemical force field representing the bonds present in the structure. Up to now, the underlying chemical force field applied in the MSM model is usually based on harmonic potentials. This simple approach comes with major drawbacks limiting the abilities of the MSM approach. In order to overcome these limitations, the present work integrates the 2nd generation reactive bond order potential (REBO), which is a sophisticated chemical force field, into the MSM approach. The development of this advanced MSM model is given in detail. As a demonstration of its capabilities, the elastic properties of different armchair and zig-zag CNTs are investigated numerically. It was found, that the results for the elastic properties differ significantly with the choice of the underlying chemical force field. The arising differences are discussed and reasons for the occurring behavior are given. The developed advanced MSM approach on the basis of the REBO potential strongly enhances the capabilities of the MSM approach while maintaining its excellent accessibility and applicability together with a low computational effort.


ABSTRACT: Curved beams are basic structural components of Nano-Electro-Mechanical-Systems (NEMS) whose design requires appropriate modelling of scale effects. In the present paper, the size-dependent static behaviour of curved elastic nano-beams is investigated by stress-driven nonlocal continuum mechanics. Axial strain and flexural curvature fields are integral convolutions between equilibrated axial force and bending moment fields and an averaging kernel. The nonlocal integral methodology formulated here is the generalization to curved structures of the treatment in [Int. J. Eng. Science 115 (2017) 14–27] confined to straight beams. The corresponding nonlocal differential problem, supplemented with non-standard boundary conditions, is highlighted and shown to lead to mathematically well-posed problems of nano-engineering. The theoretical predictions, exhibiting stiffening nonlocal behaviours, are therefore appropriate to significantly model a wide range of small-scale devices of nanotechnological interest. The nonlocal approach is exploited by analytically establishing size-dependent responses of curved elastic nano-sensors and nano-actuators that are driven by the small-scale characteristic parameter.


ABSTRACT: In this study, free vibration analyses of small-scaled trusses and frames are firstly carried out based on nonlocal elasticity of Eringen. Nonlocal matrix motion formulation is derived by using linear algebraic equations. Finite element method based weighted residual is utilized to solve the resulting equations. Various numerical studies are presented for nondimensional natural frequencies of different truss and frame models. A detailed parametric study is performed to investigate the influences of nonlocal parameter, geometric properties, direction angle, mode numbers, and length-to-diameter ratio on the natural frequencies of micro/nano trusses.
and frames. It is revealed that there is a significant relationship between the size-dependent dynamic response of these structures and the geometrical and structural properties of them.


ABSTRACT: This paper deals with the equilibrium problem of fully nonlinear beams in bending by extending the model for the anticlastic flexion of solids recently proposed by Lanzoni and Tarantino (2018) in the context of finite elasticity. In the first part of the paper it is shown, through a parametric analysis, that some geometrical parameters of the displacement field lose importance when slender beams are considered. Therefore, kinematics is reformulated and, subsequently, a fully nonlinear theory for the bending of slender beams is developed. In detail, no hypothesis of smallness is introduced for the deformation and displacement fields, the constitutive law is considered nonlinear and the equilibrium is imposed in the deformed configuration. Explicit formulas are obtained which describe the displacement fields of the inflexed beam, the stretches and the stresses for each point of the beam using both the Lagrangian and Eulerian descriptions. All these formulas are linearized by retrieving the classical formulae of the infinitesimal bending theory of beams. In the second part of the paper the theoretical results are compared with those provided by numerical and experimental analyses developed for the same equilibrium problem with the aim of justify the hypotheses underlying the theoretical model. The numerical model is based on the finite element (FE) method, whereas a test equipment prototype is designed and manufactured for the experimental analysis.

Mergen H. Ghayesh (1), Ali Farajpour (1) and Hamed Farokhi (2)
(1) School of Mechanical Engineering, University of Adelaide, South Australia 5005, Australia
(2) Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne NE1 8ST, UK


ABSTRACT: In this paper, the complex viscoelastically coupled global mechanics of fluid-conveying microtubes is examined for the first time. The externally excited microtube is assumed to be embedded in a nonlinear elastic medium. A scale-dependent theoretical model is presented with consideration of curvature nonlinearity within the context of the modified version of the couple stress theory (CST). According to Hamilton's energy/work principle, the coupled nonlinear equations of fluid-conveying microscale tubes are presented. Both the transverse and longitudinal displacements and inertia are taken into account in the continuum-based model and numerical calculations. In order to discretise the governing nonlinear differential equations, Galerkin's weighted-residual procedure is employed. The bifurcation characteristics of the fluid-conveying microsystem with clamped-clamped boundary conditions are obtained within the framework of a direct time-integration procedure. It is found that the complex global dynamics of the fluid-conveying microsystem is very sensitive to the speed of the flowing fluid.


ABSTRACT: We develop a new Finite Element to accurately model twisting of rods and capture the bifurcation scenarios leading to helical buckling and various further post-buckling states. Since standard nonlinear beam elements do not account for nonlinearities in torsional modes, as well as for coupling between axial, lateral and torsional modes, we derive a new beam element, which allows us to describe complex helical buckling bifurcation scenarios of a rod subjected to a twisting load. The formulated beam element is systematically tested to assess its predictive capabilities in determining critical torsional buckling loads and its sensitivity to number of elements used. Once the model is validated against commercial FE software (Abaqus), we focus our attention on computing bifurcation scenarios to observe various complex helical configurations and transitions between them. The analysis reveals co-existence between helices with multiple loops for certain values of twisting load.
Additionally, we trace the transition onsets between stable helical configurations. The developed FE can be applied to study complex buckling mechanics of engineering and biological structures.

Harry J. Carpenter (1), Alireza Gholipour (1), Mergen H. Ghayesh (1), Anthony C. Zander (1) and Peter J. Psaltis (2,3)
(1) School of Mechanical Engineering, University of Adelaide, Adelaide, South Australia 5005, Australia
(2) Vascular Research Centre, Lifelong Health Theme, South Australian Health and Medical Research Institute (SAHMRI), Adelaide, South Australia 5000, Australia
(3) Adelaide Medical School, University of Adelaide, Adelaide, South Australia 5005, Australia
ABSTRACT: Globally, cardiovascular diseases are seen as one of the largest economic burdens on society and the single largest cause of death, with atherosclerosis the leading cause of myocardial infarction (heart attack). Due to the complex interactions in the coronary vasculature, medical imaging technology is unable to recognise correlations between artery and fluid mechanics and disease initiation and progression, hence, biomechanical analysis of coronary arteries in patient-specific models is necessary to provide critical information in clinical settings; large variability in modelling approaches, parameters and results still, however, hamper accurate and reliable model development. This review aims to assist in filling that gap by presenting an overview of research efforts to date, from both theoretical and experimental perspectives, to assist in addressing the challenge of developing a reliable and accurate biomechanical model of human coronary arteries. Studies have been categorised primarily on their approach, either purely theoretical, purely experimental/clinical or a combined theoretical and experimental/clinical approach as well as then divided into structural, fluid, and fluid–structure interaction (FSI) analysis. From research efforts to date it is clear that the development of FSI models to incorporate the effects of shear-thinning, non-Newtonian flows in viscoelastic, realistic artery and plaque morphologies developed from in vivo, high resolution imaging is critical for accurate determination of disease initiation/progression, including atherosclerosis, plaque formation, and failure mechanisms. The inclusion of micro-constituents such as micro-calcification, endothelial cell layer, collagen cross-linking, vascular smooth muscle cell contractility and constitutive blood equations also affects stress magnitude, distribution and failure mechanisms and should be adequately accounted for. A set of appendices are also provided where studies are summarised and assessed based on their approach to modelling and are categorised by considering the imaging modality used, methodology, material and blood properties, type of coronary artery, approach to the study (theoretical, experimental, in vitro & in vivo), number of patients/specimens and a general description. It is hoped this review will assist in furthering the field of coronary artery biomechanics and contribute to developing accurate and reliable patient-specific models capable of improving our understanding of cardiovascular biomechanics and hence, the initiation/progression of related diseases to address the growing global morbidity, mortality and economic challenge of cardiovascular disease and myocardial infarction.

Mohammad Malikan (1), Maxim Krasheninnikov (2) and Victor A. Eremeyev (1,2)
(1) Department of Mechanics of Materials and Structures, Faculty of Civil and Environmental Engineering, Gdansk University of Technology, 80-233 Gdansk, Poland
(2) R. E. Alekseev Nizhny Novgorod Technical University, Minin St., 24, Nizhny Novgorod, 603950 Russia
ABSTRACT: This paper considers a single-walled composite nano-shell (SWCNS) exposed in a torsional critical stability situation. As the magnetic field affects remarkably nanostructures in the small size, a three-dimensional magnetic field is assessed which contains magnetic effects along the circumferential, radial and axial coordinates system. Based on the results of the nonlocal model of strain gradient small-scale approach and the first-order shear deformation shell theory (FSDST), the problem is estimated. Afterward, the numerical results are taken analytically and compared with other existing literature. Hereafter, the influences of various factors, such as the magnetic field, are discussed deeply. It is observed that when the magnetic field is studied in three dimensions, the transverse magnetic effect is the most serious factor that affects fundamentally the torsional stability of the shell.
References listed at the end of the paper:
The material length scale parameter used in couple stress theories is not a material constant. International Journal of Engineering Science, 133 (2018), pp. 15-25


15. Z.K.J. Kok, C.H. Wong, Molecular dynamics simulation studies of mechanical properties of different carbon nanotube systems, Molecular Simulation, 42 (15) (2016), pp. 1274-1280


22. M. Malikan, V.B. Nguyen, Buckling analysis of piezo-magnetoelastic nanoplates in hygrothermal environment based on a novel one variable plate theory combining with higher-order nonlocal strain gradient theory, Physica E: Low-dimensional Systems and Nanostructures, 102 (2018), pp. 8-28


The nanobeam is also formulated and nanobeam's energies are dynamic. Energy is formulated considering the variation nature of the material properties. Homogenisation technique. The two-scale characteristics, small and functional (FG) nanobeams subject to dynamic loads via developing a high-dimensional model. A geometric nonlinear Euler-Bernoulli theory is used to define the displacement distribution. To incorporate small-size influences a nonlocal strain gradient theory (NSGT) scheme, possessing two independent length scale characteristics, is employed. The FG material distribution is on the basis of the Mori-Tanaka homogenisation technique. The two-parameter constitutive relation is used and the corresponding potential energy is formulated considering the variation nature of the material properties. The energy due to the motion of the nanobeam is also formulated and nanobeam's energies are dynamic-wise balanced by the work of the...
external dynamic loading; this is performed in the framework of Hamilton's principle. The coupled transverse/axial motion equations in the nonlinear regime are obtained. In the framework of a weighted residual method, the truncated/discretised model is obtained and numerically solved for force/frequency diagrams for nonlinear mechanics analysis. For a simple linear version of the problem, a linear analysis is also performed via the finite element method for verification purposes.

S. Adhikari (1), T. Mukhopadhyay (2), A. Shaw (1) and N.P. Lavery (1)
(1) College of Engineering, Swansea University, Swansea, UK
(2) Department of Aerospace Engineering, Indian Institute of Technology Kanpur, Kanpur, India

“Apparent negative values of Young’s moduli of lattice materials under dynamic conditions”, International Journal of Engineering Science, Vol. 150, Article 103231, May 2020,
https://doi.org/10.1016/j.ijengsci.2020.103231

ABSTRACT: Lattice materials are characterised by their equivalent elastic moduli for analysing mechanical properties of the microstructures. The values of the elastic moduli under static forcing condition are primarily dependent on the geometric properties of the constituent unit cell and the mechanical properties of the intrinsic material. Under a static forcing condition, the equivalent elastic moduli (such as Young’s modulus) are always positive. When dynamic forcing is considered, the equivalent elastic moduli become functions of the applied frequency and they can be negative at certain frequency values. This paper, for the first time, explicitly demonstrates the occurrence of negative equivalent Young’s modulus in lattice materials experimentally. Using additively manufactured titanium-alloy lattice metastructures, it is shown that the real part of experimentally measured in-plane Young’s modulus becomes negative under a dynamic environment. In fact, we show that the onset of such negative Young’s modulus in lattice materials can be precisely determined by capturing the sub-wavelength scale dynamics of the system. Experimental confirmation of the negative Young’s moduli and the onset of the same as a function of frequency provide the necessary physical insights and confidence for its potential exploitation in various multi-functional structural systems and devices across different length scales.

Haiying Zhang (1), Zhenwen Zhou (1), Alexander Chudnovsky (1) and Hoang Pham (2)
(1) Civil and Materials Engineering, University of Illinois at Chicago, Chicago, Illinois 60607, USA
(2) Avery Dennison Corporation, Mentor, Ohio 44060, USA

https://doi.org/10.1016/j.ijengsci.2020.103258

ABSTRACT: Conformability is a property of materials that allows them to conform to the contours of a curved or rough surface. The lack of conformability of a thin plastic film lying on a non-flat substrate is commonly manifested in formation of blisters, wrinkles and other forms of delamination. The delamination is driven by elastic energy of thin film associated with the film deformation required by film application. A simple method of observation and quantitative characterization of delamination and its evolution in time is proposed. The time dependency of delamination is driven by an interplay between the stress relaxation within the film and viscous flow of adhesive. Thus, the conformability of multilayer system is controlled by the stiffness and relaxation characteristics of the film as well as the time dependent strength of adhesive. A methodology of testing the conformability and measurements of delamination growth, as well as quantitative modeling of the process are presented.

Hannah Conroy Broderick (1), Michele Righi (2), Michel Destrade (1) and Ray W. Ogden (3)
(1) School of Mathematics, Statistics and Applied Mathematics, NUI Galway, University Road, Galway, Ireland
(2) TeCip Istituto, Scuola Superiore Sant’Anna, Piazza Martiri della Liberta 33, Pisa 5612, Italy
(3) School of Mathematics and Statistics, University of Glasgow, University Place, Glasgow G12 8SQ, Scotland

https://doi.org/10.1016/j.ijengsci.2020.103280

ABSTRACT: We examine the stability of a soft dielectric plate deformed by the coupled effects of a mechanical pre-stress applied on its lateral faces and an electric field applied through its thickness under charge control. The electric field is created by spraying charges on the major faces of the plate: although in practice this
mode of actuation is harder to achieve than a voltage-driven deformation, here we find that it turns out to be much more stable in theory and in simulations. First we show that the electromechanical instability based on the Hessian criterion associated with the free energy of the system does not occur at all for charge-driven dielectrics for which the electric displacement is linear in the electric field. Then we show that the geometric instability associated with the formation of small-amplitude wrinkles on the faces of the plate that arises under voltage control does not occur either under charge control. This is in complete contrast to voltage-control actuation, where Hessian and wrinkling instabilities can occur once certain critical voltages are reached. For the mechanical pre-stresses, two modes that can be implemented in practice are used: equi-biaxial and uni-axial. We confirm the analytical and numerical stability results of homogeneous deformation modes with Finite Element simulations of real actuators, where inhomogeneous fields may develop. We find complete agreement in the equi-biaxial case, and very close agreement in the uni-axial case, when the pre-stress is due to a dead-load weight. In the latter case, the simulations show that small inhomogeneous effects develop near the clamps, and eventually a compressive lateral stress emerges, leading to a breakdown of the numerics.


ABSTRACT: In this article, the dynamic behavior of functionally graded (FG) microbeams with different porosity distributions and acted by a moving harmonic load is studied. A bi-dimensional FG microbeam with its material properties changing gradually along both the length and thickness directions in a power-law distribution form is presented. Besides, the porosities are distributed evenly and unevenly in the body of microbeams, and the small-scale effect is captured with the help of the modified couple stress theory. The equations describing the motions of the FG microbeam are obtained in the framework of Hamilton's principle in conjunction with the parabolic shear deformation theory. These equations are solved by employing the finite element formulation, which is validated by comparing the fundamental frequency and dynamic response with previous works. The effects of several key factors such as two grading indexes, small scale parameters, porous distribution pattern and volume fraction, as well as moving speed and motivation frequency of the acted load are investigated in detail. It is concluded that the bi-dimensional FG parameters and porous parameter play significant roles in the dynamic response of microbeams subjected to a moving load, which is helpful for the multi-functional and optimal design of microsystems.


ABSTRACT: A non-classical quasi three-dimensional shell theory is proposed to analyze the static phenomenon of doubly-curved nanoshells whose made of functionally graded (FG) anisotropic material. The mechanical properties vary exponentially via the z-axis. Compared to other shell theories, the proposed model needs only seven unknown variables to determine fourfold coupled (axial-shear-bending-stretching) static and buckling responses. The obtained governing equations and boundary conditions are solved analytically for simply-supported edges. Then, the static bending and buckling analysis results of the nanoshell are given, and the effects of the exponential factor, nonlocal and strain gradient parameters, and geometrical parameters on the deflection, stress and critical buckling load of the nanoshells are investigated. Furthermore, the present work investigates the accuracy of replacing a hexagonal model with an isotropic one. It is shown that a static bending and buckling results of the system can grow up to 7% differences in different conditions.


ABSTRACT: In the current work, we study the role of higher-order and micro-inertia contributions on the mechanical behavior of composite structures. To that scope, we compute the complete set of the effective static and dynamic properties of composite beam structures using a higher-order dynamic homogenization method which incorporates micro-inertia effects. We consider different inner composite element designs, with material
constituents that are of relevance for current engineering practice. Thereupon, we compute the effective static longitudinal higher-gradient response, quantifying the relative difference with respect to the commonly employed, Cauchy-mechanics formulation. We observe that within the static analysis range, higher-order effects require high internal length values and highly non-linear strain profile distributions for non-negligible higher-order effects to appear. We subsequently analyze the longitudinal, higher-gradient eigenfrequency properties of composite structural members, accounting for the role of micro-inertia contributions. Thereupon, we derive analytical expressions that relate the composite material's effective constitutive parameters with its macroscale vibration characteristics. We provide for the first-time evidence that micro-inertia contributions can counteract the effect of second-gradient properties on the eigenfrequencies of the structure, with their relative significance to depend on the mode of interest. What is more, we show that the internal length plays a crucial role in the significance of micro-inertia contributions, with their effect to be substantial for low, rather than for high internal length values, thus for a wide range of materials used in engineering practice.


ABSTRACT: As a first endeavor, the dynamic analysis of functionally graded graphene nanoplatelets reinforced composite (FG-GNPRC) cylindrical nanoshell subjected to a moving harmonic load is investigated. The effective mechanical properties of the nanocomposite are found using the Halpin-Tsai model and a modified rule of mixture. The equations of motion for the structure resting on an elastic foundation are derived based on first order shear deformation theory (FSDT) in conjunction with the nonlocal strain gradient theory (NSGT) via Hamilton's principle. Accordingly, the shear deformation, rotary inertia, softening-stiffness and stiffness-enhancement effects are considered. Afterwards, a time-dependent system of state-space is solved for the dynamic analysis of the structure with simply supported boundary conditions. After validating the approach, some novel results are prepared to investigate the impact of size-dependent effects, weight fraction index and the total number of layers of GNPs, elastic foundation parameters, and exciting frequency on the forced vibration of FG-GNPRC cylindrical nanoshells under harmonic moving load through variations in load velocity as well as time history.


ABSTRACT: The size-dependent buckling instability of shear deformable nanobeams rested on a two-parameter elastic foundation is studied through the stress-driven nonlocal theory of elasticity and the kinematic assumptions of the Timoshenko beam theory. The small-scale size effects are taken into account by nonlocal constitutive relationships, which define the strains at each point as integral convolutions in terms of the stresses in all the points and a kernel. In this manner, the nonlocal elasticity formulation is well-posed and does not include inconsistencies usually arising using other nonlocal models. The size-dependent governing differential equations in terms of the transverse displacement and the cross-sectional rotation are decoupled, and closed form solutions are presented for the displacement functions. Proper boundary conditions are imposed and the buckling problem is reduced to finding roots of a determinant of a matrix, whose elements are given explicitly for different classical edge conditions. The closed form treatment of the problem avoids the numerical instabilities usually occurring within numerical techniques, and allows to find also higher buckling loads and shape modes. Several nanobeams rested on the Winkler or Pasternak elastic foundations and characterized by different boundary conditions, shear deformability, and nonlocality are considered and the critical loads and shape modes are presented, including those for the higher modes of buckling. Excellent agreements are found with the available approximate numerical results in the literature and novel insightful findings are presented and discussed, which are in accordance with experimental observations.

ABSTRACT: The effective (homogenized) stiffnesses of the corrugated plate are calculated by solving the periodicity cell boundary-value problems (BVPs) of homogenization theory using a two-step dimension reduction procedure. The three-dimensional (3-D) periodicity cell BVPs first are reduced to two-dimensional (2-D) problems in the plate cross-sections. Then, provided that the plate is thin, the 2-D elasticity problems are reduced to a BVP for a system of ordinary differential equations (ODEs), similar to the problem of curvilinear beam bending. We solve the 1-D BVPs and obtain some formulas for computation of all effective stiffnesses of the corrugated plate in terms of ODEs solutions. Then, we find similarities between the ODEs solutions and the formulas describing the “intrinsic” geometry of the corrugation curve. By using this similarity, we express the effective stiffnesses of the corrugated plate in terms of the geometric characteristics of its corrugation.


ABSTRACT: A realistic/comprehensive biomechanical model of right/left coronary arteries is developed using the in vivo geometric and haemodynamic properties obtained from optical coherence tomography (OCT), angiography, and electrocardiography (ECG). The developed biomechanical model is constructed with the help of an image processing technique and simulated via the finite element method (FEM) for determination of regions with highest shear/von Mises stresses (which determine the potential areas for plaque rupture and initiation of myocardial infarction). A set of simulation results is compared to clinically obtained data to assess the validity of modelling/simulations. The model comprehensively incorporates information relating to three dimensionality, realistic geometry, hyper/viscoelasticity, blood viscosity, heart motion, blood pulsation, and artery bed (i.e. surrounding heart tissue). In vivo clinical data from two patients who underwent coronary angiography for clinical indications is used for modelling/simulations, one of whom had a mild (20%) stenosis in the left circumflex artery and the other had a right coronary artery (RCA) which was initially 100% occluded in its mid segment (following aspiration thrombectomy to remove clot, the RCA was left with diffuse mild (30–40%) narrowing) and then OCT was used to examine this further and showed proximal thin-capped lipid-rich plaque.


ABSTRACT: Atherosclerosis is the most common cardiovascular disease (CVD) causing increased morbidity. Although atherosclerosis is a general disease involving several factors, it preferentially affects the wall of the vessel bifurcations. The use of advanced Computational Fluid Dynamics (CFD) techniques has the potential to shed more light in the further understanding of the causes of the disease and perhaps in its early diagnosis. In this work, a three-dimensional (3D) Fluid Structure Interaction (FSI) study was carried out for a patient specific carotid artery. By considering physiological conditions, first the normal and then with hypertension disease, haemodynamic parameters were evaluated to better understand the genesis and progression of atherosclerotic plaques in the carotid artery bifurcation. Two-way FSI was performed by applying a fully implicit second-order backward Euler differencing scheme using commercial software ANSYS and ANSYS CFX (version 19.0). Arbitrary Lagrangian–Eulerian (ALE) formulation was employed to calculate the arterial response by using the temporal blood response. Due to arterial bifurcation, obvious velocity reduction and backflow formation were observed which decreased shear stress and made it oscillatory at the starting point of the internal carotid artery near the carotid sinus, which resulted in low shear stress. Oscillatory Shear Index (OSI) signifies oscillatory behaviour of artery wall shear stress. By using anatomically realistic 3D geometry and representative physiological conditions, the results obtained for shear stress are more acceptable. Comparison of the results of this study with those in the published literature shows that the regions with low wall shear stress and with OSI value greater than 0.3 pose potential risk to the development of plaques. It was observed that haemodynamics of the carotid artery was very much affected by the geometry and flow conditions. Furthermore, regions of relatively low wall shear stress were observed post stenosis, which is a known cause of plaque development and progression.

ABSTRACT: Transverse wrinkles commonly occur in a uniaxially tensile elastic membrane and can vanish upon excess stretching. The wrinkling direction is usually perpendicular to the stretching direction under isotropic elasticity. Here, we show that wrinkles are observable by material anisotropy, such as in fiber-reinforced or fibrous films, and the wrinkling orientation can be tuned by varying the stiffness and direction of fibers. To quantitatively describe large anisotropic deformations and predict morphological evolution, we develop a finite strain model by introducing anisotropic, hyperelastic constitutive law into the geometrically extended Föppl-von Kármán nonlinear plate theory. We find that the shear modulus ratio between fibers and matrix significantly affects the critical buckling threshold, restabilization point and wrinkling amplitude. The shear modulus ratio above a critical value prevents the appearance of wrinkles. Effects of the angle between fibers and stretching direction on the oblique wrinkling orientation are carefully examined. The findings could provide an effective way to design wrinkle-tunable surfaces for fiber-reinforced or biomimetic membranes.


ABSTRACT: In this paper, a two-dimensional stress-driven nonlocal integral model is introduced for the bending and transverse vibration of rectangular nanoplates for the first time. An appropriate kernel function, which satisfies all essential properties, is proposed for two-dimensional problems in the Cartesian coordinate system. Using Leibniz integral rule and Hamilton's principle, the curvature-moment relations, classical and constitutive boundary conditions, as well as the equations of motion of rectangular small-scale plates are derived. Two differential quadrature techniques are utilised to implement both classical and non-classical boundary conditions and obtain an accurate numerical solution. The solution is used to simulate the bending and vibration of nanoplates. The Laplacian-based nonlocal strain gradient model of plates is also developed for the sake of comparison. It is found that the stress-driven integral model can better estimate the size-dependent mechanical characteristics of small-scale rectangular plates with various boundary conditions.


ABSTRACT: In this study, the non-linear dynamic analysis of torus-shaped and cylindrical shell-like structures has been studied. The applied material is assumed as the functionally graded material (FGM). The structures are considered to be used for important machines such as wind turbines. The effects of some environmental factors on the analysis like temperature and humidity have been considered. The strain field has been calculated in general form and in continue the dynamic governing equations of torus structure have been derived based on the first-order shear deformation theory. The rotation around two independent axes in the torus coordinate system is considered and time-dependent equations are solved using SAPM semi-analytical method. The stresses and deformations generated in the torus and cylindrical shaped structures are plotted. The rotation of structures has been attended due to some transportation purposes. The effect of internal pressures as well as rotational speed at torus and cylindrical structures has been investigated in several numerical diagrams. The results are presented in the form of graphs that consider the rotational effects, loading, thermal and humid (hygro-thermal) environments, and size of the structures. This research can provide scientific perspectives to researchers who will examine the dynamic analysis of torus and cylindrical shaped structures.


ABSTRACT: This work compares the transition and competitive mechanism between three types of instabilities of an incompressible dielectric tube: wrinkling, pull-in instability and electric breakdown. We also see how to select one type of instability mode on demand. First, we investigate the finite response and the wrinkling of a tube subject to a combination of applied radial voltage, torsion and axial force (or stretch). We
use the surface impedance matrix method to determine the wrinkling threshold, and obtain the corresponding two-dimensional pattern shape of wrinkled surface. Second, we look at illustrative numerical calculations for ideal Mooney-Rivlin dielectrics and study the effects of actuation methods, electric voltage, torsion and geometrical parameters on the three types of instabilities. Results show that the deformation of the solid will influence the true electric field in the solid, and induce competitive effects between the applied voltage and the mechanical loading. We find that in addition to the expected contractile buckling, buckling may also occur in extension in an electrically actuated dielectric tube, a departure from the purely elastic wrinkling. Moreover, the electro-elastic behavior of the DE elastomer can be enhanced by introducing torsion. We also find that large stable actuation can be achieved and that the wrinkling pattern can be selected on demand in the tube by finely tuning the actuation, voltage, torsion and geometry, without encountering material failure.


ABSTRACT: We focus on the mechanical strength of piezomagnetic beam-like nanosize sensors during post-buckling. An effective flexomagnetic property is also taken into account. The modelled sensor is selected to be a Euler-Bernoulli type beam. Long-range interactions between atoms result in a mathematical model based on the nonlocal strain gradient elasticity approach (NSGT). Due to possible large deformations within a post-buckling phenomenon, the resultant equations are essentially nonlinear. We establish the results using an analytical approach, including a variety of boundary conditions. We visualize the effective response of the designed sensor for several key components. It was obtained that the flexomagnetic effect is meaningful for less flexible boundary conditions. Besides, it was found that the failure originated from post-buckling occurs sooner if the numerical amounts of nonlocal parameter and the strain gradient one are respectively so small and exceedingly large.


ABSTRACT: The thickness-extensional mode in layered piezoelectric plates can be inevitably interfered by some undesirable eigen-modes due to the lateral edge effect. A reported theoretical method to predict high-frequency coupled vibrations is the 2D high-order plate theory derived based on approximate dispersion relations. In this paper, based on accurate dispersion relations a novel approach called Frequency Spectrum Quantitative Prediction (FSQP) is developed to quantitatively investigate coupled vibration behaviors in piezoelectric multilayered plates operating at ultra-high frequency. Two significant sub-goals need to be achieved: one is the accurate dispersion relations of the layered structure; the other is the variational formulation for the layered plates with piezoelectric and/or elastic phases. Lastly, the objective equation, i.e., frequency spectra, describing coupling strengths between the thickness-extensional mode and unwanted eigen-modes, is derived. A reported numerical example of a piezoelectric thin-film resonator is considered to demonstrate the correctness and superiority of the proposed methodology. Mode shapes of mechanical displacements are investigated in detail to illustrate the application of frequency spectra to suppress the undesirable eigen-modes. Numerical results show that the proposed approach FSQP is efficient and more accurate than the existing 2D high-order plate theory in quantitative predictions of high-frequency coupled vibrations in layered piezoelectric plates.


ABSTRACT: By using the variational-asymptotic method, a universal asymptotic model for composite sandwich plates is established to achieve a great compromise between efficiency and accuracy through the synthesis of two competing theories: equivalent single-layer theories and layer-wise theories. When each layer of a sandwich structure can be individually considered as an elastic plate, and all material constitutive constants of such plates can be assumed to be of the same order, an equivalent plate model can be constructed from the equivalent single-layer perspective. It has an asymptotically correct energy functional, capable of capturing the transverse deformations, but still limited to the zeroth-order approximation. Then, by taking into account
mismatched constituent material properties, a universal model for predicting mechanical behavior of composite sandwich plates is then systematically derived from the layer-wise perspective. It has another asymptotically correct energy functional with respect to the core-layer’s plate variables and implements into a single unified representation for subsequent application to sandwich plate problems with any face-to-core-stiffness and length-to-thickness ratios. In particular, to resolve theoretical shortcomings found in published works, complementary theoretical procedures are incorporated and used into the present approach by considering the interlaminar transverse stress continuity conditions as essential conditions in conventional layer-wise theories and by providing three-dimensional recovery relations as necessary ingredients for theories based on various dimensional reduction processes. Finally, as a preliminary validation, several examples available in the literature are presented and investigated. Together with critical comparisons of the three-dimensional exact solutions, the close agreement demonstrates the capability and accuracy of this present approach.


ABSTRACT: We investigate the microscopic and long-wave (or macroscopic) instabilities in fiber composites (FCs) with hyperelastic phases. To study the influence of the phase stiffening behavior, we employ the phase constitutive models that are developed based on the non-Gaussian statistics of polymeric molecular chains. These non-Gaussian models accurately predict the non-linear behavior of soft materials. Moreover, they can capture the essential soft material stiffening behavior arising due to the finite extensibility of the polymer chains. In turn, the non-linear behavior of the composite phases significantly influences the elastic instabilities and the buckling patterns. Here, we illustrate the phenomenon by the example of FCs with Gent phases. We derive an explicit closed-form expression – in terms of the phase properties and composition – for the onset of long-wave instabilities. To predict the onset of finite length scale (or microscopic) instabilities, we employ the Bloch-Floquet analysis superimposed on finite deformations. We find that the matrix stiffening behavior stabilizes the composites, and can even result in an absolutely stable scenario. Remarkably, Gent FCs with identical phase stiffening characteristics are found to be more stable than their neo-Hookean counterparts for morphologies at which the microscopic instabilities are to develop first. The stiffening behavior of the phases dictates the interplay between the long-wave and microscopic instabilities, and defines the wavelength of the buckling patterns. Thus, the pre-designed phase properties can be used in tailoring the instability-induced patterns in soft fiber composites.


ABSTRACT: A new mechanical and analytical models of the human eye is presented in order to study Glaucoma disease and its complications. Mechanical modeling of the human eye is performed with a hollow sphere under internal pressure. The first-order shear deformation theory is used to obtain the governing equations of the model, which are the set of partial differential equations. The nonlinear von Kármán assumption is considered for strain field to obtain the more precise results. The viscoelastic effects on the material structure of the eye are also considered to be more consistent with the results. The obtained governing equations and boundary conditions are solved using Semi-Analytical Polynomial Method. The results are studied for Glaucoma and the effects of this disease on the patient’s vision as well as the temporary and permanent deformities caused in the patient's eyeball are further investigated. The modeling and information obtained from this study can help clinicians to provide more appropriate therapeutic strategies. Stress concentration can be identified in the eyeball tissue of patients suffering from Glaucoma using the simulations presented in this study. Given the generality of the proposed model, not only Glaucoma disease but also a wide range of eye diseases can be studied.

References listed at the end of the paper:
A. Ayyalasomayajula, R.I. Park, B.R. Simon, J.P.V. Geest, A porohyperelastic finite element model of the eye: The influence of stiffness and permeability on intraocular pressure and optic nerve head biomechanics


H.C. Li, F.Z. Pang, Y.H. Li, C. Gao, Application of first-order shear deformation theory for the vibration analysis of functionally graded doubly-curved shells of revolution, Composite Structures, 212 (2019), pp. 22-42


H.C. Li, F.Z. Pang, Y. Ren, X.H. Miao, K.F. Ye, Free vibration characteristics of functionally graded porous spherical shell with general boundary conditions by using first-order shear deformation theory, Thin-Walled Structures, 144 (2019), Article 106331


F.Z. Pang, C. Gao, J. Cui, Y. Ren, H.C. Li, H.C. Wang, A semi-analytical approach for free vibration characteristics of functionally graded spherical shell based on first-order shear deformation theory, Shock and Vibration, 2019 (2019), Article 7352901


M.B. Rubin, D. Solav, Unphysical properties of the rotation tensor estimated by least squares optimization with specific application to biomechanics, International Journal of Engineering Science, 103 (2016), pp. 11-18


ABSTRACT: The current article presents a thorough investigation into the natural frequencies and mode shapes of thin doubly curved shallow microshells by taking into account the influence of material length scale parameter. The mathematical model of system is obtained by applying the Hamilton's principle along with the modified couple stress theory and the Kirchhoff-Love's shell theory. In order to extract the free vibration characteristics of system, the finite element method is employed. Several comparative studies are then conducted to verify the quadrilateral thin shallow shell element. The numerical results are presented for the thin cylindrical, spherical, and hyperbolic paraboloidal shallow microshells with different planforms including rectangle, triangle, circle, and ellipse. Thin microplate as a special case of thin shallow microshell is also analyzed. A profound examination on the numerical results is also performed to divulge the impacts of scale-dependency accompanied by the geometrical parameters and boundary conditions on the free vibration response of system.

References listed at the end of the paper:


X. Chen, Y. Lu, B. Zhu, X. Zhang, Y. Li, Nonlinear resonant behaviors of bi-directional functionally graded material microbeams: One-/two-parameter bifurcation analyses, Composite Structures, 223 (2019), Article 110896


J. Lei, Y. He, S. Guo, Z. Li, D. Liu, Size-dependent vibration of nickel cantilever microbeams: experiment and gradient elasticity, Aip Advances, 6 (10) (2016), Article 105202


Z. Li, Y. He, J. Lei, S. Han, S. Guo, D. Liu, Experimental investigation on size-dependent higher-mode vibration of cantilever microbeams, Microsystem Technologies, 25 (8) (2019), pp. 3005-3015


C. Liebhold, W.H. Müller, Comparison of gradient elasticity models for the bending of micromaterials, Computational Materials Science, 116 (2016), pp. 52-61


S.S. Rao, Vibration of continuous systems, Wiley Online Library (2007)


ABSTRACT: The resonance phenomenon is for the first time investigated in anisotropic and functionally graded nano-switches, International Journal of Engineering Science, 158 (2020), Article 103431


The resonance phenomenon is for the first time investigated in anisotropic and functionally graded nano-size structure. The structure is considered as a doubly curved shell which is modeled exploiting a quasi-three-dimensional model and nonlocal strain gradient theory in order to predict the small-size effects. The doubly-curved nanoshell is made from aragonite with an orthorhombic crystal system. The corresponding governing equations and boundary conditions, which include simply supported edges, are obtained using Hamilton principle. Then, an analytical technique based Navier solution procedure is used for the dynamic problem in which the double Fourier series has been applied to satisfy the conditions in edges. The extended numerical examples have been shown the sensitivity of resonance position to geometrical parameters, small-size parameters, and the shape of shell panels. Furthermore, we provide a comparison between the present anisotropic model with its isotropic one to ignore the complexity in equations.

References listed at the end of the paper:
B. Karami, M. Janghorban, A. Tounsi, Variational approach for wave dispersion in anisotropic doubly-curved nanoshells based on a new nonlocal strain gradient higher order shell theory, Thin-Walled Structures, 129 (2018), pp. 251-264
B. Karami, M. Janghorban, A. Tounsi, Nonlocal strain gradient 3D elasticity theory for anisotropic spherical nanoparticles, Steel and Composite Structures, 27 (2018), pp. 201-216
F. Kazemi, A. Hajiahmadi, M. Rajabi, Flexural wave propagation analysis of single-walled carbon nanotubes using molecular structural mechanics approach, Materials Research Express, 6 (2019), Article 095048
L. Li, R. Lin, T.Y. Ng, Contribution of nonlocality to surface elasticity, International Journal of Engineering Science, 152 (2020), Article 103311
J. Liu, C. Wang, H. Sun, H. Wang, F. Rong, L. He, et al., CoOx/CoNy nanoparticles encapsulated carbon-nitride nanosheets as an efficiently trifunctional electrocatalyst for overall water splitting and Zn-air battery, Applied Catalysis B: Environmental, 279 (2020), Article 119407
M. Mohammadi, M. Ghayour, A. Farajpour, Free transverse vibration analysis of circular and annular graphene sheets with various boundary conditions using the nonlocal continuum plate model, Composites Part B: Engineering, 45 (2013), pp. 32-42
I.L. Moudrakovski, Recent advances in solid-state NMR of alkaline earth elements, in: Annual reports on NMR spectroscopy, Elsevier (2013), pp. 129-240
M.R. Nami, M. Janghorban, Resonance behavior of FG rectangular micro/nano plate based on nonlocal elasticity theory and strain gradient theory with one gradient constant, Composite Structures, 111 (2014), pp. 349-353
B. Qiu, H. Bao, G. Zhang, Y. Wu, X. Ruan, Molecular dynamics simulations of lattice thermal conductivity and spectral phonon mean free path of PbTe: Bulk and nanostructures, Computational Materials Science, 53 (2012), pp. 278-285


F. Ramírez, P.R. Heyliger, E. Pan, Static analysis of functionally graded elastic anisotropic plates using a discrete layer approach, Composites Part B: Engineering, 37 (2006), pp. 10-20


M.J. Zehetbauer, Y. Estrin, Modeling of strength and strain hardening of bulk nanostructured materials, Wiley online library (2009)


International Journal of Engineering Science, Vol. 158, Article 103431, January 2021,

More papers published in the journal, Engineering Structures (2019 and on):
http://www.sciencedirect.com/science/journal/01410296

https://doi.org/10.1016/j.engstruct.2018.09.084

ABSTRACT: In this paper, the thermo-elastic nonlinear analysis of various Functionally Graded (FG) shells under different loading conditions is studied. A second-order isoparametric triangular shell element is presented for this purpose. The element is six-noded, and each node has all six independent degrees of freedom in space. It should be added, the first-order shear deformation theory is induced. Furthermore, Voigt’s model is adopted to define the FG material properties, which are considered to change gradually from one surface to another. The
critical temperature is predicted. Both the pre-buckling and post-buckling equilibrium paths are traced. Since the linear eigenvalue analysis leads to wrong responses in the problems with strong nonlinearity, the suggested procedure is performed based on the FEM and more exact estimations are achieved using equilibrium path.

References listed at the end of the paper:

3 H.T. Thai, S.E. Kim, A review of theories for the modeling and analysis of functionally graded plates and shells, Compos Struct, 128 (2015), pp. 70-86
9 H. Huang, Q. Han, Nonlinear buckling and postbuckling of heated functionally graded cylindrical shells under combined axial compression and radial pressure, Int J Non-linear Mech, 44 (2009), pp. 209-218
10 F. Alijani, M. Amabili, F. Bakhhtiari-Nejad, Thermal effects on nonlinear vibrations of functionally graded doubly curved shells using higher order shear deformation theory, Compos Struct, 93 (2011), pp. 2541-2553
14 A. Beheshti, S. Ramezani, Nonlinear finite element analysis of functionally graded structures by enhanced assumed strain shell elements, Appl Math Model, 39 (2015), pp. 3690-3703
18 A.H. Sofiyev, N. Kuruoğlu, The stability of FGM truncated conical shells under combined axial and external mechanical loads in the framework of the shear deformation theory, Compos Struct, 92 (2016), pp. 463-476
22 X. Li, C.C. Du, Y.H. Li, Parametric instability of a functionally graded cylindrical thin shell subjected to both axial disturbance and thermal environment, Thin-walled Struct, 123 (2018), pp. 25-35
30 E.M.B. Campello, P.M. Pimenta, P. Wriggers, A triangular finite shell element based on a fully nonlinear shell formulation, Comput Mech, 31 (2003), pp. 505-518
31 P.M. Pimenta, E.M.B. Campello, Shell curvature as an initial deformation: a geometrically exact finite element approach, Int J Numer Meth Eng, 78 (2009), pp. 1094-1112

ABSTRACT: Design of multi-component absorber is a method to improve the specific energy absorption (SEA) and reduce the peak crushing load at the time of the initial accident. In this study, multi-component conical specimens are made from aluminium in the form of end-capped and non-capped. To do so, a long conical tube is divided into several shorter thin-walled conical portions, so that the thickness, length and mechanical properties of the wall vary along the tube length. The purpose of this new design on the conical absorber is to modify performance of shock absorber including decrease of initial peak crushing load and increase of SEA. Therefore, a series of quasi-static experimental tests are carried out on the end-capped and non-capped multi-component conical tubes and parameters of energy absorption, initial peak load, crush force efficiency and SEA are calculated. The results show that the maximum crushing load in simple conical tubes begins at first folding, while it is shifted to the end of the crushing process in multi-component conical tubes. Also, it is shown that the SEA and the crush force efficiency of the non-capped multi-component specimens were further in comparison with the end-capped ones. Finally, it was found that by using this type of the energy absorber, damage to the main structure and also the occupants of car was decreased.

References listed at the end of the paper:

16 G. Nagel, D. Thambiratnam, Computer simulation and energy absorption of tapered thin-walled rectangular tubes, Thin-walled Struct, 43 (2005), pp. 1225-1232
18 B. Arnold, W. Altenhof, Experimental observations on the crush characteristics of AA6061 T4 and T6 structural square tubes with and without circular discontinuities, Int J Crashworthiness, 9 (2004), pp. 73-87
Eight nodded isoparametric shell elements consisting of seven degrees of freedom per node are considered to model graphs of shells (cylindrical, elliptic paraboloid, hyperbolic paraboloid, conoidal and hypar). The extended Halpin–Tsai approach is used to obtain the temperature dependent material properties of the laminated composite shells. Eight nodded isoparametric shell elements consisting of seven degrees of freedom per node are considered to...
discretize the geometry. The accuracy and convergence of the formulation are verified by solving various examples available in the literature. Finally, parametric study is presented to investigate the influence of various parameters on the free vibration response of the graphene reinforced laminated composite shells.

References listed at the end of the paper:
10. Z. Zhao, C. Feng, Y. Wang, J. Yang, Bending and vibration analysis of functionally graded trapezoidal nanocomposite plates reinforced with graphene nanoplatelets (GPLs), Compos. Struct., 180 (2017), pp. 799-808
22. Y. Wang, C. Feng, Z. Zhao, F. Lu, J. Yang, Torsional buckling of graphene platelets (GPLs) reinforced functionally graded cylindrical shell with cutout, Int. Compos. Struct., 197 (2018), pp. 72-79
25. H. Wu, J. Yang, S. Kitipornchai, Dynamic instability of functionally graded multilayer graphene nanocomposite beams in thermal environment, Compos. Struct., 162 (2017), pp. 244-254

ABSTRACT: The present paper describes a thorough testing and finite element modelling programme on the material characteristics and local stability of welded I-sections made of a new high-chromium grade EN 1.4420 stainless steel. Structural testing was conducted on four GMA (gas metal arc) welded I-sections, and involved material testing, residual stress measurements, initial geometric imperfection measurements, eight stub column tests and eight four-point bending tests, with four for each axis of bending. A parallel numerical modelling study was then carried out, in which numerical models were developed and validated against the obtained experimental results and afterwards utilised to perform numerical parametric studies to generate additional data to supplement the test results over a broader spectrum of cross-section geometric dimensions. The experimentally and numerically obtained data were employed to evaluate the suitability of the codified slenderness limits for cross-section classification and local buckling design provisions in both Europe and America to welded I-sections made of the new high-chromium grade EN 1.4420 stainless steel. The results of the comparisons generally indicated that the established cross-section slenderness limits are applicable to the new high-chromium stainless steel welded I-sections, while the codified local buckling design rules, based on an elastic, perfectly plastic material model without taking into account the material strain hardening effect of stainless steel and the effective width method without considering the element interaction effect within the cross-section, yield safe but unduly conservative and scattered cross-section local buckling resistance predictions. The accuracy of a recently proposed continuous strength method to the design of this new type of stainless steel welded I-sections was also evaluated, indicating a substantial improvement over the established design codes, mainly owing to the rational consideration of the favourable effects of material strain hardening and element interaction in the calculation of cross-sectional capacities.

References listed at the end of the paper:
2 EN 10028-7, 2016. Flat products made of steels for pressure purposes – part 7: stainless steels, European Committee for Standardization (CEN), Brussels (2014)
5 N.R. Baddoo, Stainless steel in construction: a review of research, applications, challenges and opportunities, J Constr Steel Res, 64 (11) (2008), pp. 1199-1206
6 G. Gedge, Structural uses of stainless steel – buildings and civil engineering, J Constr Steel Res, 64 (11) (2008), pp. 1194-1198
20 ECCS. European convention for constructional steelwork: convention Europeenne de la Construction Metallique; 1976.
22 B. Schafer, T. Peköz, Computational modeling of cold-formed steel: characterizing geometric imperfections and residual stresses, J Constr Steel Res, 47 (3) (1998), pp. 193-210
25 Centre for Advanced Structural Engineering, Compression tests of stainless steel tubular columns. Investigation report S770, University of Sydney (1990)
26 T.M. Chan, L. Gardner, Bending strength of hot-rolled elliptical hollow sections, J Constr Steel Res, 64 (9) (2008), pp. 971-986
33 O. Zhao, B. Rossi, L. Gardner, B. Young, Behaviour of structural stainless steel cross-sections under combined loading – Part II: numerical modelling and design approach, Eng Struct, 89 (2015), pp. 247-259
34 O. Zhao, B. Rossi, L. Gardner, B. Young, Experimental and numerical studies of ferritic stainless steel tubular cross sections under combined compression and bending, J Struct Eng (ASCE), 142 (2) (2015), p. 04015110
36 O. Zhao, L. Gardner, B. Young, Buckling of ferritic stainless steel members under combined axial compression and bending, J Constr Steel Res, 117 (2016), pp. 35-48
40 B.W. Schafer, S. Ádány, Buckling analysis of cold-formed steel members using CUFSM: conventional and constrained finite strip method, 18th Int spec conf cold-formed steel struct (2006)
41 C. Buchanan, L. Gardner, A. Liew, The continuous strength method for the design of circular hollow sections, J Constr Steel Res, 118 (2016), pp. 207-216
42 O. Zhao, L. Gardner, The continuous strength method for the design of mono-symmetric and asymmetric stainless steel cross-sections in bending, J Constr Steel Res, 150 (2018), pp. 141-152

ABSTRACT: In this paper, the thermal buckling behavior of functionally graded plates and cylindrical shells is investigated. By considering a modified First order Shear Deformation Theory, the governing equations are elaborated. The kernel idea of the proposed model consists on assuming a parabolic distribution of the transverse shear strains across the shell thickness and imposing a zero condition of the transverse shear stresses on the top and bottom surfaces of the shell structure. Four nodes shell elements are adopted to solve the thermal buckling problem. The material properties are assumed to change continuously through the thickness according to a power-law distribution. In order to highlight the potentials of the present formulation, numerical investigations are conducted and compared with results available from the literature. The computation of the critical buckling temperature of structures under non-uniform temperature rise is based on Gauss numerical integration. The effects of material compositions, power law index, thermal loading, boundary conditions and geometrical parameters of shells on the thermal buckling behavior of FGM structures are also examined. References listed at the end of the paper:
1 M. Koizumi, FGM activities in Japan, Compos Part B Eng, 28 (1997), pp. 1-4


17. H.T. Thai, S.E. Kim, A review of theories for the modeling and analysis of functionally graded plates and shells, Compos Struct, 128 (2015), pp. 70-86


26. H.V. Tung, N.D. Duc, Nonlinear analysis of stability for functionally graded plates under mechanical and thermal loads, Compos Struct, 92 (2010), pp. 1184-1191


31. A. Hajlaoui, A. Jarraha, K. El Bikra, F. Dammak, Buckling analysis of functionally graded materials structures with enhanced solid-shell elements and transverse shear correction, Compos Struct, 132 (2015), pp. 87-97


44 R. Naj, M.S. Boroujerdy, M.R. Eslami, Thermal and mechanical instability of functionally graded truncated conical shells, Thin Walled Struct, 46 (2008), pp. 65-78
48 A.H. Soffey, Thermoelastic stability of freely supported functionally graded conical shells within the shear deformation theory, Compos Struct, 152 (2016), pp. 74-84
49 X. Zhao, Y.Y. Lee, K.M. Liew, Mechanical and thermal buckling analysis of functionally graded plates, Compos Struct, 90 (2010), pp. 161-171
50 X. Zhao, K.M. Liew, A mesh-free method for analysis of the thermal and mechanical buckling of functionally graded cylindrical shell panels, Comput Mech, 45 (2010), pp. 297-310
55 R. Kandasamy, R. Dimitri, F. Tornabene, Numerical study on the free vibration and thermal buckling behavior of moderately thick functionally graded structures in thermal environments, Compos Struct, 157 (2016), pp. 207-221
61 R. Javaheri, M.R. Eslami, Thermal buckling of functionally graded plates based on higher order theory, J Therm Stress, 25 (2002), pp. 603-625
64 H. Matsunaga, Thermal buckling of functionally graded plates according to a 2D higher-order deformation theory, Compos Struct, 90 (2009), pp. 76-86
67 L.V. Tran, P. Phung-Van, J. Lee, M. Abdel Wahab, H. Nguyen-Xuan, Isogeometric analysis for nonlinear thermomechanical stability of functionally graded plates, Compos Struct, 140 (2016), pp. 655-667
ABSTRACT: The stability and design of laser-welded stainless steel I-section beam-columns are explored in this study. Owing to the high precision and low heat input of laser-welding, structural cross-sections produced using this fabrication method have smaller heat affected zones, lower thermal distortions and lower residual stresses than would typically arise from traditional welding processes. Eighteen laser-welded stainless steel beam-columns were tested to investigate the member buckling behaviour under combined compression and bending. Two I-section sizes were considered in the tests: I-50 × 50 × 4 × 4 in grade EN 1.4301 and I-102 × 68 × 5 × 5 in grade EN 1.4571 austenitic stainless steel. The two cases of minor axis bending plus compression and major axis bending plus compression with lateral restraints were investigated. The initial
loading eccentricities in the beam-column tests were varied to provide a wide range of bending moment-to-axial load ratios. The test results obtained herein and from a previous experimental study were used to validate finite element (FE) models, which were subsequently employed for parametric investigations to generate further structural performance data over a wider range of cross-section sizes, member lengths and loading combinations. The obtained test and FE results were utilized to evaluate the accuracy of the beam-column capacity predictions according to the current European and North American design provisions and a recent proposal by Greiner and Kettler. Finally, an improved approach for the design of stainless steel I-section beam-columns is proposed.


ABSTRACT: This paper presents an analytical investigation of the thermoelastic lateral-torsional buckling of circular arches under an arbitrary radial point load in a uniform thermal environment accounting for shear deformations, which has not been reported in the literature. The interaction of thermal environment with the arbitrary load and elastic end restraints produces complex non-uniform compressive, bending, and shearing actions in the arch. The theoretical solutions of the critical load and temperature field for the elastic lateral-torsional buckling of arches accounting for shear deformations are derived. Comparisons of theoretical solutions with finite element results show that their agreements are excellent. Effects of various factors on the lateral-torsional buckling are investigated. An increase of the temperature field reduces the buckling load, while an increase of the radial load reduced the critical temperature field for buckling. The effect of shear deformations on the lateral-torsional buckling load is also explored. It is shown that the neglect of shear deformations causes errors in the prediction of the critical buckling load. When shear deformations are considered, the buckling load for arches with a small and intermediate lateral slenderness ratio under the radial point load alone is shown to be lower than that without consideration of shear deformations. However, under the uniform temperature field alone, the critical temperature field for lateral-torsional buckling of the arches considering shear deformations is higher than that neglecting shear deformations.


ABSTRACT: The nuclear containment structure is one of the most important infrastructure systems ensuring the safety of a nuclear power plant. The structural behavior of a cylindrical containment structure made of reinforced concrete (RC) with large dimensions and numerous rebars is complex and difficult to predict. The complex behavior of the RC containment structure has been investigated in an international collaboration project between the National Center for Research on Earthquake Engineering (NCREE) in Taipei, Taiwan and the University of Houston (UH), Houston, Texas. At NCREE two 1/13 scaled cylindrical RC containment specimens were tested under reversed cyclic loads [1]. At UH, a finite element simulation of the two tested specimens was developed using a finite element analysis (FEA) program SCS [2]. In the program, a new shell element, the so-called CSMM-based shell element, was developed based on the Cyclic Softened Membrane Model [3] and the formulation of an 8-node Serendipity curved shell element [4] with a multi-layer approach [5]. The UH simulated seismic behavior was close to the NCREE experimental results. This paper presents the theoretical development of the FEA program SCS and the comparisons of its predictions with the experimental structural behavior of the two RC containment specimens. This simulation model and the FEA program are excellent tools to develop effective performance-based design provisions.


ABSTRACT: A nonlinear axisymmetric simulation of axially loaded ultra-high strength circular short Concrete-Filled Steel Tubular (CFST) columns is reported in this paper. An efficient material law of Ultra-High Strength Concrete (UHSC) is employed in this axisymmetric simulation to consider the confining effects which increase the ultimate strain, stress and axial ductility. The peak loads and load-strain responses of short CFST columns predicted by the axisymmetric model are verified with the independent test data and those predicted by
the three-dimensional (3D) model. The structural characteristics of circular short CFST columns having different material and geometric parameters are subsequently examined by the axisymmetric analysis. The numerical results indicate that the column size can approximately be reduced by 50% when UHSC is used in the composite construction instead of Normal Strength Concrete (NSC). Comparisons of the current test data are made with the current structural codes including AS/NZS 5100.6, Eurocode 4, AISC and GB 50936. The comparisons demonstrate that the Australian/New Zealand and European design codes provide consistent predictions for the ultimate axial strengths of ultra-high strength circular short CFST columns. On the other hand, the North American design code is conservative, whereas the Chinese code is unconservative.


ABSTRACT: The problem of elastic stability of the shells with special shapes with corrugated middle surfaces under external pressure is debated in the presented paper. Solution of the problem is based on FEM study. Corrugated barrelled, pseudo-barrelled, and cylindrical shells of constant mass are considered. Geometrical modification of the middle surface geometry is based on sine wave along principal directions. Middle surface of the corrugated shells are described referring to differential geometry of surfaces by parametric functions in three-dimensional Euclidean space. Linear and nonlinear buckling analyses are conducted. Examples of buckling modes are presented, which differ significantly from those typical for shells of revolution with positive or zero Gaussian curvature. It is proven that corrugation may lead to serious increase or decrease of critical load for all types of presented shells.


ABSTRACT: Steel tube and sandwiched concrete jacketing has been proved to be effective in improving the load-bearing capacity and ductility of deficient reinforced concrete (RC) stub columns. However, the effectiveness of this technique for slender RC columns remains to be validated due to instability problems. In this study, nine slender specimens, including one reference column and eight retrofitted columns, were tested under axial compression. The experimental results showed that the load-bearing capacity, stiffness and ductility of the slender RC square columns were significantly enhanced. The load enhancement was not only attributed to section enlargement, but also due to the confinement provided by the steel tube. Based on the experimental results, a finite element (FE) model was developed to simulate the structural response of the retrofitted slender columns under axial load. The FE results demonstrated that the sandwiched concrete shared a higher load than the steel tube for the cross-section of this paper, justifying the use of “steel tube and sandwiched concrete jacketing”. Moreover, the confinement effects on the load-bearing capacity of the RC part and the sandwiched concrete part were quantitatively analyzed. A modified formula was subsequently proposed to predict the load-bearing capacity of the retrofitted columns, the results of which agreed well with the experimental and FE results.


ABSTRACT: This paper, based on new proposed approaches, is a numerical investigation of the behavior of thin-walled cold-formed steel built-up columns under a uniform compression. Two types of cross sections have been studied, built-up closed and open sections formed by two channels connected by battens plates. First, a nonlinear finite element model has been developed and the results obtained show a good agreement against experimental results, such as the ultimate strength, the type of deformed shapes at failure and the lateral displacement. Second, a new proposed approach based on the DSM approach where the local, distortional or global buckling has been obtained numerically, using finite element method software, the thickness at the contact area in the web is taken as 1.0 times the thickness of the plate “t”, instead of 1.5 or 2.0 times “t”. In this case, the compound section is acting as one rigidly connected section. Comparisons with experimental data give a satisfactory degree of accuracy in the proposed design method (DSM-t) and the results are more conservative than those found by the DSM-1.5 and DSM-2. The results, for either closed or open sections, are also slightly conservative for columns failing in global modes than in local ones, if compared with the AISI and EC3
sudden stress reduction or stress fluctuations can be observed for the UHPFRC in hybrid DSTCs. The brittle behavior than the hybrid UHPFRC DSTCs are likely to exhibit more strength and the dense microstructure of UHPFRC, the hybrid UHPFRC DSTCs are expected to exhibit more highly ductile behavior when a thick FRP tube is used. However, due to the ultra-high performance fiber-reinforced polymer (FRP) tube thickness, steel tube thickness, void ratio, steel fiber addition, concrete type, UHPFRC-filling inside the steel tube, and the column type. The test results indicate that the hybrid UHPFRC DSTCs can exhibit highly ductile behavior when a thick FRP tube is used. However, due to the ultra-high strength and the dense microstructure of UHPFRC, the hybrid UHPFRC DSTCs are likely to exhibit more brittle behavior than the hybrid DSTCs with NSC and HSC. Even though a high confinement level is provided, sudden stress reduction or stress fluctuations can be observed for the UHPFRC in hybrid DSTCs. The specification. Some parameters, such as the spacing channels-web length ratio (B1/D) influence the stability and strength of the built-up columns.  

ABSTRACT: Elevated temperatures significantly reduce the local buckling strengths of steel tubes and the ultimate strengths of rectangular concrete-filled steel tubular (CFST) columns exposed to fire. No fiber-based models have been developed that include local buckling effects on the fire-resistance predictions of axially loaded rectangular CFST short columns at elevated temperatures considering local buckling. The thermal analysis problem of a CFST column is solved by the finite difference method to determine the temperature distribution within its cross-section including an air gap, concrete moisture content and the emissivity of exposure surfaces. The nonlinear stress analysis of axially loaded short CFST columns under fire recognizes the stress-strain behavior of concrete and steel at elevated temperatures. The expressions for initial local buckling and effective widths of steel plates are incorporated in the computational model to include the effects of local and post-local buckling on the fire responses of CFST columns. The existing experimental and numerical results are utilized to examine the accuracy of the fiber-based model. The fiber model developed is used to undertake parametric studies on the effects of local buckling, geometric and material properties and loading ratio on the thermal and structural responses of CFST short columns and the load distribution in steel tube and concrete. The numerical model proposed is demonstrated to simulate well the fire and structural performance of axially loaded CFST short columns under fire. Moreover, computational solutions presented provide a better understanding of the thermal and structural responses of CFST columns in fire.  

ABSTRACT: Novel designs of wind turbine blades may lead to very flexible structures experiencing large deformation not only in extreme events but also on operational conditions. In this context, this work aims to compare two geometrically nonlinear structural modeling approaches that handle large deformation of blade structures: 3D geometrically-exact beam and shell finite element models. Specifically, the focus is on studying the accuracy limits of the beam model when compared to the shell model in scenarios of large deformations. Regarding the beam model, due to geometric complexity of typical cross-sections of wind turbine blades, a theory is adopted that allows for the creation of arbitrary multicellular cross-sections. Two simplified blade geometries are considered, and comparisons between the models are made in statics and dynamics. Results showed that the beam and shell models present very similar global behavior. Locally, however, extreme load cases led shell models to show local buckling phenomena close to the trailing edge, which may play a role in novel HAWT designs.  

ABSTRACT: This study presents the results of an experimental program on the compressive behavior of hybrid fiber-reinforced polymer (FRP)-concrete double-skin tubular columns (DSTCs) with ultra-high performance fiber-reinforced concrete (UHPFRC). In total 40 specimens, including 32 hybrid DSTCs and eight FRP-confined solid concrete (FCSC) specimens, were prepared and tested under axial compression. In addition to hybrid UHPFRC DSTCs, hybrid DSTCs with ultra-high performance concrete without steel fiber addition (UHPC), high-strength concrete (HSC), and normal-strength concrete (NSC) were also tested. The investigated parameters included the FRP tube thickness, steel tube thickness, void ratio, steel fiber addition, concrete type, UHPFRC-filling inside the steel tube, and the column type. The test results indicate that the hybrid UHPFRC DSTCs can exhibit highly ductile behavior when a thick FRP tube is used. However, due to the ultra-high strength and the dense microstructure of UHPFRC, the hybrid UHPFRC DSTCs are likely to exhibit more brittle behavior than the hybrid DSTCs with NSC and HSC. Even though a high confinement level is provided, sudden stress reduction or stress fluctuations can be observed for the UHPFRC in hybrid DSTCs. The
influences of FRP tube thickness, void ratio, steel fiber addition, and UHPFRC-filling inside the steel tube on the compressive behavior of the hybrid UHPFRC DSTCs are significant, while the influence of steel tube thickness is insignificant. Moreover, when compared to the FCSC specimens, the presence of an inner void is beneficial for the compressive behavior of UHPFRC in the hybrid DSTCs, especially when a thick FRP tube is used. Furthermore, the performance of existing stress-strain model to predict the compressive behavior of UHPFRC in the hybrid DSTCs is investigated.


ABSTRACT: A promising type of hysteretic damper used for seismic energy dissipation consists of a steel plate with cutouts leaving butterfly-shaped links that undergo flexural yielding when the plate is subjected to shear deformations. Butterfly-shaped links, which have linearly varying width between larger ends and a smaller middle section, have been shown in previous research to possess substantial ductility and stable energy dissipation capability, but can be prone to other limit states such as lateral torsional buckling (LTB) or shear yielding.

The current work examines the three potential limit states of LTB, flexural yielding and shear yielding, and develops methods to predict which limit state will control along with the associated strength. First, the governing differential equation for elastic LTB of a butterfly-shaped link is formulated and a relatively simple equation is developed to predict the critical shear force associated with elastic LTB. The shear yielding and flexural yielding limit states are then described and equations are presented to predict the associated shear strength of the butterfly-shaped links. The accuracy of the equations is then evaluated against a series of finite element (FE) models that are validated against previous experiments.

It was found that butterfly-shaped links that are thick enough to prevent lateral torsional buckling, experience a progression of limit states including: (1) yielding in one mode (flexural or shear), (2) geometric hardening associated with increasing tension forces in the links, and (3) further yielding associated with biaxial stresses. The equation developed for lateral torsional buckling produced an average LTB strength that was within 4% of the FE model results and the equations for flexural yielding and shear yielding predicted the strength of the FE models within 3% on average.


ABSTRACT: This paper presents an experimental investigation on concrete-filled steel tubular beam-columns with octagonal cross-sections (OCFST) under cyclic lateral loading with or without axial load. A total of nine specimens with different parameters, including the axial load level (n) ranging from 0 to 0.5 and concrete compressive cylinder strength ($f'_c$) varying from 30 MPa to 90 MPa, were tested. The failure modes, ultimate strengths, displacement ductility, effective flexural stiffness and cumulative dissipated energy are presented. The results indicate that OCFST beam-columns exhibit a ductile plastic mode and excellent energy dissipation. With the increase of axial load level, the ductility and the energy dissipation capacity decreases, while the ultimate bending capacity firstly increases then drops. Concrete grades seem to have limited influence on the ultimate strength and energy dissipation capacity. The comparison results of the ultimate bending moments and effective flexural stiffness between predictions using EN 1994-1-1 and AISC 360-16 and test results reveal their applicability to the design of OCFST beam-columns.


ABSTRACT: This paper proposes an innovative use of corrugated steel plates as the webs of the crossbeam in the tower of a suspension bridge to get better seismic performance. Three 1/4-scaled models of composite beam with corrugated steel webs considering different shear-span ratio were fabricated to conduct quasi-static test. The structural behaviors including failure modes, hysteretic curves, ductility, strength and stiffness degradation, energy dissipation capacity, deformation recovery ability, shear force distribution and strain responses were
investigated. Test results indicate that the specimen with large shear-span ratio presents ductile flexural failure, and the hysteretic curve is stable and plump with slight pinching, which indicates good energy dissipation performance. However, the specimen with small shear-span ratio fails due to brittle shear buckling of corrugated steel web, showing remarkable pinching phenomenon and poor hysteretic behavior. With the increase of shear-span ratio, the load-carrying capacity and lateral initial stiffness are reduced, but the ductility and energy dissipation ability are improved significantly. The energy dissipation capacity of such composite beam is better than that of the RC structures, the strength degradation is slight for the specimen with a proper shear-span ratio, and the deformation recovery ability is good for all test specimens. The corrugated steel web carries about 80% of the shear force and shear stress uniformly distributed along the web height. The test results demonstrate that the composite beam with corrugated steel web of a reasonable shear-span ratio can be applied in anti-seismic structure with superior energy dissipation performance. In addition, simplified formulas were proposed to evaluate the flexural strength and shear buckling strength of a composite beam with corrugated steel webs, the calculated results agree well with the test results, verifying the accuracy of these proposed formulas.

ABSTRACT: This paper focuses on a new type of precast sandwich wall panels in which the expanded polystyrene (known as EPS) insulation layers are inserted between exterior reinforced concrete panels. The exterior reinforced concrete panels are held through diagonal steel bars to allow the sandwich panel to form the composite action to resist the bending moment demands. To investigate flexural behavior of the sandwich wall panels, four specimens with representative geometries and typical materials were designed. The four specimens included one with the flat exterior reinforced concrete panels and three with the ribbed exterior reinforced concrete panels. The specimens were tested using gradually increased uniformly distributed loads. It is found that all the specimens developed the composite action when resisting the bending moment demands and exhibited the same failure mode. Test results show that the specimens consisting of the ribbed exterior reinforced concrete panels (which had lower mass per unit volume) exhibited reduced flexural resistances at the cracking limit state and the ultimate limit state in comparison with the one with flat exterior reinforced concrete panels. This paper develops a set of analytical models based on the test data and simplified strain/stress diagrams for analyzing flexural behavior of the proposed sandwich wall panel. Result comparisons show that the models can provide reasonable predictions and they can be used for future practice.

ABSTRACT: A method that evaluates the static, stability and vibration behavior of non-prismatic Euler-Bernoulli straight beam-columns resting on a two-parameter elastic foundation with generalized end conditions is presented. The static stiffness matrix and shape functions of the element are derived including the combined effects of semi-rigid connections and lateral springs at both ends using the conjugate beam principle. The fixity factors of a non-prismatic element are defined and used in the definition of its characteristic matrices according to the consistent method. It is shown that static, stability and vibration analysis of non-prismatic beam-columns under any transverse loading and axial end loads with generalized end conditions can be carried out once the main flexibility coefficients of the member are determined. Three comprehensive examples are presented that show the simplicity and accuracy of the proposed method. The calculated results using the proposed approach are compared to those available in the technical literature.

ABSTRACT: A novel rotation-free isogeometric formulation of in-plane dynamic analysis of an arbitrarily curved Bernoulli-Euler beam in the convective frame of reference is presented. The driving force behind the present study has been the development of the NURBS-based element which enables an elegant framework of in-plane vibrations of arbitrarily curved Bernoulli-Euler beams, being a function only of the global Cartesian
coordinates. Due to the fact that no additional simplifications are made, besides those related to the classic Bernoulli-Euler hypothesis and small strain theory, the formulation is particularly applicable for problems regarding the behavior of strongly curved beams.

An excellent agreement of the results is accomplished and efficiency for academic and practical use are shown. The influence of the product of the maximum curvature and the thickness of the beam on the accuracy of the solution is specially treated and debated. The effects of the hpk-refinements are thoroughly checked and a highly nonlinear convergence behavior under the h-refinement is noticed. The well-known fact that models with the highest interelement continuities return superior accuracy per degree of freedom is substantiated by an in-depth numerical analysis of order of convergence. Furthermore, the accuracy of the developed model is analyzed utilizing normalized numerical discrete spectrums. It is remarked that the accuracy per degree of freedom degrades with the complexity of reference geometry of the beam.


ABSTRACT: This paper presents an experimental and numerical study on the global buckling behaviour of doubly-symmetric Q460GJ steel beams under three-point bending. A total of eight simply-supported beams with different slendernesses and height-to-width ratios were tested in the experimental programme. To achieve the required loading and boundary conditions, a special loading system was designed for the beams so that the vertical load applied at the mid-span through a hydraulic jack could move with the beams in the lateral direction, and a set of steel rollers was placed in the supports. All eight beams failed in lateral-torsional buckling. Finite element models were also developed for the beams, in which initial geometric imperfections and residual stresses were considered. The model was validated against experimental results, and a reasonably good agreement was obtained. A series of parametric study was carried out to gain a deep understanding of the effects of slenderness and height-to-width ratio on buckling factor. Comparisons were made between numerical data and calculated values in accordance with different national codes.


ABSTRACT: Current methods adopted by the Chinese Codes for calculating the external extreme wind pressure distribution on large cooling tower structures may result in an uneconomical structural design. Similar situation might hold true for other international standards, e.g., the German Code VGB-R 610Ue and the British Code BS4485. It is important therefore to accurately calculate the external extreme wind pressure distribution to ensure the suitable structural design of these large structures. However, two issues currently exist which hinder the calculation of accurate wind pressure distributions: (1) although wind pressure samples on tower surfaces are often found to be non-Gaussian features, limited peak factor calculation methods have been deemed to be applicable to non-Gaussian samples; and (2) the effects of free-stream turbulence on wind loads on large cooling towers are generally significant, which possibly further leads to a significant influence on the extreme wind pressure distributions obtained. In light of these issues, the applicability of the Sadek-Simiu method to non-Gaussian wind pressure samples is validated in this study and, based on quantifiable data, the limited influence of the turbulence intensity on the external extreme wind pressure distribution is also observed. With these findings, the external extreme wind pressure distribution on large cooling tower structures is calculated by averaging distributions around different horizontal sections obtained using the Sadek-Simiu method. Finally, the accuracy of the obtained external extreme wind pressure distribution is validated using full-scale measurement results. The obtained external extreme wind pressure distribution is formulated in this study which will facilitate the future improvements of the Chinese Codes and the German Code VGB-R 610Ue.

ABSTRACT: The geometry of shell structures plays an essential role in their capacity to withstand earthquakes. However, seismic loading is rarely considered when determining the overall geometry of shells. This paper presents a novel form finding methodology for the conceptual seismic design of corrugated shells. The method ensures that a compression load path exists to carry lateral earthquake accelerations by deriving shell geometries from a series of funicular polygons obtained through a graphic statics procedure for combined gravity and horizontal loads. While the method can be applied to any material that resists compressive stresses, it is employed in this paper to find the shapes of corrugated thin-tile masonry shells. Non-linear pushover analysis is then used to quantify lateral capacity and evaluate form finding results in terms of material efficiency to resist lateral loads. The analysis furthermore provides insights regarding the collapse mechanisms and flow of forces. It is demonstrated that the lateral capacity before cracking in the corrugated shell shapes is up to 79% higher than the capacity of a non-form-found reference shell shapes considering identical material use. All form-found shells were found to fail through a similar collapse mechanism which is defined by four crack zones. The location of these crack zones can be manipulated through the form finding process and identify the locations where reinforcement could be most efficiently introduced. Finally, the flow of forces within the form-found shells is used to propose alternative designs that provide additional openings in the shell surface while maintaining similar seismic capacity. Thus, the paper provides a new approach for the conceptual design of safe corrugated shell structures in earthquake prone areas.


ABSTRACT: This paper reports findings of an experimental study on floor trusses fabricated from cold-formed steel lipped channel sections. In design, the members of these trusses are generally considered as pin-ended and their capacities are assessed under pure compressive and tensile loads by making use of commonly accepted design specifications. Seventeen full-scale floor trusses were experimentally investigated through four point bending tests. Thickness of lipped channels, number of connection fasteners, and type of diagonal connection were considered as the prime variables. Test results indicate that there are marked differences between the design and measured values in terms of both the strength and stiffness. The service load stiffnesses of the trusses were found to be lower than the stiffnesses obtained using two dimensional truss models due to the neglect of connection flexibility in analysis models. Additional experiments on screw connections were conducted to find out their axial stiffness. The results from connection tests were used to develop analytical expressions which can be used to simulate connection flexibility. Similar to the stiffness, the strength of the trusses were found to be lower than the predicted strength using the pin-ended member under compression approach. In addition, the observed failure modes are markedly different than the code predictions. The sources of these differences were found to arise from the unfolding of lips at the diagonal to chord member connections and the global bending effects. The strength and failure mode of trusses can be more accurately predicted by considering local buckling of channel sections with unfolded lips.


ABSTRACT: The steel-concrete-steel (SCS) sandwich structure has been proposed for containment buildings in third-generation nuclear power plants. In this paper, 27 static tests on SCS sandwich beams (by the authors and others) are adopted serially to summarize the failure modes and explore the failure mechanisms of SCS sandwich beams with different bond-slip conditions between the steel plate and concrete. Further, a three-dimensional finite element (FE) model is developed to simulate the ultimate strength of SCS sandwich beams under different failure modes. The accuracy of the developed FE model in predicting ultimate strength, cracking behaviours and bond-slip behaviours is verified by static tests. Based on the validated FE model, 65 numerical cases are calculated to investigate the effects of analytical parameters on the failure mechanism and ultimate
strength of SCS sandwich beams under different bond-slip conditions. The analytical parameters include the steel plate ratio, shear span to depth ratio, spacing of shear studs and shear reinforcement ratio. In addition, theoretical models are proposed to predict the ultimate strength of SCS sandwich beams under different bond-slip conditions. The accuracy of the theoretical model is verified by comparison with current design codes for SCS sandwich beams.


ABSTRACT: This paper presents an experimental investigation carried out to understand the behavior of reinforced concrete sandwiched panels (RCSPs) under blast load. An RCSP is composed of an EPS (Expanded Polystyrene) foam core, which is surrounded by spray-on reinforced concrete skins (like ferrocement overlay) on both sides. For this purpose blast load test on four free-standing RCSPs in 17 blast case scenarios were conducted and the physical behavior was analyzed through high quality visuals and fragility curves were developed. The fragility curve interprets the relationship between damage intensity with charge size and scaled of distance. On the basis of results it is concluded that RCSP panel has greater capability of absorbing and dissipating energy generated by blast, and stable against fragmentation as compared to other conventional building systems used in Pakistan. Based on the assessment RCSPs walls/panels are strongly recommended for protective barrier installed in the vicinity of critical infrastructure against blast loading.


ABSTRACT: There are a growing number of bridge fire events and the National Fire Protection Association (NFPA) requires that critical structural elements of the bridge be protected from elevated temperatures due to fire. However, no guidance is given on how to protect these critical elements, nor how to identify them. Further, slender steel web plates have been shown to be vulnerable to shear buckling in fire events and recent research that indicates that the load path of shear forces in thin web plates is not well understood. The overall objective of this paper is to examine the effectiveness of stiffeners for enhancing the shear capacity of slender plates at ambient and elevated temperatures. Specifically, evaluations are made regarding the effectiveness of stiffeners for increasing the shear buckling capacity through various stiffener orientations, providing lateral restraint, and providing a load path for shear forces. In particular, the elastic shear buckling load, \( V_u \), and the ultimate shear postbuckling load, \( V_c \), of the steel plate are examined. Finite element analyses, which have been validated with experimental data, are used as a basis for the study. The temperatures studied range from ambient to 1100 °C. This study provides some important insights on the behavior of plates under shear loads. For example, results indicate that the stiffener’s role is not that of a load path for the shear forces, but one of lateral restraint, regardless of its geometric orientation. Further, it is shown that for lower temperatures a stiffener oriented along the compression diagonal (opposite to a tension field) provides the most improvement in postbuckling strength.


ABSTRACT: The composite box girder bridge with corrugated steel webs and trusses is a recently proposed enhanced composite box girder bridge structure. The shear-lag effect of this kind of structure is studied in detail in this research. Two 8.744 m-long test beams with and without concrete filled in the bottom steel tubes were constructed and tested. The non-uniform distribution of cross-sectional stress in the top concrete slab was captured. The filling of concrete inside the bottom steel tubes is shown not to have a great influence on the shear-lag effect. Numerical parametric studies were carried out to study the influence of various factors on the shear-lag effect of this kind of structure. The numerical results indicate that the magnitude of the shear-lag effect increases with the width-to-span ratio and the suspension ratio. Analytical equations were derived to calculate the shear-lag coefficient for composite box girders with corrugated steel webs and trusses based on the
energy variational principle. The experimental and numerical validation indicates that the proposed equations can be well applied in engineering practice.


ABSTRACT: Concrete-filled double-skin FRP tubes (CFDST) are increasingly attracting researchers’ interests due to the advantages of their reduced self-weight and higher bending stiffness than fully filled tubes. However, the structural behaviour of CFDST, especially the non-uniform confinement in annular concrete, has not ever been well addressed. This paper presents an analytic study on axial compressed circular stub CFDST with FRP wrap/tube as outer tube and steel/FRP as inner tube. Based on existing studies on actively confined concrete, a constitutive model for non-uniformly FRP-confined concrete is developed in this paper. The dilation model for concrete fully filled FRP tubes is modified to account for the effects of void ratio so that the hoop-axial strain curve of CFDST could be reasonably predicted. Behaviours of steel and FRP tubes in CFDST are investigated and proper stress-strain models are proposed to estimate the loads shared by tubes. The stress state in annular concrete is theoretically studied by dividing the cross-section into multiple circular layers. Finally, an analysis-oriented load-strain model, which accounts for the non-uniform confinement, effects of void ratio, buckling of FRP tube, and strain hardening of stainless steel, is proposed for CFDST. As validated by the experimental data from a wide range of literature, the proposed model is reasonable and of high accuracy.


ABSTRACT: The main objective of this paper is to analyze the free vibration of arbitrary shaped thick functionally graded carbon nanotube-reinforced composite (FG-CNTRC) plates based on the higher-order shear deformation theory (HSDT) using a variational differential quadrature approach. By means of the generalized differential quadrature (GDQ) numerical operators and Hamilton’s principle, the discretized equations of motion are obtained. In order to use the GDQ differential and integral operators appropriately, the coordinate transformation is considered through the conventional finite element approach for transforming the irregular domain of the plate into the regular computational one. Employing a unified numerical approach to analyze different shapes of thick FG-CNTRC plates based on HSDT is the main novel aspect of the present study. To imply the accuracy of the present model, a wide range of comparison studies are presented. The results indicate the efficiency of the developed numerical methodology to study the vibration of arbitrary shaped thick FG-CNTRC plates. Several results are also given to investigate the impacts of geometrical parameters and material properties on the vibrational behavior of FG-CNTRC plates.


ABSTRACT: In this paper, the crush behaviour and energy absorption performance of nested tubular thin-walled structures made of aluminium alloy AA6061-O under dynamic axial loading are investigated. Theoretical solutions for Average Crush Force (O of these structures are proposed by combining the energy method, simple superposition principle, and interaction among the various components of the structures. The derived theoretical models are verified by comparing their predictions with numerical and experimental values. The energy absorption indicators of the various structures are calculated and used to compare the various structures and to determine the best performing one. It is found that the nested structure with a higher number of tubes exhibits the best crashworthiness performance due to energy absorption enhancements resulted from the interaction effects between its components as well as its capability to reduce the peak crush force.

Ziangying Guo, Yang Zhang, Wei Zhang and Lin Sun (primarily from: Beijing Key Laboratory of Nonlinear Vibrations and Strength of Mechanical Structures, College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, China), “Theoretical and experimental investigation on the nonlinear vibration

ABSTRACT: As one of the classical complex multibody structures, Z-shaped folded plates are widely applied in several engineering structures. In the present paper, the nonlinear vibration characteristics of a Z-shaped folded plate composed of three carbon-fiber composite plates were analyzed through theoretical and experimental investigation. The nonlinear dynamic model of the Z-shaped plate was developed based on the Hamilton principle, von Kármán equations, and the classical laminate plate theory, and the vibration mode shape functions of the system were calculated in ANSYS. Further, the Galerkin approach was employed to discretize the partial differential equations into a two-degrees-of-freedom nonlinear system, and the effects of transverse excitations on the nonlinear dynamic behavior of the Z-shaped folded plate were investigated through a comprehensive numerical simulation. Moreover, the obtained theoretical results were verified by experimental analysis. In addition, the vibration mode shapes of the Z-shaped folded plate were obtained by operational modal analysis (OMA). The modal parameters were first identified successfully using the PolyMAX method and then validated by modal assurance criterion (MAC). Finally, an excitation-measurement test was designed to measure the nonlinear vibration characteristics of the Z-shaped folded plate.


ABSTRACT: A new analytical approach for bending response of functionally graded single-walled carbon nanotube (FGCNT) reinforced plate resting on double-layered elastic foundations in thermal environments is presented based on Levy and Navier types solutions. The distribution of the carbon nanotubes is varied through the plate thickness in accordance with a modified power law. Four types of carbon nanotube distributions are considered. The four edges of the plate are simply supported for Navier method, whereas for Levy method, two opposite only of them are simply supported and the other ones are arbitrary. The present FGCNT plate is subjected to uniform, linear, sinusoidal or exponential distributed loadings. A refined shear deformation plate theory with four unknown functions is employed to obtain the closed form solution. The four coupled governing partial differential equations are derived utilizing Hamilton’s principle. Applying Levy solution and then the state space concept to the governing equations, a nonhomogeneous first-order linear ordinary differential system with constant coefficients is obtained. The solution of the homogeneous system (homogeneous solution) is obtained by using the matrix method. While, the method of undetermined coefficients is applied to find the particular solution of the nonhomogeneous linear system. The results obtained by Navier and Levy methods are compared with available results in the literature. Several examples are discussed for various values of the foundation stiffness, CNT volume fraction, various types of plate geometries, CNT distributions, external applied loads and boundary conditions.


ABSTRACT: Lattice towers and guyed masts are frequently used in the telecommunication industry, particularly to support antennas. These structural systems comprise a large number of elements (mainly, legs and diagonals) and for this reason, their representation by equivalent models is quite common and convenient. In a previous study, the authors derived a continuous model of a spatial lattice governed by nine differential equations (9DE). The legs trace forms a triangle and the diagonals with a zig-zag pattern are contained in three planes that join each two legs, defined as Pattern 1. Here and starting from an energy statement, the structural behavior of a 1D continuous model governed by six differential equations (6DE) which leads to a simpler representation of the lattice structure, is stated. This formulation considers the shear flexibility and the second order effect due to axial loads. Also, the inertial forces due to the legs and diagonals masses are taken into account. Numerical examples dealing with deflections, critical buckling loads and natural frequencies are solved with this 1D model. The results are compared with the outcomes found with finite element methods. A very good performance is attained with the proposed model. Finally, the equivalent properties for other patterns...
of diagonalization (Patterns 2, 3 and 4) different to the studied as well as the formulas to find the critical loads are included in Appendices.

Jiantao Wang, Qing Sun and Junxin Li (Department of Civil Engineering, Xi’an Jiaotong University, Xi’an, Shaanxi Province 710049, PR China), “Experimental study on seismic behavior of high-strength circular concrete-filled thin-walled steel tubular columns”, Engineering Structures, Vol. 182, pp 403-415, 1 March 2019, https://doi.org/10.1016/j.engstruct.2018.12.098

ABSTRACT: This paper presents the results of an experimental study on the seismic behavior of high-strength circular concrete-filled thin-walled steel tubular (HCFTST) columns with ultra-large diameter-to-thickness ($D/t$) ratios exceeding the limitations of the current construction standards. Sixteen HCFTST columns with different combinations of $D/t$ ratio, concrete cylinder compressive strength ($f_c$), and axial compression ratio ($n$) were tested under constant axial compression combined with cyclic lateral loading. The ultimate failure state was achieved when the steel tubes ruptured severely and core concrete crushing occurred. The results from hysteretic curves indicated that the HCFTST columns with ultra-large $D/t$ ratios displayed flexural failure and shear failure modes. Subsequently, the skeleton curve, ductility, energy dissipation capacity, and stiffness degradation were discussed in detail. Moreover, the effects of $D/t$ ratio, concrete cylinder compressive strength and axial compression ratio on performance were investigated so that this work could serve as a basic reference to future studies, and a strength model was proposed to predict the moment-resisting capacity. The experimental investigation indicated that (i) using high-strength Q690 steel could significantly contribute to a larger elastoplastic deformation capacity and delay the onset of post-peak behavior, even though a lower ductility capacity was provided; (ii) the proposed strength model could satisfactorily predict the moment-resisting capacity; (iii) the out-of-code HCFTST columns with reasonable design could demonstrate favorable seismic behavior and could be accepted as aseismic components in earthquake-prone regions.


ABSTRACT: Free and forced vibration and static analysis of corrugated-core sandwich plates are investigated in this study by employing the classic finite strip method. The 3D corrugated-core plate is converted to a 2D orthotropic continuum model by considering some equivalent elastic constants. Various boundary conditions and different features of these plates are explored and the geometric and mechanical factors influencing their responses, such as displacements, rotations, moments and shear forces, are evaluated. Because of the significant effect of the shear stiffness on the behavior of corrugated-core sandwich plates, the first order shear deformation theory (FSDT) is used to analyze the plate. Due to the comparatively low shear to flexural stiffness ratio of these plates compared to ordinary plates, the convergence of the results is relatively slow. Therefore, a fast numerical technique such as finite strip method which yields effective reduction of calculation cost is employed. A MATLAB program is developed to obtain the results and the validity of the proposed method is evaluated by comparing the results with those presented by previous researches.


ABSTRACT: The use of concrete-filled stainless steel tubular (CFSSST) members is relatively innovative and new. CFSSST columns can be used for bridge piers, multi-story buildings and other supporting structures. However, a common mode of failure with these type of tubular composite columns is inelastic outward local buckling occurring at the column ends. Therefore, this paper presents the results of experimental, numerical and analytical investigations into the behavior of circular CFSSST columns strengthened by carbon fiber reinforced polymer (CFRP) wrap and subjected to axial compression loading. The experimental investigation comprised three series of tests. The main variables tested were the diameter to thickness ratio of the stainless steel tube and the thickness of the CFRP wrap. 3D finite element models (FEMs) were developed for CFRP-wrapped CFSSST columns using the ABAQUS software and were validated with experimental results. An extensive parametric study was carried out by using the validated FEMs. It was shown from the experimental and FEMs results that
CFRP jacketing was highly effective in improving the axial load carrying capacity and axial shortening capacity of the CFSST columns. Finally, an analytical model based on the FE parametric study results was proposed to predict the axial load carrying capacity of the CFRP-wrapped CFSST columns.


ABSTRACT: This paper presents an advanced finite element analysis (FEA) model to predict the fire behaviour of concrete-encased concrete-filled steel tube (CSFT) columns. The sequentially coupled thermal-stress analysis method provided in the software package ABAQUS was used. Full-range fire simulation given in this paper included four phases, i.e. loading (to a certain load level) at ambient temperature, standard fire exposure (heating) with the load applied, cooling down phase and postfire loading up to final failure. Calibrated empirical models for steel tube, unconfined and confined concrete (confined by steel tube and by reinforcement, respectively) over the four phases were chosen separately and applied to the FEA model. Numerical results from the model were compared with previously reported results of the experiments on the concrete-encased CFST columns, in terms of ultimate strength at ambient temperature, temperature field, failure modes, fire resistance, axial deformation versus time relationships, load versus axial deformation relationships and postfire residual strength. It is found that acceptable agreement was reached between the predictions and experimental observations, although some aspects could be further improved. Sensitivity analyses on several identified parameters of the modelling were conducted. Recommendations on simulating the full range fire behaviour of concrete-encased CFST columns were proposed based on the numerical study presented in this paper. In addition, the calculated internal force of the tested specimens was extracted and analysed, which confirmed the design concept of the composite action of concrete-encased CFST columns in fire.


ABSTRACT: The pier is a vital structural component of bridges and thus critically considered in the seismic design. In order to provide an accurate and efficient methodology in the analysis of seismic response, a hysteretic model considering the effect of local buckling of steel plates is proposed for steel piers. In the hysteretic model, the Giuffre-Menegotto-Pinto hysteresis model is employed to establish the hysteresis curve equation, and the energy-based Ibarra-Krawinkler degradation rule is followed to describe the deterioration rule of structural bearing capacity and stiffness. In this study, a widely used Chinese steel Q345qC was taken as an example to illustrate the proposed model for steel piers. At first, the seismic performance of steel piers under horizontal cyclic load was analyzed. Then, the empirical formulae of the vital limit state points for evaluating the structural seismic performance were established, and further the identification of the decisive parameter (degradation parameter) of the hysteretic model was carried out. Moreover, the verification on the effectiveness of the proposed model was verified, and the results showed its applicability and accuracy for steel piers under horizontal cyclic loads. Finally, the application of the proposed model in the seismic calculation of steel piers was interpreted.


ABSTRACT: Use of composite construction is increasing exponentially across the world, since such structures offer the combined benefits of constituent materials and provide cost effective solutions. Concrete filled steel tube (CFST) columns have been proven to be a very efficient way of composite construction. Although the behaviour of CFST columns under many different loading scenarios has been well detailed, a search of the literature revealed few studies on the post-fire resistance of these members. This paper gives an account of internally ring stiffening of CFST columns with the aim of advancing their post-fire resistance. To this end, CFST columns with and without internal rings were subjected to a standard fire exposure. To address their post-
fire performance, fire exposed specimens and counterparts without fire exposure (in total 30 specimens) were tested under concentric compression to failure. CFST column specimens were manufactured using self-compacted high performance concrete to acquire key knowledge which could be exploited in highly stressed engineering structures. Experimental results indicate that with a proper design, internal rings are very efficient in providing high post-fire resistances. Some specific configurations achieved post-fire resistances greater than that of the capacities of classical CFST counterparts without fire exposure. Accordingly, it is shown that internal rings have the potential to eliminate the need for external coating or any other expensive fire protection measure to circumvent post-fire design concerns. The findings of this research provide novel insights and offer cost effective solutions to improve the performance of CFST columns under ambient temperature and after fire exposure.


ABSTRACT: Concrete-filled tubular (CFT) structures are exposed to increasingly complex environments with ever-broadening applications. Anticorrosion maintenance is generally difficult and expensive for established structures exposed to the air. Due to the superior corrosion resistance and the high lateral stiffness of the corrugated steel pipe (CSP), concrete-filled corrugated steel tube (CFCST) is proposed which has the similar working mechanism with the tube confined concrete columns. Such innovative composite member has advantages such as free of maintenance, ease of construction, high load-bearing capacity, good ductility and strong interlocking effect between CSP and concrete. In order to verify the load bearing reliability of concrete-filled corrugated steel tube (CFCST), twenty-one short columns including twelve CFCSTs were tested under axial compression. It was found that the CFCST is a tube confined concrete member and behaves slightly better than tubed-concrete columns. The strain and stress of CSP are discussed in detail to clarify the confinement effect. As well, solid nonlinear finite element models (FEM) were established to investigate the influence of key factors including geometries of CSP and strength of materials, which were summarized in the confinement index. Based on early studies on steel tube confined concrete and the parameter analysis in this paper, a suitable design method to predict the ultimate axial compressive load capacity for CFCST columns is proposed in this paper.


ABSTRACT: The steel tube-reinforced concrete (ST-RC) column is an innovative composite structure that has been increasingly applied in high-rise buildings and bridge piers in China. This study aims to investigate the axial capacity of the ST-RC stub column by means of a modified superposition method. Primarily, the sectional confining force equilibrium was elaborated to explain the confinement mechanism of the ST-RC column under concentric compression, which involves the confining stress induced from the inner steel tube and secondary confining stress induced from the peripheral steel hoops. Thereafter, a modified method for predicting the axial capacity of the ST-RC column, considering the secondary confinement, was developed according to a stress and strain analysis. Thirdly, 41 published specimens were collected to verify the accuracy of the proposed method. It was demonstrated that the current method fitted strongly with the tests results and exhibited satisfactory adaptability. Finally, four other methods according to ACI 318, AJI, EC 4, and CECS 188-2005 were verified in the same scenario. It was found that the current method exhibited superior correlation with the experimental results compared with conventional approaches. It will be favorable to obtain the viable axial capacity of the ST-RC column by using the presented solution.

ABSTRACT: Based on a nonparametric modelling approach, this paper presents a random vibration analysis of a subsea pipeline subjected to spatially varying ground motions. The earthquake-induced ground motions are modelled as nonstationary random processes and their spatial variations are considered. The modelling uncertainties of the subsea pipeline are taken into account using a random matrix theory, while the unilateral contact relationship between the pipeline and seabed is also considered. Thus, an uncertain computational model for the subsea pipeline subjected to a random earthquake is established, and the corresponding solutions are calculated using Monte Carlo simulation (MCS). In order to highlight the contribution of the unilateral contact effect to random responses of pipelines, comparative studies are performed between the unilateral and permanent contact models. In numerical examples, the possible convergence problems in the present computational model are firstly studied to determine the optimal numbers of reduced modes and MCS samples. Then influences of the randomness in the earthquake and modelling uncertainties in the pipeline are investigated qualitatively through three representative cases. The different propagations of randomness and modelling uncertainties in the unilateral and permanent models are also examined and discussed. It is concluded that the randomness of the earthquake and modelling uncertainties of the pipeline have significant influences on the statistical characteristics of earthquake responses of the pipeline.


ABSTRACT: Welded steel tubular structures are easily exposed to impact loading which may cause devastated damage firstly to their connecting joints. The critical joints determine the dynamic mechanical performance of the structures in those unexpected catastrophes. This paper describes an experimental and numerical impact investigation on dynamic behavior of CHS-SHS tubular T-joints, made up of a circular hollow section (CHS) brace and a square hollow section (SHS) chord. Seven CHS-SHS tubular T-joint specimens with different geometric and loading properties were tested on an in-house dropped hammer testing machine. The deformation mode of the joint specimens was identified as outward buckling of the chord side walls and indentation of the chord top surface. The experimental results indicated that increasing the geometric parameter \( \beta \) (the width ratio of the brace to chord) enhanced the impact resistance, increasing the impact velocity significantly affected the dynamic response, and changing the boundary condition had little effect on the dynamic performance of the joints. Six finite element (FE) models of the tested joint specimens were developed to simulate the dynamic behavior of the joints. The comparison of the impact force, displacement development, and deformation mode showed that the FE analysis was in good agreement with the experimental results. A parametric study was subsequently conducted to quantify the effects of the impact velocity, impact mass, and impact energy on the dynamic performance of the joints. The numerical results showed that the impact force, displacement, and energy dissipation were linearly dependent on the impact energy of the dropped hammer, and the impact duration of the impact process was directly correlated to the impact momentum.


ABSTRACT: The aim of this work is to analyse the influence of the nonlinear modal coupling and initial geometrical imperfection on the post-buckling path (perfect case) or nonlinear equilibrium path (imperfect case) of a simply supported, axially loaded cylindrical panel. The cylindrical panel is described by the Donnell nonlinear shallow shell theory and the lateral displacement field is based on a perturbation procedure, generating a precise low-dimensional model that satisfies out-of-plane boundary conditions and considers the forthcoming nonlinear modal coupling due to quadratic and cubic terms in a nonlinear equilibrium equation. The discretized equations of motion are determined by applying the standard Galerkin method. Various numerical techniques are employed to obtain the cylindrical panel’s nonlinear static equilibrium path with its structural stability analysis. The results show the influence of geometry on the nonlinear response of the cylindrical panel, unveiling an intricate competition between different types of bifurcation diagrams (stable symmetric, unsymmetrical, and unstable symmetric). Completing the presented results, the initial geometrical imperfection could change the stability of the initial nonlinear equilibrium path (from unstable to stable).
depending on the applied amplitude of the imperfection and its shape. It is possible to observe that the influence of the geometrical imperfection on the nonlinear equilibrium path of the imperfect cylindrical panel is determinant.

Z. Soltani, S.A. Hosseini Kordkheili and G. Kress (Center of Research and Development in Space Science and Technology, Aerospace Engineering Department, Sharif University of Technology, Azadi Avenue, P.O. Box: 11365-9567, Tehran, Iran and Laboratory of Composite Material and Adaptive Structures, Department of Mechanical and Process Engineering, ETH Zurich, Tannenstr. 3, CH-8092 Zürich, Switzerland), “Experimental and numerical study of geometrically nonlinear behavior of corrugated laminated composite shells using a nonlinear layer-wise shell FE formulation”, Engineering Structures, Vol. 184, pp 61-73, 1 April 2019, https://doi.org/10.1016/j.engstruct.2019.01.077

ABSTRACT: This paper presents experimental and numerical studies on the geometrically nonlinear behavior of corrugated laminated composite shells (CLCS) under quasi-static loading along the corrugated direction. A geometrically nonlinear layer-wise shell finite element formulation is adopted to study the behavior of CLCS under large deformation by modeling of incremental different moduli in the tensile and compressive regimes through the thickness, where the spatial location of neutral axis shifts with deformation. A master curve is presented to estimate the value of compressive modulus from given tensile and flexural moduli. Using the prepreg autoclave method, the paper also describes practical challenges in the manufacturing of CLCS and reveals significant influence of thickness on the nonlinear elastic behavior of two thin and moderately thick CLCS. The proprietary layer-wise shell FE formulation is verified with solid-finite-element modeling and employing a developed user material (USERMAT) subroutine in the commercial software ANSYS. Resulting improvements in numerical modelling are assessed in both general and local behaviors.

Lulu Zhang, Kang Hai Tan and Ou Zhao (School of Civil and Environmental Engineering, Nanyang Technological University, Singapore), “Experimental and numerical studies of fixed-ended cold-formed stainless steel equal-leg angle section columns”, Engineering Structures, Vol. 184, pp 134-144, 1 April 2019, https://doi.org/10.1016/j.engstruct.2019.01.083

ABSTRACT: The flexural-torsional buckling behaviour of fixed-ended cold-formed stainless steel equal-leg angle section columns was experimentally and numerically investigated in this paper. The testing programme was conducted on two press-braked austenitic stainless steel equal-leg angle sections, and involved material testing, initial imperfection measurements and sixteen fixed-ended column tests. The test setup and procedure, together with the key experimental results, load–mid-height torsional rotation histories and flexural-torsional buckling failure modes, were fully reported. Finite element models were then developed to simulate the fixed-ended cold-formed stainless steel equal-leg angle section column tests, and the numerical structural responses and failure modes were shown to match well with the corresponding experimental observations. The validated finite element models were then utilised to carry out parametric studies to generate an extensive pool of numerical data on fixed-ended cold-formed stainless steel equal-leg angle section columns susceptible to flexural-torsional buckling. The load-carrying capacities derived from both the experiments and FE modelling were compared with the resistance predictions from the established design standards in Europe, America, and Australia/New Zealand and a recently proposed direct strength method. The comparison results generally indicated that the existing design codes unduly underestimate the flexural-torsional buckling resistances of fixed-ended cold-formed stainless steel equal-leg angle section columns, while the direct strength method substantially improves the design accuracy on average, but with many overpredicted resistances, indicating that further improvements are generally required.


ABSTRACT: In this paper, the results of an experimental campaign on 9 concrete-filled round-ended steel tubular (CFRT) stub beam-columns subjected to eccentric loads are presented. Different levels of load eccentricity were considered including reference specimens subjected to concentric loads. In order to study the effect of the concrete infill strength in the ultimate capacity, two types of concrete infill were employed: normal and high strength concrete. In view of the experimental results, the dependency of the type of response on the
load eccentricity and strength of concrete infill of the beam-columns was analysed. In addition to the effect of the concrete infill, the result of the composite action and the level of ductility were also studied by means of different parameters. It was found that the cross-sectional capacity is inversely proportional to the load eccentricity and that, in addition, it is highly sensitive to the region within the cross-section where the load application point lies. The experimental ultimate loads of the specimens were compared with the corresponding failure loads given by Eurocode 4 as well as with the combined axial force-bending moment interaction curve. In this case, the comparison showed that for high load eccentricities, code predictions are too conservative. Finally, an approach based on an equivalent rectangular CFST cross-section is presented and applied to calculate the capacity of tested columns, obtaining accurate predictions.


ABSTRACT: The main aim of the present study is to investigate the effect of joint bending stiffness and initial crookedness of member on load-carrying capacity of double-layer grid with different member slenderness ratios. Firstly, a mechanical model of semi-rigidly jointed double-layer grid with initial crookedness of member is developed, followed by verification of two simple grid structures. Then, the influence of joint bending stiffness and random initial crookedness of member on load-carrying capacity of double-layer grid is systematically investigated. Finally, failure mechanism and destructive process of the double-layer grid are discussed. The results indicate that the load-carrying capacity of double-layer grid with initial crookedness of member is remarkably affected by joint bending stiffness, especially for double-layer grid with slender member. The limit load of double-layer grid markedly decreases when κ less than 1.5–2. The effect of initial crookedness of member on load-carrying capacity of double-layer grid has a close relationship with member slenderness ratio. With the increase of member slenderness ratio, the limit load reduction gradually increases. The distribution of random initial crookedness of member distinctly affects the limit load of double-layer grid, and some of them can observably reduce the limit load, especially for double-layer grid with large member slenderness ratio. The failure mode of imperfect double-layer grid is affected by distribution of initial crookedness of member and joint bending stiffness. The existence of random initial crookedness of member can aggravate P-Δ effect, and some compression members of double-layer grid lose their stability prematurely, which further leads to the instability of whole double-layer grid.


ABSTRACT: To investigate the flexural behaviors of cold-formed steel channel beams with web holes and assess the reliability of the current direct strength method (DSM) for design of cold-formed steel beams with web holes stipulated in North American Specification (NAS) (2016), ten groups of specimens with various sizes of web holes and lips were tested under four-point bending. Among them, each kind of specimens with short lips or long lips have five kinds of hole height-to-web depth ratios, 0, 0.2, 0.4, 0.6 and 0.8. It is shown that the web holes change the failure modes of beams from only distortional buckling or only local buckling to distortional-local buckling interaction controlled by distortional buckling or local-distortional buckling interaction controlled by local buckling. It is found that the moment capacities reduce slightly with a maximum reduction value of 7.0% when the ratio of hole height-to-web depth increases from 0 to 0.4, and that the moment capacities reduce dramatically with a maximum reduction value of 16.3% when the ratio of hole height-to-web depth further increases to 0.8. Moreover, ANSYS finite element (FE) program was used to simulate the beam tests, the simulation results show good agreement with the test results in terms of moment capacities and failure modes. Extensive ANSYS FE parametric analysis were carried out to verify the accurateness of critical elastic distortional buckling stress prediction method using CUFSM finite strip program and to modify the existed approximate prediction formulas of critical elastic local buckling stress applying to such beams with web holes. Furthermore, the test results and parametric analysis results were compared with the current DSM prediction results of cold-formed steel beams with web holes. It is found that the DSM in NAS (2016) provides unconservative predictions for most cold-formed steel channel beams with web holes,
ABSTRACT: Owing to the lack of a comprehensive published procedure for the design of stiffened extended shear tab connections under uniaxial compression, existing nonlinear models were benchmarked against available experimental results to evaluate their adequacy in predicting the nonlinear creep responses of CFST members. Experimental results indicated that nonlinear creep could lead to a 58–200% increase in the creep coefficient, in which case the linear creep model will underestimate the long-term deformation by 37–67%. Owing to the vertical stress redistribution between the concrete core and the steel tube and the confinement effects, no creep failure occurred during the 500-day tests, and the nonlinear creep barely influenced the cross-sectional capacity of the specimens. A model was recommended to predict the nonlinear creep deformation of CFST members.

Yue Geng, Jie Chen and Mu Zi Zhao (First author is from: Key Lab of Structures Dynamic Behaviour and Control (Harbin Institute of Technology), Ministry of Education, Heilongjiang, Harbin 150090, China), “Testing and analysis on nonlinear creep behaviour of concrete-filled steel tubes with circular cross-section”, Engineering Structures, Vol. 185, pp 26–46, 15 April 2019,
https://doi.org/10.1016/j.engstruct.2019.01.065

ABSTRACT: Owing to the excellent seismic resistance of circular concrete-filled steel tubes (CFST), no specific limitation on their in-service axial load level is provided in Chinese codes. Therefore, nonlinear creep could occur in Chinese CFST applications. This study intends to experimentally investigate the nonlinear creep behaviour and the creep failure behaviour of CFST columns. Fourteen specimens were subjected to sustained loading for 200–500 days. The sustained loading level ranged between 40% and 80% of the cross-sectional strength of the specimens. The strain state of steel tubes was monitored to determine how the confinement effects vary with time. Ultimate loading tests were finally conducted on all specimens immediately after the long-term tests to investigate the nonlinear creep effects on the cross-sectional capacity and ductility of the CFST specimens. A method was then proposed for the nonlinear creep analysis of circular CFST members with consideration of the beneficial contribution of confinement effects. Existing nonlinear models were benchmarked against available experimental results to evaluate their adequacy in predicting the nonlinear creep responses of CFST members. Experimental results indicated that nonlinear creep could lead to a 58–200% increase in the creep coefficient, in which case the linear creep model will underestimate the long-term deformation by 37–67%. Owing to the vertical stress redistribution between the concrete core and the steel tube and the confinement effects, no creep failure occurred during the 500-day tests, and the nonlinear creep barely influenced the cross-sectional capacity of the specimens. A model was recommended to predict the nonlinear creep deformation of CFST members.

Moattaieb Motallebi, Dimitrios G. Lignos and Colin A. Rogers (Primarily from: Department of Civil Engineering and Applied Mechanics, McGill University, Montreal, QC, Canada), “Full-scale testing of stiffened extended shear tab connections under combined axial and shear forces”, Engineering Structures, Vol. 185, pp 90-105, 15 April 2019,
https://doi.org/10.1016/j.engstruct.2019.01.125

ABSTRACT: In order to verify the creep results and the modified direct strength method formulas for cold-formed steel beams with web holes were proposed.


ABSTRACT: This paper presents an experimental investigation on the compression behaviour of cold-formed octagonal, circular and square tubular steel stub columns. Three octagonal hollow steel tubes were examined under axial compression while three circular steel tubes and two square steel tubes were tested for comparison. Nine existing test data on octagonal hollow steel tubes were also collated for comparison. The hollow tubes were fabricated by welding two cold-formed half-section steel plates. To examine the material characteristics, flat, curved and corner coupons were extracted and tested. Residual stress distribution in longitudinal direction was also measured by sectioning method. Fifty longitudinal strips with a nominal width of 10 mm were machined by a wire cutting machine. The test results obtained from the tensile coupon tests and residual stress measurements were examined to evaluate the effect of the fabrication process on different cross-sectional shapes. The geometric imperfections of each specimen were carefully measured. Cross-sectional capacity, load-deformation relationships and failure modes of the stub columns were presented by the stub column tests. Finite element model was developed and validated against the experimental results. The experimental cross-sectional capacities were accurately predicted by the finite element models. The test data accompanied with the FE results were assessed with reference to current design provisions on cross-section classification and a suggested cross-section slenderness limit and an alternative design approach for octagonal cross-sections were proposed.
warranted. Furthermore, design methods for this connection type under combined axial and shear forces are not well established. To address these shortcomings, full-scale laboratory tests were carried out on the double-sided configuration of stiffened extended beam-to-girder shear tab connections with full depth shear plates. These experiments were complemented by a continuum finite element (CFE) study, with which the axial force demands along with other critical parameters that affect the connection behaviour were further examined. The experiments supported by the CFE findings indicated that the primary connection damage states are mainly associated with yielding and fracture of the shear plate due to the interaction of flexural, shear, and axial force. The study demonstrated that the direction and magnitude of the applied axial force significantly affected the shear and axial demands along the centerline of the interior bolt line. The current design practice for the double-sided configuration of the full-depth extended beam-to-girder shear tab was also evaluated; a significant underestimation was observed in the prediction of a connection’s ultimate resistance.


ABSTRACT: This study aims to provide numerical formulation of the behavior of the compact concrete-filled steel tubes (CFSTs) based on constraints with the tie model permitting the two regions to fuse together. This study defined the interface between steel tubes and concrete cores with tie parameters allowing only rotation at the interface. Nonlinear finite element analyses were performed to explore the influence of tie and slip models on the flexural strength of concrete-filled steel tube members, resulting in improved predictions when the confinement provided by a steel tube was modeled with tie element. The passive confinement provided by the steel tube was hindered by the difference in the Poisson’s ratio between the steel tube and concrete when slip elements allowed for infinitesimal movement between a concrete core and steel shell. The numerical results were also consistent with results obtained by the modified strain compatibility-based simplified methods in which no relative motion was assumed between the steel tube and concrete core. The numerical results were well correlated with test data and codes supplied by prior researchers when the test specimens in which relative movement at interface between concrete core and steel jacket was infinitesimal or relative movement between interface between concrete core and steel jacket was not allowed for CFTs with shear connectors. Improved predictions by the tie model demonstrated higher accuracy compared with that of the slip models.


ABSTRACT: The dynamic behaviour of concrete-filled double-skin steel tube (CFDST) columns under close-in blast loading was investigated using experimental and numerical approaches in the present study. Field test results on three large scale CFDST column specimens subjected to different blast loading conditions were presented. High-fidelity physics-based numerical models were developed utilizing the Arbitrary-Lagrangian-Eulerian (ALE) formulation coupled with Fluid-Structure Interaction (FSI) algorithm available in the nonlinear dynamic analysis program LS-DYNA. The numerical models were verified with the experiment results and were then used to investigate the dynamic response, damage mechanism and energy absorption capacity of CFDST columns subjected to close-in explosions. The results indicated that the typical failure pattern of CFDST columns under close-in blast loading is dominated by localized denting of the cross-section directly facing the explosion with minor global deformation of the column. The concrete core suffers severe damage while the steel tubes remain almost undamaged except in a limited region in the vicinity of the detonation. The energy absorbed by each part of the CFDST columns demonstrates that the severe plastic damage of concrete core plays a significant role in the energy absorption mechanism of CFDST columns under blast loading from close-in explosion. The primary function of the steel tubes is to provide confinement to the concrete core therefore prevent concrete spall damage. In addition, the influence of explosive charge setups and level of axial loads on the structural response and damage was assessed and discussed.
ABSTRACT: The static stability of a single-layer reticulated shell has been systematically studied, but nearly all scholars have neglected the effect of the roofing system, and the simplified analytical method may lead to deviations between finite element analysis and the actual situation. In this paper, four full-scale reticulated shell substructure models with a roofing system were experimentally investigated to verify the effect of the roofing system. The finite element analysis (FEA) were established based on the experimental models, the connections between the purlin and purlin hanger were modelled as semi-rigid joints, the profiled sheets were modelled as equivalent orthotropic flat panels, and a weakened area was established to model the connection between the purlin and the roof panel. A series of finite element analysis models (FEM) of full-scale reticulated shells with roofing systems were established, and the effect of the roofing system on the full-scale reticulated shells’ static stability was analysed.

ABSTRACT: A novel model describing the shear lag of laminated composite thin-walled beams with openings has been developed. Warping of open-closed cross-sections is defined by displacements parameters at selected nodes. Vlasov’s assumption of neglecting shear strains in the middle surface is not necessary and stresses can be calculated directly from the strains. The general approach to the solution of the problem is based on the finite element method and linear stiffness matrix has been derived using the principle of virtual displacements. Computing program has been developed and numerical results for thin-walled laminated beams with openings have been presented.

Man-Tai Chen and Ben Young (First author is from: Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, China), “Structural behavior of cold-formed steel semi-oval hollow section beams”, Engineering Structures, Vol. 185, pp 392-399, 15 April 2019, https://doi.org/10.1016/j.engstruct.2019.01.069
ABSTRACT: The structural behavior of cold-formed steel semi-oval hollow sections under bending was studied through experimental and numerical investigation. The semi-oval hollow sections investigated in this study were cold-formed from hot-extruded seamless carbon steel circular hollow sections. A total of 20 beams was tested for both four-point and three-point bending configurations. The sections were bent about the major axis in both positive and negative directions. The tests were replicated numerically by means of rigorous finite element analyses. Based on the validated finite element model, an extensive parametric study was conducted on 198 beam specimens with a wide range of cross-section geometries subjected to pure bending about the major axis in both positive and negative directions. The current design rules for steel structures, such as Australian/New Zealand standards, European codes as well as American and the North American specifications, do not cover the design of semi-oval hollow sections. Therefore, the ultimate flexural capacities of beam specimens obtained from the test program and numerical investigation were only compared with the design strengths predicted by the Direct Strength Method and the Continuous Strength Method. The applicability and reliability of these two design methods were evaluated through reliability analysis. The results show that the existing design methods provide quite conservative and scattered design strength predictions for cold-formed steel semi-oval hollow section beams. In this study, modifications on the Direct Strength Method and the Continuous Strength Method are proposed, which provide better design strength predictions with improved accuracy in a reliable manner.

ABSTRACT: This paper investigates the buckling of confined thin-walled functionally graded material (FGM) arch subjected to external pressure. The confined FGM arch buckles in a single-lobed deformation expressed by an admissible radial displacement function. The critical buckling pressure of the confined FGM arch is obtained analytically by establishing the nonlinear equilibrium equations based on the classical thin-walled arch theory. Subsequently, a two-dimensional (2D) finite element model (FEM) is established to trace the pre- and post-buckling equilibrium paths. Geometric nonlinearities are introduced since large displacement and rotation occur during the whole deformation of the FGM arch. The numerical results show very close agreement with the present analytical solutions in terms of the hoop force through the FGM arch span, the critical buckling pressure, and the pressure-displacement equilibrium paths. Furthermore, the present predictions are compared successfully with other closed-form expressions for the confined homogeneous arch. Finally, the effect of volume fraction exponent on the buckling pressure, the hoop force and bending moment through the arch span is examined and discussed to further understand the buckling behavior of the confined FGM arch.


ABSTRACT: Ceiling performance of enclosed large-span buildings, i.e., stadiums, airport terminals and swimming pools, is related to safety requirements, working serviceability and energy demands. Conventional plasterboard and/or aluminum plate ceilings of large-span buildings are potential dangerous under earthquake effects and energy-consuming during normal working conditions. To ensure safety performance and manage energy performance, a retractable membrane ceiling is proposed in relation to multiple functions and building complexity. This study concerns an experimental study on overall building performance enhancement of a typical large-span swimming stadium using retractable membrane ceilings. One-parameter and two-parameter analysis are performed to quantify crucial factors. Generally, safety performance of retractable membrane ceilings is validated using drop experiments. The corresponding structural advantages are provided compared with other ceiling systems. Moreover, long-term experimental results show building performance enhancement with membrane ceilings. In detail, one-parameter analysis indicates similar effects of membrane ceiling and air conditioning on temperature performance. A temperature enhancement of 1.56 °C demonstrates the critical influence of membrane ceilings. For two-parameter analysis, different effects of solar irradiance and air conditioning in summer result in more energy consumption. In winter, similar effects of membrane and air conditioning can save more energy than that of solar irradiance and air conditioning.


ABSTRACT: This paper is concerned with the dynamic response and stability of an inclined beam under a moving vertical concentrated load. The governing equation for transverse motion of the beam is presented and it contains the effect of the compressive axial component of the vertical load on the bending stiffness capacity of the beam. This moving load problem on inclined beam is no longer simply a dynamic problem, but it involves a structural stability problem when the load is large and the speed of the moving load is low. Furthermore, with the presence of the axial load component, this problem is no longer symmetrical. In other words, the ascending moving load and descending moving load produce different beam responses. For solving this time-dependent problem, we decouple the formu-lation and adopt the semi-discrete finite element method in the space domain. The equation of motion is then solved by using the Newmark method. The present numerical approach and the assumptions adopted were verified by considering a zero angle of inclination (i.e. the horizontal beam case). Based on this developed formulation, numerical solutions on the moving load problem were obtained for various angles of beam inclination. The natural frequencies of the beam become lower as the moving load moves up the inclined beam due to the compressive axial force component that degrades the elastic bending stiffness capacity. When the compressive axial force component is large enough and the speed of the moving load is low, a structural stability problem may surface.


ABSTRACT: This paper investigates the buckling of confined thin-walled functionally graded material (FGM) arch subjected to external pressure. The confined FGM arch buckles in a single-lobed deformation expressed by an admissible radial displacement function. The critical buckling pressure of the confined FGM arch is obtained analytically by establishing the nonlinear equilibrium equations based on the classical thin-walled arch theory. Subsequently, a two-dimensional (2D) finite element model (FEM) is established to trace the pre- and post-buckling equilibrium paths. Geometric nonlinearities are introduced since large displacement and rotation occur during the whole deformation of the FGM arch. The numerical results show very close agreement with the present analytical solutions in terms of the hoop force through the FGM arch span, the critical buckling pressure, and the pressure-displacement equilibrium paths. Furthermore, the present predictions are compared successfully with other closed-form expressions for the confined homogeneous arch. Finally, the effect of volume fraction exponent on the buckling pressure, the hoop force and bending moment through the arch span is examined and discussed to further understand the buckling behavior of the confined FGM arch.


ABSTRACT: This paper is concerned with the dynamic response and stability of an inclined beam under a moving vertical concentrated load. The governing equation for transverse motion of the beam is presented and it contains the effect of the compressive axial component of the vertical load on the bending stiffness capacity of the beam. This moving load problem on inclined beam is no longer simply a dynamic problem, but it involves a structural stability problem when the load is large and the speed of the moving load is low. Furthermore, with the presence of the axial load component, this problem is no longer symmetrical. In other words, the ascending moving load and descending moving load produce different beam responses. For solving this time-dependent problem, we decouple the formu-lation and adopt the semi-discrete finite element method in the space domain. The equation of motion is then solved by using the Newmark method. The present numerical approach and the assumptions adopted were verified by considering a zero angle of inclination (i.e. the horizontal beam case). Based on this developed formulation, numerical solutions on the moving load problem were obtained for various angles of beam inclination. The natural frequencies of the beam become lower as the moving load moves up the inclined beam due to the compressive axial force component that degrades the elastic bending stiffness capacity. When the compressive axial force component is large enough and the speed of the moving load is low, a structural stability problem may surface.


ABSTRACT: This paper investigates the buckling of confined thin-walled functionally graded material (FGM) arch subjected to external pressure. The confined FGM arch buckles in a single-lobed deformation expressed by an admissible radial displacement function. The critical buckling pressure of the confined FGM arch is obtained analytically by establishing the nonlinear equilibrium equations based on the classical thin-walled arch theory. Subsequently, a two-dimensional (2D) finite element model (FEM) is established to trace the pre- and post-buckling equilibrium paths. Geometric nonlinearities are introduced since large displacement and rotation occur during the whole deformation of the FGM arch. The numerical results show very close agreement with the present analytical solutions in terms of the hoop force through the FGM arch span, the critical buckling pressure, and the pressure-displacement equilibrium paths. Furthermore, the present predictions are compared successfully with other closed-form expressions for the confined homogeneous arch. Finally, the effect of volume fraction exponent on the buckling pressure, the hoop force and bending moment through the arch span is examined and discussed to further understand the buckling behavior of the confined FGM arch.
ABSTRACT: This work presents the development of explicit equations for the prediction of elastic local buckling critical stress of castellated beams subjected to pure bending, considering the interaction between flange and web. Eigenvalue analyses are carried out for Litzka-type beams using Finite Element Method (FEM) to gather information on the buckling modes and critical stresses for combinations of usual flange-to-web width and thickness ratios. The representative compression ‘tee’ is analyzed using the Generalized Beam Theory (GBT) to study the influence of stress gradient and member length in the critical stress. The influences of flange torsional stiffness and web transverse bending in the ‘tee’ behavior are studied and an energy method is adopted to derive the prediction equations. It is shown that the proposed approach leads to a good agreement with the FEM results, with an average difference of $0.955 \pm 0.063$, whereas current guidelines may significantly over or underestimate actual critical stresses for low flange-to-web width ratios. It is finally shown that this buckling mode may become relevant for castellated beams using high-strength steel.


ABSTRACT: Thin-walled steel tubular columns with circular cross sections are widely used as cantilever piers in bridges due to their excellent structural and constructional advantages. However, local buckling, global buckling, or the interaction between both is usually the main reason for the significant strength reductions in these columns, which eventually leads to their collapse. This article investigates the behavior of thin-walled steel tubular columns with conventional uniform circular sections (Cs) and newly proposed graded-thickness circular sections (GCs) under combined constant axial and cyclic lateral loading. The analysis is carried out using a finite-element model (FEM) that takes into account both material and geometric nonlinearities. First, the accuracy of the employed FEM is substantiated using the experimental data available in the literature. Then, the GC column with a size and volume of material equivalent to the C column is introduced. The proposed GC column is proved to have significant improvements in strength, ductility, and postbuckling behavior compared with its counterpart C column. As part of the investigation, an extensive parametric study is carried out to investigate the effects of various important parameters, such as radius-to-thickness ratio parameter ($R$), column slenderness ratio parameter ($\lambda$), magnitude of axial load ($P/P$), and number of loading cycles ($N$), on the
ABSTRACT: This article presents a general solution for the free transverse vibration of non-uniform, axially functionally graded, tapered cantilever beams with tip masses. Attention is focused on undamped cantilevers that fall within the range of validity of Euler-Bernoulli beam theory. The Myklestad Method is shown to be an efficient and accurate tool for this purpose. Results are presented for a number of cases of different beam geometries and material gradients.


ABSTRACT: This paper presents the finite element analysis (FEA) results of a multi-story reinforced concrete (RC) building having precast and cast-in-place load bearing walls. Door-type cut-out openings (height: 2.1 m, width: 0.9–4.4 m) were created at the first and second story of the building. Results from experimental tests on axially loaded RC panels were used to verify the modeling approach. The influence of cut-out openings on the
response of individual RC panels, failure modes, and load redistribution to adjacent members under increasing gravitational loads was analyzed. Moreover, the wall bearing capacities obtained from FEA were compared with the values calculated from design equations. The results revealed that the robustness of multi-story buildings having RC load bearing wall systems decrease considerably with the creation of cut-out openings. However, owing to the initial robustness of the buildings, large cut-out openings could be created under normal service conditions without strengthening of the building structure. Furthermore, design equations provided very conservative predictions of the ultimate axial capacity characterizing the solid walls and walls with small openings, whereas similar FEA and analytically predicted capacities were obtained for walls with large openings.


ABSTRACT: Cementitious materials such as concrete are typically characterised as quasi-brittle with low tensile strength and low strain capacity, which hence affect the long-term durability of the structure. One of the most important issues in designing and maintaining massive concrete structures like offshore and nuclear power plants is concrete cracking, which is due to the low tensile strength of concrete. This can destroy the structural aesthetic and lead to deterioration of the structure. The addition of fibers to concrete has been proven to be a good mean to control its crack behaviour and maintain its ductility in tension. Further, since the discovery of carbon nanotubes/fibers (CNT/CNF), they have been also considered as efficient fibers for construction materials such as concrete.

This study presents the structural performance of steel-concrete (SC) elements with a fiber reinforced concrete (FRC) core using both single and hybrid fibers (i.e. consisting of two types of fibers). For this study carbon nanofibers, and steel fibers which are conventionally used in practice, are used for the FRC. Static tests were conducted on eight SC beams with different concrete types. The paper reports on the experimental results obtained from four-point flexural loading of the SC beams. The study shows considerable improvement for both the strength and ductility of the tested specimens. The research laid the groundwork for additional in-depth studies on using carbon nanofiber reinforced concrete within structural members.


ABSTRACT: The world’s first full-scale model test of the precast segmental box girder with corrugated steel webs (CSWs) is carried out in this study to examine the applicability of using the precast segmental construction technology in erecting the composite girder bridges with CSWs. This study focuses on the transverse mechanical performance of bridge segments under vehicle loads; based on the fact the transverse bending stiffness of segmental box girders with CSWs is weaker than that of bridge girders with concrete webs. It is found from the experimental results that that bending failure of the top concrete flange occurs first instead of the shear buckling of the CSWs. In addition, the result of load testing indicate that the precast segmental box girder with CSWs has a high coefficient of safety margin and a good plastic deformability. This study also presents two improved schemes of structural design to enhance the structural transverse stiffness and reduce the accumulated deformation differences caused by the self-weight in the process of segmental precasting by the short-line method.

Hoang X. Nguyen, Elena Atroshchenko, Tuan Ngo, H. Nguyen-Xuan and Thuc P. Vo (First author is from: Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne NE1 8ST, United Kingdom), “Vibration of cracked functionally graded microplates by the strain gradient theory and extended isogeometric analysis”, Engineering Structures, Vol. 187, pp 251-266, 15 May 2019, https://doi.org/10.1016/j.engstruct.2019.02.032

ABSTRACT: In this study, the vibration behaviours of functionally graded microplates with cracks are investigated by means of a simple yet rigorous version of Mindlin’s generalised continuum and the extended isogeometric analysis (XIGA). The simplified strain gradient theory which includes one material length parameter and an additional micro-inertia term is employed to capture the size effects. Meanwhile, the
displacement field of the plates is described using the refined plate theory with four unknowns and the XIGA in which enrichment functions are involved to effectively predict the responses of microplates with cracks. In addition, the IGA approach with highly smooth basis functions of non-uniform rational B-spline (NURBS) ensures a clean and efficient treatment of higher continuity requirements in the strain gradient theory. The benchmark numerical results show significant departure from those analysed by the classical continuum elasticity. Indeed, they reveal strong influences of microstructural characteristics on the vibration responses of microplates which are not shown in the platform of the classical theory and the influences are more pronounced as the size of the plates becomes comparable with the material length parameter.


ABSTRACT: Beam members, especially those that have large depth/width ratios and long spans, are prone to lateral-torsional buckling as a possible mode of failure. Laboratory testing rarely takes into account actual end conditions and initial imperfection which might have a significant impact on the buckling behavior of beams. The current research project aims to investigate the lateral-torsional buckling of wooden I-joists with realistic boundary conditions used in construction. A total of 41 joists were tested using various commercial joist hangers and enhanced connections to represent different support conditions. A numerical 3D model was also developed using commercially available finite element program ABAQUS to determine the buckling loads and associated mode shapes of joists similar to those tested. Based on the results from the current study it is recommended that 20% reduction in the critical moment capacity be considered in order to take into account the use of joist hangers typically used in construction. Finite element analysis of the linear eigenvalue buckling load was found to be in reasonable agreement with the experimental results. The nonlinear behavior of the joists was found to be influenced by the initial imperfections. The ultimate critical load was attained at large lateral displacement of the joists due to their non-linear behaviour. This observation could have a significant implication on design and should be investigated further.


ABSTRACT: The wind tunnel test of static aeroelasticity is a basic method to study the static aeroelastic phenomena of aircraft and other similar structures. As the test objects, the static models need to meet similar requirements, such as geometric similarity and stiffness similarity. The traditional models adopt a spar-frame-skin hybrid structure. The multiple frame segments (skins) of the models are separated from each other, and it is difficult to ensure the geometrical similarity of the aerodynamic shapes of the models during the tests. The overall stiffness of the models with this structure is borne by the metal spars, which makes it difficult to design and manufacture the models. Replacing the segmented frame/skins in the hybrid structure, an integrated shell structure made of additive manufacturing technology (AM) that contributes partial stiffness is proposed in this paper. Based on the structure, a static aeroelastic model is designed in two phases: the similarity design and stiffness design. The stiffness design is formulated as a constrained single-objective optimization problem, and the gradient-based optimization algorithm is adopted to implement the optimization to obtained structural dimensions of the model in the hybrid structure. The errors of the stiffness design are checked and the contribution of integrated shell to the overall stiffness is discussed. A large-aspect-ratio aircraft is chosen as the prototype and a static aeroelastic model with the integrated resin shell is designed, calibrated, and tested in this paper. The results show that the static aeroelastic model with the proposed AM integrated shell is feasible and can be used to study the static aeroelasticity reliably and efficiently.

ABSTRACT: Residual stresses and plastic strains in steel tubes are induced by their manufacturing processes and play an important role in determining their mechanical and structural behaviour. The manufacturing process of cold-formed steel hollow sections can be divided into four main stages: (1) the coiling and uncoiling of a steel strip, (2) the transverse bending of the uncoiled strip into a circular shape, (3) the welding of the circular tube along the longitudinal strip edges, and (4) the shaping of the welded circular steel tube into a specific cross-sectional shape. In this paper, a finite element-based method is presented for predicting residual stresses and equivalent plastic strains in cold-formed steel hollow sections (including elliptical, square, and rectangular shapes of both normal grade steel and high strength steel). In this method, residual stresses and equivalent plastic strains due to the coiling, uncoiling and transverse bending operations are predicted analytically, and applied as the initial state for the subsequent finite element simulations of both welding and shaping operations. Predictions from this method show satisfying agreement with experimental measurements, which demonstrate the validity of the proposed method. This method can predict the distributions of residual stresses and equivalent plastic strains across the thickness and over the cross section, which are too complex to be measured completely in laboratory. The method provides a tool for investigating the effects of different material and forming parameters on the resulting cold work and structural behaviour.

ABSTRACT: This paper presents a method to identify the critical member in a single-layer latticed dome, which in the context of progressive collapse is defined as the member whose removal causes the most severe damage. The distribution of critical members in four typical types of single-layer latticed domes, including the Kiewit dome, the Ribbed dome, the Schwedler dome and the Lamella dome, is investigated through a comprehensive Alternate Path analysis scheme composed of hundreds of individual dynamic nonlinear analyses. The Alternate Path analyses also confirm the progressive collapse mechanism of single-layer latticed domes, i.e., the nodal snap-through buckling at either end of the initially removed member. On this basis, a critical member identification method is established, using an index that implicitly estimates the relative vulnerability to node buckling following the removal of a member to determine the criticality of this member. This method along with two other methods, using either static axial force or free vibration response, are evaluated via comparison against the nonlinear dynamic Alternate Path analysis results, and this proposed method shows a beyond-compare accuracy. Furthermore, based on the established understanding of the progressive collapse mechanism and the factors influencing the node buckling resistance, three methods for increasing the progressive collapse resistance of single-layer latticed domes are presented.


ABSTRACT: The design and analysis of aerospace structures requires a detailed evaluation of stresses. Nevertheless, the complexity of large structures and the use of composite materials can significantly increase the computational costs of the models. The computational burden of such analyses can be reduced by a suitable global/local approach developed in a very general Finite Element framework. Generally, a global/local modelling approach aims at using a finer mesh in the “local” zones where a detailed evaluation of stress/strain field is required, whereas a coarse mesh is used in the rest of the structure. This work proposes a global/local methodology to set up a high-order beam model in the Carrera Unified Formulation framework only for a reduced region of the global model. The methodology makes use of two steps. In the first step, a static analysis of the global structure is done by means of a commercial software in order to identify the critical regions deserving more accurate investigations. In the second step, thus, a high-order beam model is employed for the local region based on the information from the previous global analysis. Linear elastic static analysis are considered in this work, and the attention is mainly focussed on the capability of the method to provide stable solutions and accurate 3D stress fields in the local region, even in the case of laminated composite structures. Hence, the effectiveness of the proposed approach is proven through some meaningful benchmarks.

Li-min Tian, Jian-peng Wei and Ji-ping Hao (School of Civil Engineering, Xi’an University of Architecture and Technology, Xi’an 710055, PR China), “Optimisation of long-span single-layer spatial grid structures to resist progressive collapse”, Engineering Structures, Vol. 188, pp 395-405, 1 June 2019, https://doi.org/10.1016/j.engstruct.2019.03.025

ABSTRACT: Long-span single-layer spatial grid structures are widely applied in public buildings. Given their long-span and single-layer characteristics, they can easily collapse during accidental events. In this study, a commonly used reinforcing technology was tested on four substructures that were abstracted from single-layer spatial grid structures. Although a fixed end between the member and joint was constructed, the method is not ideal to improve progressive collapse resistance. Therefore, the optimisation method was modified in two aspects to consider different failure mechanisms. First, a double-layer member was used to improve the stability performance. This realised a ductile failure process because unpredictable buckling is converted to ductile failure. Second, an unbonded member was used for optimisation relative to strength failure. The presence of the embedded pipe produced two plastic areas to promote rotation ability. The aforementioned modified optimisation method is favourable for energy dissipation, and thereby improves the performance of single-layer spatial grid structures with respect to stability and strength failure.

ABSTRACT: This paper presents a study of the structural capacity of reinforced concrete free-form shells, with hexagonal and triangular plants supported on corners. Initially, it presents the computational models for free-form shells generation and the parameters used in a linear static analysis. From the results of this analysis, the conditions of minimum thickness in which the structural behavior of the shells agrees with the membrane theory of thin shells are defined. Then, these shells are submitted to nonlinear pushover analysis, considering the plasticity and the accumulation of damage in each load increase. To determine the capacity of these shells, the parametric analysis is performed with the variation of the mechanical properties and the directions of the application of the horizontal force, taking the structure to the failure point. The results present the elastic-plastic behavior of shell structures under the action of horizontal forces. Therefore, this study aims to broaden the knowledge on the performance of the free-form shells under the action of external horizontal loading, such as structures under seismic action.


ABSTRACT: Laminated glass is often used in structures for protection against blast loads. The single-degree-of-freedom model has conventionally been used to design such structures and it continues to be widely in use today. The single-degree-of-freedom model includes mass and load transformation factors, which depend on the deflected shape of the structure. In this study, finite element models are used to derive the deflected shapes and transformation factors. The time-varying deflected shape history is taken into account in this analysis, as this is currently not included in other single-degree-of-freedom models. The analysis was conducted on a range of boundary conditions and aspect ratios along with different loading rates. For low-rate loading, the transformation factors were found not to vary during the deflected shape–time history. For high rate loading, however, the transformation factors were found to vary during the deflected shape–time history therefore requiring their inclusion in the single-degree-of-freedom design methods. These transformation factors were found to be insensitive to aspect ratios.

Chung-Che Chou and Sung-Cheng Wu (Department of Civil Engineering, National Taiwan University, Taiwan), “Cyclic lateral load test and finite element analysis of high-strength concrete-filled steel box columns under high axial compression”, Engineering Structures, Vol. 189, pp 89-99, 15 June 2019, https://doi.org/10.1016/j.engstruct.2019.03.052

ABSTRACT: This paper presents an experimental study of the seismic performance of high-strength concrete-filled box columns (CFBCs) under combined axial and cyclic lateral loads. Specimens were made of high-strength SM 570 M steel (with yield strengths between 520 and 580 MPa), and concrete with compressive strength (f_c) greater than 80 MPa. Three parameters that affect the seismic performance of CFBCs were investigated: the width-to-thickness (b/t) ratio of the steel column, magnitude of the axial load, and the addition of concrete infill. The specimens, which were 280–420 mm in width and 2000 mm in height, were tested under combined axial (4058–10,090 kN) and cyclic lateral loads. Experimental results indicated that the lateral displacement ductility decreases significantly with an increase in either the axial load or b/t ratio. The addition of concrete infill inside a hollow steel box column does not improve the lateral displacement ductility of CFBCs under high axial load. Although the CFBC specimens satisfied the b/t requirement of a highly ductile member, as per AISC Seismic Provisions (2016), specimens under high axial load (40%P) failed at 4% drift, indicating that the requirement does not guarantee that CFBCs will sustain high axial load under significant drift (i.e., >3%). The Eurocode 4 (2009), AISC Specification (2010), and Architectural Institute of Japan (2014) reasonably estimate the flexural strength of high-strength CFBCs under axial load; however, ACI 318 (2011)
does not. The finite element analysis program ABAQUS can be used to estimate the hysteretic behavior of specimens before significant strength degradation.


ABSTRACT: The current study aims to present a three-dimensional numerical analysis to predict the elastic-plastic behavior of a single-curvature, simply supported, composite sandwich panel. The PVC foam core is modeled with isotropic elastic-perfectly plastic properties based on the extended non-linear higher-order sandwich panel theory. An efficient and accurate numerical approach, a combination of differential quadrature, and Newmark methods were implemented to distinguish panel layers’ deformations and stresses. The non-linear governing partial differential equations of motion are discretized and reduced to ordinary differential equations by applying the differential quadrature method (DQM) and are solved using the Newmark method. The various failure modes of the sandwich panel, including facesheet fracture, foam shear fracture, and foam yield were investigated. The stress components and transient responses obtained from the present method are compared with the finite element solutions using commercial software ANSYS and also compare with those reported in the literature and good agreement is achieved. It is observed that significantly less computational time and hardware capacity for the proposed method is required with respect to the finite element solution. A parametric study proved that sandwich panel with H100 foam core has the highest energy absorption and this parameter increases with increasing the span of the panel.


ABSTRACT: Assessment of corrosion defects and their effect on integrity of oil/gas pipelines are critical to the burst strength capability and safe operation of pipeline systems. In this work, a 3-dimensional finite element-based model was developed to investigate the mechano-electrochemical (M-E) interaction of multiple, longitudinally aligned corrosion defects on an X46 steel pipeline in a soil solution. A multi-physics field coupling technique was employed to derive the distributions of stress, strain, corrosion potential and anodic current density at the defects. For multiple corrosion defects, a critical spacing exists, below which there is an interaction between them to enhance the local corrosion. From this work, this value is between 100 mm and 150 mm. The maximum interacting spacing increases as the defect length increases. As the defect spacing reduces, there is a strong interaction between them, resulting in a high plastic stress at the defects. Under the identical defect spacing, the hoop stress condition causes an enhanced E-C interaction between adjacent corrosion defects, while the effect due to the uniaxial stress is ignorable. The interaction between multiple corrosion defects exists not only in the mechanical stress field, but also in the electrochemical corrosion field. An increase of the defect length, while keeping its depth fixed, enhances the local stress at the defects, shifts the corrosion potential negatively, and increases the anodic current density at both the defect and the adjacent area.


ABSTRACT: The inelastic behaviour of a steel beam is complicated by reductions in the section rigidities which depend on the moment distribution and residual stress pattern. The inelastic beam is effectively tapered and mono-symmetric, and iterative numerical methods need generally to be used for the analysis. The in-plane moment distribution in an inelastic continuous beam lies between the commonly assumed rigid-plastic “plastic” path and a “yield” moment path. The yield path is the more critical for lateral buckling of the continuous beams considered in this paper. Approximations of the inelastic out-of-plane moduli of continuous beams developed from closed form lateral buckling solutions for simply supported beams in uniform bending can be used in a computer program for the
buckling analysis of tapered mono-symmetric beams. Residual stresses cause significant reductions in the inelastic buckling resistance. The AISC design code predicts strengths which are similar in shape but significantly higher in magnitude than the inelastic buckling resistances of simply supported beams in uniform bending. The predictions for beams with central concentrated loads are much higher than the corresponding inelastic buckling resistances. Closer but still conservative approximations are obtained by using the method of design by inelastic buckling, which can also be used for continuous beams. This method is much simpler than those used to obtain accurate predictions.


ABSTRACT: A stiffness reduction method for the lateral-torsional buckling (LTB) assessment of welded web-tapered steel beams is presented in this study. The method is implemented by (i) modelling a tapered steel beam using elastic beam finite elements specifically developed to represent the elastic instability response of tapered steel members, (ii) reducing the Young’s modulus E and shear modulus G of each element through a stiffness reduction function considering the bending moments and cross-section properties at the middle of each element and (iii) performing an elastic Linear Buckling Analysis of the beam with reduced stiffness, referred to as LBA-SR herein. Since the adverse influence of the development of plasticity and imperfections on the ultimate member strengths are fully accounted for through stiffness reduction, the presented method does not require any further global instability assessment using member design equations; thus, the proposed method is both direct and practical. Verification of the method is shown for a wide range of web-tapered steel beams using results from nonlinear shell finite element modelling.


ABSTRACT: An up-to-date problem in analysis of composite beams is to analyze higher-order beam theories with a considerable number of displacement variables and evaluate the influence of each term in order to reduce the model computational cost. In this paper the optimization of those higher-order beam theories to find the best theories in terms of accuracy and computational efforts is presented. The analysis is carried out by the so-called N-objective optimization evolutionary technique. The refined beam models are developed in the framework of the Carrera Unified Formulation (CUF). The influence of polynomial shape strain functions over the cross-section of the sandwich beam is investigated. The governing equations are derived from the Principle of Virtual Displacement (PVD), and Navier closed form solutions have been obtained in the case of simply supported beams subjected to bi-sinusoidal transverse pressure. The best or refined theories reported belong to a Best Theory Diagrams (BTDs), in which the optimum number of terms that should be used to achieve a desired accuracy can be read. The results of refined models are compared with the solution of a robust full model of order nineteen in two benchmark beam problems. It is shown that considering polynomial expansions can enhance the refinement of higher order models with less computational effort.


ABSTRACT: The in-plane nonlinear elastic stability of single arches has been investigated by many researchers, however, a similar research of multi-span continuous arches is not available even though they are extensively used in arch bridge engineering. This paper proposes an analytical method for the in-plane nonlinear elastic buckling and post-buckling of pin-ended parabolic multi-span continuous arches. There are four key parts in the proposed method. Firstly, the in-plane nonlinear equilibrium differential equations of each arch were derived based on the strain expression in the Cartesian coordinate system of non-circular arches and the virtual work principle. Secondly, the nonlinear equilibrium equation of continuous arches was proposed based on the deformation compatibility condition of each arch end, and three key coefficients were obtained. Thirdly,
the buckling requirements were deduced according to the force balance condition in each arch end. Lastly, analytical solutions for buckling and post-buckling predictions were derived. Comparisons with the results of finite element method, including the load-displacement curve, buckling behavior and buckling predictions, demonstrate that the proposed analytical solution is equipped with high accuracy. The results of theoretical and parametric analysis show that the deformation shape of symmetric and asymmetric buckling of multi-span continuous arches is thoroughly different from the single arches, the mechanical effect of the unloaded arches is a nonlinear horizontal spring support acting on the loaded arch, and the stability parameter ratio has a significant influence on the buckling behavior of multi-span continuous arches.


ABSTRACT: Low cycle cyclic loading tests of 7 corroded H steel columns (seismically compact section, highly ductile member) were performed, so as to investigate the effect of corrosion on the seismic behavior of H-shaped steel columns. Based on the monotonic tensile test, the relationship between mechanical properties and surface morphology of corroded steel were studied. The failure mode, lateral capacity, ductility and energy dissipation of H-shaped steel columns were studied by the low cycle cyclic loading tests. Furthermore, the effects of local corrosion and axial compression ratio on the seismic behavior of corroded H-shaped steel specimens were also investigated in the finite element analysis. The results showed that with the corrosion degree increasing, the deformation area of flange and web of corroded specimens decreased with a maximum decrease of 22%. The height of the buckling center decreased and that of some specimens decreased by 30%. The ultimate lateral capacity and stiffness of specimen H6 with the most severely corrosion degree decreased at a ratio of 27.4% and 26.3% respectively. Eventually, the degradation model of hysteretic energy dissipation and ductility coefficient of corroded H-shaped steel columns were established. In addition, the analytical results showed the hysteretic behavior of compression-bending members with flange corrosion and large axial compression ratio decreased rapidly. When the mass loss ratio reached 22% with axial compression ratio of 0.6, the peak load and hysteretic energy decreased at a ratio of 35% and 70% respectively. Consequently, the components with flange corrosion and large axial compression ratio should be paid enough attention to.


ABSTRACT: The aim of this paper was to investigate the seismic behavior of shear walls reinforced with CFRP (carbon fiber reinforced polymer) bars as longitudinal reinforcement. Three full-scale shear walls with same geometry and dimension were tested up to failure under pseudostatic cyclic lateral loading. The first one was a conventional reinforced wall (as a reference specimen). The second was reinforced with steel bars in boundary elements and CFRP bars in the wall web as vertical reinforcements. The third was reinforced with CFRP bars totally in the vertical direction. Residual deformations and cracks were of particular interest. The experimental results show that the CFRP-reinforced shear wall achieved comparable lateral strength, post-yield stiffness, acceptable lateral drift and lower level of energy dissipation compared with the reference wall. Besides, excellent self-centering behavior was observed, and the residual deformation of CFRP-reinforced shear walls decreased by more than 50% compared to the reference wall at a lateral drift of 1.0%. These promising results demonstrate the feasibility of CFRP bars as linear-elastic material to achieve self-centering behavior of shear wall.


ABSTRACT: Fiber reinforced polymer (FRP) jackets have been recently used for strengthening purpose of concrete filled steel tube (CFST) composite columns and also for the suppression of outward local buckling that CFST columns may suffer. This study intends to investigate the axial compression capacity of circular CFST columns transversely strengthened by FRP. For this, an attempt has been made to implement gene expression programming (GEP) technique for the development of axial capacity of confined CFST prediction model. The database required for the derivation of the GEP model is based on the extensive experimental results of the FRP
confined CFST columns tested in compression (92 test specimens). Moreover, these test specimens wrapped with the carbon or glass fiber sheets have different length to diameter ratios of 2.0–4.5. The input predictor variables used in the study are the properties of the FRP (the type, thickness and sheet wrap layers, tensile strength and elastic modulus of FRP), the steel tube (outer diameter, thickness, length and tensile strength of steel tube) and unconfined concrete (compressive strength of in-filled concrete). To verify the effectiveness of the model, the values from GEP were examined statistically against those of existing equations given by various researchers. After analyzing and comparing the proposed model with the existing formulas, it was found that the results obtained by GEP have significantly less errors and far more accurate.


ABSTRACT: This study focused on the structural behaviour of cold-formed steel (CFS) closed Built-up beams composed of two sigma sections primarily fail due to local buckling under four-point bending about the major axis. It is aimed to establish accurate finite element models for CFS built-up I-beam subjected to a transverse load. The numerical model was developed by using Finite Element (FE) software ABAQUS 6.13. The numerical models were discretized with S4R element, end condition as simply supported and non-linear analysis which includes material, geometric, contact non-linearities and geometric imperfections. The numerical model is validated by means of comparison with the experimental results published in the literature in terms of moment capacities, moment versus deflection curve and failure mode of specimens. For different cross-section geometries and different thickness of the built-up closed beam, the numerical parametric study has been carried out by using the verified FE model, and the obtained flexural resistances were compared with those predicted by using current DSM and DSM proposed for built-up beams. The moment capacity decreases with increase in compression flange width to thickness ratio. In general, the moment of resistance of the section increases with decreasing the aspect ratio. There is no significant effect in flexural strength of the built-up closed beams due to the change in depth of web stiffener. Based on the comparison of results, suitable modifications are proposed herein for DSM, especially for the closed built-up beams made of two sigma sections normally failed by local buckling and also the performance of the current DSM, DSM proposed for built-up beams and the DSM proposed by this study are assessed by reliability analysis.


ABSTRACT: Strained gridshells are reticulated shell structures that are erected from a flat grid of initially straight laths. The structural efficiency of a gridshell is determined by its shape, which is traditionally designed using form-finding techniques. However, these techniques are primarily used to generate structures in pure tension or compression for a single load case only. In cases where classic form-finding techniques are not applicable, such as for cantilevering gridshells or simply supported gridshells, numerical optimization can be used to find a suitable shape. In this paper, an optimization procedure is proposed that optimizes the shape of a strained gridshell for a given grid. The forces applied to erect the gridshell are chosen as the design variables. These erection forces are optimized to minimize the so-called end-compliance, which is defined as the inner product of the external loads and the resulting displacements. The method of moving asymptotes is adopted to solve the optimization problem and implicit dynamic relaxation is used to solve the nonlinear equilibrium equations. Geometric nonlinearity is taken into account by using co-rotational beam elements to model the gridshell laths. To validate the proposed approach, a 6x6 m² prototype was built. The results show that this approach allows the structure to be optimized considering multiple load cases, while accounting for practical building constraints, and potential designer constraints.


ABSTRACT: This paper presents outcomes of experimental and numerical studies completed on unreinforced, collar plate reinforced and doubler plate reinforced Square Hollow Section (SHS) T-joints subjected to axial compressive loading on the brace member. A total of nine full-scale SHS T-joint specimens were fabricated and
tested, in which six specimens were reinforced with collar plate and doubler plate. Non-linear finite element (FE) models were developed using finite element code, ABAQUS. Test data was used to validate these FE models. Subsequently, validated FE models were used to conduct an extensive parametric study to investigate the effect of various geometrical parameters of main members and reinforcement plates on the ultimate capacity of reinforced SHS T-joints. The parametric study found that use of both collar and doubler plate reinforcements significantly increase the ultimate capacity of SHS T-joints. Thickness of the reinforcing plate has a positive effect if the thickness of the reinforcing plate is limited to twice the thickness of the chord member. This study, however, found that the capacity of a reinforced SHS T-joint is not dependent on the type of reinforcing plate. The study concludes that the maximum capacity that can be achieved from a reinforced joint is about double the capacity of a similar unreinforced joint. It was found that the Eurocode EN 1993-1-8 overestimates the capacity of reinforced SHS T-joints. Therefore, a new design method for predicting the ultimate capacity of the collar plate and doubler plate reinforced SHS T-joints was developed and this new design method is presented in this paper.


ABSTRACT: Wind loads are the predominant loads of all the various loading combinations in structural design of cooling towers. Existing wind loading codes have a basic single interference factor and a simplified two-dimensional static wind pressure distribution formula, and do not enable accurate structural safety/reliability evaluation under dynamic wind loads. Among the various Equivalent Static Wind Loadings (ESWLs), the reinforcement-area-based ESWL is selected in this study, and the extreme reinforcement area considering wind directionality effect and nonuniform circumferential wind pressure is expressed as the equivalent criterion of reinforcement area envelope.

A structural safety evaluation method, based on this innovative cooling tower design criterion, is derived as the dynamic reinforcement area envelope concept. The effects of time-variant weighted internal forces and non-Gaussian peak factor for the reinforcement area envelope are considered. The reinforcement area envelopes are compared with those from three different codes based on traditional simplified ESWLs. Finally, the results show that the existing loading codes do not cover the effects of interference amplification for structural safety. An alternative framework based on the reinforcement area criterion of weighted dynamic interval forces and its extreme value envelope are proposed, which can optimize both the economy and the structural safety design of cooling towers.


ABSTRACT: A number of finite element modeling approaches for reinforced concrete (RC) structural walls have recently become available for both research purposes and design applications. Five conceptually-different state-of-the-art finite element models for RC walls are described and evaluated in this paper, including models based on either a fixed-crack or a rotating-crack approach for simulating the biaxial behavior of concrete under plane-stress state, models characterized with either a single- or a multi-layered representation of the wall cross-section, and models with or without consideration of various individual failure mechanisms (e.g., buckling of reinforcement, out-of-plane instability). Modeling approaches were validated against experimental data obtained for five benchmark RC wall specimens, all with rectangular cross-sections, yet are differentiated by a range of salient response characteristics (e.g., aspect ratio, axial load, failure mechanism), in order to assess the capabilities of the models in representing the response of isolated planar walls under uni-directional lateral loading, as well as to identify future research directions. Results presented suggest that the models considered in this study can all capture the lateral load at yield and the peak lateral load capacity of the wall specimens with ±10% accuracy, while the initial stiffness and yield stiffness can be overestimated as much as 3.0 and 1.8 times, respectively. All models can capture nonlinear shear deformations and interaction between flexural and shear responses under cyclic loading, where the analytically-predicted flexural and shear deformations are within ±30% of the experimentally-measured values. Moderate differences between the predicted crack orientations and distributions are noted between the models, and the model results for the magnitudes of principal compressive stresses in concrete and the extent of stress localization are comparable. All models can capture the
nonlinear distribution of vertical strains measured along the base of the walls, where the magnitudes of the predicted tensile and compressive strains are within ±50% of experimentally-measured strains for most models. Although some of the model formulations proved to be successful in capturing the experimentally-observed strength loss mechanisms for individual wall specimens, none of the models were capable of comprehensively simulating all of the strength degradation mechanisms observed during the tests.


ABSTRACT: The paper discusses the numerical analysis of all-steel buckling-restrained braces. These devices are designed to work in an inherently unstable regime, and their behavior is acutely sensitive both to any configuration detail in reality, and to any adopted parameter in their analysis. Their dissipative axial behavior can be reasonably well predicted by any suitable FEM model, if a good constitutive law is available. Nevertheless, it is shown here that an apparently accurate FEM calculation of the lateral contact forces, generated by the buckled core when it contacts the external containment profiles, produces results so sensitive to modelling details that they are practically devoid of an acceptable degree of accuracy. These observations might raise some doubts about the advisability of employing this type of bracing in normal engineering practice. In our viewpoint, a similar conclusion could be reached for any structural element designed to work in an unstable regime, unless the imperfections – of any type, including possible modelling details – could be explicitly taken into account, either parametrically or in a statistical way.


ABSTRACT: Local buckling behavior of welded T-section column, which was fabricated from 800 MPa high strength steel (HSS), was investigated in this study. An experimental study consisting of eleven welded T-section columns under axial compression was carried out. The failure mode characterized by local buckling of plates was found, and different load-displacement curves of specimens were established. Embedding coefficients including the effect of flange on the web buckling and the effect of web on the flange buckling were suggested. A finite element (FE) model for predicting the ultimate load of specimens was developed, which was then verified by test data. Comparison of width-thickness ratio limits for flange and web between various specifications and test data were made. Chinese Specification GB50017-2017 overestimated the ultimate load, and American Specification ANSI/AISC 360-10 was a little underestimated. A new model modified from Chinese Specification GB50017-2017 was proposed for estimating the ultimate load of 800MPa high strength steel welded T-section columns under axial compression, and a good agreement between the proposed model and test data was made.


ABSTRACT: Concrete-filled steel tubes (CFST) are increasingly used thanks to the improved structural performance, especially under compression. This is basically due to the confinement effect provided by the tube, which usually enhances ductility and strength of concrete infill. Several researchers have been focused these last decades on these sections under different assumptions, especially those issues which derive from the construction process; the fact of loading the tube before concreting in preliminary constructive stages leads to a preloading stress which implies a different response of the section than the expected. These issues must be considered in the design process and derive into undesired preloading effects on one of the two components derived from the process itself. Nevertheless, few studies treat the fact of preloading as a design method itself before being under service loads (active methods) to enhance the capacities of CFST sections. This paper analyses and compares 4 different methodologies (2 passive versus to 2 active preloading methods) by describing the potential benefits and consequences of them on the whole section; while sometimes a pre-stress ratio on one component may enhance
the global mechanical response, sometimes it does not and becomes even harmful. The ratio of confinement effect over the core and especially when it becomes activated reveals the grade of real enhancement of the compressive response of the section in terms of ductility and strength.

ABSTRACT: In this paper we derive closed-form expressions for the autocorrelation functions of the response for uniform beam placed on elastic foundation and subjected to axial deterministic load. The excitation is represented as the white noise in time, and ‘rain-on-the-roof’ excitation in space. The boundary conditions of simple support are discussed. The normal mode approach is utilized, with explicit summation of the infinite series.

ABSTRACT: Experimental research is conducted to investigate the flexural behavior of corroded High Performance Steel (HPS) beams. Four beams with various corrosion damage are designed and subjected to electrochemical accelerated corrosion process. 3D scanning technology is employed to analyze the geometric features affected by the corrosion damage. Flexural tests are carried out, and the impact of corrosion on the flexural response is discussed. Considering the randomness of corrosion pits in each area, predictive models are proposed for the flexural strength of corroded beams with an idealized elastic-plastic and linear-hardening constitutive relationship model. An analysis comparing the proposed models with Chinese and American codes is made. Results show that increasing the corrosion damage leads to a decrease of discreteness in the residual sectional area and causes a transformation from noncompact to slender. A corrosion loss less than 10% leads to slight deterioration of both strength and stiffness degradation, while further corrosion damage results in a significant decrease. The depth and length of the buckling wavelength for corroded beams decreases gradually as the corrosion damage become more serious. The analytical models IEM and LHM or the GB50017-2017 may be suitable for predicting the lower and upper limit values of the ultimate flexural moment, respectively, and results predicted by AISC are conservative.

ABSTRACT: Single-layer aluminium alloy cylindrical shells are established using the powerful finite element (FE) software package ABAQUS. Furthermore, the probability distribution models of different random parameters in structural modelling are summarized. Forty seismic ground motion records are selected to consider the uncertainty of earthquakes. Sensitivity analysis of modelling parameters is conducted to determine the parameters with the greatest influence on seismic responses. The incremental dynamic analysis (IDA) method is performed on aluminium alloy cylindrical latticed shell structures with different structural parameters. After applying the damage index and structural performance levels of the latticed shells proposed in this paper, the probabilistic seismic demand model and probabilistic seismic capacity model are established. The seismic performance and the collapse capacity of different aluminium alloy cylindrical latticed shells are discussed based on the FE results. Furthermore, vulnerability curves are obtained according to the IDA results, which can be utilized to predict the failure probability and to evaluate the structural performance of aluminium alloy cylindrical latticed shells under different levels of earthquakes.

ABSTRACT: In this study, a series of new beam-column connections was proposed for large-span steel hyperbolic towers. The mechanical performance of the connections under an out-of-plane bending moment and a shear force was studied via experimental tests and numerical simulation. Different parameters such as the connector type, row number of the bolts, and plate thickness were considered during the study. The moment–
rotation curves and main failure modes of the connections were obtained and discussed in detail. The results showed that the new beam-column connections proposed in this paper had excellent bending stiffness and ultimate bending capacities. In addition, the finite element model of the connections was established by ABAQUS software, and the experimental and numerical results were compared. The comparison results showed that the numerical model could predict the moment–rotation curve and different failure modes accurately. The new joint system and study presented in this paper are relevant references for the study of large-span steel hyperbolic towers, which are increasingly becoming the prominent options compared with concrete cooling towers.


ABSTRACT: The postbuckling capacity of HSS plate girders is larger than that of mild steel plate girders because of the differences in material properties. Hence, to fully develop the postbuckling capacity, the intermediate transverse stiffener requirement of HSS plate girders could be different from that of mild steel plate girders. The plate girders concerned in this study are without a longitudinal stiffener. To investigate the aforementioned issue, the minimum moment of inertia requirements of intermediate transverse stiffeners in HSS and mild steel plate girders are studied through the finite element analysis (FEA). After the comparison between the FEA results and the results from the design equations in AASHTO LRFD, it states that the design equations in AASHTO LRFD could not be directly used in the design of intermediate transverse stiffeners in HSS plate girders. Hence, based on the FEA results, a new equation is proposed to predict the minimum moment of inertia requirement of intermediate transverse stiffeners in HSS plate girders. Furthermore, because of the difference in the resistant capacity between HSS and mild steel plate girders, the maximum additional out-of-plane deflection of the intermediate transverse stiffener in HSS plate girders corresponding to the ultimate shear resistance is significantly larger than that of the intermediate transverse stiffener in mild steel plate girders. Hence, there is a noteworthy adverse effect caused by the additional out-of-plane deflection of the intermediate transverse stiffener on the shear resistance of HSS plate girders with the maximum limit value set.


ABSTRACT: Vertical uplifting of the tank base is perhaps the most relevant characteristic of the seismic behaviour of unanchored cylindrical liquid storage tanks made of steel. When an unanchored tank is subjected to lateral loads due to the earthquake-induced hydrodynamic pressures, a portion of the base plate tends uplift locally. Analysis of the base plate uplifting of unanchored tanks implies many sources of nonlinear behaviour mechanisms such as the varying contact of the base plate with the foundation, large deflections, the material yielding and the plastic rotation of the base plate. This paper presents a comprehensive analysis of the partially uplifted base plate of two thin-walled cylindrical tanks (one slender and one broad). First, a nonlinear quasi-static cyclic analysis with a finite element model and a simplified model is carried out for each tank. Next, an efficient method for three-dimensional dynamic analysis is proposed and used in order to obtain the nonlinear time history response of each tank. The simplified non-linear model proposed in this paper was capable to provide a good estimation of both the rocking resistance of the liquid-loaded base plate and the stress distribution on the tank wall in contact with the foundation. A set of seven seismic ground motions was used for the time history analysis. Finally, the distribution of the tank wall stresses and the critical responses of the tanks are discussed. Both anchored and unanchored tanks may present a high compressive axial stress due to the seismic effect.


ABSTRACT: Multicell columns have becoming increasingly attractive in crashworthiness applications due to their high efficiency of material utilization. Meanwhile, an urgent need exists to develop new structures to achieve the aim of light weight without sacrificing crashworthiness. A novel multicell column with axially-varying thickness (AVT) is proposed in this study. Quasi-static crushing tests were firstly performed experimentally to investigate crushing behaviors. Subsequently, corresponding numerical simulation models
were built, validated, and used to conduct a parametric study. Finally, analytical equations for the mean crushing force for AVT multicell columns were derived and used to assess the crashworthiness of multicell columns according to SFE (super folding element) method. The numerical results agreed well with experimental results in terms of deformation mode and crushing forces, and the theoretical predictions were validated by the experimental results. It was concluded that the thickness gradient of AVT multicell columns could effectively reduce the initial peak crushing force while maintaining energy absorption capacity over a long crushing distance. From this perspective, the AVT multicell columns demonstrated competitive advantages over uniform columns as energy absorbers. Moreover, the analytical prediction could be a powerful tool for designing crashworthy structures.

Zhilin Zhong, Airong Liu, Yong-Lin Pi, Jian Deng, Hanwen Lu and Sen Li, “Analytical and experimental studies on dynamic instability of simply supported rectangular plates with arbitrary concentrated masses”, Engineering Structures, Vol. 196, pp Article 109288, 1 October 2019,
https://doi.org/10.1016/j.engstruct.2019.109288
ABSTRACT: This paper presents innovative analytical and experimental investigations of transverse dynamic instability of a simply supported rectangular plate attached with arbitrary concentrated masses owing to parametric resonance excited by an in-plane uniformly distributed periodic load along two opposite edges, which has not been reported in the literature. Based on the von-Kármán large deflection theory of thin plate, differential equations of transverse motion are established by using the Galerkin method. The analytical results of dynamic instability regions and nonlinear response curves of the plate having arbitrary concentrated masses for various instability modes are obtained. Tests investigating the influence of concentrated mass on the out-of-plane dynamic instability of various modes of a plate under the in-plane periodical loading presented in the paper are first time reported in the literature. Independent swept frequency tests are carried out to investigate instability frequency-amplitude regions for transverse dynamic instability of the plate and the test results agree well with the theoretical counterparts. It is shown that concentrated masses significantly influence out-of-plane dynamic instability of the plate. The investigation leads to the following novel findings: (1) When the concentrated masses are located at positions corresponding to non-zero modal displacements, the masses increase the rate of energy dissipation and damping ratio of the plate, leading to an increase of the critical excitation amplitude for dynamic instability of the plate, but to a decrease of the natural frequencies of the plate and the critical excitation frequencies for dynamic instability of the plate. (2) Under the same excitation amplitude, the excitation frequencies and the widths of excitation frequency region for dynamic instability of the plate as well as excitation frequency intervals for nonlinear dynamic instability of the plate decrease with an increase of the concentrated masses, which are located at positions corresponding to non-zero modal displacements. (3) When the concentrated masses are located at positions corresponding to zero modal displacements, the concentrated masses almost do not affect the critical excitation frequency and the widths of excitation frequency region for dynamic instability of the plate as well as excitation frequency intervals for nonlinear dynamic instability of the plate. (4) The widths of excitation frequency regions for dynamic instability of the plate as well as excitation frequency intervals for nonlinear dynamic instability of the plate increases when masses move away from the position of the largest modal displacement of the plate.

Zhaochao Li, Fujian Tang, Yizheng Chen, Xingxing Zou, “Stability of the pipe-liner system with a grouting void surrounded by the saturated soil”, Engineering Structures, Vol. 196, pp Article 109284, 1 October 2019,
https://doi.org/10.1016/j.engstruct.2019.109284
ABSTRACT: The rehabilitation of the deteriorated pipe is most commonly undertaken by installing a thin-walled close-fitting cured-in-place pipe (CIPP) polymer liner. The lining procedure results in a small shrinkage gap between the liner and its surrounding pipe. Such a small gap is expected to be eliminated by the grouting technique. However, a small crown grouting void is inevitable between the liner and its host pipe due to the bubbles in the grout and the gravity effect. This grouting void may result in different buckling behavior from the perfectly-confined liner. Therefore, this paper studies the confined liner with a grouting void under water pressure. Firstly, the analytical solutions are derived to predict the buckling pressure of the confined liner with a grouting void. Then, a two-dimensional (2D) simulated model is developed to trace the buckling and post-buckling pressure-displacement equilibrium path, from which the maximum pressure (critical buckling pressure) is obtained. After that, the numerical buckling pressure is compared and shows excellent agreement with the analytical solution, as well as other available experimental data. Finally, the parametric study indicates...
that the grouting void reduces the pressure capacity dramatically and should be avoided in engineering applications.


ABSTRACT: This research is dedicated to propose a high-performance locking-free triangular plane element, which is based on the novel mixed finite element formulation. The new element has six nodes with two transitional degrees of freedom at each node. To improve the displacement and stress responses, a proper mixed interpolation of the strain fields is propounded. Moreover, Mixed Interpolation of Tensorial Components (MITC) has been employed to alleviate in-plane shear locking. The advantage of the employed method is that no additional degrees of freedom are introduced, and spurious instabilities have not been seen. The tensorial forms of the equations are employed in this paper to summarize the formulations. The element passes the numerical tests, which are required to show the accuracy, capability and convergence rate in the structural analysis. Both linear and geometrically nonlinear problems can be solved by the presented formulations. To incorporate the large deformations, Total-Lagrangian formulation will be utilized. Due to completely trace the equilibrium paths of plane problems, especially those with snap-through behavior, a Generalized Displacement Control Method (GDCM) is used as a nonlinear solver. Outcomes of several benchmark problems and some new plane structures, which are analyzed separately, illustrate the high accuracy and advantages of the proposed element, especially in curved structures and nonlinear problems.


ABSTRACT: This paper studies the structural stability of thin-walled cylindrical pipe surrounded by soft bilayer medium, subjected to uniform pressure. A two-dimensional (2D) finite element model (FEM) is developed by assuming a plane strain condition. Both the geometric and material nonlinearities are taken into account for the simulation. An elastic pipe confined in a uniform soft medium and bilayer medium is investigated, and the numerical results are compared with available closed-form analytical solutions. Then, the steel pipe with inelastic properties is investigated by tracing the pressure-displacement equilibrium paths of the crown position where the maximum radial displacement occurs. The pressure shows a significant drop after reaching the maximum level (critical buckling pressure). Furthermore, a geometric thickness parameter is introduced to define the border of the upper and bottom layer of the bilayer medium around the steel pipe. In addition, parametric studies show that the response of the steel pipe is significantly affected by the initial gap, the out-of-roundness imperfections, the deformable soft bilayer medium, and insensitive to the yield stress of inelastic pipe and the friction in the pipe-medium system. Finally, the present numerical results show close agreement with the experimental results for the inelastic confined pipe with an initial gap between the pipe and medium.


ABSTRACT: Empty open-top cylindrical steel tanks are susceptible to buckling when subjected to external pressure due to wind or partial vacuum due to blocked vents. A “wind girder” is commonly used at the top of the tank wall to increase its strength against external pressure instability. The wind pressure varies around the circumference of the tank, but is relatively constant up its height. A series of cosine functions is typically used to describe the variation of wind pressure around the circumference. Expressions for stress resultants, that form the basis of widely used design specifications such as API 650 and SH 3046, are based on simple mechanical models that adopt simplified pressure distributions and ignore interactions between the wind girder and the tank shell. Furthermore, in classical treatments a tributary height is postulated for wind loading on the girder, and this height is taken as independent of the properties of the girder and the shell. The purpose of this study is to develop a rational procedure to determine the stress resultants in a wind girder. Pursuant to this goal, Vlasov’s curved beam theory is used to derive the stress resultants and displacements for an isolated wind girder under a pressure distribution defined in terms of cosine functions. A parametric study employing finite element analysis
is conducted to investigate the interaction of the wind girder with the tank shell. The stress resultants and the tributary height are found to be closely related to a shell-girder stiffness ratio that is devised in this study. This stiffness ratio was developed by considering the relative radial stiffness of the cylindrical shell and that of the wind girder. The changes in response quantities are expressed as functions of the shell-girder stiffness ratio. The developed expressions are presented in a form that is immediately useful for adoption into design standards.


ABSTRACT: Estimation of sound transmission loss (TL) due to the piezoelectric effects, as an attenuation of acoustic waves, is studied for a thick-walled piezo-composite cylindrical shell excited by an oblique incident plane wave. The cylinder is filled with and submerged in an acoustic medium. The three-dimensional (3D) exact theory of elasticity and piezoelectricity are engaged to model the cylindrical shell, while the classical Helmholtz equation governs the propagation of waves through the internal cavity and external surrounding fluid. A state space method, as well as the transfer matrix technique is utilized to describe the deformation and stress in the cylindrical shell. TL is calculated by exact integration over the shell’s outer surface. The validity of the current analytical solutions is cross-checked with various data from the simplified case found in the relevant literature as well as a finite element package known as Comsol Multiphysics. Parameter studies are conducted to investigate the effects of piezoelectric material properties, piezoelectric polarization direction, shell thickness ratio, electrical boundary conditions and functionally graded piezoelectric material (FGPM) on the sound transmission loss due to the piezoelectricity. New results and findings provide guidance of piezoelectric coupled with thick shell design for passive wave absorption.


ABSTRACT: This study investigates the buckling behavior of aboveground storage tanks (ASTs) subjected to storm surge and wave loads during hurricane events and explores the importance of dynamic effects on the buckling behavior. First, a computational fluid dynamics model is developed to estimate water pressures on ASTs subjected to wave loads. The modeling assumptions of this model are also validated with experimental data. Next, a methodology is presented to perform dynamic buckling analysis of ASTs subjected to surge and wave loads by adapting procedures commonly used for ASTs subjected to wind or seismic loads; the methodology is illustrated with a case study AST located in the Houston Ship Channel. For comparison, static buckling analyses are also performed to determine the significance of dynamic effects. Lastly, design of experiments principles and regression analyses are employed to investigate the effects of varying AST and loading parameters on the buckling behavior and the relative importance of dynamic effects. Results indicate that wave loads can significantly affect the buckling behavior of ASTs subjected to storm surge and need to be considered, while the dynamic effects induced by waves have a negligible influence on the buckling strength of ASTs. Simpler and computationally inexpensive static buckling analysis provides reasonable estimates for ASTs subjected to surge and waves. However, dynamic buckling analysis might still be required if the objective is to assess the post-buckling behavior of ASTs subjected to waves, rather than only to estimate the critical load.


ABSTRACT: In this paper elastic major-axis flexural buckling of thin-walled lipped channel column members with slotted webs is discussed. Though slotted webs are applied in order to enhance the thermal properties (this is why these members are also known as thermal studs), the slots have non-negligible effect on the mechanical behaviour. The primary aim of the presented research is to understand the behaviour, by identifying the major factors that influence buckling. As a tool, the recently developed constrained finite element method has been used, which makes it possible to separate the behaviour/buckling modes, as well as provides full control on the details of the calculations. It is found that, though other factors have some influence on the buckling results, the most important factor is the in-plane shear deformations of the slotted web, which may either be disregarded, or considered partially or fully in the calculations. An analytical model is also proposed for the calculation of
critical force of slotted-web members, able to consider the effect of shear deformations, the degrading effect of the slots on the axial and bending rigidly, as well as the effect of longitudinal second-order strain terms. Numerical studies have been conducted covering a wide range of column lengths and slot geometries. The results of the numerical studies confirm the applicability of the constrained finite element method, and show that the analytical model estimates the critical loads with reasonable accuracy.


ABSTRACT: This article is a study of vibroacoustic behaviour of sandwich shell panels with laminated composite faces under concentrated harmonic loading in a hygrothermal environment by means of a higher-order finite-boundary element model. The system governing equations of the vibrating structure are derived using the higher-order shear deformation shell theory coupled with finite element and boundary element approach. The corrugated composite material properties due to temperature and moisture variation are included in the model macroscopically. The stiffness, mass tensors and modal values of the hygro-thermally stressed vibrating panel are first obtained and the acoustic radiation responses are then computed by solving the Helmholtz wave equation discretized on the structure boundary. The proposed scheme is implemented via a domestic MATLAB program to compute the desired responses. The results for natural frequencies, critical buckling moisture, critical buckling temperature and radiated sound power are found to be more accurate when matched with the available benchmark solutions. Additional numerical simulations are also performed with commercial software to authenticate the correctness of the present model. Finally, numerous numerical experimentations are carried out to reveal the versatility of the present scheme. The influence of hygrothermal conditions, geometrical parameters, support conditions and lamination scheme of the faces on the hygro-thermo-acoustic responses of laminated composite sandwich shell panels are probed and deliberated in detail.


ABSTRACT: This study proposes a buckling-restrained brace (BRB) which is composed of round steel bar cores restrained by inner round steel tubes and an outer square steel tube. One advantage of using the round steel bar cores against the steel plates and tubes is that the bar-ends can be connected to the structural members using screw-joints. The cyclic loading tests were conducted on two test specimens to examine the hysteretic performance of the proposed BRBs. Test results revealed the applicability, restraining capacity, and end-coupler performance of the proposed brace. With an increase in the number of contraction allowance zones, efficacy and performance of the brace became more satisfactory. Furthermore, a theoretical method for designing the proposed BRB in a simplified and optimal way is discussed. For the creation of the design guideline, the braces were analyzed comparatively over a wide range of sections, lengths, and different load conditions, which are most suitable for low to mid-rise buildings. It was found that the design is governed by the heaviest components of the brace, and that the pin connection to the frame was a key component for optimal design.


ABSTRACT: Square concrete-filled double steel tubular (CFDST) beam-columns consisting of an internal circular steel tube have increasingly been utilized in composite building structures because of their high structural performance. This paper describes experimental and numerical studies on the structural responses of square thin-walled CFDST columns loaded eccentrically. Tests on twenty short square CFDST columns were undertaken that included sixteen columns under eccentric loading and four columns under concentric loading. The parameters examined in the experiments included the cross-sectional dimensions, the width-to-thickness ratios of outer and internal tubes and loading eccentricity. The measured ultimate strengths, load-shortening responses, load-lateral displacement curves, stress-strain curves and observed failure modes are presented. A numerical model incorporating the fiber analysis is developed that predicts the moment-curvature responses and axial load-moment strength envelopes of CFDST columns. The model explicitly accounts for the influences of
the confinement exerted by the internal circular steel tube on the core concrete and the progressive post-local buckling of the external steel tube. Efficient computer algorithms implementing the inverse quadratic method is developed to produce converged solutions to the nonlinear dynamic equilibrium equations generated in the analysis. Measurements from the tests are employed to validate the proposed numerical model. It is shown that there is a good agreement between theory and experiment. The computer model is utilized to demonstrate the significance of various parameters on the behavior of thin-walled short CFDST beam-columns.

ABSTRACT: An issue that frequently occurs during the installation of a spatial grid structure is that the tube exhibits bending under installation eccentricity, and the buckling stability of the tube significantly decreases. In the study, eccentric compression tests of circular steel tube with a bolt–ball joint are carried out, in which three types of joint specifications and three types of installation eccentricities are considered. The degradation characteristics of the buckling stability of circular steel tubes under different installation eccentricities are obtained via tests. Similar phenomena of tube buckling are observed under different installation eccentricities. Additionally, detailed finite element models with bolt threads are established via ANSYS. A comparison of simulation and test results indicate good agreement, and this confirms the validity of the numerical simulation method. Then, a total of eighteen simulation schemes for the buckling behavior of tube under different eccentricities are studied, regarding three different joint specifications with six tube specifications for each. The results indicate that the stability capacity decreases in an approximate linear manner with respect to the installation eccentricity in the range of 0–15 mm, which is consistent to the test results, and the decreasing speed slightly drops while the eccentricity goes large. A reduction factor is proposed as the reference for considering the reduction of stability capacity of the tube under different eccentricities in engineering design.

ABSTRACT: The sandwiched concrete in a circular double-skin concrete-filled aluminum tubular (DCFAT) column is subjected to the lateral confinement from inner and outer aluminum tubes. The effects of double-skin confinement have not been considered in the existing numerical models for the analysis of DCFAT stub columns. This paper describes a numerical model for the simulation of concentrically compressed circular DCFAT short columns. The numerical model is developed using the fiber element methodology. A new expression for determining the lateral confining pressures on the sandwiched concrete in circular DCFAT stub columns is proposed based on experimental results and incorporated in the computational technique. The stress-strain relations for determining the material performance of aluminum and confined sandwiched concrete are described. The numerical model is validated through comparisons with the experimental results of circular DCFAT stub columns. The numerical predictions correlate well with the tested column results, especially the aluminum stress-strain responses, load-strain responses, and ultimate axial load. A parametric study is performed to ascertain the influences of geometric and material variables on the behavior of DCFAT stub columns. The numerical results reveal that the use of aluminum instead of steel in a composite column could reduce the column weight by about 22.5%. The comparison of experimental results with the ultimate loads obtained by the design approaches specified in AISC 360-16, Eurocode 4, and Liang’s design model indicates that the codified methods generally either underestimate or overestimate the strengths of DCFAT columns, and Liang’s design model gives accurate predictions.

ABSTRACT: We propose a consistent higher-order beam theory in which cross-sectional deformations defining degrees of freedom are derived in the framework consistent with the mechanics of the proposed one-dimensional beam theory. This approach contrasts with earlier methods in which the procedure used to derive sectional deformations and the final beam theory are based on models of different levels. An advantage of the proposed consistent approach is that the generalized force-stress relation even for self-equilibrated forces such as bimoments can now be explicitly written. Also, sectional deformations can be systematically derived in closed form by the recursive and hierarchical approach. Accordingly, the accuracy in both displacement and stress can be adjusted so that obtained results are fully comparable with plate/shell results. We mainly conduct analysis of membrane deformations occurring in thin-walled box beams subjected to doubly symmetric loads such as axially-loaded forces. This case is elaborately chosen to better explain the fundamental concepts of our newly proposed approach. A brief description is also provided to show that these concepts are applicable to other types of loads such as bending and torsion. We confirm the accuracy of the theory proposed here by calculating stress and displacement in several examples.


ABSTRACT: The reinforced concrete filled composite plate shear walls (CPSW) system employs two steel plates with infilled reinforced concrete. Based on an experimental study of four flexural critical CPSW specimens under high axial compression ratio ranging from 0.313 to 0.542 and reciprocal lateral load, the seismic performance of shear studs connected CPSW systems with orthogonal reinforcement in wall web and longitudinal reinforcement in boundary element is examined. The failure mode, load-displacement relationship, flexural strength, displacement capacity, stiffness degradation and equivalent damping ratio are reported in detail. The compression yielding of boundary element was observed before its local buckling, and yielding of faceplate was observed before faceplate local buckling. The fracture failure of the boundary element and crushing of infilled concrete were observed at the descending branch. The test results showed that the CPSW systems connected by shear studs had adequate ductility, and the ultimate drift ratio ranged from 1.17% to 1.78%. The overstrength ratio of the moment capacity ranged from 1.06 to 1.18 in the test. Based on the plasticity theory, the strain measurement results of steel faceplates were used to calculate the shear force contribution of the steel plate. The influence of axial compression ratio on the internal force transfer and ultimate capacity is investigated. In addition, a database of 47 flexural critical CPSW specimens with boundary element was established, and the overstrength ratio for the anchorage design was proposed with adequate safety.

Dejun Liu (1,2), Jianping Zuo (1), Jun Wang (3), Pan Li (4), Kang Duan (5), Dongming Zhang (2) and Song Guo (1)
(1) School of Mechanics and Civil Engineering, China University of Mining and Technology, Beijing 100088, China
(2) Key Laboratory of Geochemical and Underground Engineering of Minister of Education, Tongji University, Shanghai 200092, China
(3) School of Civil Engineering, Shandong Jianzhu University, Jinan 250100, China
(4) School of Urban Rail Transportation, Soochow University, Suzhou 215131, China
(5) School of Civil and Hydraulic Engineering, Shandong University, Jinan 250061, China


ABSTRACT: Concrete-filled steel tubular (CFST) support is an innovative and effective support technology, which has been broadly applied in underground roadways. However, failure is still possible, and the primary failure locations are commonly the vault and the springline. In order to reveal the failure mechanism and provide an effective solution, the inner forces of a circular CFST support were investigated analytically. To improve the flexural performance, firstly, the flexural behavior of CFST beams strengthened by welded steel at soffit was investigated experimentally. A total of 6 beams were tested under a four-point bending load, and the investigated parameter was welded steel diameter. The corresponding nonlinear three-dimensional finite
Richard O’Hegarty (1), Roger West (2), Aidan Reilly (1) and Oliver Kinnane (1)
(1) School of Architecture, Planning and Environmental Policy, Richview Research, University College Dublin, Ireland
(2) Department of Civil, Structural and Environmental Engineering, Trinity College Dublin, Ireland

ABSTRACT: The wrinkling process of a monolayer silicene sheet subjected to an increasing in-plane shear strain is investigated by molecular dynamics (MD) simulation. The results show that due to the weak in-plane stiffness of silicene, wrinkles can initialize and grow rapidly as shear displacements increase. Finally, an ordered arrangement of wrinkles can be formed, with crests parallel to each other and approximately the same size. The wavelength and amplitude of the wrinkles are largely dependent on the shear strain until the strain reaches a critical value that makes the size of wrinkles controllable. A continuum model is also employed to estimate the size of wrinkles, which is consistent with the MD simulation results. The findings in this work could advance understanding of the shear resistance of silicene sheets and promote their potential applications in strain sensors, flexible electronics and energy storage devices.

Yen-Chen Chiang and Sukru Guzey (Lyles School of Civil Engineering, Purdue University, West Lafayette, IN 47907, USA), “Dynamic analysis of aboveground open-top steel tanks subjected to wind loading”, Engineering Structures, Vol. 198, Article 109496, 1 November 2019, https://doi.org/10.1016/j.engstruct.2019.109496

ABSTRACT: Aboveground steel tanks are prone to buckle under wind loading if they are empty. Geometrically nonlinear explicit dynamic analysis of empty open-top tanks subjected to wind loading are conducted using element model was established in the ABAQUS software and was validated using the experimental results. Then, the effect of welded range and welded location on the support bearing performance was investigated numerically. Finally, the proposed method was validated by an application example. Results show that CFST support bearing performance is greatly improved when the lateral pressure coefficient is equal to 1.0, because there is no bending moment, and the thrust force is equally distributed along the perimeter of the support. When the lateral pressure coefficient is not equal to 1.0, the sections at vault, invert, and springline, where the maximum bending moments located, are the most vulnerable. Welding steel at locations dominant by the bending moment is an effective way to improve flexural bearing capacity. The optimal flexural strengthening method for the support is welding steel at the vault and the springline, respectively, named ‘three-arcs welding.’
finite element analysis (FEA). Tanks with five different height to diameter aspect ratios, 4.0, 2.0, 1.0, 0.4, and 0.2, are adopted. Tanks are subjected to a gust of wind which fluctuates in magnitude over time to investigate whether a minor fluctuation, 10% of the average pressure, will trigger resonant behavior. Tanks with geometrical imperfections are also investigated using both dynamic analysis and static geometrically nonlinear analysis including imperfection (GNIA). It is found that, no matter if the tank does or does not have geometrical imperfections, resonance is not observed. Thus, a static analysis may be adequate for a practical tank design. The natural vibration frequencies of empty open-top tanks are studied as well, and comparisons with theoretical solutions and FEA results from the literature are presented. The effective modal mass is discussed to investigate the dynamic characteristics of the tanks examined. Insights for conducting an explicit dynamic analysis, including converged mesh size and time step limits, are also presented.

Ji-Ke Tan (1), Yu-Hang Wang (1), Mei-Ni Su (2), Hai-Bin Zhang (3) and Yuan-Yuan Peng (4)
(1) School of Civil Engineering, Chongqing University, Chongqing 400045, China
(2) School of Mechanical, Aerospace and Civil Engineering, University of Manchester, M1 3NJ, UK
(3) Laiwu Iron & Steel Group Ltd., Laiwu 271100, China
(4) Department of Capital Construction and Planning, Chongqing University, Chongqing 400045, China

ABSTRACT: In this paper, a new type of steel section is proposed comprising adjacent H-sections linked together by intermediate steel plates welded along their flanges. Experiments on three hot-rolled steel built-up H-sections and five columns infilled with concrete are conducted, with results showing that both variants having much better ductility compared to conventional columns (i.e. hollow section columns and concrete filled steel tube (CFST) columns). Experimental results showed that the bearing capacity of the built-up hot-rolled steel hollow section column improved by 45.1% to 55% after it was filled with concrete. A finite element software ABAQUS is used for parametric study. The newly developed finite element models were validated against test results in terms of failure modes and load-displacement curves. A total of 482 numerical results, 132 hot-rolled steel built-up section columns and 350 concrete-filled built-up section columns, have been generated. Based on the experimental and numerical results, the compressive behaviours of hot-rolled steel built-up section columns and concrete-filled built-up section columns are studied. A new design method for the compression capacity of these two types of columns is proposed. It is found that the newly proposed design method could provide accurate and consistent predictions – the mean value of experimental to predicted results are 0.963 for hollow section columns (with coefficient of variation being 0.061) and 1.04 for composite section columns (with coefficient of variation being 0.043).

Zhaochao Li (1), Junxing Zheng (1), Yizheng Chen (2) and Zhen Zhang (1)
(1) Department of Civil, Construction and Environmental Engineering, Iowa State University, Town Engineering Building, Ames, IA 50011, USA
(2) Department of Electrical and Computer Engineering, Clemson University, Clemson, SC 29634, USA

ABSTRACT: This paper investigates the stability behavior of the thin-walled functionally graded material (FGM) cylinders encased in the saturated permeable medium. Water pressure generates at the outer surface of the cylinder, resulting in “single-lobe” or “two-lobe” deformations due to the confinement of the medium. The critical buckling pressure of the FGM cylinder is obtained analytically by exploring the total potential energy function. It is found that the two-lobe deformation sustains a higher pressure capacity than the single-lobe deformation. A two-dimensional (2D) finite element model (FEM) is developed to obtain the maximum pressure (buckling pressure) by plotting the pressure-displacement equilibrium curves. The comparison shows that the analytical solutions are in very close agreement with the numerical results in terms of the buckling pressure, as well as the equilibrium paths. Finally, the effect of volume fraction exponent (n) on the hoop strain, stress, force and bending moment through the cylinder wall is fully examined, indicating the non-symmetrical distribution of the material properties to the mid-surface of the FGM cylinder has a significant influence on the buckling pressure.

https://doi.org/10.1016/j.engstruct.2019.109472

ABSTRACT: Stochastic dynamic analysis of offshore structures considering both fluid-structure interaction and system uncertainties is a challenging research task. This paper proposes a novel method to evaluate the statistical characteristics of offshore structural responses with consideration of uncertainties in the fluid and structure. The fluid behavior is simulated by a finite number of particles with particle finite element method (PFEM), and the dynamic behavior of the offshore structure is modelled with finite element method (FEM). A PFEM-FEM scheme is used to model the fluid-structure interaction. To evaluate the statistical characteristics, spectral representations method is used for uncertainty propagation. The output of fluid particles position/pressure, structural vibration, etc. are represented by using polynomial chaos (PC) expansion, and their coefficients are obtained from the least squares method. Statistical characteristics of the responses, such as mean value and variance, can be evaluated with the obtained PC coefficients. Three numerical examples are studied in this paper. The first example is a simple structural model, which is used to demonstrate the convergence and accuracy of the uncertainty analysis method. The second example is a benchmark dam break problem. Statistical characteristics of the fluid particles position due to uncertainties in the mass density are evaluated. Numerical results are verified with experimental data and observations. In the third example, PFEM-FEM scheme is used to conduct fluid–structure interaction analysis. The marine riser structure is modelled with beam elements. In the fluid domain, PFEM is used. Uncertainties in both the fluid domain and structural domain are considered. Results demonstrate that the proposed approach can be used to evaluate the statistical characteristics of responses in the fluid-structure interaction analysis accurately and efficiently.

W. Zhang (1), J.H. Yang (1,2), Y.F. Zhang (3) and S.W. Yang (1)
(1) Beijing Key Laboratory of Nonlinear Vibrations and Strength of Mechanical Structures, College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, PR China
(2) Beijing Vocational College of Agriculture, Beijing 102208, PR China
(3) Faculty of Aerospace Engineering, Shenyang Aerospace University, Liaoning 110136, PR China


ABSTRACT: In this paper, the nonlinear vibrations of the laminated composite piezoelectric cantilever plate subjected to the transverse and in-plane excitations are investigated. Based on the Reddy’s third-order plate theory and von Karman nonlinear strain-displacement relation, the nonlinear partial differential governing equations of motion are established for the laminated composite piezoelectric cantilever plate under combined the transverse and in-plane excitations by applying Hamilton’s principle. Employing Galerkin’s approach, we discretize the continuous nonlinear dynamic equations of motion into the ordinary differential equations with four modes. Substituting the actual geometric and physical parameters of the laminated composite piezoelectric cantilever plate into the governing equation of motion, we use numerical method to investigate the effects of the lay-up parameters and the geometric parameters on the dimensionless natural frequencies of the cantilever plate. The amplitude-frequency response curves and the basin boundary diagram of two coexisting steady-state solutions are plotted for the laminated composite piezoelectric cantilever plate. The nonlinear dynamic responses of the laminated composite piezoelectric cantilever plate under combined the transverse and in-plane excitations are investigated by changing the lay-up parameters, the transverse excitation, the voltage excitation and the in-plane excitation. The periodic, the quasi-periodic, the chaotic motions and the nonlinear stiffness characteristics can be found. The nonlinear dynamic behaviors help us to optimize the structural and physical
parameters of the laminated composite piezoelectric cantilever plate under combined the transverse and in-plane excitations.

Salam Al-Rubaye (1), Taylor Sorensen (1), Robert J. Thomas (2) and Marc Maguire (1)
(1) Department of Civil and Environmental Engineering, Utah State University, Logan, UT 84322-4110, USA
(2) Department of Civil and Environmental Engineering, Clarkson University, Potsdam, NY 13699-5710, USA


ABSTRACT: Partially composite sandwich wall panels (SWP) have been used in the construction industry for at least twenty years. Currently there is limited codified guidance for designers of partially composite concrete SWP, but they are being designed safely and routinely. Design is often guided by the composite connector manufacturers who sell proprietary composite connectors often using a variation of truss-type matrix methods for prediction of elastic behavior of SWPs. The purpose of this paper is to quantify the accuracy of such a model in a uniform manner by developing a generalized version of these matrix models called the beam-spring model (BSM). The primary benefits of the model are its simplicity and versatility making it suitable for design and variations of this model are already in use today. Its accuracy was established in this paper by comparing to 51 specimens from the literature and found to be similar to that of other methods related to strength and cracking of concrete members in the literature. These results indicate that this BSM, or the very similar methods that are already standard practice, provides an adequately safe elastic analysis. On average, the BSM predicted cracking load within 2% with a coefficient of variation (COV) of 7%, out-of-plane panel stiffness within 3% with a COV of 17%, and cracking deflection within 2% with a COV of 18%. These results also indicate that the United States precast industry’s use of (math) for predicting the cracking moment is acceptable for partially composite precast panels. A parametric study performed with the BSM presents several different design situations and can be used as a rudimentary design tool for preliminary behavior and arbitrary connectors.

Giulia Tomasello (1), Sigrid Adriaenssens (2) and Stefano Gabriele (3)
(1) Department of Engineering, Roma Tre University, Italy
(2) Form Finding Lab, Department of Civil and Environmental Engineering, Princeton University, United States
(3) LaMS – Modeling and Simulation Lab, Department of Architecture, Roma Tre University, Italy


ABSTRACT: Civil thin shell structures are generally designed with the objective to achieve an ideal membrane behavior and pursuing criteria of structural efficiency and minimization of the material used. During the shell form finding process, gravity loads are considered, while the role of horizontal loading is ignored. Today shells with complex geometries are being designed and built, and are used to shelter people during extreme events such as earthquakes, but the dynamic behavior of civil thin shells has always been subjected to limited research. This paper investigates the effects of dynamic loading on the behavior of civil thin shells form-found under gravity loads. A two-phased methodology is presented. In the first phase a modal analysis of the shell is performed and the R-Funicularity Ellipse Method is applied to the modal stress distribution obtained to observe which modes show a more funicular behavior. In the second phase, the structure is analyzed performing a time-history analysis under single and multi frequencies spectra defined using ad hoc functions based on the outputs of phase one. The results of such a phased approach applied to benchmark studies, show that the frequency content of the different areas of the shell can give insights onto its membrane behavior. Finally the form-found shell is analyzed under the action of the L’Aquila Earthquakes (Italy, 2009) to prove how the methodology proposed can help to identify the vulnerable area of a shell under a real seismic event.

Zhi-Yu Wang (1), Fang Yuan (1), Yang Chen (1), Qingyuan Wang (1), Tao Chen (2), Xiafang Zhou (1) and Zifeng Liu (1)
(1) Key Laboratory of Deep Underground Science and Engineering (Ministry of Education), School of Architecture and Environment, Sichuan University, Chengdu, PR China
(2) Key Laboratory of Performance Evolution and Control for Engineering Structures (Ministry of Education), Tongji University, Shanghai, PR China

ABSTRACT: Slender trapezoidal corrugated web does generally possess notable post-buckling capacity with certain reserve of shear resistance. Repeated secondary bending stresses due to post-buckling at the boundaries of the subpanel of the trapezoidal corrugated web, however, may result in potential local fatigue failure. A series of fatigue experimental tests on the slender profiled web girders with stiff flanges subjected to the action of predominant shear is outlined. The fatigue test results are presented in terms of stiffness deterioration and fatigue failure induced by out-of-plane deflection as the applied load exceeds the elastic critical load. It was found that fatigue cracks due to predominant shear action propagate much faster than these due to combined shear and tearing. Recommendations are prescribed for evaluating the fatigue resistance of post-buckled slender trapezoidal corrugated webs with appropriate detail categories codified in the Eurocode 3. Previously published analytical models correlating normalized shear resistances with relative plate slenderness ratios are compared against test data and discussed for their applicability. Based on the test results, a new mathematical representation is derived based on von Kármán’s effective width concept for ultimate loads. The derived formula is demonstrated to correlate well with test data since reasonable allowances are given for the tension field theory and geometric characteristics of the trapezoidal corrugated webs.

Xianggang Zhang (1,2) and Xiang Gao (2)
(1) Henan Province Engineering Laboratory of Eco-architecture and the Built Environment, Henan Polytechnic University, Jiaozuo 454000, China
(2) School of Civil Engineering, Henan Polytechnic University, Jiaozuo 454000, China


ABSTRACT: The research purpose was to explore the hysteretic behavior of recycled aggregate concrete-filled square steel tube (S-RACFST) columns. With the replacement ratio of recycled coarse aggregate and axial compression ratio as the variation parameters, 6 S-RACFST columns were carried out for the hysteretic behavior test, and the hysteretic behavior indexes such as failure mode, hysteretic curve and backbone curve were investigated through the test. Based on the experimental research, a feasible finite element analysis model was established. Meanwhile, the finite element expansion analysis of 32 full-scale specimens was carried out to reveal the influence of the design parameters on the hysteretic behavior indexes. It is shown that the damage of the specimen is mainly concentrated at the column roots, the square steel tubes bulge outwards in a “lantern” shape, and the interior recycled concrete has a large area of crushing and spalling. The hysteretic curves of all the test specimens are full and stable, the backbone curves are relatively complete with a smooth descending segment. The hysteretic behavior indexes of all full-scale specimens are less affected by the replacement ratio of recycled coarse aggregate, while the parameters such as steel ratio, aspect ratio and axial compression ratio have an enormous impact on the hysteretic behavior indexes such as peak load-bearing capacity, ductility and energy dissipation.

T. Jiang (1), X.M. Wang (1), G.M. Chen (2), J.J. Zhang (3) and W.P. Zhang (3)
(1) Space Structures Research Center, Department of Civil Engineering, Zhejiang University, Hangzhou 310058, China
(2) State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou 510641, China
(3) School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou 510006, China


ABSTRACT: Waste brick accounts for a significant fraction of China’s construction and demolition (C&D) waste. A new reprocessing approach in which the waste brick is crushed into blocks (recycled brick blocks, RBBs) distinctly larger in size than normal-sized aggregate and mixed with fresh concrete to form a new type of compound concrete (recycled brick block concrete, RBBC) is proposed in this paper. To improve the compressive behavior of RBBC, an outer fiber reinforced polymer (FRP) tube is used in this study as both the confining and protective device for RBBC; it simultaneously serves as a stay-in-place formwork (i.e., RBBC-
filled FRP tubes, RBBCFFTs). Compression tests were conducted on RBBC and RBBCFFTs with the mix ratio and size ratio of RBBs and thickness of FRP tube as variables. The test results show that RBBC has a compressive strength between those of the RBBs and the fresh concrete, and it can derive significantly enhanced strength and deformability under FRP confinement. However, the tested RBBCFFTs exhibited increased discreteness in compressive behavior owing to the large difference in strength between the RBBs and the fresh concrete, and the inhomogeneous spatial distribution of RBBs. In addition, the first portion of RBBC’s stress–strain curve appears elongated under FRP confinement. This phenomenon is believed to be due to the delay in formation of the major cracks in RBBC when it is confined in an FRP tube, allowing the integrity of RBBC to be sustained until a higher axial stress level than when the FRP tube is absent. Finally, a design-oriented stress–strain model for RBBCFFTs is developed within the framework of Lam and Teng’s design-oriented stress–strain model for FRP-confined normal concrete. The proposed model is shown to have reasonably good accuracy.

J.M. Rotter (1), R.J. Goodey (2) and C.J. Brown (3)
(1) University of Edinburgh, Institute for Infrastructure and Environment, The King’s Buildings, Edinburgh EH9 3JN, UK
(2) City, University of London, School of Mathematics, Computer Science & Engineering, London EC1V 0HB, UK
(3) Brunel University London, College of Engineering Design and Physical Sciences, Uxbridge UB8 3PH, UK


ABSTRACT: An experimentally validated finite element model of filling pressures in rectangular silos with flexible walls is used to predict the stress regime in the stored solid in squat and intermediate aspect ratio silos. The model predicts the state of stress in the stored solid and the pressures imposed on the flexible walls of the silo. The non-uniform horizontal pressure distributions at each depth at the end of filling are explored. It is known that an empirical relation for the horizontal pressure variation on each straight wall derived from experimental observations in an earlier study closely matches the computational predictions. The coefficients of this relation are found to vary with depth below the stored solid surface, and depend on the relative stiffness of stored solid and the silo wall. Following many calculations involving different solids, an empirical relationship is derived that is suitable for practical design for a range of different stored solids for which relevant properties are known. The resulting expression is well suited to the practical determination of filling pressures in rectangular silos, and provides a silo design pressure proposal that is based on theoretical, rather than empirical findings.


ABSTRACT: Numerous size effect laws of concrete materials have been proposed by scholars, while the size effect laws for concrete filled steel tubular members are still under study. A three-dimensional meso-scale numerical model that can consider the heterogeneities of concrete and concrete-steel tube interactions was established to study the size effect in concrete filled steel tubular columns. The failure behavior of axial-loaded circular/square concrete filled steel tubular columns having different structural sizes under different lateral constraints (represented by confinement coefficients) were investigated based on the meso-scale method. The influence of lateral confinement on nominal axial compressive strength for concrete columns and corresponding size effect were also explored. As the simulation results indicating, with increasing the specimen size, the nominal axial compressive strength decreases, and size effect is weakened as the confinement coefficient increases. Moreover, combining with the influencing mechanism of steel tube on compressive strength for axial-loaded concrete column, a theoretical formula that can describe the influence of lateral constraint on size effect was established according to the available size effect law for concrete materials. Comparing with the simulation results and reliable test data, the accuracy and rationality of the theoretical formula is well verified.

Chuan-Chuan Hou (1,2), Lin-Hai Han (2), Fa-Cheng Wang (2) and Chang-Ming Hu (2)
(1) School of Transportation Science and Engineering, Beihang University, Beijing 100191, PR China
(2) Department of Civil Engineering, Tsinghua University, Beijing 100084, PR China

ABSTRACT: This paper presents an experimental and numerical study on the lateral impact behaviour of concrete-encased concrete-filled steel tubular (CFST) box beams and columns. A total of 20 specimens with test parameters including the impact energy, the boundary conditions and the axial load level, are tested under a drop hammer impact apparatus. The experimental results, namely the failure modes, the time-history of the impact force and mid-span deflection, as well as the whole impact process, are analysed. It shows that the specimens fail in a shear-flexural pattern under the impact. The major features of the impact force and mid-span deflection curves are summarised and analysed. The influence of test parameters on the impact behaviour of the specimens, namely the peak value of the impact force, the impact duration and the residual mid-span deflection, are also discussed. A finite element analysis (FEA) model is established to investigate the composite effects between the RC and CFST components. The analysis shows that the RC component is the major impact resistance component in the structure. The CFST components, on the other hand, is well protected by the RC component and do not experience severe damage. The composite effects make the structure safer under impact loading and easier to be restored after impact.

Dinh Gia Ninh (1,2), Nguyen Duc Tien (2) and Vu Ngoc Viet Hoang (2)
(1) Department of Aerospace Engineering, Embry-Riddle Aeronautical University, Daytona Beach, FL 32114, United States
(2) Department of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Viet Nam


ABSTRACT: The paper focuses on nonlinear dynamical responses of circular cylindrical shell made of carbon nanotubes reinforced polymer conveying to internal and external fluid flow. The fluid flows are assumed incompressible. The governing equations are derived from the Third order shear deformation theory (TSDT), the fluid velocity potential, then using the Galerkin’s technique and the fourth-order Runge-Kutta method to give the characteristics of nonlinear dynamics of fluid-structures interaction. The product of the velocity U.V of the two liquid streams (swirling flow and straight flow) is considered to investigate the stable domain of the structure under the effect of two velocity factors. In addition, the dynamical behaviors as time histories and bifurcation diagram as well as the effects of materials, geometries and the critical velocities of losing stability caused by internal and external flow fluid are scrutinized in the present. The obtained results are also compared and validated with those of other studies and can be used as benchmark solutions for an analytical approach serving in further research.

Soner Guler (1), Demet Yavuz (2) and Muhammet Aydin (1)
(1) Department of Civil Engineering, University of Yuzuncu Yil, Van, Turkey
(2) Department of Civil Engineering, University of Ege, Izmir, Turkey


ABSTRACT: The main aim of this study is to compare the axial load, ductility, and toughness capacities of square concrete-filled carbon steel (CFCST), stainless steel (CFSST) and aluminum tube (CFAT) columns filled with plain concrete, single (steel) and hybrid (steel + synthetic) fiber-reinforced concrete under axial compression. To this end, the enhancement in axial load, ductility and toughness capacities of steel and hybrid fiber-reinforced CFCST, CFSST, and CFAT columns were obtained with regard to fiber volume ratio (0.5 and 1.5%), compressive strength of concrete (30 and 70 MPa) and the steel tube thickness (2, 3 and 4 mm). A total of 99 hollow, steel and hybrid fiber-reinforced CFCST, CFSST, and CFAT columns were tested under axial compression. The results showed that although the use of steel and synthetic fibers in single and hybrid form is very limited for enhancement of the axial load capacities of CFAT, CFCST and CFSST columns, the enhancement in ductility and post-peak toughness capacities are notable especially for CFCST and CFSST columns. However, the effects of steel and synthetic fibers on post-cracking behavior of the CFAT columns are not significant due to early rupture of AL tubes that cause highly brittle behavior after first peak load. In
Mateus Zimmer Dietrich (1), Adenilcia Fernanda Grobério Calenzani (2) and Ricardo Hallal Fakury (3)
(1) Department of Civil Engineering, Federal Institute of Espírito Santo, Nova Venécia, ES, Brazil
(2) Department of Civil Engineering, Federal University of Espírito Santo, Vitória, ES, Brazil
(3) Department of Structural Engineering, Federal University of Minas Gerais, Belo Horizonte, MG, Brazil
ABSTRACT: In hogging bending moment regions of continuous and semi-continuous steel-concrete composite beams, the bottom flange of the steel profile is compressed, and if the web is not rigid enough to avoid lateral bending, it will undergo distortion, causing a lateral displacement and a rotation of the compressed flange. These displacements characterize the mode of instability called lateral-torsional buckling (LTB). European Standard EN 1994-1-1:2004 presents a procedure to verify the ultimate limit state of LTB based on the elastic critical moment that depends on the rotational stiffness of the composite beam. In this paper, numerical models, simulating the inverted U-frame model for inner and edge composite beams, were developed with the support of the software ANSYS to evaluate the procedure presented by EN 1994-1-1:2004 to calculate the rotational stiffness of steel-concrete composite beams. The numerical results agreed reasonably well with the predictions of EN 1994-1-1:2004, however, the accuracy of the analytical procedure can be improved by a small adjustment in the slab rotational stiffness equation. It was also observed that, in certain situations, the rotational stiffness of composite beams can be determined in a simplified manner only as function of the value of the rotational stiffness of the web of the steel profile, without loss of precision.

Chun-Lin Wang (1), Yuan Gao (1), Xiaoqiang Cheng (1), Bin Zeng (2) and Senlin Zhao (3)
(1) Key Laboratory of Concrete and Prestressed Concrete Structures of the Ministry of Education, Southeast University, Nanjing 210096, China
(2) Central Research Institute of Building and Construction, MCC Group, Beijing 100088, China
(3) Zhejiang Building-Tech Energy Dissipation Technology Co., Ltd, China
ABSTRACT: For the development of buckling-restrained braces (BRBs) with high bearing capacity and light weight, a new type of all-steel buckling-restrained braces with H-section steel core (HBRBs) is proposed. The restraining member of the new HBRB mainly consists of the restraining plates and the steel channels. The outside of flange of the H-section steel core is restrained by the restraining plate, the edge parts of the inside of flange are restrained by the steel channel, and web of the H-section steel core is unrestrained. There is adequate operation space for welding stiffeners in the elastic segment of the H-section steel core, and the cross-section of the restraining member is uniform along the longitudinal direction. Thus, the processing complexity of the new HBRB is reduced. First, cyclic tests are performed on the new HBRBs and one conventional HBRB of which the inside of flange is unrestrained. Then, numerical simulations are carried out to further investigate the hysteretic performance and deformation mode of the new HBRB. Test and numerical simulations demonstrate that the new HBRB shows stable hysteretic performance, and the energy absorption capacity of the HBRB can be significantly improved when the inside of flange is partially restrained. Decreasing the restrained width of the inside of flange is capable of reducing the normal contact force between the H-section steel core and the restraining member, also reducing the compression strength adjustment factor of the new HBRB. There is no visible decrease in the compressive strength of web with the strain amplitude, demonstrating that web can be effectively restrained by the top and bottom flanges.

Alifujiang Xiamuxi (1), Maimaitiyasen Maimaitimin (1), Xiaorui Liu (1) and Akira Hasegawa (2)
(1) College of Architecture and Civil Engineering, Xinjiang University, Urumqi, China
(2) Department of Environmental and Civil Engineering, Hachinohe Institute of Technology, Hachinohe, Japan

ABSTRACT: Experimental investigations were conducted to understand the effects of transverse reinforcements on the overall performance of a circular section reinforced concrete-filled steel tubular (R-CFST) column subjected to axial loads. Compression tests were then conducted with 34 column specimens divided into three test series. In these tests, the transverse reinforcements were configured in spiral and flat hoop patterns, and the flat hoop patterns were configured with tightly and loosely arranged longitudinal spacing. Additional test variables included the specimen size, strength of materials, and ratio of longitudinal reinforcements. Based on the experimental results, a comprehensive analysis was performed on the load transfer performance, ductility, confinement, composite effect, and failure mode. The analysis results demonstrated the following: the before-peak loading performance and ultimate load-bearing capacity are not relevant to the hoop patterns; differences in spacing of the flat hoops will not cause significant changes in the mechanical performance, and thus larger spacing is recommended to obtain a time- and work-saving construction process; compared to flat hoops, spiral hoops will improve the ductility and post-peak loading performance further, and thus, the spiral hoop is recommended when the ductility or seismic performance is the main concern. Moreover, prediction methods for the ultimate load-bearing capacity of the member were investigated, and a new equation was proposed.


ABSTRACT: This paper investigates the nonlinear stability and buckling behavior of the composite functionally graded material (FGM) arches subjected to pressure and temperature loadings. By introducing an admissible displacement function, the total potential energy is expressed explicitly following the thin-walled shell theory. The nonlinear equilibrium equations are calculated by the variation of the potential energy function, and the critical buckling pressure is predicted analytically. The verification is taken by the numerical simulation that traces the pre- and post-buckling equilibrium paths, indicating that the numerical results are in good accordance with the analytical predictions. It is found the temperature rise increases the thermal upward displacement, which is beneficial to the buckling pressure, and reduces Young’s modulus, which is unbeneficial to the buckling pressure. Therefore, the buckling pressure is nonlinear to the temperature rise. Finally, a series of parametric evaluations are mainly focused on the effects of volume fraction exponent and temperature rise on the distributions of hoop strain, stress, force and bending moment.

Yong Yang, Yang Chen and Shiqiang Feng (School of Civil Engineering, Xi’an University of Architecture & Technology, Xi’an, Shaanxi 710055, China), “Study on behavior of partially prefabricated steel reinforced concrete stub columns under axial compression”, Engineering Structures, Vol. 199, Article 109630, 15 November 2019, https://doi.org/10.1016/j.engstruct.2019.109630

ABSTRACT: This paper aims to investigate the axial behavior and axial ultimate strength of partially prefabricated steel reinforced concrete (PPSRC) stub columns subjected to axial load. Eleven solid PPSRC column specimens and three hollow PPSRC column specimens were tested to examine the failure mode, the load-displacement response and the axial bearing strength of PPSRC columns. The effects of stirrup spacing, cast-in-place concrete strength and flange shear studs on the axial performance of PPSRC columns were also analyzed. Furthermore, an effective confinement stress from steel shape on the concrete was established on the basis of existing literature. The test results indicated that the PPSRC stub columns exhibited high axial load capacity and good deformability. Higher strength of inner concrete and smaller spacing of stirrups results in higher axial resistance, but the shear studs on the flange of steel shape were not effective on enhancing the axial-carrying capacity. Calculation formula to predict the compressive capacity of PPSRC columns was proposed based on the tested results. By comparison, it was found that the calculated results agreed well with the test results, which indicated that the proposed method had adequate accuracy and can be used in engineering application.

ABSTRACT: In this paper, experimental and numerical investigations into the performance of circular unfilled and concrete filled stainless steel tubular stub columns strengthened by carbon steel bars welded to the inner surface were presented. The carbon steel bars were fabricated to be a structural component of the stub column and directly participate in supporting the axial load. Ten stub columns of 141.3 mm outer diameter and 3.4 mm thickness were tested under axial compression load for different numbers and sizes of carbon steel bars. 3D finite element models (FEMs) were carried out for the strengthened stub columns by using finite element program ABAQUS and validated with the experimental results. The validated numerical work was utilized to carry out a parametric study to assess (i) the practical configuration of the carbon steel bars, (ii) the possible reduction of stainless steel thickness, which can be compensated for by the addition of carbon steel bars, (iii) the effect of the diameter to thickness ratio (D/t) on the stub column performance. The numerical work was further utilized to generate extensive data to validate the load carrying capacity predicted by the ACI and Eurocode4 codes and the continuous strength method (CSM). The experimental and numerical results demonstrated that this strengthening technique enhanced the axial load carrying capacity for unfilled and filled stainless steel stub columns. The results from the parametric study confirmed that (i) strengthening by two carbon steel bars is the most practical configuration to minimize the welding process, (ii) a substantial reduction in stainless steel thickness can be achieved by using carbon steel bars, (iii) the ultimate load carrying capacity is inversely proportional to the D/t ratio. CSM was the most accurate method for predicting the failure load of the strengthened stainless steel tube.

Shao-Dong Shen (1), Yao Cui (2), Peng Pan (3) and Jun-Yu Ren (1)
(1) Department of Civil Engineering, Tsinghua University, Beijing 100084, China
(2) State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, Dalian 116024, China
(3) Key Laboratory of Civil Engineering Safety and Durability of China Education Ministry, Tsinghua University, Beijing 100084, China

ABSTRACT: In a wall-frame system, shear walls are considered to be components with high load-bearing capacity and stiffness to provide lateral resistance. However, the ductility of shear walls is commonly far weaker than the frame. When high deformation is generated in a structure during earthquakes, shear walls are often damaged whereas the frame remained intact, which leads to their uncoordinated and restricted deformation. Furthermore, insufficient energy dissipation is exhibited within the limited deformation. This study is aimed at developing an innovative composite energy-dissipating slotted shear wall (CDSW). The CDSW features concrete-filled-tube wall segments, vertical slots, and H-shaped soft steel connectors, and it is endowed with significantly elevated deformability and energy dissipation. A quasi-static test was performed to investigate the seismic behavior of the CDSW, which showed high ductility. Finally, based on the calculation process of the conventional D-value method for frame structures, a modified D-value method was proposed to calculate the internal force and strength of slotted shear walls. The skeleton curve of the CDSW calculated by the modified D-value method agreed well with that obtained from the testing.


ABSTRACT: This paper presents an experimental investigation into concrete-filled steel tubular beams with octagonal cross-sections (OCFST) under monotonic or cyclic flexural loading. A total of eight tests, including four cyclic specimens and four monotonic counterparts, were conducted. Three concrete grades with measured compressive cylinder strength (f’c) varying from 54.5 MPa to 105.6 MPa were used to infill the OCFST specimens. The failure modes, ultimate bending moments, effective flexural stiffness, cumulative dissipated
ABSTRACT: The nonlinear stress-strain relationship of a thin plate or stiffened panel under in-plane load is represented by a load-shortening curve. The curves are used to evaluate the buckling and ultimate collapse behaviour of these structural elements, and furthermore forming the input data to analytical progressive collapse methods for large scale box girder structures such as ships. This paper develops a novel analytical method that predicts the load-shortening curve of plates and stiffened panels under cyclic in-plane load. This provides the framework to account for load reversals in an enhanced cyclic progressive collapse method. A parametric study using nonlinear finite element analysis is completed to investigate the characteristic behaviour of simply supported plates under cyclic compression and tension. The investigation covers a range of aspect ratios and slenderness ratios typical for ship-type structures. Single-cycle and ten-cycle loading protocols are applied, which demonstrate progressive reduction in strength and stiffness together with a response convergence after several cycles. An analytical method to predict multi-cycle load-shortening behaviour is then derived using a response and updating rule based on the observed characteristics from the parametric study. A validation of the analytical method is performed on a range of unstiffened plates and stiffened panels under various cyclic loading protocols. A good comparison with the results of finite element analysis is obtained, which confirms the validity of the proposed analytical method.

V. Rai (1), H. Ghasemnejad (1), J.W. Watson (2), J.A. Gonzalez-Domingo (1) and P.F. Webb (1)  
(1) Centre for Structures, Assembly and Intelligent Automation, Cranfield University, MK43 0AL, UK  
(2) Cranfield Impact Centre (CIC), Cranfield University, MK43 0AL, UK  
ABSTRACT: This paper aims to investigate the effect of a trigger mechanism on the crush force efficiency of aluminium tubular absorbers. Various trigger mechanisms such as cut-out holes, circumferential notch and end-fillet, were studied using the validated numerical model. Initially, tubes made of aluminium displayed better crashworthiness behaviour when compared with steel tubes based on numerical and experimental results. Then the trigger mechanism consisting of three cut-out holes was found more efficient than the ones with an end fillet and a circumferential notch based on a comparative study. According to these results, the developed trigger mechanisms have a significant change in crashworthiness performance of tubular absorbers. Crush force efficiency was doubled with the help of this trigger mechanism while stroke efficiency and specific energy absorptions were reduced by 4% and 15% respectively.

Guo-Qiang Li (1,2), Yan-Wen Li (2), Hai-Jiang Wang (2), Meng-De Pang (2), Liu-Lian Li (3) and Jian-Yun Sun (4)  
(1) State Key Laboratory for Disaster Reduction in Civil Engineering, Tongji University, Shanghai 200092, China  
(2) Department of Structural Engineering, Tongji University, Shanghai 200092, China  
(3) The First Construction Engineering Company LTD. of China Construction Second Engineering Bureau, Beijing 100176, China  
(4) Laboratory of Structural Engineering, China State Construction Technical Centre, Beijing, China  
ABSTRACT: This paper aims to investigate the seismic behavior of coupled shear wall with buckling restrained steel plates (CW-BRSP) under cyclic lateral loading. The quasi-static cyclic test on a 1/3-scaled CW-BRSP specimen was conducted. The response of CW-BRSP under cyclic loads, including the damage and failure modes, lateral force-displacement relationship, strength and stiffness degradation, energy dissipation, were observed as well as compared with those of the solid and coupled concrete shear walls. Yielding and plasticity of the buckling restrained steel plates developed with the increment of loading amplitude. Flexural cracks developed at the base of the wall piers. Test results indicated that the proposed CW-BRSP system has stable lateral load resisting and energy dissipation capacity. In addition, refined nonlinear finite element model of the CW-BRSP was developed and validated. Parametric study results indicated that the axial load ratio, degree of coupling and strength of buckling restrained steel plates has significant effect on seismic behavior of the CW-BRSP.

Vlad Alexandru Silvestru (1), Georg Kolany (1), Bernhard Freytag (2), Jens Schneider (3) and Oliver Englhardt(1)
(1) Institute of Building Construction, Graz University of Technology, Lessingstraße 25, 8010 Graz, Austria
(2) Laboratory for Structural Engineering, Graz University of Technology, Inffeldgasse 24, 8010 Graz, Austria
(3) Institute of Structural Mechanics and Design, Technische Universität Darmstadt, Franziska-Braun-Straße 3, 64287 Darmstadt, Germany


ABSTRACT: The structural efficiency of transparent façades can be increased by achieving a composite structural behaviour between the framing elements and the glass panes. The use of suitable intermediary materials is substantial for obtaining a composite structural behaviour for both out-of-plane and in-plane loading. This article presents two novel configurations for such glass-metal elements. For the first configuration, a perimetal bonding with a silicone adhesive between the glass pane and the filigree metal framing is responsible for transferring stresses in out-of-plane direction, and grouting blocks are used near the glass pane corners for transferring stresses in in-plane direction. In the case of the second configuration, a perimetal bonding with an acrylic adhesive between the glass pane and the filigree metal framing is responsible for transferring stresses in both out-of-plane and in-plane direction. Full-scale tests and finite element simulations with loads acting in three different directions, both separately and combined, are performed for the two configurations. The results of the tests performed under in-plane shear loading reveal a high load-bearing capacity of both configurations and show that failure is initiated within the adhesive joints. The numerical models, which include previously derived non-linear material models for the adhesives, allow a good prediction of the mechanical response of the investigated glass-metal elements. The presented load vs. displacement diagrams illustrate that the elements with acrylic adhesive behave stiffer both under out-of-plane and under in-plane loading before the adhesive starts to yield. Overall, the configuration with silicone adhesive and grouting represents a solution which can be applied in real projects based on existing technical approvals for the involved materials in similar applications. On the other hand, the configuration with acrylic adhesive indicates the potential of glass-metal elements with stiffer adhesives, assuming that the knowledge on such adhesives will continue to grow and that, eventually, new enhanced products will be developed by the adhesive industry.


ABSTRACT: Modern structural design codes strongly rely on the dissipative capacity of structural elements to resist the relevant seismic actions at ultimate limit state. The full exploitation of dissipative capacities can, however, be achieved only in presence of adequate local and global ductility. Local ductility in cast-in situ and precast reinforced concrete buildings refers to curvature ductility of the critical part of the structural elements where plastic hinges are expected to occur. Bidirectionality of the seismic action is taken into account by the standards, in a more or less conventional manner, for the evaluation of stresses on the structure. Nevertheless, there are no specific indications of how to take biaxial bending into account in verifying the curvature ductility
of reinforced concrete short columns. On the basis of this observation, a specific parametric investigation was planned and performed, with different values of angle between neutral axis and section principal axis, longitudinal reinforcement ratio, transverse reinforcement ratio, normalized axial force and section aspect ratio. Its results allowed for verification of the influence of bending moment directionality and of other parameters on the deformation capacities of reinforced concrete short columns beyond their own elastic limits.

N. Grillanda (1), A. Chiozzi (2), G. Milani (1) and A. Tralli (2)
(1) Department of Architecture, Built Environment and Construction Engineering ABC, Technical University of Milan, Piazza Leonardo da Vinci 32, 20133 Milan, Italy
(2) Department of Engineering, University of Ferrara, Via Saragat 1, 44100 Ferrara, Italy
“Collapse behavior of masonry domes under seismic loads: An adaptive NURBS kinematic limit analysis approach”, Engineering Structures, Vol. 200, Article 109517, 1 December 2019,
https://doi.org/10.1016/j.engstruct.2019.109517

ABSTRACT: The ultimate limit state behavior of masonry domes under axisymmetric gravity loads is nowadays well known and it has been proved how a generalization of the thrust line method used successfully for arches is quite effective also in this case. However, the behavior of a dome under horizontal loads, which is important in case of seismic action, becomes incredibly hard to tackle and still remains an open issue.

The present paper aims at presenting a fast and reliable automatized kinematic limit analysis approach able to accurately predict the actual behavior of masonry domes subjected to horizontal static loads. The model uses a rough discretization of the dome obtained by means of few rigid-infinitely resistant NURBS generated elements, adapting step by step the initial mesh in order to progressively overlap the element edges (where all dissipation is lumped) with the hinges forming the failure mechanism. The adoption of a rough mesh makes the code extremely fast, much more competitive than a standard FE model, allowing at the same time to approximate the actual geometry and load distributions in an extremely accurate way. The utilization of geometries obtained with laser scanner acquisitions is straightforward and the presence of pre-existing cracks can be accounted for as well. Three complex case studies are analyzed in detail to benchmark the approach proposed, relying into existing domes belonging to the Italian cultural heritage. The first example has the geometrical parameters of a typical late Renaissance dome, the Cathedral of Montepulciano, the second is the dome of Anime Sante church (collapsed during the L’Aquila 2009 earthquake with a paradigmatic failure mechanism) and the last is the dome of Caracalla baths, whose causes of collapse remain still unknown. In all cases inspected, the approach proposed quickly provides collapse accelerations and active failure mechanisms at a fraction of the time needed by non-linear FE analyses, providing interesting hints into the actual behavior of such kind of structures under horizontal loads.


ABSTRACT: This work presents an analysis of the lateral buckling of pipelines triggered by internal pressure. Geometrical imperfection amplitudes and friction of pipeline-soil are studied concerning their influence on the critical load and on the post-buckling configuration. To perform the analyses, numerical models are developed using geometrically-exact 3D Timoshenko beam finite elements, which may undergo large displacements and finite rotations. The interaction between the pipeline and the soil is simulated through a contact model. Geometrical imperfections are addressed by imposing prescribed displacements and considering uneven surfaces to represent the soil. The latter, by the way, allow to input concomitant vertical and lateral imperfections to the models. Varying vertical and lateral imperfection amplitudes and soil friction coefficients, the results show that all the parameters together influence the lateral buckling concerning critical loads and shape, order and amplitude of post-buckling configurations of the pipeline. Comparisons with analytical models are also presented.

Jin Jiang (1,2), Z.J. Ye (1,2), W. Bao (1,2), X. Wang (1,2), Y.B. Wang (3) and X.H. Dai (4)
(1) School of Civil Engineering, Guangzhou University, Guangzhou 510006, China
(2) Complex Steel Structure Research Centre of Guangdong Province, 510006, China
(3) School of Civil Engineering, Tongji University, Shanghai 200092, China
(4) School of Engineering, University of Bradford, BD7 1DP, UK


ABSTRACT: The paper describes a numerical study on columns fabricated from high strength steel (HSS) plates with nominal yield stress of 690MPa. The study comprised 4 benchmark models validated by testing data and 144H-section parametric study models. The benchmark models were firstly created and validated against testing data for the accuracy. A full-scale parametric study was carried out to investigate effect of flange width/thickness ratio (α), web height/thickness ratio (β), geometrical imperfection (D) and residual stress (R) on overall buckling behaviour of the columns. The purpose of the study was to understand the relationship between section geometry, imperfections and column strength fabricated by welding from 690MPa high strength steel plates. The H-section HSS columns were studied in this paper for the buckling behaviour along the minor axis in which direction those columns have smaller stiffnesses.

It is shown that all those factors can be classified into three groups according to their impact on column strength (expressed with strength reduction factor χ): favourable factor (α), adverse factor (β and D) and uncertain factor (R). α and χ are positively correlated: χ increases at different rates as α increases. It is an effective way to increase α to improve column strength when α is a small value. χ decreases with the increase of β at very low rate and the effect of β on χ is not very obvious. D could produce more pronounced deterioration effect on ultimate strength of columns with higher α. The effect of residual stress (R) on H-section column strength is related with α: for the columns with higher α value, higher residual stress could produce more serious strength reduction effect. Residual stress does not always have negative effect on χ. It could produce beneficial effect on the ultimate strength of high strength steel H-section columns as long as α is reasonably small.

The paper also shows a comparison of analysis results with existing standards including Eurocode 3 and GB50017-2017. For Eurocode 3, curve a0 can accurately predict with when D=0.03%. When D=0.20%, curve b gives the best-fit prediction.

Tatiana Sá Marques (1), Vítor Dias da Silva (2) and Eduardo N.B.S. Júlio (1)
(1) CERIS, Department of Civil Engineering, Instituto Superior Técnico, University of Lisbon, Portugal
(2) INESC-C, Department of Civil Engineering, Faculty of Sciences and Technology, University of Coimbra, Portugal


ABSTRACT: The use of spring cells as an alternative to finite element method (FEM) analysis of deformable continua has numerous advantages, such as its discrete representation and unidimensional stress states. This paper presents an innovative alternative approach to the continua FEM analysis, based on a new discrete model algorithm of bar elements framing a triangulated grid - lattice spring model. A non-uniform optimized thickness distribution, in both continua and discrete models, was implemented. This novel feature is a vital aspect to the optimization of the final shape.

Two discrete models were developed, the classic/stiffness model and the innovative/flexibility model, that differ by the calculatory cross-section areas assigned to the bars of the cell. Results demonstrate that the latter performs better, not only for the independency of the mesh quality, but also for the approximation of the results (when compared to the continua model). An incremental shape definition algorithm is also applied to keep the horizontal coordinates unchanged.

This new discrete approach led to a structural model that is easier and faster to program than FE method. It is also very accurate, since the final shapes obtained by the continuum method and the discrete methods are practically coincident.


ABSTRACT: Unlike unstiffened steel plate shear walls (SPSWs), very little research has been conducted to assess the seismic performance of stiffened SPSWs. This paper presents a new component strength deterioration model for stiffened infill plate to evaluate the seismic performance of stiffened SPSWs using FEMA P695
procedure. The newly developed component strength deterioration model is first validated against the available experimental results. A total of three multi-storey (7-, 10-, and 13-storey) stiffened SPSWs with panel aspect ratio of 1.39 are then analysed using the proposed component strength deterioration model. Static pushover and incremental dynamic analyses using a suite of 44 ground motions compatible to Western Canada are conducted for all archetypes. Adjusted collapse margin ratios obtained for stiffened SPSWs designed with similar response parameters of those for unstiffened SPSWs are compared with allowable limits given in FEMA P695. The results indicate that currently recommended seismic response modification factor, ductility related force modification factor and overstrength related force modification factor, for unstiffened SPSW can be used for design of stiffened SPSW. In addition, seismic response parameters such as variation of maximum interstorey drift and shear demand in different components of stiffened SPSW, boundary columns and infill plates, are estimated in all stories for all designed archetypes during incremental dynamic analysis. Furthermore, seismic response sensitivity of stiffened SPSWs to the variation of post-yielding parameters (i.e., ductility capacity and post-cap stiffness ratio) in infill plate is investigated. Sensitivity analysis shows that the capacity of stiffened SPSW is more sensitive to ductility capacity changes, while the variation of post-cap stiffness has a lesser effect on overall performance of the system.

Tung-Yu Wu (1), Sherif El-Tawil (2) and Jason McCormick (2)
(1) Department of Civil Engineering, National Taiwan University, Taipei 10617, Taiwan
(2) Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI 48109, United States


ABSTRACT: Cyclic flange local buckling typically occurs when plastic hinges form in the beams and columns of special moment resisting frames subject to seismic excitation. While local buckling in beam plastic hinges has been investigated in the past for monotonic loading situations, the effect of cyclic flange local buckling on beam and column behaviours is not yet well understood. In order to address this shortcoming, nineteen half-scale T-section specimens are tested under cyclic axial loads in a configuration intended to replicate the cyclic demands imposed on flanges of beams and columns in their plastic hinge region. The main experimental variables are flange slenderness ratio, level of web restraint, and loading scheme (monotonic versus cyclic). Validated computational studies are performed to expand the parameter space. The test data and computational results show that T-section members that meet the current highly ductile limit can suffer excessive axial strength degradation under cyclic axial loading. The effect of slenderness ratios on column compression capacity due to strength degradation of flanges is evaluated and quantified.


ABSTRACT: There are three possible modes of buckling of thin-walled straight steel columns: flexural buckling, torsional buckling, and flexural-torsional buckling. These modes of buckling are considered in the specification for the design of steel structures, such as Eurocode 3, which includes the particular case of torsional-flexural buckling of centrically loaded members with monosymmetric cross-sections. The system of differential equations that governs the stability of centrically loaded weightless members was presented in the mid-twentieth century and has been widely addressed in both steel structures and instability books. In this work, a simpler way to obtain the differential equations of stability for both torsional and flexural-torsional buckling modes by using equivalent forces is presented. The presented idea is especially useful in the academic context of civil engineering. Students and faculty members will appreciate the deduction of the instability equations governing the equilibrium in a few simple steps.

Binglin Lai (1), J.Y. Richard Liew (1) and An Le Hoang (2)
(1) Department of Civil and Environmental Engineering, National University of Singapore, Blk E1A, #07-03, 1 Engineering Drive 2, 117576 Singapore, Singapore
ABSTRACT: This paper presents an experimental program that studies the structural behaviour of high strength Concrete Encased Steel (CES) composite columns. The structural performance under compression, including the damage pattern, load-carrying capacity, post-peak ductility, and load-displacement response is experimentally investigated. A total of 14 specimens were tested under concentric compression. The parameters studied in this program include concrete compressive strength, steel yield strength, stirrup spacing, incorporation of steel fiber, as well as the shape of the structural steel section. To evaluate the material compatibility between high strength concrete and high strength steel, two concrete grades (C90, C130) and two steel grades (S500, S690) were used to prepare the test specimens. In addition, 0.5% volume fraction of steel fiber was added in concrete mix to minimize the inherent brittleness of high strength concrete. The comparison between test results and analytical predictions reveals the inability of existing design codes to estimate high strength CES columns, unless steel fiber and dense reinforcement are used in combination. The effect of material strength, steel fibers, volumetric ratios of hoop reinforcement, and shape of steel section on both strength and ductility of CES columns was assessed through a comprehensive parametric study. The analysis of test results demonstrates that steel contribution ratio plays a dominant role in the ductility, whereas increasing hoop reinforcement ratio and adding steel fiber has negligible effect. Finally, a simplified formula is proposed to evaluate ductility of high strength CES columns.


ABSTRACT: The instability of beam-columns with crossarms and externally prestressed cable stays is studied analytically, where the combination of bending and compression is assumed to be derived from the system self-weight acting orthogonally to the applied axial load. Three principal zones of behaviour are identified with two of these each having two sub-zones that relate the critical buckling load to the initial prestressing force applied to the stay cables. The ultimate load-carrying capacity of the beam-columns is evaluated by conducting nonlinear finite element analysis within the commercial package ABAQUS. Results show that the analytically derived critical buckling loads generally provide safe predictions of the ultimate loads due to significant post-buckling strength. It is found that releasing the geometric double symmetry of the system can make for a significantly more efficient structure due to the effect of pre-cambering against the self-weight. The strength and efficiency of stayed beam-column systems opens up a range of potential applications, including lighter alternatives to conventional props to support wide excavations, which currently utilize very heavy steelwork.

Mizan Ahmed (1), Qing Quan Liang (1), Vipulkumar Ishvarbhai Patel (2) and Muhammad N.S. Hadi (3)
(1) College of Engineering and Science, Victoria University, PO Box 14428, Melbourne, VIC 8001, Australia
(2) School of Engineering and Mathematical Sciences, La Trobe University, Bendigo, VIC 3552, Australia
(3) School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia

ABSTRACT: Circular concrete-filled double steel tubular (CFDST) columns in high-rise building structures possess high ductility and strength performance owing to the concrete confinement exerted by the external and internal circular steel tubes. However, the behavior of circular CFDST short columns that are loaded eccentrically has not been investigated either experimentally or numerically. Particularly, numerical studies on the moment-curvature responses, strength envelopes, confinement effects and moment distributions in circular CFDST beam-columns have not been reported. In this paper, experimental and computational investigations into the structural responses of circular CFDST short columns loaded eccentrically are presented. Nineteen short circular CFDST columns with various parameters under axial and eccentric loads were tested to failure to measure their structural responses. Test results are presented and discussed. A mathematical simulation model
underlying the method of fiber analysis is proposed that simulates the axial load-moment-curvature relationships as well as the strength interaction curves of CFDST beam-columns composed of circular sections. The mathematical modeling technique explicitly takes into account the confinement of concrete on the responses of CFDST columns. The computational procedure and solution method are given. The accuracy of the computer simulation model is evaluated by comparing computations against experimental data. The significance of material and geometric properties, concrete confinement and axial load ratio on the responses of moment-curvature and strength envelopes of CFDST columns and the moment distributions in concrete and steel components are investigated. The mathematical model proposed not only simulates well the experimentally observed responses of CFDST columns but also can monitor the moment distributions in the steel and concrete components of such composite columns.

Hui Ma (1), YunChong Chen (1), Hengyu Bai (1) and Yanli Zhao (2)
(1) School of Civil Engineering and Architecture, Xi’an University of Technology, Xi’an, China
(2) School of Architecture, Chang’an University, Xi’an, China


ABSTRACT: To study the eccentric compression performance of composite columns composed of recycled aggregate concrete (RAC)-filled circular steel tube and profile steel, 17 static loading tests of the columns under eccentric compression loading were performed in this study. The design parameters of these columns were recycled coarse aggregate (RA) replacement percentage, diameter–thickness ratio of circular steel tube, profile steel ratio, eccentricity, RAC strength grade, slenderness ratio and section form of profile steel. The load–lateral displacement curves, load–strain curves, lateral deflection and bearing capacity of the columns were established and assessed in detail. The results showed that the failure of the columns began with the yield of profile steel in the middle of compression side, and then the yield strength of circular steel tube was reached at the compression side. Subsequently, the core RAC was crushed, and local buckling occurred in the middle of the circular steel tube, thereby resulting in the loss of the eccentric bearing capacity of the columns. The eccentric bearing capacity of the columns decreased with the increase in RA replacement percentage. Reducing the diameter–thickness ratio of circular steel tube and increasing the profile steel ratio can improve the eccentric bearing capacity of the columns. Meanwhile, the increase in eccentricity and slenderness ratio was disadvantageous to the eccentric bearing capacity of the columns. In summary, the columns generally show good ductile deformation capacity and high eccentric bearing capacity. On the basis of the failure mechanism and calculation model of these columns, the calculation formulas suitable for the eccentric bearing capacity of the columns were deduced, and the calculation results were verified compared with the test results.

Lulu Zhang (1), Fangying Wang (1), Yating Liang (2) and Ou Zhao (1)
(1) School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
(2) School of Engineering, University of Glasgow, Glasgow, UK


ABSTRACT: This paper reports an experimental and numerical investigation into the cross-section behaviour and compression resistances of press-braked S690 high strength steel angle and channel section stub columns. The experimental study was carried out on four equal-leg angle sections and eight plain channel sections with a range of cross-section sizes (covering both non-slender and slender sections), and included thirty-six material tensile flat and corner coupon tests, initial local geometric imperfection measurements and twenty-four concentrically loaded stub column tests. The experimental study was then supplemented by a numerical modelling programme, where numerical models were firstly developed to simulate the test structural responses and subsequently adopted to derive further numerical data. The experimentally and numerically derived results
were utilised to assess the applicability of the Eurocode Class 3 slenderness limits for hot-rolled and welded sections to their cold-formed (press-braked) counterparts. The results of the assessment generally revealed that the Eurocode Class 3 slenderness limits for hot-rolled and welded sections can be safely adopted for the classification of press-braked (cold-formed) S690 high strength steel angle and channel sections subjected to compression. The accuracy of the codified design provisions established in Europe, North America and Australia/New Zealand as well as the direct strength method (DSM) to the design of press-braked S690 high strength steel angle and channel section stub columns was also assessed, based on the test data and numerical results. The North American, Australian and New Zealand standards were found to result in accurate and consistent compression capacity predictions for press-braked S690 high strength steel channel section and non-slender angle section stub columns, but greatly underestimate the compression capacities for those slender angle section stub columns, while the European code and DSM were shown to yield overall precise and consistent design compression capacities.

Ye Yao (1), Wai-Meng Quach (1) and Ben Young (2)
(1) Department of Civil and Environmental Engineering, University of Macau, Macau, China
(2) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China


ABSTRACT: The paper presents a numerical study on the stub-column behavior of cold-formed steel elliptical hollow sections (EHS). In the paper, a finite element model for the stub columns of cold-formed tubular sections is presented, in which residual stresses, strength enhancement, geometric imperfection resulting from cold forming are predicted by using a rigorous finite element simulation of the roll-forming process. The accuracy of the finite element model for stub columns was verified by comparing the numerical predictions with test results. By using the verified finite element model, a parametric study on the stub-column behavior of cold-formed steel EHS was carried out for a wide range of section sizes and steel grades (covering both normal grade steels and high strength steels). Based on the generated finite element data, predictive models for the strength enhancement and local geometric imperfection of cold-formed steel EHS are proposed. Furthermore, the cross-section classification for cold-formed steel EHS were examined according to the slenderness limits of circular hollow sections (CHS) in current design codes. It can be found that the equivalent diameter method together with the current CHS slenderness limits in existing design codes can be safely adopted for cold-formed steel EHS. In addition, a new yield slenderness limit for cold-formed steel EHS is proposed.

Yan-Gang Zhao (1,2), Xi-Feng Yan (1) and Siqi Lin (2)
(1) Department of Architecture and Building Engineering, Kanagawa University, Kanagawa 2218686, Japan
(2) Key Laboratory of Urban Security and Disaster Engineering of Ministry of Education, Beijing University of Technology, Beijing 100124, China


ABSTRACT: Circular hollow centrifugal concrete-filled steel tubes (HCCFSTs) are employed widely as structural components, such as power station structures and building foundations, in virtue of their exceedingly good structural performance features. It is essential to comprehend the compressive behavior of circular HCCFST columns and suitably evaluate their compressive strength for practical engineering design. However, limited researches on HCCFST columns have almost not resulted in the development of appropriate design formulae in current international standards. This paper aims to propose a practical formula for estimating the compressive strength of circular HCCFST stub columns that have a wide range of parameters. A new confinement coefficient reflecting the confinement effect of concrete strength in circular HCCFST short columns is proposed, and using the proposed confinement coefficient, a novel strength design formula is developed to estimate the compressive strength of circular HCCFST short columns. The proposed formula is investigated using collected experimental data from literature and finite element analysis results. It is shown that the proposed confinement coefficient can reflect the interaction effect between the steel tube and infilled concrete, and the developed axial capacity formula in this paper offers better predictions of compressive strength than current design formulae.

ABSTRACT: In this work the dynamic behaviour of free layer damping plates with thick unconstrained viscoelastic layer is analysed. With this aim, the Kirchhoff–Love thin plate formulation is adapted to take shear stiffness into account by using a frequency dependent equivalent flexural stiffness. To check the validity of the proposed formulation, it is implemented in a finite element model and compared to both the Oberst model and a reference 3D solid model in terms of eigenvalues and dynamic response across a wide range of boundary conditions – clamped in all edges, free, simply supported at edges, clamped in a single edge and simply supported at corners. In all the cases the material of the viscoelastic layer presents fractional damping, its modulus thus being complex and frequency dependent. The results show that the proposed model is in good agreement with the 3D model and that it provides better accuracy than the Oberst model, specially as the thickness of the damping layer, and consequently the effect of the shear, increases. Hence, the need of developing a 3D solid model can be avoided as well as the storage and computation time problems it arises, that are specially critical in industrial practical applications.

X.Z. Cui (1), Y.G. Li (2) and H.P. Hong (1)
(1) Department of Civil and Environmental Engineering, University of Western Ontario, London N6A 5B9, Canada
(2) School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, Xi'an, China


ABSTRACT: Latticed shells are extensively used for large-span structures. Their design is often governed by the global instability requirement stipulated in the Chinese design code for the specified gravity load and initial geometric imperfection (IGI). However, the reliability-basis for the recommended design requirement that a critical load factor of 2 need to be achieved is unknown. In the present study, it is proposed that the spatially varying IGI can be adequately modeled using the conditional autoregressive model. It is shown that this model is sufficiently flexible in modeling spatially varying correlated imperfection and can cope with irregular grid systems. By using this model for IGI and considering global instability, the probability distributions of the load capacity and the failure probabilities of spherical and cylindrical latticed shells designed according to the Chinese design code are evaluated. The evaluation is also carried out by representing the IGI shape using the spatially independent Gaussian model and the first eigen buckling mode (1EBM) that is recommended by the design code. It is shown that the use of the 1EBM to represent the IGI shape does not necessarily lead to conservative estimates of the failure probabilities as compared to those obtained by considering spatially varying stochastic imperfection shapes. The results shown that the estimated failure probability is sensitive to the assumed stochastic model for and standard deviation of the IGI at each joint of the latticed shells. Furthermore, the failure probability of the spherical latticed shell differs from that of the cylindrical latticed shell. The reliability analysis results also indicate that the use of a critical load factor of 2 implemented in the code for design of the latticed shell, in general, lead to an annual failure probability for global instability less than 10−5. A sensitivity analysis indicates that the code recommended critical load factor can be reduced to 1.75 while achieving a target reliability index often adopted for design code calibration.


ABSTRACT: Thin-walled structures are used for crashworthiness energy absorption applications such as automobile vehicles and aircraft. Structures of sinusoidally corrugated profiles were of great interest because of...
their ability to reduce the peak crushing forces and provide stable energy-absorbing patterns. Studies on structures of sinusoidally corrugated profiles are limited to numerical studies due to manufacturing limitations. Advancement in additive manufacturing enables the fabrication of structures of complex profiles such as corrugated tubes. This could solve the issue of mass productions of such structures for energy absorption applications. This paper aims to additively manufacture and test sinusoidally corrugated tubes experimentally. A sample of 8 sinusoidally corrugated tubes was additively manufactured and tested under a quasi-static displacement rate of 20 mm/min. The results showed that corrugated tubes exhibit lower and stable crushing forces compared to conventional straight tubes. It was found that increasing the wavelength from 10 to 20 mm results in changing deformation mode from ring to diamond, while increasing the amplitude from 1 to 2 mm has no effect when the thickness is 1 mm. Corrugated tubes achieved a maximum peak force reduction of 75%, and a maximum crushing force efficiency increase of 63%. However, they also resulted in a reduction of 46 and 55% in energy absorption and specific energy absorption, respectively.

Binglin Lai (1), J.Y. Richard Liew (1), An Le Hoang (2) and Mingxiang Xiong (3)
(1) Department of Civil and Environmental Engineering, National University of Singapore, E1A-07-03, 1 Engineering Drive 2, 117576 Singapore, Singapore
(2) Division of Construction Computation, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(3) Protective Structures Centre, School of Civil Engineering, Guangzhou University, Guangzhou, China


ABSTRACT: This paper presents a unified approach to evaluate the axial force and moment interaction strength curve of Concrete Encased Steel (CES) composite columns made of different steel and concrete grades. A database was established by collecting the test results of CES composite columns in the literature covering concrete compressive strength ranging from 20 to 104 MPa and steel yield strength from 280 to 913 MPa. A sensitivity study was then carried out to investigate the effect of different design parameters on the accuracy of the current design method EN 1994-1-1 in predicting the ultimate strength of CES composite columns. These design parameters include characteristic strength of materials, steel contribution ratio, concrete cover thickness ratio, longitudinal reinforcement ratio, and volumetric ratio of transverse reinforcement. Analytical study was performed through a self-compiled computer program which was developed based on materials strain compatibility principle. The comparison between the analytical results and test results confirms the validity of the proposed method to provide reasonable prediction of cross-sectional axial-moment interaction curves for CES columns for a wide range of steel and concrete grades. The existing EC4 method, which is based on plastic design principle, was found to be un-conservative in predicting the cross section resistance of CES composite columns with high strength concrete and high strength steel. Further enhancement was made to the proposed method to include both the strain gradient effect and concrete confinement effect to achieve a better agreement with the test results reported in literature. Finally, a simplified method was proposed to construct the axial-moment interaction curves of CES columns, which can be used as a unified approach to design such columns with normal and high strength steel and concrete materials.

Shen Yan (1,2), Kim J.R. Rasmussen (2), Xinlu Liu (1), Liusi Dai (3) and Xianzhong Zhao (1)
(1) College of Civil Engineering, Tongji University, China
(2) School of Civil Engineering, the University of Sydney, Australia
(3) School of Civil Engineering, Shanghai University, China


ABSTRACT: When a truss roof is subjected to sudden local damage, purlins are capable of bridging the damaged truss unit, thereby increasing the robustness of the integrated roof system. To investigate the bridging capacity purlins can provide, experiments were carried out on bolted fin plate connections that join thin-walled H-section purlins to the main truss, investigating their behaviour under a main truss-removal scenario. Eight specimens with varied connection details were tested. Results of all experiments are provided in detail, including the full-range vertical resistance versus displacement curves, the collapse-resisting mechanisms, and the failure modes, being either bolt shear failure or combined bolt bearing and net-section tensile failure.
Experimental results showed that better bridging capacity can be achieved by adopting relatively larger diameter bolts, reducing the bolt group height, applying higher preloading force when installing bolts, and increasing the end distance for the bolt holes. Meanwhile, a theoretical model is proposed to predict the vertical resistance versus displacement response of the purlin-to-connection assembly. This model is capable of capturing the slip of bolts, and the gradual yielding and failure of the connection components, and thus gives predictions that are in reasonably good agreement with the experimental results.


**ABSTRACT:** Current structural steel design codes typically feature a step in the cross-sectional resistance functions at the Class 2 slenderness limit due to the abrupt switch between elastic and fully plastic capacities. To address this issue, new design rules, featuring a gradual transition between elastic and plastic resistances, have been recently developed for semi-compact (Class 3) I- and box sections to account for the partial spread of plasticity. This approach is extended herein to the cross-section and member buckling design of semi-compact elliptical hollow sections (EHS). Finite element models were first established and validated against previous test results; particular attention was given to the modelling of local geometric imperfections. Parametric studies were then conducted, where over 4000 structural performance data were numerically generated covering a wide range of cross-section aspect ratios, material properties, local and global slendernesses and load combinations. Upon completion of the numerical simulation programme, structural design rules of semi-compact EHS were developed. The classification of EHS under biaxial bending and compression plus biaxial bending was initially addressed. Following this, new design expressions featuring elasto-plastic section properties were developed to exploit partial plasticization at both cross-section and member buckling levels. The accuracy of the design proposals was evaluated through comparisons between the test/numerical data and the resistance predictions; the comparisons revealed that the proposed elasto-plastic cross-section and member buckling design rules lead to both improved accuracy and consistency over the existing elastic provisions. The reliability of the proposals was verified through statistical analyses in accordance with EN 1990, demonstrating their suitability for incorporation into the next revision to EN 1993-1-1.

References listed at the end of the paper:
2 X.L. Zhao, J.A. Packer, Tests and design of concrete-filled elliptical hollow section stub columns, Thin-Walled Struct, 47 (2009), pp. 617-628
8 J.W. Hutchinson, Buckling and initial postbuckling behavior of oval cylindrical shells under axial compression, J Appl Mech, 35 (1968), pp. 66-72
11 M.T. Chen, B. Young, Material properties and structural behavior of cold-formed steel elliptical hollow section stub columns, Thin-Walled Struct, 134 (2019), pp. 111-126
13 K.H. Law, L. Gardner, Buckling of elliptical hollow section members under combined compression and uniaxial bending, J Constr Steel Res, 86 (2013), pp. 1-16
Struct, 45 (5) (2007), pp. 517-527


ABSTRACT: Multi-cell L-shaped concrete-filled steel tubular (CFST) columns have the advantages of avoiding column protrusion, saving room space and good mechanical behavior. They can be used as the corner columns in building structures. In practical engineering, the columns may be subjected to earthquake action from different directions. However, there are few experimental and numerical studies on this kind of columns at different loading angles. This paper presents four tests carried out on multi-cell L-shaped CFST columns subjected to combined constant compression and lateral cyclic loads. The main variables were loading angles (0°, 45° and 135°) and axial load levels (0.25 and 0.5). The failure modes, lateral load – displacement hysteretic curves, envelope curves, stiffness degradation, ductility, energy dissipation, deformation and moment – curvature curves were obtained. A finite element model was developed to simulate the multi-cell L-shaped CFST columns at different loading angles, and the predicted results agreed well with the test results. Moreover, the parametric analysis was conducted to investigate the effects of various parameters on lateral load – displacement curves of the columns under diagonal loading.

References listed at the end of the paper:

2 L.H. Han, W. Li, R. Bjorhovde, Developments and advanced applications of concrete-filled steel tubular (CFST) structures: members, J Constr Steel Res, 100 (2014), pp. 211-228
6 JRA, Design specifications for highway bridges and commentary. Part I: common part, Part II: Steel Bridges, Japan Road Association (JRA), Tokyo, Japan (2012) [in Japanese]
8 Q. Al-Kaseasbeh, I.H.P. Mamaghani, Buckling strength and ductility evaluation of thin-walled steel stiffened square box columns with uniform and graded thickness under cyclic loading, Eng Struct, 186 (2019), pp. 498-507
13 Z. Tao, L.H. Han, D.Y. Wang, Strength and ductility of stiffened thin-walled hollow steel structural stub columns filled with concrete, Thin-Wall Struct, 46 (10) (2008), pp. 1113-1128
28 ATC-24, Guidelines for cyclic seismic testing of components of steel structures, Applied Technology Council, Redwood City(CA) (1992)
30 L.H. Han, Concrete-filled steel tubular structures – theory and practice, (3rd ed.), China Science Press, Beijing, China (2016) [in Chinese]
40 M.S. Hassan, S. Salawdeh, J. Goggins, Determination of geometrical imperfection models in finite element analysis of structural steel hollow sections under cyclic axial loading, J Constr Steel Res, 141 (2018), pp. 189-203
41 A. Ucak, P. Tsopelas, Accurate modeling of the cyclic response of structural components constructed of steel with yield plateau, Eng Struct, 35 (2012), pp. 272-280
42 Z. Tao, B. Uy, L.H. Han, Z.B. Wang, Analysis and design of concrete-filled stiffened thin-walled steel tubular columns under axial compression, Thin-Wall Struct, 47 (2009), pp. 1544-1556
44 L.H. Han, G.H. Yao, Z. Tao, Performance of concrete-filled thin-walled steel tubes under pure torsion, Thin-Wall Struct, 45 (1) (2007), pp. 24-36

ABSTRACT: The load-deformation response of Fiber Reinforced Concrete (FRC) elements subjected to pure shear is still matter of strong debate within the scientific community. In this paper, the tests on six fiber reinforced concrete panels under pure shear are presented and discussed. The tests were conducted under displacement control and a peculiar loading frame was designed to ensure that a pure shear state of stress was established. Steel fibers were added in relatively low amounts (20 and 50 kg/m^3), and two steel reinforcements (0.21% and 0.74%) were selected, aiming at simulating lightly reinforced elements. A critical discussion on the influence of fibers on both global and local behavior (tension stiffening, cracking formation and propagation, post-cracking stiffness and residual strength) is presented. Finally, a novel crack spacing formulation, extended to FRC, is proposed and compared against available experimental data.

References listed at the end of the paper:
1 V.C. Li, R. Ward, A.M. Hamza, Steel and synthetic fibers as shear reinforcement, ACI Struct J, 89 (5) (1992), pp. 499-508
5 is missing in the paper.
7 is missing in the paper.
9 F.J. Vecchio, M.P. Collins, The response of reinforced concrete to in-plane shear and normal stresses. Publication No. 82–03, Department of Civil Engineering, University of Toronto (1982), p. 332
17 is missing in the paper.
doi:10.3.234/suco.201700278
21 Moser M., Prove sperimentali a taglio puro su materiali fragili”, Master Thesis, Department of Civil, Environmental, Architectural Engineering and of Mathematics, Università di Brescia, Italy; 2013 [in Italian].
22 Coccoli L., Elementi in calcestruzzo fibrinforzato soggetti a taglio puro. Master Thesis, Department of Civil, Environmental, Architectural Engineering and of Mathematics, Università di Brescia, Italy; 201, [in Italian].
ABSTRACT: Hollow concrete columns (HCCs) reinforced with steel bars have been employed extensively for bridge piers, ground piles, and utility poles because they use fewer materials and offer higher structural efficiency compared to solid concrete columns with the same concrete area. Many experimental studies have been conducted to investigate the behavior of HCCs under different loading conditions and found that the structural performance of HCCs is critically affected by many design parameters. If not designed properly, HCCs exhibit brittle failure behavior, due to longitudinal bars buckling or the concrete wall failing in shear. In addition, the corrosion of steel bars has become an issue in reinforced-concrete structures. Therefore, this paper critically reviews the different design parameters that affect the performance of HCCs and identifies new opportunities for the safe design and effective use of this construction system. Moreover, the use of GFRP bars as reinforcement in hollow concrete columns is explored with the aim of developing a non-corroding and structurally reliable construction system.

ABSTRACT: This paper reports an experimental and numerical investigation into the local stability of press-braked stainless steel angle and channel sections. The experimental programme was performed on two equal-leg angle sections and two plain channel sections, and included material testing, initial local geometric imperfection measurements, eight stub column tests and ten laterally restrained beam tests (about the geometric axes for angle sections and minor principal axes for channel sections). This was supplemented by a numerical simulation programme, where finite element models were firstly established to replicate the test structural responses and then employed to derive further numerical data through parametric studies. The results obtained from the structural testing and numerical modelling were adopted to evaluate the accuracy of the codified local buckling design provisions established in America, Europe and Australia and New Zealand. The evaluation results revealed that all the design codes greatly underestimate the cross-section resistances of press-braked stainless steel equal-leg angle and plain channel section stub columns and laterally restrained beams, mainly attributed to the neglect of the pronounced material strain hardening effect of stainless steel in the design. The continuous
strength method (CSM) is an advanced deformation-based design method, allowing for a rational utilisation of material strain hardening in determining cross-section resistances, and its scope of application has been recently extended from doubly-symmetric (I- and tubular) sections to mono-symmetric and asymmetric (angle, channel and T-) sections. Quantitative evaluation of the CSM was conducted through comparing the predicted cross-section resistances against the experimental and numerical results. The CSM was found to yield substantially more accurate and consistent design cross-section resistances for press-braked stainless steel equal-leg angle and plain channel section stub columns and laterally restrained beams than the established design codes.

João Paulo Silva Lima (1,2), Marcelo Langhinrichs Cunha (2), Elizaldo Domingues dos Santos (2,3), Luiz Alberto Oliveira Rocha (4), Mauro de Vasconcellos Real (2,3) and Liércio André Isoldi (2,3)
(1) Federal University of Goiás (UFG), Mucuri St., CEP: 74968-755 Aparecida de Goiânia, Goiás, Brazil
(2) Federal University of Rio Grande (FURG), Graduate Program in Ocean Engineering (PPGEO), School of Engineering, km 8 Itália Ave., CEP: 96203-900 Rio Grande, Rio Grande do Sul, Brazil
(3) Federal University of Rio Grande (FURG), Graduate Program in Computational Modeling (PPGMC), km 8 Itália Ave., CEP: 96203-900 Rio Grande, Rio Grande do Sul, Brazil
(4) University of Vale do Rio dos Sinos (Unisinos), 950 Unisinos Ave., CEP: 93020-190 São Leopoldo, Rio Grande do Sul, Brazil


ABSTRACT: Several engineering structures used in civil, aeronautical and, mainly, naval and offshore industries consist of steel stiffened panels formed by beams welded into thin plates. These beams are called stiffeners, being arranged longitudinally and/or transversely aiming to increase the mechanical strength of the plate. So, it is desirable to obtain an optimal geometric configuration for these structures which maximizes its ultimate buckling stress. In this context, it has been used the Constructal Design Method associated with the Exhaustive Search technique and the Finite Element Method (by ANSYS software) in a geometric optimization study of plates with stiffeners subjected to elasto-plastic buckling. Initially, it was adopted a simply supported plate buckling stress, and its ultimate buckling stress as a reference value for the study. After that, part of its volume has been transformed into stiffeners, which were incorporated into the plate. For this, the volume fraction (ϕ) parameter, which represents the ratio of the volume of stiffeners (V_s) and the total volume of the structural element plate/stiffeners (V_p), has been adopted, without varying the final volume of the plate. Moreover, the number of longitudinal (N_l) and transverse (N_t) stiffeners, as well as the ratio between the height of the stiffener and its thickness (h/t), were considered as degrees of freedom. The study considered two total steel volume values V_p = 0.040 m^3 and V_p = 0.028 m^3. The results indicated that the variation of the geometrical configuration significantly affects the mechanical behavior of stiffened panels under buckling. Therefore, it was possible to determine the optimum geometry that leads to a maximized ultimate buckling stress, near the yield strength of the material. The stiffened plates with volume V_p did not present relevant improvements if compared with the reference plate, since the optimal geometry achieved an improvement of 7.38% concerning the ultimate buckling stress of the reference plate. On the other hand, the study of the plates with volume V_p showed significant improvements in the value of the ultimate buckling stress, so that the optimized geometric configuration among all analyzed geometries reached an improvement of 88.50% when compared with the ultimate buckling stress of the reference plate.

Wen-Bo Ning (1), Minglin Shi (2), Suqin Jiang (1), Yundong Li (3) and Mingjun Zhong (4)
(1) Faculty of Mechanical and Material Engineering, Huaiyin Institute of Technology, Huai’an 223003, People’s Republic of China
(2) Tianjin Lishen Battery Joint-Stock Co., Ltd, Tianjin 300384, People’s Republic of China
(3) School of Mathematics and Statistics, Sichuan University of Science and Engineering, Zigong 643000, People’s Republic of China
(4) Nuclear Power Institute of China, Chengdu 610015, People’s Republic of China

ABSTRACT: The instability characteristics of an out-cylindrical shell subjected to an annular flow, where the fluid is flowing through the annulus between the inner shell and the outer shell, are investigated based on the zero-level contour method and the travelling wave solutions. The inviscid fluid-dynamic forces, related to shell vibrations, are determined by the potential flow theory. The time-mean Navier-Stokes equations are utilized to obtained steady viscous forces based on the fully developed turbulent flow theory. The Flügge's thin shell theory is used for shell motions. Adopting the zero-level contour method and the Galerkin's method, the behaviors of losing stability of the flow-shell system are given and physical reasons for the instability of the system are explained. Detailed studies are performed in order to elucidate quantificationally the effects of pre-loads related to the steady viscous forces, geometry parameters on the loss of stability. Especially, the influence of the swirl number on the instability characteristics of the system is discussed.


ABSTRACT: This paper presents Best Theory Diagrams (BTDs) constructed from non-polynomial terms to identify best shell theories for bending analysis of cross-ply single skin and sandwich shell panels. This structure presents a constant radia of curvature. The shell theories are constructed using Axiomatic/Asymptotic Method (AAM). The different shell theories are described using the Carrera’s Unified Formulation. The governing equations are derived from the Principle of Virtual Displacement (PVD), Navier-Type closed form solution is used for solving the bending problem of simply supported doubly curved shell panels subjected to bi-sinusoidal transverse pressure. The BTDs built from non-polynomial functions are compared with Maclaurin expansions. Spherical shell panels with different layer-configurations are investigated. The results demonstrated that the shell models obtained from the BTD using non-polynomial terms can improve the accuracy obtained from Maclaurin expansion for a given number of unknown variables of a displacement field.

Huidong Zhang (1), Xinquan Zhu (2) and Shu Yao (1)
(1) Tianjin Key Laboratory of Civil Buildings Protection and Reinforcement, Tianjin 300384, PR China
(2) School of Civil and Environmental Engineering, University of Technology Sydney, NSW 2007, Australia

ABSTRACT: Currently, nonlinear dynamic analysis for large-scale single-layer domes is commonly performed using deterministic numerical methods. However, in practical engineering cases, complex large-scale single-layer domes have many uncertain parameters that cannot be considered using deterministic methods. Therefore, there is a growing awareness that classical deterministic methods need to be extended towards the introduction of the uncertain aspects in dynamic analysis, and a non-deterministic analysis method for large-scale spatial structures is required. In this paper, a new method is presented by introducing uncertainties into the nonlinear dynamic analysis for large-scale single-layer lattice domes. The method accounts for uncertainties in material properties, structural imperfections, loads, and damping with bounds. The focus is on the treatment of uncertainty in damping and the adopted geometric shape, which is different from that of conventional approaches. Finite element dynamic analyses for sample structures with multiple sources of uncertainty subjected to dynamic loads are performed. Results show that the variability of the variables with an associated uncertainty imposes significant negative effects on the dynamic properties, dynamic demands, and safety of a dome. Uncertain damping in a structure plays the most important role in determining structural performance. The numerical results reveal the differences between conventional analysis methods with deterministic parameters used in previous practical applications and the uncertain analysis method. Finally, a parametric study is performed, and the impacts of sample size on statistical dynamic demands, single uncertain source on structural failure, and single uncertain source on damping coefficients are discussed.

ABSTRACT: This work presents the numerical analysis of elastoplastic contact problems of compact and thin-walled metallic structures. The emphasis is on the use of higher-order 1D elements with pure displacement variables and based on the Carrera Unified Formulation (CUF) to capture localized effects and cross-sectional distortions. Contact interactions are normal and frictionless via a node-to-node contact algorithm with the penalty approach for contact enforcement. The analysis considers the material nonlinearity via the von Mises constitutive law. Numerical assessments compare the CUF solutions with 3D finite element analysis concerning the solution quality, computational size, and analysis time. The results show the ability of 1D CUF models of accurately evaluating localized deformations and plasticity. The CUF results are in good agreement with reference 3D finite element solutions, and require an order of magnitude fewer degrees of freedom and analysis time, making them computationally efficient.

An He (1), Yating Liang (2) and Ou Zhao (1)
(1) School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
(2) School of Engineering, University of Glasgow, Glasgow, UK

ABSTRACT: The structural behaviour and residual compression resistances of circular high strength concrete-filled stainless steel tube (HCFSST) stub columns after exposure to fire were experimentally and numerically investigated in this paper. The experimental study was performed on 12 circular HCFSST stub column specimens after exposure to the ISO-834 standard fire for three levels of heating durations (15 min, 30 min and 45 min) as well as 4 unheated circular HCFSST stub column specimens (i.e. reference specimens). The experimental study was supplemented by a numerical modelling study, where two types of finite element (FE) models, namely heat transfer and mechanical FE models, were firstly developed to simulate the thermal and mechanical responses of the circular HCFSST stub column specimens, and then used to perform parametric studies to derive additional numerical results. Due to the lack of existing design codes for concrete-filled stainless steel tube members and concrete-filled carbon steel tube members after exposure to fire, the corresponding codified design provisions for circular concrete-filled carbon steel tube members at room temperature, as established in Europe, Australia and America, were evaluated for their suitability to circular HCFSST stub columns after exposure to fire, based on the test and numerical parametric study results. It was generally found that both the European and Australian codes yield a high level of accuracy and consistency in predicting the residual compression resistances of circular HCFSST stub columns after exposure to fire, while the American specification leads to rather conservative and scattered design residual compression resistances.

Shreya Thusoo (1), Susumu Kono (2), Junji Hamada (3), Yoichi Asai (4)
(1) Dept. of Civil and Environmental Engineering, Tokyo Institute of Technology, Nagatsuta 4259, #G5-1, Midori, Yokohama 2268503, Japan
(2) Dept. of Architecture and Building Engineering, Tokyo Institute of Technology, Japan
(3) Research Development Institute, Takenaka Corporation, Japan
(4) Concrete Pile and Pole Industrial Technology Association, Japan

ABSTRACT: Steel-encased concrete (SC) piles are frequently used in development of earthquake resistant pile systems in Japan where SC section is used near pile head to increase moment and shear capacities. Focus of this research is on the experimental investigation of flexural performance of hollow spun SC piles made of high-strength concrete. Total of seven prefabricated SC pile specimens were tested as cantilevered columns under constant compressive axial and quasi-static reverse lateral loading. Tests were conducted on sections of diameter 400 mm and height 1.2 m with test variables as axial load ratio (0–0.35), steel casing thickness (4.5–6.0 mm), concrete layer thickness (50–68 mm) and filling material (hollow, cement paste, concrete). Theoretical
behavior was assessed by sectional analysis of simple fiber model in OpenSees. The study discusses the failure modes, and influence of concrete crushing and local buckling of steel casing on moment carrying capacity of test piles while paying attention to the ultimate behavior, maximum moment capacity and ultimate curvature.

Xia Yang (1), Chao Tang (1), Yu Chen (2) and Tian-Yang Qiao (1)
(1) School of Urban Construction, Yangtze University, Jingzhou 434023, China
(2) College of Civil Engineering, Fuzhou University, Fuzhou 350116, China

ABSTRACT: This paper presents the results of axial compression tests of steel-reinforced concrete-filled square steel tubular (SRCFSST) stub columns after exposure to elevated temperature. A total of 135 SRCFSST specimens are designed and tested, including 27 specimens that are unheated and 108 that are heated for different times. Each test examines the effects of concrete strength, width-to-thickness ratio of the square steel tube, section steel ratio and heating times on the strength, deformation and ductility characteristics of the specimen. Test results indicate that the section steel ratio has the greatest effect on the post-yield behavior of the SRCFSST stub columns. On the other hand, temperature has the greatest effect on the residual bearing capacity of the SRCFSST stub columns. The section steel ratio has the second greatest effect on the residual bearing capacity, followed by the concrete strength grade and the width-thickness ratio of the steel tube. Equations are proposed to predict the ultimate strength of the composite columns at room temperature and after exposure to elevated temperature. The computed values from the formulae are consistent with the experimental results.

Wen Ma, Zhixiang Li and Suchao Xie (Key Laboratory of Traffic Safety on Track, Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha 410075, China; Joint International Research Laboratory of Key Technology for Rail Traffic Safety, Central South University, Changsha 410075, China; National & Local Joint Engineering Research Center of Safety Technology for Rail Vehicle, Central South University, Changsha 410075, China), “Crashworthiness analysis of thin-walled bio-inspired multi-cell corrugated tubes under quasi-static axial loading”, Engineering Structures, Vol. 204, Article 110069, 1 February 2020, https://doi.org/10.1016/j.engstruct.2019.110069

ABSTRACT: This paper proposes a bio-inspired multi-cell corrugated tube for use in energy absorption. The proposed structure consists of two parts: an inner rib and a corrugated tube into which the inner rib is inserted. The structure of the corrugated tube is specified using a cosine expression based on two parameters, that is, the number of cosine wave crests and their amplitude. Two inner ribs with different sections (X-shaped and Y-shaped) were designed and the crashworthiness of the resulting tubes was analyzed. The crashworthiness was determined using the finite-element program LS-DYNA. The numerical results show that the modes of collapse of the multi-cell corrugated tubes can be classified into four types: unstable, diamond, ring, and mixed modes. Each mode is strongly affected by the number of cosine wave crests and their amplitude. By analyzing the force–displacement performance and crashworthiness indicators, it was found that tubes with appropriate number of wave crests and amplitudes, and inner rib shape experience lower initial peak forces and increase energy absorption and specific energy absorption (compared with a traditional straight tube with the same inner rib). The undulation in the load-carrying capacity is also decreased. Thus, the multi-cell corrugated tubes have good crashworthiness.

Triputresh Deb Singha (1), Mrutyunjay Rout (2), Tamnjoy Bandyopadhyay (3) and Amit Karmakar (3)
(1) Mechanical Engineering Department, Govt. College of Engineering and Textile Technology, Serampore, Hooghly 712201, India
(2) Mechanical Engineering Department, Govt. College of Engineering, Bhawanipatna, India
(3) Mechanical Engineering Department, Jadavpur University, Kolkata 700032, India

ABSTRACT: This paper presents a finite element based method to study the influence of elevated temperature and moisture absorption on the free vibration behavior of rotating pretwisted sandwich conical shells consisting of two composite face-sheets and a synthetic foam core. The sandwich structure is assumed to contain single or
multiple debonding present either in the face-sheets or at the interface between the face-sheets and core. The
finite element formulation consists of an eight-noded isoparametric shell element having five degrees of
freedom at each node. Lagrange’s equation is employed to derive the governing equation for free vibration
analysis at moderate rotational speeds while the multi-point constraint algorithm is used to model the debonding
region present in the composite sandwich shells. Numerical results are presented to depict the effects twist
angle, thickness ratio of core to face-sheets, rotational speed and single or multiple debonding on the natural
frequency of the composite sandwich conical shells at elevated temperature and moisture concentration.

Yang Qu, Yongfeng Luo, Qinglong Huang and Zhaochen Zhu (Department of Structural Engineering, Tongji
University, Shanghai 200092, China), “Seismic response evaluation of single-layer latticed shells based on
equivalent modal stiffness and linearized iterative approach”, Engineering Structures, Vol. 204, Article 110068,

ABSTRACT: Seismic evaluation methods based on the modal decomposition principle highly depend on
whether the dominant modes of a structure are correctly identified, but current modal pushover methods usually
ignore this core issue. Firstly in this paper, the established threshold value method for mode identification is
enhanced with a stronger theoretical basis considering the harmonic loading and resonance, so that the dominant
modes can be truncated more convincingly. Then due to the rough description of capacity curve in the
conventional modal pushover method using the base shear and roof displacement, overall coupling responses
are incorporated into the derivation of the equivalent modal stiffness, who associates the modal properties with
the overall ones. On this basis, the capacity curve is obtained and the equivalent single-degree-of-freedom
system is generated, which essentially differs from that of the conventional method. Seeing the capacity curve
featured with strong nonlinearity, a linearized iterative approach is proposed for accurate estimation of the
performance point. Thus, an improved modal pushover procedure is established. For detailed comparative
evaluation, three single-layer latticed shells and a practical engineering structure, named Shanghai International
Convention Center, are employed as analytical models with initial geometrical imperfection and member
buckling considered. Calculating results of nodal displacements, element stresses, as well as the quantity of
yielding members, demonstrate the unfavorable underestimation from the conventional method. Meanwhile,
good agreement on response estimation is reached between the improved procedure and the nonlinear response
history analysis method, attesting the satisfying accuracy of the improved procedure.

G.B. dos Santos and L. Gardner (Department of Civil and Environmental Engineering, South Kensington
Campus, Imperial College London, London SW7 2AZ, UK), “Design recommendations for stainless steel I-
sections under concentrated transverse loading”, Engineering Structures, Vol. 204, Article 109810, 1 February

ABSTRACT: Recent investigations have highlighted the need for improved provisions for determining the
resistance of stainless steel I-sections under concentrated transverse loading. Such provisions, which reflect the
particular characteristics of the material, have been developed and are described herein. A review of the existing
European design formulae for members under concentrated transverse loading is firstly presented. Then a series
of parametric studies, based on validated finite element models are described covering I-sections with a range of
web slenderness values and different stainless steel grades. On the basis of the numerical results, together with
existing experimental data, revised design equations are presented and assessed through reliability analysis
performed in accordance with Annex D of EN 1990. The new provisions yield enhanced ultimate load
predictions and are expected to be included in the next revision of EN 1993-1-4.

Fangying Wang (1), Ou Zhao (1) and Ben Young (2)
(1) School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
(2) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China

“Testing and numerical modelling of S960 ultra-high strength steel angle and channel section stub columns”,
Engineering Structures, Vol. 204, Article 109902, 1 February 2020,
https://doi.org/10.1016/j.engstruct.2019.109902

ABSTRACT: A comprehensive experimental and numerical study of the cross-sectional compressive behaviour
and resistances of press-braked S960 ultra-high strength steel (UHSS) angle and channel section stub columns
is reported in this paper. The experimental study was carried out on four equal-leg angle sections and eight plain
channel sections, and comprised material testing, initial local geometric imperfection measurements and 18 stub column tests. The experimental setups, procedures and key observations were fully presented. The experimental study was then supplemented by a finite element (FE) simulation programme, in which FE models were firstly developed to replicate the test structural responses and subsequently used to generate further numerical data over a wide variety of cross-section sizes. It is worth noting that the current international standards established in Europe, America and Australia/New Zealand only cover the design of structural members with material grades up to S700, and thus the examined S960 UHSS angle and channel section stub columns are out of the scope of the existing design standards. In this study, the experimentally and numerically acquired data was adopted to assess the applicability of the codified provisions and formulations to the design of S960 UHSS angle and channel section stub columns. The assessment results generally indicated that the current European code leads to overall consistent and accurate predictions of cross-section compression resistances, but with many overestimated predicted resistances for S960 UHSS channel section stub columns, while the American and Australian/New Zealand standards yield unduly scattered design cross-section compression resistances, with unsafe and overly conservative predicted resistances respectively for S960 UHSS channel section stub columns and slender angle section stub columns. Revised codified design rules were also proposed, and shown to yield safe, accurate and consistent design cross-section compression resistances for S960 UHSS angle and channel section stub columns.

Fengcheng Liu (1,2), Ruoqiang Feng (2), Konstantinos Daniel Tsavdaridis (1) and Guirong Yan (3)  
(1) School of Civil Engineering, University of Leeds, Woodhouse Lane, LS2 9JT Leeds, UK  
(2) The Key Laboratory of Concrete and Prestressed Concrete Structures of Ministry of Education, Southeast University, Nanjing 211189, China  
(3) Department of Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology, 1401 N. Pine St., Rolla, MO, USA  

ABSTRACT: At the initial design stage of a grid structure, shape optimisation is an effective way to find the optimal structural form. However, most of the shape optimisation methods do not take into consideration the imperfections, thus the actual buckling load capacity of the optimised structure is usually low. In this paper, an improved shape optimisation method is proposed, one that is considering the effect of structural imperfection sensitivity. In this method, the bending strain energy ratio is taken as a constraint, and when the total strain energy decreases, yet there is a certain proportion of bending strain energy in the structure. Consequently, the resulted shape is not sensitive to the initial geometry imperfection, and therefore, an efficient structure with higher buckling load capacity and low imperfection sensitivity is obtained. In order to evaluate the redundancy performance of the optimised structure, an index called structural overall redundancy, based on damage model is proposed herein. The damage model is simulated by removing a key rod of the structure. The results demonstrate that the overall redundancy of the structure obtained by the proposed method is higher than that obtained by the traditional method, thus an optimal design of a grid structure is obtained.

Yi Hui (1), Siu-Seong Law (1), Weidong Zhu (2) and Qingshan Yang (1)  
(1) School of Civil Engineering, Chongqing University, Chongqing 400044, China  
(2) Department of Mechanical Engineering, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA  

ABSTRACT: The incremental harmonic balance (IHB) method is popularly used in the nonlinear analysis of dynamic systems. It is, however, only applicable to polynomial type geometrical nonlinearity which greatly limits its application to more general nonlinear systems. The IHB method is extended (EIHB) in this report to overcome this limitation with a simple procedure for evaluating the stiffness matrix. The EIHB is versatile in dealing with any type of continuous nonlinear functions including the piecewise linear function and hysteretic restoring force function. Several nonlinear Single-Degree-of-Freedom (SDoF) systems are adopted for illustration of the proposed method. One more simple 7-DoFs suspension bridge deck and one more complicated 48-DoFs frame structure with buckling restrained braces are analyzed. New observations are noted.
from the analysis which would otherwise be difficult to obtain via existing methods. The proposed method is concluded to be simpler and convenient for nonlinear dynamic analysis of complicated structural systems than existing methods.

Tianxiang Xu (1), Jiepeng Liu (1), Xuanding Wang (1), Ying Guo (1) and Y. Frank Chen (2)  
(1) School of Civil Engineering, Chongqing University, Chongqing 400045, China  
(2) Department of Civil Engineering, The Pennsylvania State University, Middletown, PA 17057, USA  
“Behaviour of short CFRP-steel composite tubed reinforced normal and high strength concrete columns under eccentric compression”, Engineering Structures, Vol. 205, Article 110096, 15 February 2020,  
https://doi.org/10.1016/j.engstruct.2019.110096

ABSTRACT: The use of steel tubed reinforced concrete (STRC) column maximizes the confinement effectiveness of steel tube as the steel tube is disconnected at the beam-column joint. However, for high-strength and high performance concrete, the confinement from the steel tube would be limited. Also, certain measures need to be implemented to prevent the corrosion of steel tube. Carbon fibre reinforced polymer (CFRP) has the advantages of high strength-to-weight ratio and good corrosion resistance. However, the complicated construction procedures and relatively brittle post-peak behaviour limit its application to new concrete buildings. The combination of CFRP and STRC column is a good alternative to solve the concerning problems. This study experimentally investigated the behaviour of CFRP-steel composite tubed reinforced concrete (C-STRC) columns under eccentric compression. The observed failure modes, load-deformation curves, and load-stress curves of the steel tube and longitudinal reinforcing bars are presented. The test results show that the load capacity and deformability of the C-STRC columns with normal concrete strength are enhanced due to the use of CFRP and steel tube. The plastic stress distribution method was employed to analyse the axial load versus moment interaction curves and the results were found to be generally in good agreement with the test ones.

Hong-Song Hu (1), Peng-Peng Fang (2), Yang Liu (2), Zi-Xiong Guo (2) and Bahram M. Shahrooz (3)  
(1) Intelligence and Automation in Construction Fujian Province Higher-educational Engineering Research Centre, College of Civil Engineering, Huaqiao University, Xiamen 361021, China  
(2) College of Civil Engineering, Huaqiao University, Xiamen 361021, China  
(3) Dept. of Civil and Architectural Engineering and Construction Management, University of Cincinnati, 765 Baldwin Hall, Cincinnati, OH 45221-0071, USA  
“Local buckling of steel plates in composite members with tie bars under axial compression”, Engineering Structures, Vol. 205, Article 110097, 15 February 2020,  
https://doi.org/10.1016/j.engstruct.2019.110097

ABSTRACT: Tie bars have been frequently used in square or rectangular concrete filled steel tubular (CFST) columns and concrete-filled steel plate (CFSP) composite shear walls for delaying local buckling of the steel plates and also improving the concrete confinement. This study investigated the entire response of steel plates in composite members with tie bars. Twelve specimens were designed and tested under axial compression. In these specimens, only the steel plates resisted the axial load, and the concrete was only used to restrain the inward buckling of the steel plates. The effects of the width-to-thickness ratio of the steel plate and the ratio of the vertical spacing of the tie bars to the steel plate width (abbreviated as vertical-spacing-to-width ratio) were investigated. It was found that the increase in the performance of the steel plates due to the tie-bar restraint was quite limited when the vertical-spacing-to-width ratio was 1/2 and became more significant when this ratio decreased to 1/3. The elastic buckling stresses of rectangular plates having boundary conditions similar to those in composite members were computed using the finite element method for further strength evaluation of the steel plates. It was found that the effect of the columns of tie-bars on the elastic buckling stress increased as the vertical-spacing-to-width ratio decreased and was negligible when this ratio was larger than 0.6. Simplified equations for estimating the maximum strength and reserved strength (defined as the average stress corresponding to the average strain of 3%) of the steel plates in composite members with tie bars were developed based on the test results and elastic buckling analyses.

Vipulkumar Ishvarbhai Patel (School of Engineering and Mathematical Sciences, La Trobe University, Bendigo, VIC 3552, Australia), “Analysis of uniaxially loaded short round-ended concrete-filled steel tubular beam-columns”, Engineering Structures, Vol. 205, Article 110098, 15 February 2020,  
https://doi.org/10.1016/j.engstruct.2019.110098
ABSTRACT: Round-ended concrete-filled steel tubular (RCFST) columns exhibit low resistance to running water, strong y-axis bending strength and aesthetic appearance for their use in bridge piers. However, the behavior of RCFST beam-columns under uniaxial loading has not been studied numerically. This paper describes the computational simulation and design of uniaxially compressed short RCFST beam-columns. The nonlinear simulation is based on the numerical fiber-based methodology. The flange local and post-local stability in terms of outward buckling of the flat plate and circular-rectangular concrete confinement are considered in the fiber-based simulation. The simulation procedures for generating the load-strain responses, moment-curvature curves, and nonlinear strength envelopes are described. The computed axial capacity, ultimate bending strength and load-strain performance of short RCFST beam-columns are assessed against the independent experimental results. The statistical results reveal the accuracy of the fiber-based simulation for exploring the compression and bending behavior of short RCFST beam-columns. The parametric analysis is conducted using the fiber-based model to examine the local buckling, bending axis, aspect ratio, and material strength influence on the performance of uniaxially compressed RCFST short beam-columns. The design of eccentrically loaded short beam-columns based on Eurocode 4 provisions is described.

Xiaoyu Zhang (1), Liang Tang (2), Xuewei Li (2), Xianzhang Ling (2) and Andrew Chan (3)
(1) School of Civil Engineering, Guangzhou University, Guangzhou, Guangdong 510006, China
(2) School of Civil Engineering, Harbin Institute of Technology, Harbin, Heilongjiang 150090, China
(3) School of Engineering and ICT, University of Tasmania, Hobart, Tasmania 7001, Australia
ABSTRACT: Even with modern design guidelines, collapse of pile-supported structures in liquefiable deposits are still observed after strong earthquakes, and buckling instability of piles has been cited as a possible mechanism of failure in liquefiable soils. However, the buckling failure of pile under the combined action of lateral load and axial load has received little attention. This paper presents a shake-table test to study the failure mechanism of an end-bearing pile partly embedded in a saturated sand layer. It is found that pile with a large mass at the top failed in buckling after the soil fully liquefied. In addition, a pseudo-static analysis method is proposed to evaluate the buckling instability of the pile under the combination of lateral and axial load. The buckling load of the pile was found to decrease with the increase in lateral inertial load. It is hence important for the designers to consider the level of lateral loading during buckling analysis of pile in liquefiable ground. Finally, a possible boundary for safe design is proposed to avoid buckling failure of the pile while considering the effect of inertial load.

ABSTRACT: This paper presents the results of an experimental study aimed at evaluating the effect of important design parameters on the flexural behavior of unbonded post-tensioned rectangular concrete-filled fiber-reinforced-polymer (FRP) tubes (CFFTs) beams. Four full-scale beams were constructed and tested to failure in four-point bending over a simply supported span of 3,000 mm. The design parameters are the confinement effect of using FRP tube or steel stirrups, the concrete compressive strength, and the FRP tube thickness. The results showed that reinforced concrete (RC) rectangular CFFT beams prestressed with unbonded steel strands can achieve substantially higher flexural strength, inelastic flexural deformation, ductility, and energy absorption capacity than conventional prestressed RC beam without FRP tube. The ultimate strength, deformation capacity, ductility, and energy absorption were increased by 2.43, 1.89, 1.63 and 3.87 times than the prestressed RC beam. The results also showed that increasing the FRP tube thickness of the prestressed CFFT beams from 6.0 to 7.4 mm has led to the increase of the ultimate capacity, ductility, and energy absorption by 19%, 28% and 18%, respectively. Prestressed CFFT beams with high strength concrete (HSC, 70 MPa) enhanced the initial stiffness before cracking, increased the ultimate flexural moment capacity by 7%, with no significant change in the ultimate deflection, compared to normal strength concrete (NSC, 46 MPa). Based on the results of this study, the effect of increasing the FRP tube thickness is more effective in
ABSTRACT: A series of compressive tests of high tensile steel stiffened plates with multiple openings have been conducted. Different degrees of openings represented by different sets of openings are considered, and enhancing the flexural strength and stiffness of the prestressed CFST beams than increasing the concrete strength. An analytical model based on plane sectional analysis using partially confined and unconfined concrete models as well as an empirical design equation are proposed to predict the flexural moment capacity of the tested beams. The proposed models using partially confined and unconfined concrete models and empirical equation successfully predict the flexural moment capacity with satisfactory accuracy on average of $1.00 \pm 0.03$, $1.23 \pm 0.04$ and $1.01 \pm 0.08$, respectively. It was also found that ignoring concrete confinement would highly underestimate the flexural strength. More investigations, however, are needed to assess the effect of a wide range of key influencing parameters to better model the flexural behavior of prestressed rectangular CFST beams.


ABSTRACT: In this paper, experimental, numerical and analytical investigations were carried out to study the structural behavior of concrete-filled stainless steel tubular (CFSST) stub columns externally wrapped by carbon fiber reinforced polymer (CFRP) composites under eccentric compression loading. In the experimental work, twelve stub columns of 101 mm outer diameter and 2 mm thickness were tested. The main variables considered were the thickness of the CFRP wrap ($t$) and the load eccentricity to the outer diameter ratio ($e/D$). A 3D finite element (FE) simulation was developed for the CFRP-bonded CFSST stub columns using the well-known commercial FE program ABAQUS and validated against the experimental results. The validated FE models were further utilized to generate more data with different variables. From the experimental and numerical results, it was found that the CFRP wrapping effectively improves the ultimate strength of the CFRP-bonded CFSST stub columns. Finally, an analytical axial force-bending moment (P-M) interaction model was proposed. It provided conservative predictions when compared to the experimental and FE results.

Peng Dai (1), Lu Yang (1), Jie Wang (2) and Yuhang Zhou (1)
(1) Beijing Engineering Research Centre of High-rise and Large-span Prestressed Steel Structures, Beijing University of Technology, Beijing 100124, China
(2) Department of Architecture and Civil Engineering, University of Bath, Bath BA2 7AY, UK


ABSTRACT: Concrete-filled stainless steel tube (CFSST) members combine the advantages of the outstanding corrosion resistance of stainless steel and the composite action in concrete-filled steel tube (CFST) system. However, accurate calculation methods for this type of structures are currently limited and research into CFSST members with hot-rolled stainless steel tubes are not available. In this paper, the compressive behavior of CFSST stub columns has been investigated through a comprehensive experimental and numerical program. A total of 18 specimens, including 9 concrete-filled austenitic stainless steel tube (austenitic CFSST) and 9 concrete-filled duplex stainless steel tube (duplex CFSST) stub columns, were tested under compression. The varying parameters in the experimental study included the thickness of the stainless steel tube and the strength of the concrete. Finite element (FE) models duplicating the tests were developed, which were subsequently used in parametric study to generate a wider range of data and to investigate the influence of the tube thickness and concrete strength on the ultimate capacities of CFSST stub columns. Based on the generated data, it was found that the current European and Chinese standards for concrete-filled carbon steel tubes underestimate the resistances of CFSST members significantly. To this end, new calculation methods developed based on these European and Chinese design rules have been proposed, which were shown to provide improved strength predictions for both the austenitic and duplex CFSST members.

their effect on the ultimate carrying capacity is explored. The results are discussed, and several conclusions are stated. Based on the experimental results, several relationships predicting the ultimate axial capacity of high tensile steel stiffened plates with multiple openings as a function of remaining volume and degree of openings are developed. Also, a failure assessment diagram of stiffened plates with openings is defined. Finally, a comparison with other published experimental results for deteriorated mild steel plates with multiple opening is performed.

Y.G. Li (1) and H.P. Hong (2)
(1) School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, Xi’an 710072, China
(2) Department of Civil and Environmental Engineering, University of Western Ontario, London N6A 5B9, Canada

LABSTRACT: Damage of latticed shells due to the earthquake has been observed and the damage can affect the critical load for global instability. In the present study, an investigation of the critical load factor of a spherical latticed dome after sustaining seismic excitation is carried out. The evaluation of the damage factor is presented based on the initial and remaining critical load factors for global instability before and after the structure sustained an earthquake. The statistics and the probabilistic model of the damage factor of the latticed shell are presented by considering the record-to-record variability and the use of the uni- and bi-directional seismic excitation. The results show the importance of considering bidirectional ground motions to assess the damage factor. Fragility curves are estimated and are used as a basis to develop an approach for practical and rapid post-disaster quantification of a latticed shell for temporary emergency use. The qualification can be carried out using the observed ground motion record at the structural site. If the record of the sustained seismic event is unavailable, a practical chart for qualifying the structure for temporary emergency use is recommended based on the magnitude and epicentral distance of the seismic event.


LABSTRACT: The torsional response of laminated rectangular panes composed by $N$ glass plies of arbitrary thickness, coupled by polymeric interlayers, is here analyzed. Under the quasi-elastic approximation, that considers the secant stiffness of the polymer, we use the classical hypothesis that the all glass plies rotate of the same angle of twist to derive the shape function for the strain field, whose actual form is found by energy minimization. When the width of the pane is much less that its length, we find formulae that apply to the geometry of a beam, representing the counterpart for laminates of the solution à la de Saint Venant for elements with thin rectangular cross sections. This approach extends to the case of torsion the Enhanced Effective Thickness (EET) method, already proposed for bending, and generalizes other previously proposed engineering methods, which are only applicable for beams composed of a limited number of glass plies. Comparison with numerical results for different geometries confirms the accuracy of the proposed formulation. This method can be conveniently applied for the preliminary design of cold-bent laminated cells for façades, as well as to study the lateral torsional buckling of in-plane-bent beams.

Smail Kechidi (1,2), David C. Fratamico (3), Benjamin W. Schafer (3), José Miguel Castro (1) and Nouredine Bourahla (4)
(1) Department of Civil Engineering, Faculty of Engineering, University of Porto, Porto, Portugal
(2) Department of Civil Engineering, Faculty of Technology, University of Blida 1, Blida, Algeria
(3) Department of Civil Engineering, Johns Hopkins University, Baltimore, MD, USA
(4) Department of Civil Engineering, National Polytechnic School, Algiers, Algeria
ABSTRACT: The objective of this paper is to validate finite element (FE) modeling protocol for screw connected, back-to-back built-up cold-formed steel (CFS) columns. The protocol is developed and validated using results from previously conducted experiments. The effort is motivated by two applications: (1) to augment experimental findings on built-up CFS columns, particularly for fastener demands and (2) to provide a simulation path for modeling the built-up CFS columns that are used as shear wall chord studs. Shell FE-based models were created in ABAQUS and include monotonic loading, nonlinear geometric and material behavior, geometric imperfections based on laser scanned measurements of tested specimens and a contact model that includes friction. Additionally, the screw fasteners were integrated into the modeling protocol using user-defined element subroutines capable of reproducing strength and stiffness deterioration under monotonic load as well as the pinching that occurs when screw fasteners are subjected to cyclic loads. Monotonic, concentric compression tests on 17 back-to-back CFS columns using two cross-section sizes and varying fastener layouts with sheathing conditions were simulated. Deformations, strength, and collapse mechanisms obtained by the models were in close agreement with the experimental results. An assessment of the loading demand on screw fasteners reveals the conservatism in built-up column fastener layout and design as required by the North American Specification for the Design of Cold-Formed Steel Structural Members (AISI S100-16 Section I1.2). Also, under the tested semi-rigid column end conditions, there is a little boost in axial capacity with the addition of member end fastener groups (EFGs) at the top and bottom of the columns. Numerical models are also used to assess the cyclic performance of axially-loaded columns so that chord stud buckling limit states could be captured in seismic simulations of CFS-framed shear walls in future work.

Soomin Choi (1) and Yoon Young Kim (2)
(1) Soft Robotics Research Center, Seoul National University, Gwanak-ro 1, Gwanak-gu, Seoul 08826, Republic of Korea
(2) School of Mechanical and Aerospace Engineering, Seoul National University, Gwanak-ro 1, Gwanak-gu, Seoul 08826, Republic of Korea

ABSTRACT: Thin-walled box beams generally exhibit complex sectional deformations that are not significant in solid beams. Accordingly, a higher-order beam theory suitable for the analysis of thin-walled box beams should include degrees of freedom representing sectional deformations. In a recent study, a recursive analysis method to systematically derive sectional membrane deformations has been proposed to establish a consistent higher-order beam theory. In this study, another recursive analysis method is proposed that is suitable for the closed-form derivation of new sectional bending deformations representing the bending of edges (or walls) of the cross-section shown in a box beam under doubly symmetric loads. A consistent 1D higher-order beam theory appropriate to include these additional deformation modes as beam degrees of freedom is also established. The proposed theory provides explicit formulas that relate stresses to generalized forces including self-equilibrated forces such as bimoments. Furthermore, sectional modes are hierarchically derived so that the level of solution accuracy can be effectively and systematically controlled. Thus, the accuracy for static displacement/stress calculations and eigenfrequencies can be adjusted to be fully comparable with plate/shell results. When general doubly symmetric loads are applied to a box beam, the edge membrane modes derived in an earlier study can also be used as additional degrees of freedom besides the edge-bending modes derived in this study. The validity of the proposed beam approach is verified through the analyses of static displacements and stresses as well as eigenfrequencies for free vibration problems.

Kyungkoo Lee (1), Jinwon Shin (2), kapsun Kim (3) and Amit Varma (4)
(1) Department of Architectural Engineering, Dankook University, South Korea
(2) Department of Architectural Engineering, Catholic Kwandong University, South Korea
(3) Central Research Institute, Korea Hydro & Nuclear Power Co., LTD, South Korea
(4) Lyles School of Civil Engineering, Purdue University, West Lafayette, IN, United States
ABSTRACT: This paper presents an experimental study to investigate the local response of steel plate-concrete (SC) composite walls subjected to impact loads. Seven SC-wall specimens of an intermediate scale with plane dimensions of 2100 × 2100 mm and thicknesses in the range 320–360 mm are tested with target impact projectile velocities in the range 122–159 m/s. Wall thickness, steel-plate thickness, reinforcement ratio, yield strength of the steel plate, and tie bars are considered as the main design parameters for SC walls. For the projectiles, the impact velocity and weight are varied with the wall design parameters. Test results are evaluated using the design equations presented in AISC N690s-1 Appendix N9 based on the three-step method developed using an experimental database comprising the results of 130 prior tests. The impact tests conducted in this study indicate that the three-step method tends to be overly conservative, requiring an improved method to predict accurately the impact behavior of SC walls for beyond design basis impact evaluation. The effects of tie bars and strain rate, which were not addressed in the three-step method, are also examined. The test results and new findings provided in this paper are valuable for more reasonably predicting the impact responses of SC walls and improving the current design methods.

Alejandro Giraldo Soto (1), Alejandro Pérez Caldentey (2), Hugo Corres Peiretti (2) and Jorge Calvo Benítez(3)
(1) Institute of Structural Engineering (IBK), Swiss Federal Institute of Technology (ETH) Zurich/dsp Ingenieure & Planer AG, Hönggerberg, HIL E 41.2, Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland
(2) Technical University of Madrid/FHECOR Consulting Engineers S.A, Barquillo, 23, 2º, 28004 Madrid, Spain
(3) Sping Servicios Profesionales de Ingeniería S.L, Infanta Mercedes, 34, 28020 Madrid, Spain

ABSTRACT: The results of two unique experimental campaigns carried out on composite box girder sections subjected to moment-shear interaction and moment-shear-torsion interaction are presented. They involve the behaviour of the box sections both in positive and negative bending. The effect of the flexibility of the connection is measured and accounted for. A finite element model is implemented to account for this effect, resulting in an improvement in the accuracy of the stiffness of the sectional behaviour. One of the main results is a significant over-resistance in relation to the shear capacity of the sections, which is very clear in the tests involving bending shear and torsion. This effect is attributed to the contribution to the shear capacity of the concrete slab.

Yong-Ha Hwang (1), Keun-Hyeok Yang (2), Ju-Hyun Mun (2) and Seung-Jun Kwon (3)
(1) Department of Architectural Engineering, Kyonggi University, Graduate School, Suwon, Kyonggi-Do, South Korea
(2) Department of Architecture Engineering, Kyonggi University, Suwon, Kyonggi-Do, South Korea
(3) Department of Civil & Environmental Engineering, Hannam University, Deajeon, South Korea

ABSTRACT: This study aims to examine the potential of approaches proposed for transverse reinforcement arrangement in the jacket section of existing non-seismic or deficient columns to enhance the axial performance of these columns. To satisfy the requirements for the seismic details of column design specified in ACI 318-14, an original technique of arranging V-clips across the overlapped legs of channel-shape bars was proposed to form peripheral closed-hoops in the jacket section while avoiding the interruption of the existing column. Ten column specimens with large-scale dimensions were prepared by considering the jacketing method and the amount of transverse reinforcement in the jacket section as test parameters, following which they were tested under concentric axial loads by using a 40000-kN-capacity steel frame. In the test, concrete jacket columns prepared using the proposed V-clip technique showed an axial performance equivalent to that of the counterpart concrete jacket columns prepared using prefabricated bar units, the effectiveness of which was previously demonstrated in terms of the enhancement of axial stiffness, strength, and ductility as well as easier buildability for forming peripheral closed-hoops and supplementary ties in the jacket section. The restriction of the opening of the channel-shape bars by V-clips delayed the buckling of longitudinal reinforcing bars and resulted in less severe damage to the core concrete in the jacket section. Thus, concrete jacket columns reinforced with the
proposed techniques exhibited higher values of axial ductility than conventional concrete jacket columns or columns jacketed with steel plates and carbon-fiber laminates.


**ABSTRACT:** This paper presents and discusses elastic geometrically non-linear Generalised Beam Theory (GBT) results on simply supported cylindrical steel panels under in-plane bending stresses, extending the knowledge on curved panels under uniform compression recently reported by the authors. Due to its inherent modal nature, GBT enables the acquisition of in-depth knowledge on the behaviour of these complex structural elements, which cannot be obtained with standard shell finite element analysis. In particular, a modal analysis investigation is conducted to assess the imperfection sensitivity of curved panels characterised by distinct curvatures and by considering (i) four distinct loading conditions (including the pure bending case), (ii) two distinct critical-mode initial geometrical imperfection shapes (first two bifurcation modes), and (iii) three distinct amplitudes – whenever relevant, three ‘positive’ and ‘negative’ amplitudes are considered. The work begins by the GBT buckling analysis of the selected panels followed by an in-depth investigation on the corresponding post-buckling behaviour. These results provide the evolution, along the equilibrium paths, of relevant modal displacement profiles, modal participation diagrams and deformed configurations. For comparison and validation purposes, ABAQUUS shell finite element results are also reported.

Tingting Liu (1), Zheng He (1) and Yang Yang (2)
(1) Department of Civil Engineering, Dalian University of Technology, Dalian, China
(2) School of Naval Architecture and Ocean Engineering, Dalian University of Technology, Dalian, China


**ABSTRACT:** This paper presents an approach for quickly predicting vulnerable areas of long-span spherical lattice shells under vertical earthquakes using the equivalent continuum analogy. According to the moment theory from classical shell mechanics, the equations for locating the position of maximum nodal displacement are deduced in the elastic range, while considering the heterogeneity in equivalent stiffness. Based on the plastic limit analysis theory, a defined relative stiffness index is proposed by integrating the curvature variation over the corresponding node-bearing area to predict the position of maximum nodal displacement in the plastic range. Several spherical single-layer lattice shells are analyzed using the finite element method to verify the proposed method, and the relative stiffness index, which could be used as an indicator to validate and adjust structural design configurations. As a large-span shell is expected to perform better when each ring has a similar equivalent stiffness index, thereby avoiding abrupt changes in stiffness. The case study indicates that the vulnerable area in such a long-span single-layer lattice shell can be predicted and controlled based on the relative stiffness index values. Additionally, the desired seismic damage-endurance capacity can be obtained by adjusting the relative stiffness index of each ring to ensure that the structure is sufficiently resilient. The method for predicting displacement-based vulnerable areas using the equivalent continuum analogy provides a practical tool for a quick assessment of preliminary design schemes of new lattice shells and can be also applicable to existing and ready-for-retrofit lattice shells.

Fangying Wang (1), Ben Young (2) and Leroy Gardner (3)
(1) Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, China
(2) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China
(3) Department of Civil and Environmental Engineering, Imperial College London, London, UK


**ABSTRACT:** The use of concrete-filled double skin tubular (CFDST) cross-sections for compression members has become increasingly popular in construction. A recently proposed innovative form of CFDST cross-section, utilising stainless steel for the outer tube, offers the combined advantages of the composite action seen in
CFDST member alongside the durability and ductility associated with stainless steel. CFDST sections with stainless steel outer tubes, for which there are currently little experimental data, are the focus of the present study. A comprehensive experimental and numerical investigation into the compressive behaviour of CFDST sections with square stainless steel outer tubes is presented in this paper. A total of 19 specimens was tested under uniform axial compression, and the test observations are fully reported. The ultimate loads, load-displacement curves and failure modes from the tests were used for the validation of finite element (FE) models. Parametric finite element analyses were then performed. The combined set of experimentally and numerically derived data was employed to assess the applicability of the existing European, Australian and American design provisions for composite carbon steel members to the design of the studied CFDST cross-sections. Overall, the existing design rules are shown to provide generally safe-sided (less so for the higher concrete grades) but rather scattered capacity predictions. Modifications to the current design codes are also considered—a higher buckling coefficient $k$ of 10.67 to consider the beneficial restraining effect of the concrete on the local buckling of the stainless steel outer tubes, as well as a reduction factor $\eta$ to reflect the reduced relative effectiveness of higher concrete grades. Overall, the comparisons demonstrated that improved accuracy and consistency were achieved when the modified design rules were applied.


ABSTRACT: Two finite element solutions are developed for the lateral torsional buckling analysis of timber beam-deck assemblies consisting of two beams braced by decking through fasteners. In contrast to past solutions, both solutions capture the rotational flexibility provided by the connections between the deck boards and the beams. The first solution is intended for systems with partial lateral restraint provided by the deck boards allowing lateral sway while the second solution is intended for systems that are restrained from lateral movement at the deck level. An experimental program is conducted to quantify the rotational stiffness of beam-deck connections for different types of fasteners and the results are input into the finite element formulations to evaluate the corresponding buckling capacities for beam-deck systems. The results indicate that the buckling capacity of beam-deck systems can be significantly increased with commonly used fasteners while high-capacity fasteners can achieve buckling capacities nearly identical to those where rigid rotational connections are assumed.


ABSTRACT: The thin toroidal shell offers exciting possibilities as a lightweight enclosure for working and recreational spaces. In this paper, we use shell theory to investigate the strength and stability of thin toroidal domes of prolate elliptic cross-section. We assume the shell is provided with membrane-type supports so that bending effects at the edges of the shell are insignificant. Focussing attention on the effects of self-weight and the weight of any cladding that may be attached to the shell, we derive the membrane stress resultants for arbitrary values of the shell geometrical parameters, and explore the influence of these parameters on the distribution of stresses in the shell. We then conduct a linear eigenvalue buckling analysis of the shell using a finite-element programme, in order to gain some insight on the stability behaviour of the shell. The main conclusions are that stresses due to gravitational loads are very small in toroidal domes of the type in question, while for the range of geometric parameters (ratio $a/b$ of semi-axes of the toroid; ratio $a/A$ of horizontal semi-axis to mean radius of the toroid) likely to be encountered in practice, buckling is unlikely to govern the design of the shell.

Jian Yang, Xu-Hao Huang and Hui-Shen Shen (School of Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, People's Republic of China), “Nonlinear flexural behavior of temperature-dependent FG-CNTRC laminated beams with negative Poisson’s ratio resting on the Pasternak foundation”,
ABSTRACT: Nanocomposite materials, such as carbon nanotube-reinforced composites (CNTRCs), have emerged as a novel engineering material. They have received growing attentions in various engineering sectors. The fabrication process has also offered the possibility to design and make this type of material to have desired features, such as being functionally graded (FG) or/and having negative Poison’s ratio. This paper reports an investigation on the nonlinear flexural behavior of auxetic laminated beams with each layer is made of CNTRC. Each layer may have different CNT volume fractions and the functional grading occurs in the thickness direction of the beam in the piece-wise pattern. The extended rule of mixture model is used to evaluate the temperature-dependent material properties of CNTRCs. The governing equations for the nonlinear bending of FG-CNTRC laminated beams are derived based on the high order shear deformation beam theory. These equations include the geometrical nonlinearity in the von Kármán sense and take into account the thermal effect and the beam-foundation interaction. The nonlinear bending solutions can be obtained by employing a two-step perturbation approach. The nonlinear flexural responses of FG-CNTRC laminated beams under a uniform pressure in thermal environments are revealed and examined in details through a parametric study. Results showed that the negative Poisson’s ratio has a significant impact on the nonlinear flexural behavior of CNTRC laminated beams.

M. Muthuraman (1), R. Anuradha (2), P.O. Awoyera (3) and R. Gobinath (4)
(1) Department of Civil Engineering, University VOC College of Engineering, Thoothukudi, Tamil Nadu, India
(2) Department of Civil Engineering, SNS College of Technology, Coimbatore, Tamil Nadu, India
(3) Department of Civil Engineering, Covenant University, Ota, Nigeria
(4) Centre for Construction Methods and Materials, S R Engineering College, Warangal, India
ABSTRACT: The demand for lightweight materials in construction has become very popular due to its flexibility and economical importance. Cold-formed steel beams and columns are used for provision of lightweight, durable and cost-efficient structures, and its usage also helps to optimize the construction time. Cold-formed steel section exhibits post-buckling strength, in which hot rolled section is deficient. However, more theoretical background on design and behavior of cold form section is still required, especially when it is subjected to axial loading. Thus, this paper presents numerical and theoretical behavior of pin-jointed cold-formed steel (CFS) column section (built-up battened Lip channel) under axial loading. The numerical modeling was done by using ABAQUS 6.10 software. Based on American Iron and Steel Institute (AISI) specifications, two types of sections were selected for single lipped channel, and it was ensured that the selected chord spacing permits both moment of inertia about the major axis and minor axis are equal. The numerical and theoretical study were done using a varying batten number and section slenderness ratio. The ultimate loads were obtained under the two approaches, for the lipped channel built-up columns, and were compared for the effective section proposed. From the results, the prediction of buckling mode and the failure load of the column were found to be stable and approximately relevant to the FEM results from slenderness ratio ranging from 20 to 60. Also, flexural buckling of all column sections occurred about the axis parallel to the webs, where there is an opportunity for composite action.

ABSTRACT: The design and manufacture of structural nodes for gridshell structures are complicated due to complex geometries and loading conditions. The validation of the design concepts of these nodes is even more challenging, because complex design loads are difficult to be applied in a laboratory test. In this paper, a testing rig is proposed and manufactured to test two different additively manufactured nodes. The two nodes are symmetrical and each connecting three members. These nodes are designed to sustain pure axial loads and pure out-of-plane bending moments, respectively. The results of the experiments show the importance of the bolt tolerance in the design of such a testing setup. Subsequently an innovative and inexpensive experimental setup
is developed for testing nodes under dominant design loading conditions in gridshell structures. The proposed testing method is generalized, which can be applied to both individual and combined loading conditions, and the new testing rig can be easily fabricated at a low cost.


ABSTRACT: L-shaped and T-shaped concrete-filled steel tubular (CFST) columns are becoming attractive to researchers and engineers owing to their advantages of avoiding column protrusion from walls and they can save space. In addition, these columns can be used as corner and edge columns in civil engineering applications. Numerous research studies have been conducted on the behaviour of L-shaped and T-shaped CFST columns under axial compression; however, the design methods require further investigation. In this study, finite element (FE) models were developed to simulate the axial behaviour of unstiffened, stiffened, and multi-cell L-shaped and T-shaped CFST stub columns. The FE models were verified by the experimental results of 103 specimens collected from the literature. A parametric study of 804 examples covering a wide range of parameters was conducted based on the FE models. Predictions of the ultimate strength using Eurocode 4 and a previously reported design formula were compared with the FE results, in which unsatisfactory deviations were observed. New design models for the axial compressive strength and the stiffness were proposed by performing regression for different types of L-shaped and T-shaped CFST stub columns.


ABSTRACT: In the past decades, great progress has been made in analyzing lateral torsional buckling of slender beams. The phenomena has been accurately described by differential equations, closed form solutions are available for specific cases and the solution for any load and any boundary condition can be obtained by finite element analysis. Timber and steel design standards provide a procedure based on equivalent moment factors. With this procedure, beams can be designed straightforwardly. However, modern designers continue to push the envelope and more irregular load patterns are found, on which the design standards do not provide solutions. Consequently, designers are forced to determine the equivalent moment factors based on case-specific literature and/or conservative assumptions. Unfortunately, this makes many challenging modern designs uneconomical. Furthermore, significant inconsistencies between the different design procedures are found. For that purpose, this paper proposes a solution in the form of a general formulation to determine equivalent moment factors for any loading on a single-span beam for both free and restrained lateral bending and/or warping at the supports, for both I-sections and rectangular slender sections loaded in the shear center. It is shown that the obtained moment factors are accurate and in good agreement with design standards and literature, and a wide range of irregular load patterns is considered.

Mizan Ahmed (1), Qing Quan Liang (1), Vipulkumar Ishvarbhai Patel (2) and Muhammad N.S. Hadi (3)
(1) College of Engineering and Science, Victoria University, PO Box 14428, Melbourne, VIC 8001, Australia
(2) School of Engineering and Mathematical Sciences, La Trobe University, Bendigo, VIC 3552, Australia
(3) School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia


ABSTRACT: Thin-walled square and circular hollow steel tubes are designed to support the permanent and construction loads of several upper composite floors before filling the concrete into the tubes to form concrete-filled double steel tubular (CFDST) columns. The influences of preloads acting on the steel tubes on the structural responses of slender square CFDST columns have not been investigated either experimentally or
ABSTRACT: This paper presents a fiber-based computational model for the determination of the interaction behavior of local and global buckling in axially and eccentrically loaded CFDST thin-walled square slender columns including preload effects. The computational modeling method accounts for the influences of the deformations induced by preloads, local-global interaction buckling, geometric imperfections, second-order, and geometric and material nonlinearities. The accuracy of the computational algorithms developed is validated by comparing computations with test data on concrete-filled steel tubular (CFST) columns and finite element results of double-skin CFST (DCFST) columns with preload effects. The computer algorithms are employed to quantify the influences of preloads on the local-global interaction buckling responses of CFDST columns with various important parameters. Proposed is a design method for calculating the ultimate loads of concentrically loaded slender square CFDST columns considering preloads. The computational and design models developed are shown to be efficient modeling and design tools for square CFDST slender columns taking into account the construction method of high-rise composite buildings.

B. Siriguleng (1), W. Zhang (2), T. Liu (2) and Y.Z. Liu (2)
(1) Department of Mechanics, Inner Mongolia University of Technology, Hohhot 010051, PR China
(2) Beijing Key Laboratory of Nonlinear Vibrations and Strength of Mechanical Structures, College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, PR China

ABSTRACT: This paper investigates the vibration modal experiments and the modal interactions for a large space deployable antenna with the ring-truss structure. The reduced scale model of the large deployable ring-truss antenna is firstly introduced briefly. The reduced experimental scale model of the ring-truss structure is designed and is manufactured. The experimental measurements of the vibration modals are carried out for reduced scale model of the ring-truss structure. The natural frequencies and the corresponding modal shapes are obtained. The forced vibration experiments of the reduced scale model are also performed for the ring-truss structure. The displacements of the joint point under different excitation frequencies are obtained and analyzed. A finite element (FE) analysis is finished for the reduced scale model of the ring-truss structure through applying Nastran. The results of the finite element method (FEM) verify the dynamic behaviors of the experimental model. The modal results of the vibration experiments are compared with those of the theoretical analysis and are indicated to be at a good agreement. The phenomena of the energy transfer from the low frequency mode vibration to the high frequency mode vibration are observed from the vibration experiments. We also find these phenomena in the process of studying the theoretical model for the ring truss antenna. It is demonstrated that there exist the phenomena of the energy transfer from the low frequency mode vibration to the high frequency mode vibration for the ring truss antenna when the excitation frequency is consistent with the lower order frequency of the vibration.

Rui Nie (1,2), Baiyan He (1), Shaoze Yan (2) and Xiaofei Ma (3)
(1) Mechanism Theory and Equipment Design, Tianjin University, Tianjin 300350, China
(2) Tribology, Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China
(3) Xi’an Institute of Space Radio Technology, Xi’an, Shanxi 710000, China

ABSTRACT: Mesh reflector antenna plays an important role in the future advanced satellite communication and broadcasting systems, earth observation, land sensing, deep space exploration, and space communication systems. The form of mesh surface is heavily dependent on cable tensions and vice versa. So, the form finding and optimization design of cable networks are extremely important. However, the current design methods conduct optimization under ambient temperature and ignore the shape errors caused by the thermal deformation in space thermal environment. The active on-orbit shape adjustment is limited by the on-orbit measurement and control techniques in the application. The present preliminary adjustment before launch only considered the cable network’s thermal effects and ignored the influences of the truss elastic and thermal deformation on the surface accuracy. Here we proposed an optimization design method for mesh reflector antennas aiming at improving the surface accuracy and tension distribution in the space thermal environment. The truss model is

ABSTRACT: A numerical solution for the three-dimensional static analysis of functionally graded shells with constant curvature is presented. The solution is based on three-elasticity equations written in orthogonal curvilinear coordinates which are valid for spherical, cylindrical shell panels and rectangular plates. The equations in term of the mid-surface variables are solved using a summation of harmonics in term of Navier method which is valid only for simply supported structures. The equations in term of the thickness direction are solved numerically by the Differential Quadrature method (DQM) which permitted to easily calculate the approximate derivative of a function using a weighting sum of the functions evaluated in a certain grid. The layers of the structure are discretized separately by the Chebyshev-Gauss-Lobatto grid and Lagrange interpolation polynomials are considered as the basis functions. The inter-laminar continuity of transverse shear is imposed as part of the boundary conditions for the presented method. The boundary conditions of out-of-plane stresses at the top and the bottom due to the applied loads on the shell are also considered for the analysis, as a result this method can predict the correct behavior of through-the-thickness distribution of transverse stresses. This method permitted easily to discretize the material in term of the thickness direction and several types of single functionally graded layer and sandwich structures with functionally graded core are analyzed. Several shells subjected to bisinusoidal and uniform distributed load are analyzed. The results are compared with other three dimensional solutions proposed in the literature and accurate two dimensional models.

Jiří Witzany (1), Miroš Pirner (2), Radek Zigler (1) and Shota Urushadze (2)
(1) CTU in Prague, Faculty of Civil Engineering, Department of Building Structures, Thákurova 7, Prague, Czech Republic
(2) Institute of Theoretical and Applied Mechanics of the Czech Academy of Sciences, Prosecká 809/76, Prague, Czech Republic


ABSTRACT: The article briefly recalls the issue of historical buildings located in seismically active areas. In the introduction of the paper, the issue of the change of the dynamic response of the structure as a method for determining the possible damage of the structure, which can be difficult to detect by other diagnostic procedures, is discussed. Furthermore, the article outlines the procedure for determining some significant characteristics (such as bending stiffness etc.) by means of the dynamic response of the structure, and simplified relationships and recommendations for diagnosing arch structures based on its dynamic response. The focus of the paper is on the general analysis of the results of experimental tests of five segmental barrel vaults, of which two were reinforced with CFRP strips subjected to alternating static and dynamic loads. Due to the structure of the vault - single-layer masonry with a thickness of 150 mm - a loading mode was required. In the article conclusion the test results are interpreted with regard to the above mentioned facts (extent of experimental loading, specific vault structure) and it is stated that they have demonstrated the possibility of using a change of dynamic characteristics as a possible diagnostic method of the origin and development of defects on the vault structure.

ABSTRACT: This paper investigates the flexural-torsional buckling behaviour about the symmetric axis of axially loaded concrete-infilled double steel corrugated-plate walls with T-section (T-CDSCWs). The T-CDSCW is composed of steel corrugated-plates, infilled concrete and intermediate bolts, among which a positive composite effect further improves load-bearing capacities effectively and thus reduces the thickness of composite walls. The failure mode of the T-CDSCW with high height and small thickness is governed by global instability, and flexural and flexural-torsional buckling may occur for the T-CDSCW under axial compression. This paper focuses on numerical and theoretical analyses of the flexural-torsional buckling behaviour. Based on the refined finite element (FE) model validated by previous experimental researches, parameter analysis is carried out to investigate the elastic and inelastic flexural-torsional buckling behaviour. The formulas of the elastic flexural-torsional buckling load are derived and prove it feasible to design flexural-torsional buckling in accordance with torsional buckling. Numerical results show that the strength reduction factor of flexural-torsional instability can be delineated well by the height-to-thickness ratio of the web and the normalized torsional slenderness ratio of the T-CDSCW. Together with the design formulas of flexural instability, the design formulas of flexural-torsional instability proposed in this paper supplements the design method of axially loaded T-CDSCWs, and provides the foundation for further investigation into global instability of T-CDSCWs under combined compression and bending.

Hongfei Chang (1,2), Wenkang Zuo (1), Junwu Xia (1,2), Bo Xu (1), Renwei Ma (1) and Lihai Zhang (3)
(1) Environmental Impact and Structural Safety in Engineering, China University of Mining and Technology, Xuzhou, China
(2) Geomechanics and Deep Underground Engineering, China University of Mining and Technology, Xuzhou, China
(3) Department of Infrastructure Engineering, The University of Melbourne, Victoria, 3010, Australia


ABSTRACT: In present study, the normalized axial compressive strength (Q) of the vertical inner-plate reinforced (VIPR) square hollow section (SHS) T-joints was systematically investigated under various geometrical design parameters of the joint, such as width ratio of the brace and the chord (β), thickness ratio of the vertical inner plate and chord flange (η), ratio of the outstretch length of the vertical inner plate from the brace to the width of the chord (ξ), height and width ratio of the brace (η). First, a finite element (FE) model of the VIPR SHS T-joint was developed and validated by using experimental data. Then, a large scale of parametric studies was carried out to identify the critical geometrical design parameters that influence the Q of the VIPR SHS T-joint. The results show that Q increases with the increase of β, and the rate of increase becomes more obvious under a large β. In addition, under a relatively small β (i.e. β < 0.6), the yielding of the chord flange is mainly controlled by the vertical inner plate, whereas the yielding of the chord flange is controlled by the brace under a large β. It also demonstrates that the vertical inner plate can mitigate the risk of buckling failure of chord web, and Q increases with the increase of η. Furthermore, this study proposed an empirical equation which could potentially be used by the practicing engineers to evaluate the axial compressive strength of VIPR SHS T-joints under various geometrical design parameters.

Madhup Pandey and Ben Young (Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China). “Structural performance of cold-formed high strength steel tubular X-Joints under brace axial compression”. Engineering Structures, Vol. 208, Article 109768, 1 April 2020, https://doi.org/10.1016/j.engstruct.2019.109768

ABSTRACT: The experimental investigation presented in this study focused on the static strengths and load-deformation behaviour of cold-formed high strength steel tubular X-joints made up of S900 and S960 steel grades. The X-joints include brace members made up of square, rectangular and circular hollow sections, while chord members were made up of square and rectangular hollow sections. The nominal yield strengths of square
and rectangular tubular members were 900 and 960 MPa, while the nominal yield strength of circular tubular members was 900 MPa. Two configurations of tubular X-joints were fabricated, first, where both brace and chord members were made up of square and rectangular hollow sections, and second, where circular hollow section braces were welded to square and rectangular hollow section chord members. The welds were laid using semi-automatic gas metal arc welding process. A total of 34 tests was conducted where an axial compression was applied through the brace members without any chord preload. The ratio of brace-to-chord width (\( \beta \)) ranged from 0.34 to 1, brace-to-chord thickness (\( \zeta \)) from 0.53 to 1.28, chord width-to-thickness (\( \varphi \)) from 20.2 to 38.9, and chord side wall slenderness (\( h/t \)) from 12.7 to 39.0. In order to assess the applicability of the existing design provisions, test strengths were compared with the nominal strengths obtained from the Eurocode 3 (EC3) and CIDECT. It is shown that the existing design provisions are not capable of providing accurate and reliable predictions for cold-formed high strength steel tubular X-joints made up of S900 and S960 steel grades.


ABSTRACT: Steel cantilevers are very different from the simply supported beams under uniform bending which provide the basis for designing steel members against lateral buckling. Cantilevers have different end restraint conditions, while the most critical loading condition for cantilevers is one of concentrated end load leading to a linear moment distribution. Thus the elastic lateral buckling formulations for uniform bending of simply supported beams used more generally for design are inappropriate for cantilevers.

The mono-symmetric yield patterns in simply supported beams with residual stresses in uniform bending are of opposite sense to those of cantilevers because of the opposite sense of the bending moments. Thus formulations which take account of the effect of mono-symmetry on the inelastic lateral buckling of simply supported beams are inappropriate for cantilevers. Further, the linear cantilever moment distribution leads to very localised yielding instead of the uniform yielding of beams under uniform bending.

This paper studies the inelastic lateral buckling of cantilevers in order to produce better design guidance than that currently based on the inelastic buckling of simply supported beams in uniform bending. The effects of mono-symmetry on the elastic buckling of beams and cantilevers are first investigated, and then the effects of the mono-symmetric non-uniform yielding patterns which complicate the prediction of the inelastic buckling resistances of cantilevers are studied. Cantilevers with reduced (instead of rigid) end warping restraints occur in overhanging beams, and so the effects of yielding on overhanging segments are also studied. These studies are used to develop simple approximate methods for designing cantilevers and overhanging segments against inelastic lateral buckling.

Quan Shi (1), Michael T. Heitzmann (2) and Joseph M. Gattas (1)
(1) School of Civil Engineering, University of Queensland, Australia
(2) School of Mechanical and Mining Engineering, University of Queensland, Australia


ABSTRACT: Characterisation of the rotational stiffness of fold lines is necessary to analyse the compliant behaviour of origami-inspired structures, however limited data exists for fold lines manufactured from high-strength materials such as steel. This paper establishes a reliable characterisation of perforated steel fold lines, with three improvements to existing knowledge of their mechanics. First, a manufacture and testing method was developed for consistent measurement of fold line moment responses, over a large rotation range from an unfolded 0° up to 140°. Second, testing data showed inconsistencies with the bilinear analytical model commonly used to describe nonlinear fold line responses, so an enhanced nonlinear model was adapted and shown to give an improved fit over the initial elastic-plastic transition stage. A thick panel clash behaviour was also identified as causing a complex stiffening behaviour at large rotation angles; an ‘over-kerf’ manufacturing strategy was developed to eliminate this clash behaviour, allowing the enhanced model to give a good description of fold rotational stiffness over the complete tested range of rotation. Third, a parametric experimental study obtained fold line responses over a range of steel thicknesses and fold line parameters. This
was used to give additional insight in the relative efficacy of bilinear and enhanced models and the interaction between clash behaviour, sheet thickness, and manufacture kerf.

Anatoliy Orzhelkovskiy (1), Iurii Priadko (2), Anton Tanasoglo (1) and Serafim Fomenko (1)
(1) Theoretical and Applied Mechanics Department, Donbas National Academy of Civil Engineering and Architecture, Ukraine
(2) Beijing International Education Institute, 38 East 3rd Ring North Road, Chaoyang, Beijing 100026, China
ABSTRACT: The article discusses method for the selecting cross-section of steel rod elements of the roof structure placed above the stands of stadiums. Particular attention is paid to ensuring a given level of structural reliability. An algorithm to determine the actual safety factors for the most critical elements in the roof structure is proposed. Snow load, cross-sectional area of the elements, ultimate stress of the material, settlement of the base, mounting imperfections and defects are considered as the stochastic parameters in calculation of the reliability indicators. All specifications of the distributions for these magnitudes are based on the real experimental data. Since the building regulations do not provide a clear algorithm for calculating the reliability indicators of unique (and any other) building structures, it is possible to apply the proposed methodology both to ensure the design reliability of the whole structure as well as the separate most critical structural elements. It also might be applied to other kinds of spatial steel rod structures whose elements work as trusses. The internal force factor in the elements of such structures is longitudinal force. The method has been tested on the stadium structures of FC Olympic in Donetsk city (Ukraine).

ABSTRACT: The composite box girder with corrugated steel webs (CSWs) and trusses is a bridge structure developed on the basis of traditional box girders with CSWs. In this research, experimental, numerical and analytical studies were carried out to investigate the flexural performance of simply supported composite box girders with CSWs. Two 1:5 scale models of a real bridge were fabricated and tested, including one with concrete filled steel tubes and another with hollow steel tubes. The test results show that the two specimens have good ductility and failed in a ductile manner. The concrete filled inside steel tubes reduces the deflection and increases the yield load. The cross sections of the two specimens basically satisfy the “plane section assumption”. Finite element models were also developed for the two specimens and validated based on the experimental results. Afterwards, a parametric study was carried out with the validated finite element models, which shows that the steel ratios and the structure of bottom trusses strongly influences the flexural behavior. At last, a theoretical model is developed to calculate the bending moment of composite beams at the ultimate load.

ABSTRACT: A cable dome system is a spatial network of cables and struts that are pin-jointed, and whose forces are eventually brought to balance by a perimeter ring beam and supporting walls or columns. This paper provides insights about the structural design and behavior of prestressed radial-type cable domes. Through a study of parametric effects, the paper emphasizes careful selection of geometric parameters and cable prestressing forces. A simplified planar model equivalent to that of a three-dimensional model is derived for efficient analysis and design under symmetric loading conditions. The equivalent planar parameters are obtained using the geometrical and nodal force equilibrium relationships, and the Principle of Virtual Work. Results from planar analysis are compared and validated with the three-dimensional analysis results. The calculation of initial member sizes and initial cable prestressing forces is explained. This is followed by a discussion of the structural behavior of cable domes under asymmetric snow loads and wind uplift and the ensuing stability issues. The analysis results revealed that either strut buckling or overall system stiffness were the dominant limit states, the former being the governing limit state in domes with fewer hoops. A design
enhancement in the form of cable-stayed struts is as such recommended to not only increase the strut buckling strength, but also to substantially increase a dome’s load bearing capacity.

Yunying Zhou (1), Jun Zhu (2) and Dongying Liu (3)
(1) Department of Architectural Engineering, North China Institute of Aerospace Engineering, Langfang 065000, China
(2) College of Mechanical Engineering, Zhejiang University of Technology, Hangzhou 310014, China
(3) School of Civil Engineering, Guangzhou University, Guangzhou, 510006, China

ABSTRACT: The method of reverberation-ray matrix (MRRM) has been successfully utilized to study the transient waves in beams, plates and laminated solids. In this work, the MRRM is adopted to study the transient responses and wave propagation of piezoelectric cylindrical shells with finite size. Based on the Donnell shell theory, the reverberation matrix formulation in the cylindrical shell is derived. Using Laplace transformation, the transient responses under imposed impact load can be predicted. Through the numerical simulations, the early short time transient responses can be further elucidated. Furthermore, the effects of the geometric parameters of the composite shells on the wave propagating in the laminated piezoelectric shells are also analyzed.

Hetao Hou (1), Wenhao Wang (1), Bing Qu (2) and Chunxue Dai (1)
(1) School of Civil Engineering, Shandong University, Jinan, Shandong Province 250061, China
(2) Dept. of Civil and Environmental Engineering, California Polytechnic State University, San Luis Obispo, CA 93407, USA

ABSTRACT: This paper focused on the panel which sandwiches an Expanded Polystyrene (EPS) layer between two Steel Reinforced Concrete Layers (SRCLs). The EPS layer provides thermal insulation in the panel while the two exterior SRCLs are connected by Glass Fiber Reinforced Plastic (GFRP) shear connectors to form the composite action and hence achieve a higher flexural resistance in the panel. Four types GFRP shear connectors which consist of diagonal web members, webs with circular perforations, webs with slotted perforations and solid webs, respectively, were considered in this research. To experimentally address the flexural responses of the panels with the four types of GFRP shear connectors, four full-scale experimental specimens were constructed and tested. The test results show that generally any of the four GFRP shear connectors can enable the panel to exhibit satisfactory flexural performance although the GFRP shear connectors with the solid webs tend to increase the ultimate flexural resistance of the panel. Beyond the experimental work, an analysis model based on the transformed cross-section approach and elastic beam theory was developed for capturing the flexural response of the panel up to the cracking limit state. Moreover, an analysis model based on the assumed strain and stress diagrams was established to compute the ultimate flexural resistance of the panel.

Luca Praticò (1), Joel Galos (2), Enrico Cestino (1), Giacomo Frulla (1) and Pier Marzocca (2)
(1) Department of Mechanical and Aerospace Engineering (DIMEAS), Politecnico di Torino, Torino, Italy
(2) Department of Aerospace Engineering and Aviation, School of Engineering, RMIT University, Melbourne, Australia

ABSTRACT: Curvilinear stiffened panels are being developed for aerospace structures and other applications. This paper presents an experimental and numerical study into the vibration response of three curvilinear stiffened square plates clamped at the edges. The experimental modal analysis was performed using laser Doppler vibrometry (LDV) and an impact hammer test. Two of the three plates was constructed with curvilinear stiffener geometry, while the third was a straight stiffened plate with the stiffeners oriented at an angle to the edge of the plate. Even though the natural frequencies of the plates are similar, the different stiffening patterns was sufficient in providing unique directional properties and therefore distinct mode shapes. The numerical modal analysis of the plates was performed using finite element analysis (FEA). A comparison of the experimental and numerical results was carried out in terms of natural frequencies and mode shapes, using
relative differences and modal assurance criterion (MAC), respectively. The experimental and numerical results were in good agreement for all the three plates. The difference between experimental and numerical natural frequencies was typically less than 5% and the diagonal MAC values typically ranged from 0.8 to 1. This is in line with previously published results in the literature. The reasons for differences between the experimental and numerical results, and the practical significance of the findings, are also discussed.


ABSTRACT: Most existing formulations for determining shear strength due to web-post buckling by shear (WPBS) in castellated steel beams depend on many variables, are not applicable to fire situation or do not have a normative approach. In order to provide a simpler and more practical formulation, also applicable to the fire situation, this study presents a semi-empirical formulation based on numerical results of validated models, considering the hypothesis of uniform temperature distribution along the profile and the analogy between the strut model and the compressed diagonal of a web-post subject to WPBS. This semi-empirical model is based on the formulation of EN 1993-1-2:2005 and ABNT NBR 14323:2013 to obtain the resistance of compressed members at elevated temperatures and it is applicable to Litzka, anglo-saxon and Peiner type castellated beams.


ABSTRACT: A novel curved beam quadrature element is presented for geometrically nonlinear analysis of spatial curved beams. Starting from the incremental virtual work equation of the curved beam, the weak form quadrature element method (QEM) is employed to derive the elastic stiffness, geometric stiffness, and induced moment matrices of the curved beam with due account taken of the large rotations in three-dimensional space. All the stiffness matrices are adopted in the incremental-iterative analysis using the generalized displacement control (GDC) method, with specific considerations for the predictor and corrector phases. By testing the constructed curved beam quadrature element with four benchmark problems, it is demonstrated that the element avoids the shear and membrane locking phenomena due to its convenient feature of high-order approximation. In addition, the element is capable of predicting large displacements and rotations, as well as postbuckling paths of spatial beams. Especially, the presented element is featured by unifying the analyses for both curved and straight beams.

Shaoyu Zhao (1), Zhan Zhao (2), Zhicheng Yang (3), LiaoLiang Ke (4), Sritawat Kitipornchai (1) and Jie Yang(2)
(1) School of Civil Engineering, The University of Queensland, St. Lucia, QLD 4072, Australia
(2) School of Engineering, RMIT University, PO Box 71, Bundoora, VIC 3083, Australia
(3) College of Urban and Rural Construction, Zhongkai University of Agriculture and Engineering, Guangzhou, China
(4) School of Mechanical Engineering, Tianjin University, Tianjin 300350, China


ABSTRACT: Owing to their superior mechanical properties, e.g. exceptionally high Young’s modulus, high strength, large specific surface area, and good thermal conductivity, graphene and its derivatives such as graphene platelets (GPLs) are excellent reinforcing nanofillers for composite materials. The most recently developed functionally graded graphene platelets reinforced composite (FG-GPLRC) where GPLs are non-uniformly dispersed with more GPLs in the area where they are most needed to achieve significantly improved mechanical performance has opened up a new avenue for the development of next generation structural forms with an excellent combination of high stiffness, light weight and multi-functionality. Research activities in this emerging area have been rapidly increasing since it was first proposed in 2017. The present paper (i) briefly reviews the mechanical properties of graphene and graphene composites; (ii) summarizes the characteristics of functionally graded materials (FGM) and reports the fabrication of FG-GPLRC; (iii) discusses the existing micromechanics models for the prediction of effective mechanical properties of GPLRC; (iv) presents a
comprehensive review on the mechanical analyses of FG-GPLRC structures; and (v) discuss the key technical challenges and future research directions.


ABSTRACT: Over the years, the wind energy industry has grown rapidly because of its eco-friendly and sustainability features. The development of wind industry demands larger wind turbines, which brings more issues because of higher dynamic loads. Passive, active and semi-active control are major techniques to resolve these issues. This paper reviews the characteristics of these control methods and the recent development of novel controls are discussed. The challenging issues related to structural control of wind turbines due to mechanical vibration are summarized. Recent modeling as well as numerical techniques to simulate wind turbines’ behavior under multihazard dynamic loadings are presented. To evaluate the efficacy of recent control methods under different conditions and environments, a comparative procedure is proposed. The procedure relates the output characteristics and system performance to different types of inputs through modeling of structure and external stressors. The National Renewable Energy Laboratory (NREL) prototype and coupled Lagrange method are the reference model and modeling technique, respectively. An example application of comparing several dampers using the proposed procedure is presented. The comparison of displacement, acceleration, shear and overturning moment reductions are discussed, and the viscous dampers have the best efficacy among other passive control systems.

P. Eigenraam (1), A. Borgart (2), J. Chilton (3) and Q. Li (4)
(1) Delft University of Technology, Julianalaan 134, 2628BL Delft, the Netherlands
(2) Delft University of Technology, the Netherlands
(3) University of Nottingham, United Kingdom
(4) Nanjing University, China


ABSTRACT: This paper presents a detailed structural analysis of a bubble shell engineered by Heinz Isler. Through 3D scanning the geometry of this shell structure has become available to the authors. Structural analysis has not been possible before since the geometry of the shell was not available. The bubble shell was Isler’s most built type of shell. In the paper first the process of reverse engineering the geometry of the shell is described. Second, the effect of pre-stress in the edge beams is described. Third, the load distribution throughout the shell and the membrane behaviour relative to bending behaviour is assessed.


ABSTRACT: A new type of composite column, recycled aggregate concrete (RAC)-encased recycled aggregate concrete-filled steel tube (RACFST) composite columns, promotes the RAC extensive utilization considering synergistic effect between the RAC and the steel tube, which is an attempt to develop environmentally sustainable concrete in high-rise buildings. In this paper, experimental research investigated the axial compressive behavior of RAC-encased RACFST composite columns. Twenty 1:3-scaled specimens were fabricated to test until failure under axial compressive loading. The main variable parameters affecting the behaviour of specimens were recycled coarse aggregate replacement ratio (range from 0% to 100% with 10% increase), stirrup spacing (s = 50 mm, 70 mm, 100 mm, 120 mm), diameter of steel tube (D = 89 mm, 114 mm), concrete strength grade (RC40, RC60) and longitudinal reinforcement ratio (4 12, 8 12). The failure modes, the whole load-deformation curves and the mechanical performance of specimens were also obtained based on static loading experiments and theoretical analysis. It was found that RAC-encased RACFST composite columns, which were subjected to identical axial loads, exhibited more favorable bearing capacity and deformation than those of a comparative reinforced recycled aggregate concrete columns (RACC). The replacement ratio of RCA had a slight effect on the mechanical performance of RAC-encased RACFST
obtaining full aluminum face sheets, balsa wood with an average density of 125 kg/m² and E-glass woven fabric. For obtaining full-field strains and deflection distribution, a digital image correlation (DIC) technique was applied to measure the strains and displacements.

Wei Zhang (1), Zhenyu Huang (1), Zhanxia Fu (1), Xudong Qian (2), Yingwu Zhou (1) and Lili Sui (1)
(1) Durability for Marine Civil Engineering, Shenzhen University, Shenzhen 518060, China
(2) Department of Civil and Environmental Engineering, National University of Singapore, 1 Engineering Drive 2, Singapore 1175762, Singapore


ABSTRACT: This study develops a new steel-concrete-steel (SCS) sandwich beam with hybrid shear connectors comprising both J-hooks and overlapped headed studs. For partially composite SCS sandwich beams, bond-slip is a critical factor influencing the transverse shear resistance of the beam. Thus, this study examines the effect of the degree of composite action and the mechanism of such sandwich beams by testing eight SCS sandwich beams with different shear span-to-depth ratios, steel contribution ratios, types of shear connectors, and spacing of shear connectors. The parametric study thoroughly discusses the effects of these variables on the beam failure modes and beam shear resistance. Based on existing design models, this paper proposes a new analytical model that considers the bond-slip effect to predict the ultimate resistance of SCS sandwich beams. The new model includes contributions from the concrete, shear connectors, and steel plates. Available test data from 57 specimens successfully validated the proposed model.

Man-Tai Chen (1) and Ben Young (2)
(1) Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
(2) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China


ABSTRACT: An experimental study on cold-formed steel elliptical hollow section (EHS) beam-columns is described in this paper. Forty-two beam-column members with two different specimen lengths were tested at different eccentricities to investigate the load-moment interaction relationship. The initial geometric imperfections were determined before the formal tests. The ultimate load-carrying capacities and full load-displacement responses are presented and discussed. The design of cold-formed steel EHS subjected to compression plus bending is not covered by the current design specifications. Hence, the beam-column strengths derived from the experimental investigation were used to assess the design predictions by incorporating the equivalent diameter method, the equivalent rectangular hollow section approach and the conventional design methods using equivalent diameter for bending and compressive strength predictions with the interaction curves adopted in the current design rules for structural use of steel. The reliability of these design rules was evaluated. The comparisons reveal that the predictions by these design methods are generally quite conservative and reliable for cold-formed steel EHS subjected to compression plus bending, except that the design method incorporating the equivalent rectangular hollow section approach with the interaction relationship specified in European Code is unreliable.


ABSTRACT: This study aims to investigate the effect of the insertion of a corrugated composite into the typical balsa core sandwich structure under four-point bending (FPB). The proposed sandwich structure is composed of aluminum face sheets, balsa wood with an average density of 125 kg/m² and E-glass woven fabric. For obtaining full-field strains and deflection distribution, a digital image correlation (DIC) technique was applied to measure the strains and displacements.
employed. Based on continuum damage mechanics (CDM), a three-dimensional finite element model (FEM) was developed to predict the ultimate load-bearing capacity and failure mechanisms of the sandwiches. To this end, the material damage models for balsa wood and corrugated composite were implemented in ABAQUS software via VUMAT subroutine. After validating the numerical model, the effect of geometric parameters of the corrugated composite on the response of the sandwich structure was explored numerically. The findings demonstrated that the proposed hybrid core not only prevents catastrophic failure but also increases weight-specific strength by 38.4%. However, it appears that the hybrid core has no significant influence on the weight-specific stiffness under FPB. The parametric study showed that with increasing the corrugation angle and thickness, the specific strength/stiffness exhibits an ascending trend. Moreover, rectangular-shaped corrugation contributed to the best mechanical performance.


ABSTRACT: The fibre beam element (FBE) method has been widely used to investigate the behaviors of concrete-filled steel tube (CFT) columns for its high efficiency and accuracy. The existing models were generally developed or calibrated by using specimens with relatively small size, in which the size effects were ignored or poorly incorporated. Additionally, most existing FBE models focused on CFT stub columns. In this paper, a new FBE model for nonlinear analysis of concentrically loaded stub and slender columns was proposed, in which the size effects on the effective stress-strain relationships of steel tube and core concrete were well incorporated. The proposed FBE models were then used to develop an ultimate strength model for the design of both stub and slender columns. A total of 1029 specimens assembled from 72 previous studies were used to verify the proposed models. The results suggested that the proposed FBE model performs quite well for both small- and large- size CFT stub columns and predicts the behaviors of slender columns with reasonable accuracy. Moreover, the ultimate strength model developed based on the proposed FBE models was found to make satisfying prediction of test results.


ABSTRACT: The proper sizing of Cross Laminated Timber (CLT) walls for the construction of high rise buildings requires to take into account their low shear stiffness and their viscoelastic properties and to integrate them into the framework of actual building codes which are all based upon Ayrton-Perry approach of imperfect columns. The present paper starts thus by recalling the framework of Linear Buckling Analysis of shear weak columns using the Timoshenko beam model. Then, Ayrton-Perry approach of the buckling of imperfect columns is introduced and used to develop a normal stress strength criterion for CLT walls but also an additional shear strength criterion. Both criteria are compared for three characteristic sizes of initial imperfections. Afterwards, orthotropic creep is introduced and its effect on long term stability of shear weak members is investigated and an extension of the previous criteria to long term behaviour is developed. Throughout the study, three numerical examples are used for illustration (a low strength panel, a high strength and an aerated panel) revealing the importance of proposed shear strength verification and the need of experimental characterisation.


ABSTRACT: In this study, a novel energy absorbing connector with polyurethane (PU) foam and multiple pleated (MP) plates was contrived to dissipate energy, and the energy absorbing response was experimentally, numerically and analytically examined. First, quasi-static loading tests on the connectors were performed, from which the deformation modes, force–displacement curves, and energy absorbing performances (such as specific energy absorption (SEA) and crushing force efficiency (CFE)) were obtained. In addition, a numerical method was adopted to facilitate the evaluation of energy absorbing performance of the connectors. It was found that
SEA could be increased by increasing the MP plate thickness, angle between the MP plate and flat plate ($\theta$), and filling PU foam. Moreover, the PU foam-filled connector was also found to be superior to the empty connector with regards to higher CFE. Finally, an energy-balance based analytical model was established to forecast the force–displacement response of the proposed connector. The experimental and analytical results were found to be similar.


ABSTRACT: In this paper, single-layer and double-layer reticulated domes were taken as two typical research objects. Through the dynamic time history analysis of reticulated domes in full process domain, log-linear regression was performed with a large number of example results to compare the degrees of correlation and efficiency about 11 common ground motion intensity measures, and PGA was selected as the most applicable one for fragility analysis of reticulated domes with aftershock influence. Then, considering that main shock usually caused structural damage, with incremental dynamic analysis method, fragility analysis of reticulated domes under multiple earthquakes was conducted from two aspects as follows. One part was main shock-aftershock sequence fragility analysis of intact structures. The other part was aftershock fragility analysis of damaged structures with four different damage levels caused by main shocks. Based on the fragility curves, the aftershock influence on fragility of reticulated domes and the aftershock collapse probability of damaged reticulated domes with four different damage levels caused by main shocks were investigated. It was found that when the damage level reached severe damage under main shocks, the aftershock collapse probability of reticulated domes would increase significantly. The results expanded the application scope of traditional fragility analysis in seismic engineering and realized the prediction and evaluation of seismic performance of reticulated domes under aftershocks.

Kulmani Mehar (1), Subrata Kumar Panda (2) and Nitin Sharma (3)
(1) Department of Mechanical Engineering, Madanapalle Institute of Technology & Science, Madanapalle, Andhra Pradesh 517325, India
(2) Department of Mechanical Engineering, National Institute of Technology Rourkela, Rourkela, Odisha 769008, India
(3) School of Mechanical Engineering, KIIT Bhubaneswar (Deemed to be University), Bhubaneswar 751024, Odisha, India


ABSTRACT: The modal responses of multi-walled carbon nanotube-reinforced composite sandwich structural plate are computed under the elevated temperature environment using a higher-order polynomial kinematic model and the isoparametric finite element steps. The proposed model accuracy has been verified with experimental modal values under the influence of elevated temperature and ambient conditions. To perform the modal experiment the nanotube-reinforced composite sandwich panel filled with the epoxy core is fabricated. Further, the experimental elastic properties of epoxy, nanotube/epoxy composite and the sandwich are obtained individually for the current computational purpose. A tailor-made finite element computer code (MATLAB environment) is prepared using the multiscale mathematical formulation for the evaluation of thermal frequencies of the nanotube sandwich panel. The impact type vibration analyser has been utilized for the current testing purpose with the help of three components i.e. hardware (compact data acquisition system, cDAQ-9178), software (LAB-VIEW) and a microcontroller controlled thermal chamber (to maintain temperature profile).

Finally, wide varieties of numerical examples are solved using the proposed computational model for the different design-related parameters. The intrinsic behaviour of each parameter on the epoxy-filled nanotube sandwich construction including the elevated temperature loading is discussed in details.

Essam Eltayeb (1,2), Xing Ma (1), Yan Zhuge (1), Osama Youssf (1,2), Julie E. Mills (1), Jianzhuang Xiao (3) and Ashesh Singh (4)
(1) University of South Australia, School of Natural and Built Environments, Adelaide, SA, Australia

ABSTRACT: This research investigates the feasibility of using rubber particles with lightweight foam concrete as an infill material in double-skinned profiled composite walls through experimental, finite element modelling (FEM), and analytical modelling. Two concrete mixes were used in the course of this study, namely, lightweight foam concrete (LFC) and lightweight foam rubberised concrete (LFRC) with rubber content of 8.5% by total volume of concrete. The two mixes had similar density of about 1584 kg/m³. Five profiled steel-concrete composite walls with 100 mm width, 550 mm length, and 600 mm height were tested under axial compressive loads. A digital image correlation (DIC) technique was used to measure and analyse strains and deformations of the profiled steel sheets and the results were compared with the results obtained from the strain gauges. FEM was conducted using ABAQUS software. An analytical model to predict the wall section capacity by considering concrete compressive strength and steel sheet buckling performance was developed. Finally, a parametric study based on FEM and the proposed analytical model was conducted to investigate the structural effect of different concrete strengths and/or steel sheet thicknesses. Although, LFRC had 20.1% lower strength than LFC, the experimental results showed that the average axial capacity of LFRC walls was reduced by only 16.8% with relatively less damage. The analytical and finite element modelling results agree well with experimental results.

W.H. Pan (1,2), J.Z. Tong (1,3), Y.L. Guo (3) and C.M. Wang (2)
(1) College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310058, China
(2) School of Civil Engineering, The University of Queensland, St Lucia, Queensland 4072, Australia
(3) Department of Civil Engineering, Tsinghua University, Beijing 100084, China


ABSTRACT: This paper is concerned with the optimal (or least weight) design of steel buckling-restrained braces against global buckling. First, the global buckling prevention criterion of steel buckling-restrained braces (BRB) is reconstituted to take on a symmetric expression, i.e., \((P/P-1)[M/(vP) -1] \geq 1\), so as to provide clarity on the equal importance of the stiffness and strength requirements of the restraining member, where \(P\) is the elastic buckling load, \(M\) the yield moment resistance, and \(v\) the initial imperfection of the restraining member whereas \(P\) is the ultimate compressive load of the core under cyclic axial loads. It is shown herein that the optimal design of the restraining member satisfies (1) the boundary of the global buckling prevention criterion, and (2) the relationship between the stiffness term \(P/P\) and the strength term \(M/(vP)\) in view of the maximum feasible cross-sectional height-to-thickness ratio as specified by the adopted design code recommendation. The satisfaction of these two conditions furnishes a unique optimal design of the restraining member. The optimal design can be expressed as an explicit equation in terms of the second moment of area of all-steel BRB designs based on the proposed design equation.


ABSTRACT: In this study, experimental works on four curved steel-concrete-steel (C-SCS) sandwich shells were carried out to assess their behaviors when subjected to concentrated loading with a 100-mm diameter hemispherical steel hammer through analyzing the failure mode, load–displacement relationship, strain, and deformation. The influences of the concrete and steel plate thicknesses, shear connector spacing, and rise–span ratio were numerically investigated. The results showed that the ultimate strength of C-SCS shells was improved with increasing concrete and face steel plate thicknesses and with decreasing shear connector spacing. The optimal rise-span ratio was found to be between 0.25 and 0.33. Moreover, to predict the nominal yield
strength and the ultimate strength of C-SCS shells, an analytical model was developed, which matched well with the experimental and FE results. This analytical model can be used as a quick method to calculate the resistances of C-SCS shells under concentrated loading by a hemispherical steel hammer.


ABSTRACT: Elastic buckling properties of thin-walled storage rack columns under compression, e.g., critical buckling loads, are often the input parameters for analytical design solutions (e.g., the direct strength method in AISI_S100 2016). This paper deals with the accurate estimation of the elastic buckling properties of \( \Sigma \)-shaped rack sections with patterned holes. The investigation of the elastic buckling behaviour of three different \( \Sigma \)-shaped rack sections (with and without patterned holes) under compression is presented. More than 4000 finite element simulations were performed on these rack sections using the finite element program, ANSYS 18.1. The influences of the holes, perforation pattern, number of buckling half-wavelengths, and boundary conditions on the section’s buckling behaviour were studied. An alternative method is proposed to generate signature curves for solid rack sections, and its effectiveness has been tested to generate signature curves for perforated rack sections. Multi-half-wavelengths method is proposed to determine the critical buckling loads and critical buckling half-wavelengths of perforated rack sections, which has been proved to be unbiased and accurate. The results show that by considering the holes, the critical buckling loads of the rack sections decreased while the critical buckling half-wavelengths increased. The alternative method failed to generate the signature curves of perforated rack sections accurately since the shape functions used for describing the shapes of buckling modes of perforated rack columns are significantly different from those used for solid rack sections.


ABSTRACT: Truss-confined buckling-restrained braces (TC-BRBs) are composed of conventional double steel tube BRBs and additional installation of external truss-confining systems. The truss-confining systems make TC-BRBs fulfil the need of the long-span bracing and enable economic and rational design. The previous experimental and numerical investigation of TC-BRBs suggested that the lower limit of the restraining ratio to ensure a stable cyclic behaviour was an empirical value of 3.0 for preliminary and conservative design. This paper aims to propose more rigorous design formulas for estimating the lower limit of the restraining ratio based on the numerical and theoretical analyses of typical TC-BRBs, triple- and quadruple-TC-BRBs (TTC- and QTC-BRBs). First, the formulas of the elastic buckling load of TC-BRBs are derived. Then, the load-carrying behaviour of TC-BRBs with the initial geometric imperfection is investigated with consideration of the most disadvantageous bending direction. The internal force variation of the external restraining members is discussed with increasing the restraining ratio, and it is found that the failure of TC-BRBs is governed by the compressive chord at the mid span. Furthermore, according to the criterion that the external restraining members do not fail before the core reaches the required axial displacement, the rigorous formulas for predicting the lower limit of the restraining ratio are derived. The formulas assure more rational and economic design of the load-carrying capacity of TC-BRBs.

Shaobo Qi (1), Xudong Zhi (1), Feng Fan (1) and Richard G.J. Flay (2)
(1) Structure Dynamic Behaviour and Control, Harbin Institute of Technology, Harbin 150090, China
(2) Department of Mechanical Engineering, The University of Auckland, Private Bag 92019, Auckland 1142, New Zealand

ABSTRACT: Dome structures are often employed for industrial buildings and may be potential targets of terrorist attacks or accidental explosion. Military design manuals that are commonly used for structural design practice are based on the assumption that the blast wave reflects on an infinite or finite flat surface. These semi-
empirical formulae ignore the blast wave propagation behaviour on a finite and variable-curvature reflector. The purpose of this research work is to estimate the blast load on dome structures during an external explosion. To achieve this objective, two laboratory-scale spherical dome structures were tested experimentally with 11 different blast cases. Following the experimental analysis, numerical parametric analysis based on ANSYS/AUTODYN was carried out to study the propagation and reflection on dome roofs. In addition, the performance of the Mach effect, reflection effect, diffraction effect, clearing effect and decay coefficient of the blast wave on the dome roof were investigated for different structural and explosion parameters. Based on this, a series of empirical equations are proposed to describe the temporal and spatial blast load distribution on a dome roof mounted on a supporting structure. This new load model described in the paper has been validated as it is able to predict the results of the experimental measurement on dome structures within experimental error.

Ming-Xiang Xiong (1,2) and J.Y. Richard Liew (2)
(1) Protective Structures Centre, School of Civil Engineering, Guangzhou University, Guangzhou 510006, China
(2) Department of Civil and Environmental Engineering, National University of Singapore, 119077, Singapore


ABSTRACT: Modern building codes do not cover the use of ultra-high strength concrete (UHSC) in design of composite columns. This paper investigates the structural fire performance of UHSC filled steel tubular (CFST) columns. Experimental studies were carried out on 9 CFST columns with C170/185 concrete under standard ISO fire. The columns were subjected to concentrated or eccentric compressions and then heated to failure to record the fire resistance time. The simple calculation model in EC 4 was examined by predicting the fire resistance time and comparing them with the test results; the axial force–moment (N-M) interaction strength model for room temperature design was extended to predict the fire resistance. The test results showed that the CFST columns with UHSC exhibited similar fire performance to those with normal/high strength concrete with respect to thermal expansion, axial contraction and failure modes. Adding 0.1% polypropylene fibers in UHSC was found to be effective in preventing explosive spalling especially when it was heated rapidly under the standard fire. The N-M interaction strength model gave better predictions than the EC 4 model as it gave less scattered results when compared to the test data. EC 4 buckling curve “c” was found to be conservative in predicting the fire resistance time of CFST columns with UHSC subjected to pure compression. Parametric study showed that the fire resistance of CFST columns with UHSC reduced faster than those with normal strength concrete (NSC) and high strength concrete (HSC) in early stage of heating but slower at the later heating stage. Within the practical range of load level (i.e., ≤0.7), the CFST columns with UHSC employed by this study had better fire resistance than those columns infilled with NSC and HSC.


ABSTRACT: An H-beam welded hollow spherical joint is a new kind of spatial grid structure. In this study, the eccentric-loaded behavior of H-beam welded hollow spherical joints was studied, and the influential law of material strength, joint size, and stiffening rib on its mechanical properties was analyzed through experimental research and numerical simulation. Parametric analyses were conducted to study the eccentric-loaded behavior of H-beam welded hollow spherical joints subjected to pure bending or the combined action of axial force and bending moment using a finite element model verified through experiments. The calculation formula of the bending bearing capacity of the joints and the axial force-bending moment curve were also obtained. Finally, the design rule for eccentric compression was proposed and verified through test results.

R. Vaezi Vazna (1) and M. Zarrin (2)
(1) Department of Civil Engineering, Sahand University of Technology, Tabriz, Iran
(2) Department of Civil Engineering, K. N. Toosi University of Technology, Tehran, Iran

ABSTRACT: Collapse behavior of double layer dome space structures depends on different factors such as load pattern, material mechanical properties, and member’s physical characteristics, which have a random nature that makes it difficult to predict accurate behavior of this type of structure. In this paper, in order to comprehensively assess the double-layer dome space structure behavior, different uncertain parameters such as the mechanical characteristics of steel material, mass and applied gravity load, and also structure’s and members’ geometric imperfection are taken into account in nonlinear static pushover analysis. Different models with rise to span (R/S) ratios of 0.1, 0.2, and 0.3 under incremental symmetric and asymmetric snow loads are investigated. In order to determine the importance of these uncertain parameters and rank them according to their effects on the structural response parameters, two different methods of Tornado Diagram Analysis (TDA) and First-Order-Second-Moment (FOSM) are utilized. Using these methods enables the sensitivity analysis of the collapse behavior of the structures to the considered random variables. The results of the analyses reveal that there is a close agreement between the TDA and FOSM analyses results in ranking the random variables according to their importance. In addition, these methods highlight the high sensitivity of the structural response parameters to the various sources of uncertainty, and indicate the necessity of applying these uncertainties in the analysis and design of this type of structure.

Krzysztof Woloszyk (1) and Yordan Garbatov (2)
(1) Faculty of Ocean Engineering and Ship Technology, Gdansk University of Technology, G. Narutowicza 11/12 st., 80-233 Gdansk, Poland
(2) Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico, Universidade de Lisboa, Avenida Rovisco Pais 1049-001 Lisboa, Portugal
ABSTRACT: The objective of this work is to explore the possibility of corrosion degradation modelling of thin steel plate specimens with the use of random field approach. The mechanical properties are obtained via the nonlinear Finite Element Analysis with the use of an explicit dynamic solver. The fully nonlinear material model is adopted to obtain the proper stress-strain response. Sensitivity analysis considering the main statistical descriptors of the random field is performed. The results of the analysis are validated with the available experimental data showing a good agreement for lower levels of Degree of Degradation and significant deviations for severely corroded specimens. The analysis shows that the irregularities in the corroded plate surface are one of the main reason for the mechanical properties reduction. Random field modelling revealed to be a swift and practical tool for representing the corroded surfaces in steel structures.

ABSTRACT: We introduced a simplified method to measure the buckling severity of the cylindrical structures subjected to axial compression. The method is intended for the cylindrical structures with a buckling mode comprising a repetition of similar single tiers, and estimates an upper bound of the deformed surface shape of the structure from measurements of a few data points. Moreover, this method helps monitor the magnitude of surface distortion of the large-sized buckled cylindrical structures with full-field surface shapes that are usually problematic for measurement. The discussion of classical buckling theory reveals that the point-to-point variation of radial displacements on cylindrical structures with periodic buckling pattern is similarly distributed even when the buckling mode changes depending on the structure’s size. A fundamental probability distribution model governing the point-to-point variation of the radial displacements is established from the results. A computation procedure for the conservative upper bound (CUB) of radial displacements from measurements at a few data points is proposed. A buckling experiment on cylindrical structures under axial compression demonstrated that the CUB from the proposed method appropriately envelopes the radial displacement of the buckled cylindrical structure within a designated probability, confirming the effectiveness of the proposed method. The study offers a novel method to compute the magnitude of the surface distortion of buckled cylindrical structures from a few measurements.

M. Anbarasu (1) and M. Adil Dar (2)
ABSTRACT: This paper deals with the numerical investigation aimed to study the axial capacity and the nonlinear deformation response of pin ended cold-formed steel (CFS) built-up columns under monotonic axial loading, applied concentrically. The built-up sections were constructed by adequately spaced channel sections in a back-to-back configuration, connected through webs by means of connecting elements (CFS channels) called spacers. Self-driving screws were used as fasteners to assemble together the lipped channels and spacers. Finite element (FE) models were established and verified against the previously published built-up columns with similar configuration. An extensive parametric study was conducted by varying the key parameters like plate slenderness of the lipped channels, unbraced chord slenderness, and global slenderness in order to investigate their variation on the ultimate compression resistance of these built-up columns. The effective width method was used to determine the design strengths for these built-up columns using the AS/NZ Specifications and European Specification on cold-formed steel structures, which were later compared with the results obtained from the numerical parametric study. This study indicated that the provisions that are given in the current AS/NZS and European Specification in predicting the strengths of the built-up column with spacers had shortcomings. Therefore, new design equations for the reliable design strength predictions of the CFS built-up column composed of lipped channels with spacers were proposed. The incorporation of spacers curtailed the local buckling half-wave length, which improved the buckling resistance, predominantly in the columns failing by local buckling.


ABSTRACT: The lateral thrust — the total contact force exerted by the buckled core of a buckling-restrained brace (BRB) against its restraining profiles — in bolted all-steel BRBs was studied mainly by means of laboratory tests. The primary purpose was to obtain a better understanding of the “predictability” of the lateral thrust for a given set of boundary conditions. Eleven nominally identical all-steel, reduced-scale BRB samples were subjected to the same cyclic loading, and data were recorded concerning (i) the value of the total lateral thrust, (ii) the relative slip between the buckled core and the restraining surfaces, and (iii) the longitudinal strain at opposite faces of the buckled core. A very high scatter among the peak values of the lateral thrust was observed. The experimental results concerning points (ii) and (iii) were integrated by the results of a refined 3D Finite Element analysis. Very little core-restraining profiles relative slip was observed in the tests. The elastic-plastic core buckling seems to be of the von Kármán type, i.e., with simultaneous loading and unloading at the opposite sides of the core.

C.K. Lee (1), M.K.I. Khan (1), Y.X. Zhang (2) and Mohammad M. Rana (1)
(1) School of Engineering and Information Technology, The University of New South Wales, Canberra ACT 2600, Australia
(2) School of Computing, Engineering and Mathematics, Western Sydney University, NSW 2751, Australia


ABSTRACT: The use of high strength steel (HSS) in the construction of concrete encased steel (CES) composite columns is often limited by the strain incompatibility issue between HSS and concrete at peak-load. This study proposes an alternative approach to confine the high strength concrete with Engineered Cementitious Composite (ECC) to improve its compatibility with high strength steel. The main purpose of this study is to experimentally evaluate the axial compressive performance of the proposed composite column cross-section configuration. Behaviours of fifteen short columns including twelve ECC-CES columns are investigated in terms of failure modes, load-deformation curves, ductility and energy absorption capacity. The test parameters included ECC and concrete strengths, ECC cover thickness, steel section shape and column section’s aspect ratio. It was found that ECC generally improved the failure behaviour of high strength steel CES columns and increased the deformation and energy absorption capacity. On average ECC-CES columns showed around 12%
ABSTRACT: The concrete confinement provided by the circular steel tubes improves the performance of circular concrete-filled double steel tubular (CFDST) columns, which have increasingly been employed as high-performance structural members in tall buildings. This paper presents computational and design models for the simulation and design of high strength CFDST slender columns composed of circular thin-walled sections that are eccentrically loaded. The formulation of the computational model is described, which takes into account the influences of concrete confinement, geometric imperfection, second-order, gradual plasticity of steel, and geometric and material nonlinearity. The inverse quadratic method is implemented in computational algorithms which solve the highly nonlinear equilibrium function of slender CFDST circular columns. The computations are compared with experimentally measured results to validate the mathematical modeling procedure developed. The behavior of slender circular CFDST columns made of high-strength concrete is investigated by utilizing the developed computational model taking into consideration the important material and geometric parameters. Proposed are design models that determine the ultimate loads of CFDST slender columns loaded concentrically and the axial load-moment strength interaction curves of slender thin-walled CFDSCT columns.
CFDST columns under eccentric loads. It is shown that the computational simulation method proposed can efficiently and accurately capture the experimentally measured behavior of CFDST slender columns. The design models give good strength predictions of CFDST columns and can be employed in designing CFDST composite columns.


ABSTRACT: Steel–ultra-high-performance concrete (UHPC) composite decks, which are composed of thin steel–UHPC layers and large U-ribs, are an innovative bridge deck system. In this study, experimental and numerical approaches were combined to investigate the dynamic properties of a steel–UHPC composite deck. A large-scale steel–UHPC composite deck specimen was fabricated and tested under hammer impacting. The effects of the impact force characteristics on structural vibrations and noise were evaluated, and the vibration transmission characteristics in the deck were explored. The experimental results revealed that the steel–UHPC composite deck with large U-ribs exhibited complicated dynamic properties in different frequency bands. A finite element (FE) model was built and validated through comparison with the experimental natural frequencies and frequency responses. FE analysis was then used to compare the steel–UHPC composite deck with two other bridge deck systems (a conventional orthotropic steel deck and a steel–concrete composite deck). The numerical results indicated that the thin UHPC layer guaranteed the stiffness of the steel deck plate in the low-frequency range. At frequencies above 200 Hz, the vibration energy of the conventional orthotropic steel deck was approximately 0.45 times that of the steel–UHPC composite deck. Two countermeasures for reducing vibration (i.e., adjusting the crossbeam spacing and filling the large U-ribs with plain concrete) were found to be effective. Based on the simulation results, filling the U-ribs with plain concrete was the most effective approach and reduced the vibration energy by an average of 285% in the center frequency range of 63–1600 Hz.

H. Wu (1), A. Liew (2), T. Van Mele (1) and P. Block (1)
(1) ETH Zurich, Switzerland
(2) The University of Sheffield, UK


ABSTRACT: There appears in the construction of modern multi-storey buildings in recent years, a prevailing trend for large bay sizes, lightweight floor systems and reduced dividing partitions. These tendencies have aroused a greater awareness of potential vibration problems when the structural floor systems are subjected to human induced activities such as footfall loading, as vibration performance may become an influential factor in the design of lightweight floor structures. A rib-stiffened vaulted floor described in this paper, can achieve sufficient structural stiffness and load-bearing capacity in an ultra-lightweight construction system. The aim of this study was to obtain a fundamental understanding of the floor’s dynamic behaviour and to develop appropriate measures to improve its dynamic performance. Dynamic analyses and assessment were conducted on 180 mesh models of the floor with different combinations of geometric parameters and compared against acceleration acceptance criterion. After the parametric performance evaluations, qualitative and quantitative relationships among the geometric parameters, modal parameters and dynamic performance were found, where it was shown that most floors failed to meet the acceptance criterion. Different approaches were then taken to improve the dynamic performance of the floors, using manual distribution of additional mass or optimised relocation of constant total mass. Selective distribution of mass in targeted areas accomplished considerable improvements in the dynamic performance. This paper identifies that statically optimised low-mass floors may be particularly sensitive to footfall loading, and establishes a reliable procedure for dynamic analysis using the dynamic characteristics of a rib-stiffened vaulted floor, revealing improvements to dynamic performance and providing insight into high frequency floors.

Craig Buchanan (1), Ou Zhao (2), Esther Real (3) and Leroy Gardner (1)
(1) Department of Civil and Environmental Engineering, Imperial College London, London, UK
(2) School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
(3) Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya, Barcelona, Spain
ABSTRACT: The present work was prompted by shortcomings identified in existing design provisions for stainless steel circular hollow section (CHS) beam-columns. First, addressing a lack of existing experimental data, a series of ferritic stainless steel CHS beam-column tests was undertaken at the cross-section and member levels. In total, 26 beam-column tests, including two section sizes (a non-slender class 3 and slender class 4 cross-section), two member slenderness values for each cross-section type and a wide range of loading eccentricities were carried out to investigate the interaction between local and global buckling. Following validation of finite element (FE) models, a numerical study was then undertaken to explore the buckling response of stainless steel CHS beam-columns, covering austenitic, duplex and ferritic grades with a wide range of local and global slendernesses and applied loading eccentricities. Over 2000 numerical results were generated and used to assess new design proposals for stainless steel beam-columns, featuring improved compression and bending end points and new interaction factors. The new proposals are more consistent and more accurate in their resistance predictions than the current EN 1993-1-4 (2015) design approach. The reliability of the new proposals has been verified by means of statistical analyses according to EN 1990 (2005).

Huidong Zhang (1), Xiao Liang (1), Zhanyuan Gao (1) and Xinjun Zhu (2)
(1) School of Civil Engineering, Tianjin Chengjian University, Tianjin 300384, PR China
(2) School of Civil and Environmental Engineering, University of Technology Sydney, NSW 2007, Australia
“Seismic performance analysis of a large-scale single-layer lattice dome with a hybrid three-directional seismic isolation system”, Engineering Structures, Vol. 214, Article 110627, 1 July 2020;
https://doi.org/10.1016/j.engstruct.2020.110627
ABSTRACT: A large number of studies and applications have been carried out on horizontal seismic isolation systems, and their effectiveness has been indicated. For long-span spatial structures, vertical seismic load plays an important role. However, vertical seismic isolation technology has not been extensively investigated. In this paper, a hybrid bearing with three-directional seismic isolation effects is proposed, in which the triple friction pendulum component and the viscous damping component are combined in series. Compared with other seismic isolation systems, the advantages of this hybrid seismic isolation system are that it can not only greatly lengthen the structural periods but also dissipate the seismic energy in all three directions. A hybrid numerical modeling method for this hybrid seismic isolation bearing is also developed. The seismic performance of a welded large-scale single-layer lattice dome with this hybrid seismic isolation system subjected to near-field ground motions is analyzed. The results show that the important dynamic demands in the dome are significantly suppressed compared with the base-fixed dome. The seismic isolation effects are evaluated in all three directions, and the effectiveness of the hybrid isolation system is verified. Finally, a comparative study is performed, and the mechanical parameters of this hybrid bearing are discussed. It is found that the damping energy dissipation in the seismic isolation bearings is not the most important factor in reducing structural dynamic demands. The proposed seismic isolation system and its numerical modeling method provide an attractive and effective alternative for the design of long-span spatial structures with hybrid seismic isolation systems.

Chenghui Xu (1), Dalun Rong (2), Zhenhuan Zhou (2), Zichen Deng (1) and C.W. Lim (3)
(1) School of Mechanics, Civil Engineering and Architecture, MIIT Key Laboratory of Dynamics and Control of Complex Systems, Northwestern Polytechnical University, Xi’an 710072, PR China
(2) Structure Analysis of Industrial Equipment, Department of Engineering Mechanics, International Center for Computational Mechanics, Dalian University of Technology, Dalian 116024, PR China
(3) Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong Special Administrative Region, PR China
“Vibration and buckling characteristics of cracked natural fiber reinforced composite plates with corner point-supports”, Engineering Structures, Vol. 214, Article 110614, 1 July 2020;
https://doi.org/10.1016/j.engstruct.2020.110614
ABSTRACT: This paper is concerned with the accurate free vibration and buckling analysis of a partially or internally cracked natural fiber reinforced composite (NFRC) plate with corner point-supports by sympletic elasticity method. Mechanical degradation of NFRC plate during the hygrothermal ageing is described by using a theoretical damage model. Crack effects on the plate derived by using the line spring model (LSM) are
considered in the governing equation of motion in the form of crack compliance coefficients. In the framework of symplectic elasticity, free vibration and buckling eigenvalue problems for three types of boundary conditions can be reduced into a set of algebraic equations by a superposition of boundaries. Highly accurate critical buckling loads, fundamental frequencies and corresponding mode shapes are solved simultaneously. A comparison of the new proposed model with finite element method is presented to validate the accuracy and effectiveness of the present method. Subsequently, the influence of hygrothermal ageing and crack parameters on the free vibration and buckling behaviors of cracked NFRC plates is rigorously presented. The research results conclude that both length and crack location are important factors that affect the hygrothermal ageing of NFRC plates.

Changjiang Liu (1,5), Xiaowei Deng (2), Jian Liu (1,5), Tianju Peng (3), Shaopeng Yang (3) and Zhoulian Zheng (4)
(1) School of Civil Engineering, Guangzhou University, Guangzhou 510006, China
(2) Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong 999077, China
(3) College of Environment and Civil Engineering, Chengdu University of Technology, Chengdu, China
(4) School of Civil Engineering, Chongqing University, Chongqing 400045, China
(5) Guangdong Engineering Technology Research Center for Complex Steel Structures, Guangzhou University, Guangzhou 510006, China

ABSTRACT: In this paper, the dynamic response of a typical four-point pretensioned saddle membrane structure under hail impact load is investigated by numerical simulations and experimental studies. Firstly, the initial shape of saddle membrane is obtained by form-finding analysis using the finite element analysis software ANSYS. The complex mechanical process of hail impact on the flexible membrane is simulated by LS-DYNA/Explicit dynamic analysis program, and the dynamic response of membrane, including displacement, velocity and acceleration, etc., is characterized. Then the experiment of saddle membrane under hail impact is carried out by applying the same loading conditions with the numerical analysis. The comparison between the numerical and experimental results shows good agreement, which verifies the reliability of the numerical simulations. It is discovered that the pretension relaxation induced by the hail impact may decrease the critical wind speed of membrane, and significantly increase the risk of membrane instability subject to hailstorm. Finally, the dynamic characteristics of typical four-point tensioned saddle membrane are summarized, which may provide reference for the design, construction and maintenance of membrane structures.

Elien De Smedt (1), Marijke Mollaert (1), Robby Caspeele (2), Wouter Botte (2) and Lincy Pyl (1)
(1) Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussel, Belgium
(2) Universiteit Gent, Technologiepark-Zwijnaarde 60, 9052 Gent-Zwijnaarde, Belgium

ABSTRACT: Membrane structures are widely used because of their lightweight properties and expressive architectural shapes. However, there does not yet exist a unified design approach for membrane structures as is available for conventional buildings. Because of their flexibility, membrane structures exhibit a different structural behaviour than conventional buildings. Membrane structures are doubly curved, prestressed and the prestress contributes to the stiffness. The structural response of these structures is non-linear, and the hanging and arching directions interact. A probabilistic framework for tensioned membrane structures is developed herein. Using this tool, partial factors are calibrated for a representative tensioned hypar membrane structure made of PVC-coated polyester fabric. Reliability analyses are performed using a First Order Reliability Method in combination with Latin Hypercube Sampling. The approach is illustrated for two load cases, i.e. considering snow load and wind uplift load, respectively. Three hypars are investigated, each with a different rise to span ratio. The partial factors are determined through a minimisation process. As a result of the performed process, the recommended partial factor for prestress is 1.0, for snow load is 2.0 and for wind uplift load is 2.0 for the investigated membrane structure. In this study, the hanging direction under snow load proves to be decisive for the calibration of the partial factors. The obtained partial factors are not in line with the partial factors found in the Eurocode (1.5 for variable loads). Alternatively, when considering a partial factor for snow load and wind

ABSTRACT: The out-of-plane buckling characteristics of a prestressed (PS) system that consists of a steel H-beam, rectilinear tendon cable, anchorages and deviators is newly reported, in which the girder is subjected to combined compressive force and bending moment introduced by the tendon. For this, new lateral-torsional buckling theories were analytically formulated and solved for the PS system having no deviator, one intermediate deviator, two deviators at regular intervals and multiple deviators. In order to verify the validity of the proposed theories, numerical examples for the PS system are given and compared with the analysis results by ABAQUS models, which are composed of thin-walled beam, rigid beam and truss cable elements. The results showed that un-bonded deviators installed externally restrain lateral and torsional deformations of the steel beam sufficiently strongly to greatly improve its lateral-torsional buckling strength.
(3) Department of Civil Engineering, Shanghai University, Shanghai, China; formerly, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong, China

“Experimental and numerical investigation on stub column behaviour of cold-formed octagonal hollow sections”, Engineering Structures, Vol. 214, Article 110669, 1 July 2020,
https://doi.org/10.1016/j.engstruct.2020.110669

ABSTRACT: This paper presents an experimental and numerical investigation into stub column behaviour of cold-formed steel octagonal hollow sections (OctHSs). A total of 16 OctHS stub columns were tested. Tensile coupons were extracted from both flat and corner portions of hollow sections to determine corresponding material properties. Finite element (FE) models were developed using commercially available software ABAQUS to replicate the test results generated in this study. The degree to which the enhanced material properties at corners should be extended was investigated. It was found that FE models with corner material properties extended to a width of material thickness beyond the corner portions offer the best agreement with test observations. The validated FE models were then adopted to conduct parametric studies to supplement test database. Cross-sectional slenderness limits specified in current design codes, including EN 1993-1-1, ANSI/AISC 360-16, ASCE/SEI 48-11 and AISI S100-16 (DSM) were evaluated against the test results in conjunction with the FE results. It was found that current limits are not suitable for the design of OctHSs. New cross-sectional slenderness limits in accordance with EN 1993-1-1, ANSI/AISC 360-16, ASCE/SEI 48-11 and DSM were then proposed based on the test and FE results. Cross-sectional capacity predictions obtained from EN 1993-1-1, ANSI/AISC 360-16, ASCE/SEI 48-11 and DSM were also compared with test and FE results. It is shown that the capacity predictions for slender sections from ASCE/SEI 48-11 are slightly unsafe, and ANSI/AISC 360-16 produces relatively satisfactory capacity predictions.

Jing-Shen Zhu (1), Yan-Lin Guo (1), Meng-Zheng Wang (1), Xiao Yang (1) and Yong-Lin Pi (2)

(1) Department of Civil Engineering, Tsinghua University, Beijing 100084, China
(2) Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW 2052, Australia

https://doi.org/10.1016/j.engstruct.2020.110601

ABSTRACT: The Concrete-infilled Double Steel Corrugated-plate Wall (CDSCW) consists of a corrugated part and two vertical boundary elements. The corrugated part is composed of two steel corrugated plates (SCPs) and infilled concrete, where high-strength bolts connect the two SCPs. The two vertical boundary elements are concrete filled steel tubulars. Obviously, owing to the corrugation configuration of SCPs as well as the positive interactive effect among SCPs, infilled concrete and vertical boundary elements, a CDSCW can attain high axial load-bearing efficiency and good seismic performance. This paper presents the experimental seismic performance of CDSCWs by exerting horizontal cyclic loads under constant axial compressions. Eight specimens were tested, with axial compression ratio, shear span to depth ratio and eccentricity of in-plane compressive load as the main research variables. The experimental results indicated all the specimens subjected to compression-bending failure with failure modes closely related to their axial compression ratios. There was a significant negative correlation between the axial compression ratio and the ductility of CDSCW specimens. In addition, the shear to span depth ratio had an important influence on the ductility of CDSCW specimens. Moreover, the experiment showed that the sectional axial strain distribution of CDSCW specimens conformed to the plane section assumption before reaching their peak load-bearing capacities, and most of the steel fibers except the ones near the neutral axis could be considered as plastic when the CDSCW specimens subjected to in-plane combined compression-bending-shear loads. Based on this, the formulae for estimating the load-bearing capacity of the CDSCW specimens under the combination of constant axial compressions and horizontal cyclic loads are established. The comparison between the formula values and the experimental results proves that the formulae are accurate and conservative. The conclusions of the experimental investigation provide fundamentals for the establishment of CDSCW seismic design method.

Moussa Leblouba (1) and Sami W. Tabsh (2)

(1) Department of Civil & Environmental Engineering, College of Engineering, University of Sharjah, United Arab Emirates
ABSTRACT: The available literature on the shear strength of corrugated web steel beams (CWSBs) includes a wealth of methods that specify the nominal buckling capacity, but with no consideration of reliability-based design. In the framework of Load and Resistance Factor Design (LRFD) codes, the design of steel members requires load factors to amplify the load effect and a resistance factor to scale-down the resistance based on a target reliability index. Therefore, for full integration of the shear design of CWSBs into the current design codes, resistance factors must be developed and calibrated for use within the LRFD context. This is crucial since the use of existing resistance factors that were specifically developed for welded plate girders for the design of CWSBs may lead to a level of safety that is not consistent with the philosophy of the code. Using a curated database of test results, the present paper attempts to address the lack of a reliability-based design method specific to CWSBs. Two North American design standards were selected in this study, namely, AISC 360 and CSA S16. A series of reliability analyses are performed first to verify the consistency of reliability indices for welded plate girders designed following the two standards. Then, a probabilistic-based approach is used to calibrate the resistance factors for the shear limit state of CWSBs in accordance with the AISC 360 and CSA S16 considering dead, live, wind, and snow loads. Finally, an iterative step-by-step procedure is then developed within the LRFD framework to aid in the design of corrugated webs to resist shear loads at ultimate. Findings of the study showed that the current AISC 360 resistance factor for welded plate girders when used for the shear design for CWSB, does not yield a safety level that is consistent with the target reliability; thus, a new factor equal to 0.85 is proposed. For CSA S16, the current resistance factor of 0.90 for welded plate girders is found to be appropriate for corrugated web steel beams.

Oliver Kinnane (1), Roger West (2) and Richard O. Hegarty (1)
(1) UCD Architecture, Planning and Environmental Policy, College of Engineering and Architecture, University College Dublin, Belfield, Dublin 4, Ireland
(2) Department of Civil, Structural and Environmental Engineering, Trinity College, University of Dublin, Dublin 2, Ireland

ABSTRACT: Precast concrete sandwich panels are an increasingly popular means of building cladding. They can be designed with high thermal resistance by embedding abundant insulation between two concrete wythes. Steel, in the form of thin plate connectors, remains one of the most common tie materials to support the outer wythe of concrete vertically, and transmit lateral forces from the external rain-screen to the internal structural wythe. The optimum design of steel shear connectors must satisfy thermal and strength capacity constraints. An extensive experimental study analyses the structural shear performance of precast concrete sandwich panels with steel plate connectors of various dimensions that give rise to different load capacities, stiffnesses and failure modes.

Jia-Ji Wang (1,2), Xin Nie (1), Fan-Min Bu (3), Mu-Xuan Tao (1) and Jian-Sheng Fan (1)
(1) Dept. of Civil Engineering, Tsinghua University, Beijing 100084, China
(2) Dept. of Civil Engineering, University of Houston, Houston, TX 77054, United States
(3) CCCC No. 4 Highway Testing Technology Company, 100084, China


ABSTRACT: Many skyscrapers have used the Reinforced Concrete (RC) filled Composite Plate Shear Walls (CPSW). Based on in-plane shear tests on six shear-critical CPSW specimens and a RC shear wall specimen, the behavior of CPSW systems with stud or tie bar connectors, various connector spacings, and various axial compression ratios were reported. In the test program, the Concrete Filled Steel Tubes (CFSTs) are applied for each specimen as boundary elements to simulate the engineering design of CPSW in skyscrapers. This paper presents the test observations, the ultimate capacity, the lateral stiffness, the ductility and the energy dissipation...
results. Based on the test results, the CPSW specimens with CFST boundary element failed in shear compression failure and the reference RC shear wall failed in shear tension failure. The weld fracture was generally found at boundary element (CFST) in the descending branch. Compared to the RC shear wall, the shear capacity of the CPSW systems were enhanced by 104–129%. The difference between CPSW systems with stud connectors and those with tie bars was insignificant in terms of ultimate capacity. Subsequently, a new database including 38 test specimens was established from the aforementioned test program and available literatures. The database results indicate the compressive capacity of infilled concrete is the dominating factor influencing the shear capacity, instead of the yield capacity of steel. In addition, a design formula for the in-plane ultimate capacity of shear-critical CPSW systems is proposed. Comparisons demonstrated that the proposed model was consistent and exhibited a reasonable level of consistency.

Yazhi Zhu (1) and Amit Kanvinde (2)  
(1) Department of Structural Engineering, Tongji University, Shanghai 200092, China  
(2) Department of Civil and Environmental Engineering, University of California, Davis, CA 95616, United States  


ABSTRACT: Steel beam-columns subjected to seismic loading often experience inelastic cyclic local buckling, which leads to strain amplification within the locally buckled region. These strains are ultimately responsible for Ultra Low Cycle Fatigue or fracture. An approach is presented to estimate the evolution of local buckling induced strain at critical locations in steel wide-flanged members subjected to cyclic loading. The main scientific basis for the approach is a series of 26 Continuum Finite Element (CFE) models that investigate a range of configurations (member cross section, axial load, loading history). Based on these simulations, a 3-dimensional post-buckling mechanism defined by yield lines, rigid facets, and yielding zones is proposed. This mechanism provides a bridging relationship between member plastic hinge rotations and local buckling induced strains at the continuum level. Guidelines for estimating various parameters that define this mechanism are presented. The approach is extended to predict strain evolution under cyclic loading; this extension accounts for history effects associated with buckling, straightening, and re-buckling of the cross-section. The method is validated by comparing the predicted strain evolution to its counterpart as determined from CFE simulations. The results indicate that the proposed method is highly effective in predicting the evolution of local buckling induced strain, and shows minimal bias with respect to configurational parameters and loading history. As such, the method is a computationally efficient alternative to CFE simulations, which are currently the only means for estimating cyclic local buckling induced strains. Applications of the method are outlined along with a discussion of its limitations.

Vuong Nguyen Van Do (1) and Chin-Hyung Lee (2)  
(1) Applied Computational Civil and Structural Engineering Research Group, Faculty of Civil Engineering, Tong Duc Thang University, Ho Chi Minh City, Viet Nam  
(2) Department of Civil and Environmental Engineering, Daelim University College, 29, Imgok-ro, Dongan-ku, Anyang-si, Gyeonggi-do 13916, Republic of Korea  


ABSTRACT: This study makes an attempt at analyzing numerically the bending and free vibration behavior of multilayered composite cylindrical and spherical panels reinforced with graphene platelets (GPLs). A numerical model for the static and dynamic analyses of the GPL reinforced composite curved panels based on isogeometric analysis (IGA) combined with higher-order shear deformation shell theory is developed for the first time. NURBS (non-uniform rational B-spline) based IGA considered in the present investigation is capable of constructing exactly the complex geometries of the shell-type structures. The cylindrical and spherical panels are fabricated by stacking several layers in which the GPL concentration alters in a layerwise manner to form functionally graded (FG) structure. Uniform, FG-O, FG-X and FG-A types of GPL dispersions are taken into account. The Halpin-Tsai model is adopted to determine the effective modulus of elasticity, whilst the modified rule of mixture is utilized to estimate Poisson’s ratio and the mass density of the nanocomposite curved panels.
The motion equations for the static and dynamic problems are derived from the higher-order shear deformation shell theory established based on the Reddy’s shell theory, and NURBS based isogeometric formulation is made to obtain the central deflections and natural frequencies of the multilayered FG GPL strengthened composite curved panels. The validity of the present IGA method is first evidenced, followed by the illustrative parametric studies to further scrutinize the static and dynamic responses of the nanocomposite cylindrical and spherical panels with the various reinforcement schemes.

Fangying Wang (1), Yating Liang (2) and Ou Zhao (1)
(1) School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
(2) School of Engineering, University of Glasgow, Glasgow, UK

ABSTRACT: Grade S960 ultra-high strength steel is receiving increasing attention owing to its excellent strength-to-weight ratio. However, its application in construction engineering is rather limited due to the lack of adequate design rules, as the current established codes in Europe, North America and Australia/New Zealand only cover the design of steel components with material grades up to S700 (or S690). This prompts investigations into different types of S960 UHSS structural components and development of accurate and efficient design rules for them. The present paper focuses on press-braked S960 UHSS channel section columns prone to flexural buckling about the minor principal axes, with their behaviour and resistances thoroughly examined through experiments and numerical modelling. An experimental programme was firstly performed on two non-slender press-braked channel sections, with five column specimens of varying member lengths employed for each cross-section, and included initial global and local geometric imperfection measurements and pin-ended column tests about the minor principal axes. This was followed by a parallel numerical modelling programme, where finite element (FE) models were developed to simulate the experimental results and afterwards adopted to perform a parametric study to generate additional numerical data over a broader spectrum of cross-section dimensions and member lengths. It is worth noting that there were two orientations associated with minor-axis flexural buckling of press-braked S960 UHSS channel section columns, namely ‘C’ orientation (indicating that columns buckled towards the webs) and ‘reverse C’ orientation (indicating that columns buckled towards the flange tips), and both of the two types of failure modes were carefully examined in the present study. It was found that channel section columns failing by flexural buckling in the ‘reverse C’ orientation generally exhibited superior resistances relative to their counterparts with failure in the ‘C’ orientation. The experimental and numerical data were also used to assess the applicability of the codified provisions for press-braked S700 (or S690) channel section columns failing by flexural buckling about the minor principal axes to the design of their S960 counterparts. The assessment results indicated that (i) the existing European code leads to overall conservative and scattered design flexural buckling resistances, especially for those relatively short and intermediate press-braked S960 UHSS channel section columns with failure in the ‘reverse C’ orientation, and (ii) the North American specification and Australian/New Zealand standard result in a higher degree of design accuracy and consistency than the European code, but with many over-predicted flexural buckling resistances for press-braked S960 UHSS channel section short and intermediate columns failing in the ‘C’ orientation.

Ying Zhang (1), Yuanqing Wang (1), Zhongxing Wang (1), Yidu Bu (1), Shenggang Fan (2) and Baofeng Zheng (2)
(1) Department of Civil Engineering, Tsinghua University, Beijing 10084, PR China
(2) School of Civil Engineering, Southeast University, Nanjing 211189, PR China

ABSTRACT: The structural performance of aluminium alloy unequal angle columns was investigated in this study. Fourteen columns made of two extruded aluminium alloy unequal angle cross-sections were tested. Complementary material property tests and geometric imperfection measurements were also carried out. The test setup, procedure and results were fully reported. After the tests, numerical models were developed to replicate the tested pin-ended extruded aluminium alloy unequal angle column behaviour. The validated finite
element models were then adopted to analyse the effect of the configuration of initial geometric imperfections, which proved to be pivotal in mode interaction of the column buckling performance. Parametric studies were carried out with specific initial imperfection configuration to generate further numerical data. The ultimate resistances derived from the experiments and finite element analyses were employed to evaluate the applicability of the current codified standards. The result comparison shows that current design provisions yield unsafe predictions for pin-ended unequal angle columns since the buckling mode interaction is not considered. The development of applicable design proposals and further investigation into buckling modal participation for pin-ended extruded aluminium alloy unequal angle columns are required.

Jaeho Ryu (1), Seung-Hee Lho (2), Chang-Hwan Lee (3) and Young K. Ju (4)
(1) Technical Research Center, TechSquare Co., Ltd., 25 Banpo-daero, Seocho-gu, Seoul 06710, Republic of Korea
(2) Korea Agency for Infrastructure Technology Advancement, 286 Simin-daero, Dongan-gu, Anyang-si, Gyeonggi-do 14066, Republic of Korea
(3) Department of Architectural Engineering, Pukyong National University, 45 Yongso-ro, Nam-gu, Busan 48513, Republic of Korea
(4) School of Civil, Environmental and Architectural Engineering, Korea University, 145 Anam-ro, Seongbuk-gu, Seoul 02841, Republic of Korea


ABSTRACT: In this paper, research on the flexural behavior of prestressed composite beams with sandwich floor panels, rather than concrete slabs, is presented. The sandwich plate system (SPS) consisting of top and bottom steel faceplates with a high-density polyurethane core between the faceplates was used for the floor panels in this study. Full-scale experiments were conducted to investigate the flexural performance of prestressed SPS composite beams (PSCBs). The test results demonstrate that the PSCB specimen exhibited excellent ductile behavior after yielding, with ductility ratio as high as 12.6. The failure mode at the ultimate limit state was fracture of the installed steel strands, and the ultimate load was increased by 14% due to the strengthening effect of the steel strands. Transfer of forces between an SPS floor panel and steel beam was accomplished through bolted connections, and the specimen behaved well as fully composite beams. A theoretical method for estimating the flexural strength and stiffness of PSCBs is established, and a finite element model capable of predicting the flexural behavior of PSCBs is also proposed.


ABSTRACT: This paper presents the results of an experimental investigation on the fire behaviour of restrained composite columns made with square concrete filled double-skin and double-tube hollow sections. In the fire resistance tests the columns have been tested for different parameters that may influence their behavior, as for example the type of cross-section, the concrete filling of the tubes (ordinary, high-strength and light-weight concrete), the load level and the stiffness of the surrounding structure to the testing columns. These columns had two concentric steel tubes, where the inner one had approximately half the side of the outer one. The double-tube columns had both tubes filled with concrete and the double-skin ones had only concrete between tubes. As major conclusions, it was observed that the load level had a small influence on the reduction of the critical times but some influence on the reduction of the ultimate collapse times of the tested columns. The stiffnes showed an insignificant influence on the critical time but again a higher influence on the ultimate collapse time of the columns being those smaller for the higher stiffness values. The concrete infill showed some influence, presenting the columns with high-strength concrete in the inner tube higher ultimate collapse times than those with ordinary concrete. The use of light-weight concrete between tubes did not show advantages when comparing with the ordinary concrete. The double-tube columns presented in general advantages over the double-skin columns being the ultimate collapse times of the first higher than those of the second.

ABSTRACT: Concrete-filled steel tube (CFST) columns have been widely used in super tall buildings. Since these columns are subjected to very high axial loads, the use of high-strength concrete (HSC) is preferred in order to reduce their cross-sectional size. For applications in seismic regions, additional confinement to the HSC may be needed to ensure ductility. Among various approaches, spiral confinement is an effective and practical way for square CFST columns. Six spiral-confined concrete-filled steel tube (SCCFST) columns and three CFST columns with the concrete compressive strength of 111 MPa were tested under eccentric axial loading. The behavior of the columns under different levels of eccentricity ratio was investigated, and the use of high-strength spirals to further enhance confinement was also examined. Concrete crushing was found to be the main cause for the loss of the load-carrying capacity. Spiral reinforcement is not effective in increasing the load-carrying capacity; however, it can considerably improve ductility, which is improved with an increase of the yield strength of spiral reinforcement. Based on the test results, an equivalent uniaxial stress–strain model was developed for the HSC in CFST and SCCFST columns. A fiber beam-column element using the proposed stress–strain models was found to provide good predictions of the measured load–displacement responses. Such fiber element can be used for modeling of SCCCFST columns with HSC in nonlinear structural analysis of tall buildings.


ABSTRACT: This paper studies the characteristics of square concrete-filled double-skin steel tubular (CFDST) short columns with inner circular steel tube by performing a series of nonlinear finite element (FE) analysis. The precise definitions of the behavior of the material are the initial requirement of numerical modeling. The existing models for predicting the behavior of the concrete core confined by the circular tube are not suitable since the mechanism of the concrete confinement in square composite columns is different from that of the circular ones. Also, ignoring the confinement effects on improving the concrete strength may lead to conservative results. In this paper, the confinement effects provided by the steel tubes on the concrete core in square CFDST columns are taken into account in the concrete constitutive model. The verified FE model is utilized to investigate the effects of important parameters on the ultimate axial strength, energy absorption capacity, ductility, and interaction performance of CFDST columns. A new design equation is suggested based on stress distribution over the concrete cross-section. It is shown that material properties and dimensions of composite columns can highly affect their performance. Also, the thickness of the inner tube must be controlled to prevent its premature failure. Validation of the design equation shows that it leads to the satisfactory predictions of the ultimate strengths of square CFDST short columns under axial loading.


ABSTRACT: The impact and post-impact behaviours of H-shaped steel members are investigated experimentally and numerically in this paper. The drop-hammer impact tests and the axial compression tests after impact were firstly performed on thirteen specimens, in which two boundary conditions and four impact energies (drop height ranged from 1.04 m to 2.50 m) were used. Experimental results such as failure patterns, impact force–time histories, permanent deformations and post-impact axial load-lateral deflection curves were presented. Subsequently, finite element models were established using ABAQUS software. The impact test and the axial compression test after impact were reproduced using the explicit and implicit algorithms in ABAQUS, respectively. Finally, case studies were carried out using the validated FE models to assess the residual load-carrying capacities of impact-damaged H-shaped steel members in industrial plants. The results showed that the boundary condition had an influence on the failure pattern and impact force response during impact. Within the
parameter range of this work, the residual load-carrying capacity of H-shaped steel members was primarily affected by the global deformation at the mid-height induced by impact.


ABSTRACT: A steel–timber composite (STC) column made of H-shaped steel and glulam is proposed in this paper. This STC column is constructed by wrapping the H-shaped steel with the adhesive-applied glulam, which provides confinement to reduce the buckling behaviour of the inner steel. Six STC specimens with lengths of 1100 mm, 1700 mm and 2300 mm were studied using an axial compression test in comparison to three steel and three timber specimens. The distinctive behaviours of the specimens were identified, including the failure mode, load–axial displacement relationship, load–lateral deflection relationship and load–axial strain response. The results demonstrated that the mechanical properties of the STC column are significantly affected by column length. The interaction mechanism between the steel and timber materials was evaluated by analysing the yield strain and the ductility coefficient. The composite effect of the STC column was also discussed by comparing the average strengths. Furthermore, the load-carrying capacity calculation formula including parameter selection of the STC column when yielding was proposed.


ABSTRACT: Aiming to expand the structural applications of recycled aggregate concrete (RAC), the innovative approach of using the hybrid form of RAC-filled glass-fiber-reinforced polymer (GFRP)–steel composite tube columns (RACFCTs) is particularly striking because of their optimal combining of fiber-reinforced polymer (FRP), RAC and steel. The existing research relevant to RACFCTs is limited and is mainly concerned with seismic performance. This paper presents the first-ever axial compression test on RACFCTs having three different slenderness ratios ranging from 20 to 40; the effect of the recycled coarse aggregate (RA) replacement ratio is also examined. The main performance aspects evaluated in this study were the failure mode, ultimate condition, axial load–lateral deflection curves, load–strain curves, and dilation behavior. The test results clearly show the benefit of the GFRP–steel composite tube on the compression behavior of the columns. The test results also demonstrate that the RACFCTs with a high RA replacement ratio and a high slenderness ratio had more ductile behavior. Finally, a design equation for predicting the maximum capacity of RACFCTs was derived, and its applicability was examined. The proposed formula produced a close estimate of the test results.


ABSTRACT: Concrete-filled steel tube (CFST) columns have been widely used in the construction industry because of their excellent compression capacity and torsion resistance. Regarding traditional CFST columns, the H-CFST column with an additional H-section steel member embedded in the core concrete provides improved fire and compression resistance. In this study, the seismic performance of nine H-CFST columns under cyclic torsional and compression–cyclic torsional loads was experimentally analysed. In the experiments, the failure mode, torque versus torsional angle hysteresis, torque versus torsional angle skeleton, torsional stiffness degradation, and energy dissipation capacity were determined. The hysteretic curves of the H-CFST columns under torsion were relatively plump in shape and exhibited no ‘pinching’ phenomenon, and the torsional stiffness of the H-CFST columns under unloading and reverse loading was approximately equal to the initial torsional stiffness. In addition, the applied compression had remarkable effects on the torsional capacity, torsional ductility, torsional stiffness, and hysteretic loop energy dissipation of the H-CFST columns. The shear capacities of the steel and concrete under normal stress or combined normal and shear stress were determined based on the latest theories and test results. Moreover, design method for the determination of the torsional capacity of H-CFST columns under compressive torsion is proposed based on the test results, and the
theoretical contribution ratio of the H-section steel, steel tube, and concrete in the H-CFST columns to the torsional capacity was determined.

ABSTRACT: This paper presents a novel form of rectangular fiber-reinforced polymer (FRP)-concrete-high strength steel (HSS) hybrid columns referred to as rectangular double-tube concrete columns (DTCCs). These columns consist of a rectangular FRP tube filled with concrete and an elliptical HSS tube as internal reinforcement. The inner elliptical steel tube encloses most of the concrete in the rectangular section and therefore most of the concrete in the section is effectively confined. The high susceptibility of the HSS elliptical tube to local buckling is expected to be suppressed by the confined concrete, leading to full utilization of the high strength of HSS. This paper demonstrates the excellent performance of the new columns due to the above beneficial interactions between different components in the column through an experimental study. In the experimental study, twelve rectangular DTCCs covering different FRP tube thicknesses and aspect ratios were tested under axial compression. Finally, an existing stress–strain model for FRP-confined concrete in rectangular columns is modified to be applicable to the concrete in the new column by accounting for the confinement effect from the inner elliptical HSS tube. It is found that the modified model provides more accurate predictions on the stress–strain curves of confined concrete in the rectangular DTCCs than the original model.

ABSTRACT: Steel tube confined concrete (STCC) is widely used in the vertical members of high-rise buildings such as columns. The axial load is not directly resisted by the steel tube in STCC, but is resisted via the interfacial frictional stress between steel tube and concrete core, which is different with that of concrete filled steel tube (CFT) members and would effectively suppress the outward local buckling of steel tube at early stage. Recently, fibre-reinforced polymer (FRP) confined STCC presents a potential to enhance the ductility and durability of such vertical elements. This paper presents an experimental study on monotonic axial compressive behaviour of carbon FRP (CFRP) confined STCC (CFRP-STCC) stub column and an analytical study on the confinement mechanism of and the ultimate axial bearing capacity of the elements. A three-stage confinement mechanism involving the different contributions of the steel tube and the CFRP wrap in CFRP-STCC elements was proposed based on the test results. A prediction model of the ultimate axial bearing capacity of CFRP-STCC stub columns was developed subsequently. Results show that the presence of CFRP wrap enhances effectively the load-bearing capacity and the ductility of steel tube confined plain concrete and reinforced concrete elements, and significantly prevents the local buckling of the steel tubes in the elements. The proposed prediction model of ultimate axial bearing capacity assesses test results with a great agreement.

ABSTRACT: Concrete-filled fiber-reinforced polymer (FRP) tubes (CFTs) are an attractive form of hybrid members, in which the FRP tube is typically manufactured by filament-winding with fibers suitably oriented for desired mechanical properties. A significant number of studies have been conducted on the behavior of CFTs under axial compression, in which the FRP tube is commonly assumed to have linear-elastic behavior, and is often taken to be under a uniaxial stress state (i.e., hoop tension), especially when the fibers are oriented close to the hoop direction. However, in reality, FRP tubes in CFTs are subjected to biaxial stresses (hoop tension in combination with axial compression) and may exhibit significant nonlinear behavior. This paper presents an improved model for the axial compressive behavior of CFTs with the nonlinear biaxial behavior of the FRP tube duly taken into account. To verify the proposed model, seven circular CFTs were tested under axial
compression. Ancillary tests on bare FRP tubes were also conducted to determine the material properties of the FRP tubes. Comparison between predictions and test results indicates that the proposed model leads to more accurate predictions of the CFFT behavior than the existing ones in which the biaxial nonlinearity of the FRP tube is ignored.


ABSTRACT: In this paper, the free and forced vibration of joined cylindrical-spherical shells (JCSSs) subjected to classical boundary conditions are investigated by a variational method. A JCSSs is divided into its components (i.e., cylindrical and spherical shells) at the cylinder-sphere junction. The interface continuity and geometric boundary conditions are approximately enforced by means of a modified variational principle and least-squares weighted residual method. Donnell shell theory is used to formulate the theoretical model. Double mixed series are adopted as admissible displacement functions for each shell component. In addition, the forced vibration response of the JCSSs is gained through the Newmark-β method. Through the comparison and analysis study, it is obvious that the proposed method has a good stable and rapid convergence property and the results of this paper closely agreed with those obtained by published literatures and the finite element method. The influence of structural parameters and different loading modes on free and forced vibration characteristics of JCSSs are considered.


ABSTRACT: A new joint system for connecting aluminum alloy rectangular hollow section (ARH) members is proposed to overcome the problem of connecting rectangular tubes using the traditional Temcor joint. The structural performance of the ARH joint system under an out-of-plane bending moment is studied experimentally. The moment-rotation ($M$-$\Phi$) curves, stress variation, and failure modes of the ARH joint obtained from the tests are discussed. A bilinear model is proposed to summarize the $M$-$\Phi$ curves of the joint. The influence of the key parameters, gusset thickness and bolt quantity on the mechanical behavior of the ARH joint is analyzed. Subsequently, finite element analysis is conducted to investigate the moment rotational behavior of the ARH joint. The comparison between the experimental and numerical results proves that the proposed finite element model is accurate enough and can be used to study the moment resistance behavior of the ARH joint system. The results show that the proposed ARH joint, for connecting rectangular hollow section members, can be considered as a semi-rigid connection. This study provides a reference for the practical application of the ARH joint in reticulated structures made of aluminum rectangular members.


ABSTRACT: The European design code for steel structures, Eurocode 3 Part 1-1, defines the buckling resistance criterion, which enables initial imperfections to be taken into account without including them in the model structure. The initial imperfections are taken into account by the reduction factor for buckling $\chi$. This reduction factor depends on the imperfection factor $\alpha$ defined in Table 6.1 of Eurocode 3 Part 1-1. Several full-scale tests have showed that initial imperfections for cold-formed hollow tubular sections, defined in Eurocode 3, are overestimated compared to the experimental results. Indeed, the initial imperfections of a cold-formed hollow tubular section are closer to the initial imperfections of the buckling curve “a” than to those of buckling curve “c”. Furthermore, a considerable difference was observed between the findings of the interaction formulae for the beam-columns in Eurocode 3, without modelling the initial imperfections, and the findings obtained with the cross-section resistance criterion, by modelling the initial imperfections. This difference is due to the buckling coefficient $\chi$ defined for a structure loaded to its full potential. To overcome this problem, a
new design procedure is proposed for beam-columns without lateral-torsional buckling. This procedure involves new buckling coefficients $\chi^*$ and new interaction formulae, which enable the following points to be taken into account: the intensity of the loads applied to the structure, the type of analysis (1st or 2nd order) and the required level of the criterion in line with cross-sectional properties (elastic, linear plastic or non-linear plastic).


ABSTRACT: Inflated membrane tubes are popularly used as supporting members in civil engineering and aerospace engineering. The stiffness and bearing capacity of the tube originate from the tensile stress of the membrane induced by the inner air pressure. Deformation of the tube under load results in a change in this pressure and hence influences the tensile stress of the enveloping membrane and the stiffness of the tube. The latter would affect the deformation again. Such an interaction between the deformation of the enveloping membrane and the inner air pressure plays an important role in the mechanical behavior of the tube, and yet it has not received any attention according to the literature. This paper experimentally studied the air-membrane interaction of an inflated tube under both axial compression and transverse bending and its influence on the critical wrinkling load and ultimate bearing capacity with variations in the initial pressure, constraint type, axial load and slenderness ratio. A special experimental setup and test procedure were designed and developed to test the inflated tubes. The experimental results reveal quantitatively the air-membrane interaction and its significant influence on the mechanical behaviors of an inflated membrane tube which are sensitive to the four influencing factors studied. The results can be helpful to the understanding of the behavior of inflated membrane tubes with the air-membrane interaction, and may therefore improve the reliability of the tubes in civil and aerospace engineering applications.


ABSTRACT: In this paper, the overall hysteretic behavior of uniform (BB) and proposed graded-thickness (BGB) thin-walled steel square box columns under constant axial force and circular bidirectional cyclic lateral loading is investigated. First of all, the adopted finite element model (FEM) in ABAQUS is verified with the experimental results in the literature and employed for the analysis. Second, the proposed BGB column, with the same cross-section size and volume of material equivalent to the BB column, is evaluated. Then, the strength and ductility deterioration of both BB and BGB columns under circular bidirectional cyclic loading path over the unidirectional path are emphasized. Finally, an intensive parametric study is conducted to investigate the effect of main design parameters including: width-to-thickness ratio parameter ($R$), column slenderness ratio parameter ($\lambda$), magnitude of axial load ($P/P$), and number of loading cycles ($N$) on the overall hysteretic behavior of BB and BGB columns under constant axial force and circular bidirectional cyclic lateral loading. Subsequently, design formulae have been derived to predict the ultimate strength and ductility capacities of the BB and BGB columns.


ABSTRACT: The performance of concrete-filled steel tube (CFST) columns including scrap-tire rubber under compression and in particular changes in their behavior after thermal treatment has remained mostly understudied. This has led to the lack of the use of rubberized concrete in these columns. This study attempted to examine the post-heating performance of CFST columns subject to several temperatures (20, 250, 500, and 750 °C) with regard to the amount of scrap-tire rubber aggregate used as a volume fraction of sand (0, 5, and 10%), quantity of steel fibers in volume (0, 1, and 1.5%), and the ratio of the outer diameter to thickness of the steel tube (43 and 25.4). The specimens had high-strength concrete cores and seamless steel tubes. The total
number of manufactured confined and unconfined cylindrical specimens was 114, which were then exposed to heat and axial compressive testing. Through these tests, the loading capacity, ductility, toughness, and compressive load-strain curves of different specimens were explored. Based on the results, although including the scrap-tire aggregate (by 10%) in the concrete mixture lowered the strength of the confined specimens (by 12%), thermal treatment had no particular increasing effect on this decline. Furthermore, as the quantity of steel fibers and the thickness of the steel tube in the heated and non-heated CFST specimens increased, toughness increased in all the specimens, and the ductility had an ascending trend in most specimens. In addition, the optimum quantity of steel fibers used here was 1%. In this regard, although the fibers affected the compressive strength of the CFST specimens negligibly, they demonstrated a considerable improving effect on the ductility and absorbed energy in all specimens particularly the heated ones. Up to 250 °C, the decline in strength was negligible, while above this temperature, this decline in strength was much more considerable, and also, the post-peak slope of all the curves decreased. Finally, due to the importance of predicting the strength of CFST columns after exposure to heat, a relationship for predicting the loading capacity of these columns under heat was proposed and the associated results were compared with the experimental results of this work as well as the experimental results reported by others. Good consistency was seen between the predicted and experimental results.


ABSTRACT: This paper presents an experimental and numerical investigation into residual stresses of S690 cold-formed circular hollow sections (CFCHS) due to transverse bending and longitudinal welding. It is generally expected that adverse effects of residual stresses on both cross-section and member resistances in the S690 CFCHS are proportionally less pronounced, when compared with those in S355 CFCHS owing to increased yield strengths of the steels. Hence, there is a need to determine the distribution of residual stresses in the S690 CFCHS through a rational experimental and numerical investigation in order to provide accurate data for subsequent structural assessment on these sections. A total of four S690 CFCHS are fabricated with 6 mm thick plates with (i) transverse bending, and (ii) longitudinal welding. Surface temperature history at selected positions of these sections are measured with thermocouples during welding while surface residual stresses are measured with the sectioning method after welding. Owing to various practical constraints in measuring residual stresses of these sections accurately, a total of three coordinated finite element models are established in which their numerical results are integrated for rational analyses. The transverse bending process is simulated with two-dimensional models with plane-strain elements which undergo extensive plastic deformations to generate residual stresses after springback. The longitudinal welding process is simulated with two coupled three-dimensional models with solid elements to perform a sequentially-coupled thermomechanical analysis in the presence of those residual stresses due to transverse bending. Consequently, a rational distribution of the residual stresses due to both transverse bending and longitudinal welding in these sections are readily determined with these coordinated finite element models after careful calibration against measured data.


ABSTRACT: The flexural buckling behaviour and resistances of circular high strength concrete-filled stainless steel tube (HCFSST) columns were examined based on experiments and numerical modelling, and reported in the present paper. The experimental programme was conducted on 12 circular HCFSST columns with various member relative slendernesses, and included material tests, initial global geometric imperfection measurements and pin-ended column tests, with their procedures and setups fully described. The experimentally observed results, including the failure loads and modes as well as the load-deformation curves (load-end shortening curves and load-mid-height lateral deflection curves) of the circular HCFSST column specimens and the development of the longitudinal strains of the outer stainless steel tubes, were presented and discussed. The experimental programme was then supplemented by a numerical modelling programme, where finite element models were developed and validated against the test results, and then used for conducting parametric studies to generate further numerical data on circular HCFSST columns over a broad spectrum of cross-section...
dimensions and member lengths. Owing to the lack of international design codes for stainless steel–high strength concrete composite structures, the relevant codified design rules for circular normal strength concrete-filled carbon steel tube columns failing by flexural buckling, as used in Europe, America and Australia/New Zealand, were assessed for their applicability to circular HCFSSST columns, based on the obtained experimental and numerical data. The assessment results indicated that the design rules, as given in the Australian/New Zealand standard and American specification, lead to many unsafe flexural buckling resistance predictions when used for circular HCFSSST columns, while the design rules, as adopted in the European code, result in more safe and reliable design resistances for circular HCFSSST columns failing by flexural buckling.

ABSTRACT: The inelastic buckling of longitudinal steel bar is one of the major damage states of reinforced concrete (RC) column under seismic loading, which may result in a reduction of section moment capacity and ductility. However, the relationship between bar buckling and deterioration in seismic behaviors of RC column has normally been proposed based on the theoretical analysis, direct experimental verification is scarce, and the differences between the buckling behavior of individual steel bar and that of longitudinal bar in RC column remain unclear. In this paper, a series of experiments on cantilever RC columns and individual bars were conducted to study the buckling behavior by means of the measured lateral buckling displacements of the bars. A new method was proposed to measure two components of the lateral buckling displacements of longitudinal bars and individual bars in orthogonal directions, the reliability and accuracy of the proposed method have been identified by the comparison of measured buckling displacement of corner bars in two identical RC specimens. Based on the measured lateral buckling displacements of reinforcing bar in RC columns and corresponding individual bar, the onset of buckling and the buckling direction of the two kinds of steel bars were analyzed. It is found that buckled main bars in RC columns behave differently with individual steel bars due to the constraint effect of cover concrete. The equivalent average stress of main bar was determined by creating a mapping between the buckling displacement of bar in RC section and the average stress of individual bar. On the basis of the measured lateral buckling displacements and the equivalent average stress, the effects of bar buckling on the post-peak bearing capacity and the displacement ductility of RC column were investigated. The results show that the degradation of the post-peak lateral force of RC column is generally weaker than the strength deterioration of buckled steel bar due to the load redistribution between longitudinal reinforcement and surrounding core concrete.

ABSTRACT: This paper presents a study to investigate the equivalent viscous damping (EVD) for the hysteretic response of a multiple cosine-curved dome (MCCD) system. The system comprises of several serially connected units with elastic multistable behavior. The system relies on consecutive snap-through buckling events of the connected units to elastically dissipate energy. The study aims to facilitate the direct displacement-based design of structures incorporating such systems as the main damping mechanism to dissipate seismic energy. Time-history analyses of linear and nonlinear single degree of freedom systems were performed to compare spectral displacements and EVD ratios of the hysteretic response of MCCD systems to their substitute linear systems in terms of maximum displacements. A set of 62 ground motion records were considered for the analysis. A statistical study was conducted on the resulting displacements and the EVD ratios to develop expressions for EVD ratios of the hysteretic response. Results show that using proposed EVD ratios for the substitute linear systems yields good approximations for the peak spectral displacements compared to the original nonlinear systems.

ABSTRACT: The computational cost of the frequency response within the frequency interval may be high for large-scale structures. An efficient method for calculating the frequency response of a proportional damping system over a given frequency interval which starts from zero is proposed. The Sturm sequence number is used to adaptively determine the number of low-order modes that need to be calculated. The complementary part of the contribution of the calculated low-order modes is approximated by the partial sum of the power series that is proven to converge. The number of terms in the sum is adaptively determined only by the highest excitation frequency. The resulting frequency response expression is valid for the entire frequency interval. One numerical example is presented to demonstrate the high accuracy and effectiveness of this method.


ABSTRACT: The study investigates the mechanical response of glass shells cold bent into hyperparaboloid shapes used in building technology. Focus is addressed on two subjects: the application of the cold bending procedure to vertically oriented rather than horizontal plates, which allows to minimize the disturbance produced by the initial deflection due to self-weight, and the effect of wind load on curved glass panels installed in glazing façades. The particular case of a vertical monolithic glass plate (2000 × 2000 × 10 mm) loaded symmetrically on two diagonally opposite corners is studied experimentally and numerically, developing a finite element model, and the results compared each other. Both experiments and numerical analyses show that a mechanical disturbance, introduced e.g., on the centre of the plate, promotes a change in the deformation mode during the bending process. Geometrical instabilities which impair the optical quality of the glass, and trigger a serviceability limit state failure, are evidenced. A parametric analysis is conducted to investigate the influence of the size and the aspect ratio of the glass plate on the cold forming procedure. The examined response parameters include the geometrical distortion of the glass plate, involving the possible occurrence of optical distortion and the maximum tensile stress in the plate. In the second part of the study, the effect of wind load on curved glass shells is numerically evaluated. The results point out the possible trigger of a limit equilibrium stability, with a “snap-through” transition from an equilibrium state to another non-adjacent equilibrium configuration which can result in a sudden break of the glass plate. This phenomenon is affected from the size of the glass plate and the curvature imposed to the plate during cold bending. The proposed methodology could represent a convenient tool to assist practitioners in selecting the appropriate thickness of façade glass panels.


ABSTRACT: Concrete-filled galvanized corrugated steel tubular (CFGCST) column is potentially an economic member to overcome the corrosion of outdoor structures, of which the anticorrosive corrugated steel pipe (CSP) can be used conveniently as the corrosion protection and permanent concrete formwork. The confinement effect provided by CSP essentially contributes to the structural advantages of CFGCST, whilst it, brings about complexities in corresponding load-resisting mechanism. Apart from the non-uniform distribution of stresses of CSP through thickness and height due to its curved shape, the confinement also varies across cross-sectional depth due to eccentric compression. The in-depth understanding and accurate quantification of the confinement effect of such member become a key issue that needs to be addressed. To investigate the impact of confinement on cross-sectional behavior, 24 specimens were tested with 5 load eccentricity ratios and 2 confinement factors. The non-uniformities of confinement along with height and cross-sectional depth were studied based on finite element modelling, validated via measured strains and load bearing capacities. A theoretical derivation was then conducted to characterize the non-uniform confining stress by fully considering the bidirectional curvatures of CSP, as well as the influence of debonding failure on the confinement. In each period of corrugation, the calculation method of equivalent confining stress was proposed based on the uniformization of stresses and geometry.

ABSTRACT: This paper presents the cyclic behavior of double-skin composite (DSC) walls for mid- to high-rise buildings, which consist of concrete filled steel tubes (CFTs), a pair of steel faceplates connected by tie bolts, and infill concrete. Four 1/3-scale DSC wall specimens, varying in faceplate profile and tie bolt spacing, were tested under combined axial and cyclic lateral loading. All specimens failed in flexure with a progression of steel tube fracture, steel faceplate buckling, and concrete crushing at wall bottom. The corrugated DSC walls and the flat DSC wall with standard bolt spacing were able to achieve an ultimate drift ratio around 3.4% and a ductility ratio greater than 5.4, while the flat DSC wall with bolt spacing 50% over code limit presented early faceplate buckling and undesired seismic performance. Compared to flat DSC walls, corrugated DSC walls, even with a doubled tie bolt spacing, had considerably higher initial stiffness, ductility ratio and energy dissipation. Formulations are proposed for predicting the lateral strength and drift capacity of corrugated DSC walls without elastic local buckling. The difference between the predicted and measured capacity for either lateral strength or drift is on average less than 6%.


ABSTRACT: Carbon nanotubes (CNTs) have become an important element in strengthening elastic structures. Different types of CNT strengthened structures have been fabricated in the past decades each with different applications and advantages. This review paper highlights the efforts performed on producing CNT strengthened deformable structures, fabrication procedure, and modelling and analysing the mechanical behaviour by focusing mainly on engineered CNT distributions through the matrix. Since combining high amounts of CNTs with matrix could be costly, the papers concentrating on the importance of grading, aligning and positioning the CNT fibres in order to reach the highest efficiency are also reviewed. Moreover, the influence of different types of CNT grading on static, stability and dynamic response of different types of structures in the frameworks of both linear and non-linear analyses is discussed.


ABSTRACT: The hollow circular steel tubes support the permanent and construction loads of several upper floors during the construction of a high-rise building structure before the concrete is filled into the steel tubes to form circular concrete-filled double steel tubular (CFDST) columns. The preloads acting on the steel tubes may cause a marked reduction in the performance of slender CFDST columns. This paper presents a numerical modeling technique underlying the method of fiber elements for quantifying the behavior of circular slender CFDST beam-columns loaded eccentrically with preloads acting on the hollow steel tubes. The numerical model considers the concrete confinement, second-order effects, initial geometric imperfection, deformations induced by preloads as well as geometric and material nonlinearities. The dynamic nonlinear equilibrium functions are solved using efficient computational solution algorithms developed. The validation of the numerical modeling technique is made by comparing computations with existing results obtained by experiments and finite element analyses. The influences of preloads on the structural behavior of slender CFDST beam-columns with various important parameters are investigated by means of utilizing the developed computer model. It is shown that the numerical modeling method is an efficient computational simulation and design tool for slender CFDST columns including preloads.

ABSTRACT: The present paper describes a comprehensive experimental and numerical study of the local–flexural interactive buckling behaviour and compression resistances of slender welded I-section columns made of a new grade EN 1.4420 high-chromium stainless steel. A testing programme, adopting two high-chromium stainless steel slender welded I-sections – I-150 × 150 × 5 and I-200 × 100 × 5, was firstly conducted and included ten pin-ended column tests as well as supplementary initial global and local geometric imperfection measurements on the column specimens. The testing programme was followed by a numerical modelling programme, where finite element models were developed and validated against the test results, and then employed to perform parametric studies to generate further numerical data over a wide range of cross-section dimensions and member effective lengths. The obtained test and numerical results were adopted to evaluate the applicability of the codified design rules for normal stainless steel slender welded I-section columns failing by local–flexural interactive buckling, as set out in the European code and American design guide, to their new high-chromium counterparts. Specifically, the European code adopts the design concept of using effective width method to account for local buckling and buckling curves to consider global buckling, and was shown to yield accurate, consistent and safe interactive buckling resistance predictions when used for the new high-chromium stainless steel slender welded I-section columns. The American design guide employs net section reduction factors to consider local buckling in slender plate elements, based on which a reduced design flexural buckling stress is determined; the predicted interactive buckling resistances, compared with the test and numerical failure loads, indicated a marginally high degree of conservatism and scatter of the American design guide. It can thus be concluded that (i) the design rules given in the European code and American design guide can be safely applied to the new high-chromium stainless steel slender welded I-section columns failing by local–flexural interactive buckling, and (ii) the European code results in more accurate and consistent predictions of interactive buckling resistance than the American design guide. The reliability of the codified design rules, as given in the European code and American design guide, was confirmed by means of statistical analyses.


ABSTRACT: Over the last years, different methods, physical and mathematical, were used to find the optimal shape, minimizing the internal stresses, of shallow grid shells. As far as their original organic shape is concerned, the design of grid shell structures inspired architects and structural engineers in more than one way. Throughout history, the resolution of the problem related to the structural form-finding buried its roots on the activity of researchers and innovators. In the present paper an original approach for the form-finding is obtained by dynamic numerical simulation of hanging net, subjected to gravity load, over the time domain. In particular, the proposed method for the definition of the form is based on a multi-body rope approach (MRA) with masses connected by inextensible ropes characterized by a certain slack coefficient (sc) and by the degree of the constraint conditions. These parameters played a fundamental role in the definition of the shallowness ratio of the grid, and therefore in the effect of the instability of the reversed shape (grid shell) under loading. Moreover, in the case of shells with a very large number of nodes, a combined procedure based on non-uniform rational basis-splines (NURBS) formulation is proposed for the form-finding. Finally, step-by-step nonlinear analyses for the grid shells obtained by MRA were performed by a displacement control scheme, applying vertical incremental displacement to the nodes. Three circular grid shells were generated and analysed considering the effects of geometrical imperfections on the coupled instabilities varying the shallowness ratio.


ABSTRACT: A meshfree radial point interpolation method (RPIM) based on a higher-order shear deformation theory (HSDT) is here developed to investigate the free vibration and buckling behavior of multilayer functionally graded graphene platelets reinforced composite (FG-GPLRC) perforated plates under an in-plane edge loading. The non-uniform initial stresses in the multilayer FG-GPLRC perforated plates are evaluated accurately by solving the equilibrium equations derived from the same approach. The mixed collocation-Lagrange multiplier technique is employed to enforce the various boundary conditions. The multilayer FG-
GPLRC plates are built up as perfectly-bonded composite layers reinforced with a uniform distribution of graphene platelets (GPLs), randomly oriented. Perforated plates with three different cut-out shapes are analyzed. Several numerical examples are provided to demonstrate the high performance, the fast convergence rate and the high accuracy of the proposed method. Then, we study the influence of different GPLs distribution patterns, GPLs weight fraction, shape and size of cut-outs on the free vibration and buckling behavior of the multilayer FG-GPLRC perforated plates under an in-plane edge loading.


ABSTRACT: We study a problem of oscillations of an isotropic inhomogeneous hollow prestressed cylinder under the action of an axisymmetric periodic load. We analyze the amplitude-frequency characteristic depending on prestressed state types in order to identify the frequency ranges most sensitive to the prestress. On the basis of the perturbation method, we derive formulas allowing to find approximately changes in the resonant frequencies caused by the presence of a given inhomogeneous prestress field. We analyze the effect of prestress levels on the change in the cylinder’s natural frequencies.


ABSTRACT: The objective of this paper is to quantify and compare the environmental and economic Life Cycle impacts of two alternative types of composite sandwich panels for the rehabilitation of degraded wooden floors of old buildings: (i) a second-generation composite sandwich panel made of glass-FRP (GFRP) skins (or blades) and a polyurethane (PUR) foam core; and (ii) a hybrid sandwich panel consisting of a glass-carbon-FRP bottom skin, a steel fibre reinforced micro concrete (SFRMC or UHPFRM) layer as top skin, and a PUR core. This works intends to find which design alternative is more eco-efficient. Life Cycle Assessment (LCA) was the method used for the quantification and comparison of environmental and economic impacts of the studied solutions. The environmental and economic LCA of this type of construction products are presented for the first time in this paper. These LCA were completed following European and international standards. The results obtained demonstrated that, for both alternatives, in terms of environmental LCA of the production, the stage of raw materials extraction (A1) is the most influential for all the studied environmental impact categories. By comparing the two alternatives, it was found that the second panel (hybrid sandwich panel) presents the highest environmental impact. More specifically, the results obtained show that the use of SFRMC for the top skin and of carbon fibres significantly increases the environmental impact of the product. Furthermore, an economic comparison of the production showed that the hybrid panel is a more expensive alternative as well. It was found that panel a1 is better than panel b1 because, in addition to the lower cost (the production cost of the latter is 24% higher than that of panel a1), it is also more environmentally friendly at the production stage (impacts of panel b1 are between 3% and 27% higher than panel a1 in categories PE-NRe, PE-Re, ADP, GWP and EP, while the latter presents impacts between 2% and 10% higher than panel b1 in categories POCP, AP and ODP). As so, the most efficient profile both economically and environmentally is profile a1, which is composed of GFRP and PUR.


ABSTRACT: In this paper, a three-dimensional numerical solution for the bending study of laminated composite doubly-curved shells is presented. The partial differential equations are solved analytically by the Navier summation for the mid-surface variables: this method is only valid for shells with constant curvature where boundary conditions are considered simply supported. The partial differential equations present different coefficients, which depend on the thickness coordinates. A semi-analytical solution and the so-called Differential Quadrature Method are used to calculate an approximated derivative of a certain function by a weighted summation of the function evaluated in a certain grin domain. Each layer is discretized by a grid point
distribution such as: Chebyshev-Gauss-Lobatto, Legendre, Ding and Uniform. As part of the formulation, the inter-laminar continuity conditions of displacements and transverse shear stresses between the interfaces of two layers are imposed. The proper traction conditions at the top and bottom of the shell due to applied transverse loadings are also considered. The present results are compared with other 3D solutions available in the literature, classical 2D models, Layer-wise models, etc. Comparison of the results show that the present formulation correctly predicts through-the-thickness distributions for stresses and displacements while maintaining a low computational cost.


ABSTRACT: The present study provides a formal generalization of the elastic lateral torsional buckling solution based on the Vlasov theory, initially intended for monolithic sections, to extend its applicability to any number of cross-sections connected together to form a monosymmetric assembly. The theory applies the well-known Vlasov kinematic assumptions to each of the components and augments them by assuming no relative slip between the components, as would be the case when components are bolted or welded. The formulation naturally leads to general expressions for effective sectional properties for the assembly (e.g., location of the shear centre, warping constant, monosymmetry parameter, and the Saint-Venant torsional constant). By adopting the effective sectional property definitions arising from the theory, the resulting lateral torsional buckling variational principle for the assembly is cast in a form analogous to that of monolithic sections. Alternative techniques are proposed to estimate the effective warping constant and monosymmetry parameter for assemblies. The solution shows that assemblies of sections connected through plug welds have lower critical moments than those continuously welded at the edges, while assemblies with intermittent welds have intermediate critical moment values. It is shown that treating the assembly as a monolithic section yields higher critical moments than assemblies with plug welds. The theory is used to quantify the critical moments in a number of built-up applications. Comparisons with the predictions of shell finite element model in Abaqus and S-Frame demonstrate the validity of the formulation.


ABSTRACT: This paper is concerned with the development of the so-called Hencky bar-chain model for the bending, buckling, and vibration analyses of non-uniform thick beams. The conventional Hencky bar chain model comprises a finite number of rigid segments connected by frictionless hinges and elastic rotational springs and lumped masses at the joints. The key contribution of this paper is to enhance the Hencky bar chain model for the analysis of thick beams through the adoption of a third-order shear deformable (or Reddy) beam theory to allow for the effect of transverse shear deformation. The paper also shows the validity of the analogies between the enhanced Hencky bar-chain model and the central finite difference method for solving partial differential equation systems that have been observed for the Euler-Bernoulli beam model.


ABSTRACT: The compression behavior of octagonal concrete-filled thin-walled tube (OCFT) columns was investigated. Eight OCFT columns with different tube sections were tested under monotonic compressive loading. The tests showed that the thin-walled tubes underwent elastic or inelastic local buckling, and the slenderness ratio (or width-to-thickness ratio) and section shape of the tubes significantly affected their buckling modes. Despite such local buckling, the load-deformation behavior of the OCFT columns all was highly ductile, due to confinement to the infilled concrete. The design strengths of AISC 360-16 agreed well with the test strengths. In this study, effective stress–strain relationships of the tube and infilled concrete were proposed to account for the local buckling and confinement. The maximum strength and post-buckling behavior were estimated through the strain-compatibility analysis, and the results were compared with the tests.
ABSTRACT: Corrosion is still one of the most important causes of structural failure of and incidents in pipelines. Up until now, most finite element studies have considered modelling corrosion defects as a single or multiple idealized defects and their interactions. This paper presents an original methodology that has been developed for the automatic modeling of the complex geometry needed to represent real corrosion defects, using data obtained by field inspection, and also for building an appropriate finite element mesh for these defects. This new methodology enables a more in-depth finite element analysis and uses information already available from data obtained in inspections, which are currently only used to create clusters of idealized defects. The methodology enables the structural assessment of corroded pipelines to be further improved, giving more headroom to explore pipelines affected by corrosion. The methodology was validated by non-linear failure analysis, which were compared against semi-empirical methods and experimental results. The results are very promising and the computation efficiency is attractive.

ABSTRACT: Compared with natural sand, manufactured sand (MS) is more economical and environmentally friendly. This paper experimentally evaluates the axial compressive behavior of circular steel tube short columns filled with manufactured sand concrete (MS-CFT). 63 specimens were designed and tested to study the following test parameters: the source of sand, the content of stone powder, the diameter-to-thickness ratio of steel tube, and the compressive strength of concrete infill. Test results showed that the axial compressive strength of MS-CFT short columns increased with reducing the diameter-to-thickness ratio of steel tube or increasing the compressive strength of concrete infill, but was not appreciably affected by the type of stone used to manufacture the sand or the content of stone powder. Several design codes for conventional CFT columns were used to estimate the axial compressive capacities of the MS-CFT specimens tested in this experimental program to evaluate the applicability of these codes. It was shown that these design codes could provide conservative estimations.

ABSTRACT: Non-prismatic beam-like structures are widespread in many engineering and science applications. Important examples include the rotor blades of wind turbines and helicopters. Their mechanical behaviour can be simulated using 3D beam models, which are computationally efficient, accurate and explicitly consider such structures’ main geometric features, the large deflection of their reference centre-line and 3D warping of their transverse cross-sections. This paper proposes a mathematical model for such structures. A variational approach and the smallness of the warping and strain fields are exploited to obtain the model. Analytical and numerical results obtained with the proposed modelling approach are presented and compared to those from nonlinear 3D-FEM simulations.

ABSTRACT: The innovative use of seawater sea-sand concrete (SSC) with fiber-reinforced polymer (FRP) has the potential to offer significant advantages in marine constructions, which leads to extensive projects conducted to investigate the mechanical performance of FRP-SSC composite structures. This paper therefore
presents an experimental study of CFRP partially wrapped square seawater sea-sand concrete columns under axial compression. Six CFRP strengthening schemes were designed for the external confinement and the effects of concrete type, clear spacing ratio, CFRP thickness and strengthening strategy on the stress-strain relationship were also investigated in this study. The test results show that similar axial compressive behavior was observed for CFRP partially wrapped normal concrete and seawater sea-sand concrete columns. Moreover, for the SSC specimens partially wrapped with two-layer CFRP strips, the average ultimate strengths were increased by 13.6–36.6% with the decrease of clear spacing ratio, while the average ultimate strains were improved by 22.3–91.9%. Furthermore, the maximum enhancement of 57.6% and 108.8% can be achieved for the ultimate strength and strain respectively when the thickness of CFRP sheets was double increased. In addition, a comprehensive analysis of existing stress-strain models for FRP confined concrete in square columns was conducted and a test database was also assembled to examine the performance of several selected models in predicting the ultimate conditions. Finally, a new stress-strain model was proposed for FRP partially wrapped square concrete in this study and the proposed model was proven to be superior to all the other selected models by comparing the experimental observations with theoretical predictions.


ABSTRACT: This work presents the buckling resistance of a novel active multidisciplinary sandwich plate (AMSP) under in-plane mechanical load or temperature change. The proposed sandwich plate includes an advanced porous core reinforced with carbon nanotubes (CNTs) integrated between two active piezoelectric faces. Functional graded (FG) profiles are considered for the dispersions of CNTs and porosity along the thickness of core layer. In addition, the effect of CNT agglomeration in core layer on the buckling resistance of the proposed AMSP has been studied by employing Eshelby-Mori-Tanaka (EMT)'s approach. A third order shear deformation theory (TSDT) of plates is adopted to obtain governing Eigen value equations for the thermal and mechanical buckling analyses of AMSP. The critical buckling resistance of each analysis has been extracted from the governing equations through a developed mesh-free solution based on moving least squares (MLSs) shape functions. The impacts of porosity, CNTs and geometrical dimensions on the buckling resistance of AMSPs have been investigated. The results show that embedding porosity in core results in a slight reduction in mechanical responses and a significant improvement in thermal buckling resistance. Moreover, reinforcing core layer with CNTs leads to remarkable drop and increase in thermal and mechanical buckling resistances, respectively. However, the formation of CNT agglomerations significantly reduces such CNTs impacts.


ABSTRACT: In this paper, an effective placement of viscoelastic dampers on single-layer reticulated shell structures is proposed to mitigate seismic response. For comparison, an existing placement of viscoelastic dampers is also investigated. The effectiveness of the proposed placement of viscoelastic dampers is investigated from both deterministic and probabilistic perspectives. The single-layer reticulated shell structure is driven by the stochastic seismic ground motions, which are modeled via the random function based spectral representation method. The probability density evolution method is then implemented for probabilistic response and reliability analyses of the shell structure. A series of deterministic numerical simulations are first implemented under different earthquake excitations, including both actual and artificial seismic ground motions, to compare the control effects in deterministic sense. Then, the control effects of the proposed placement and the existing placement are compared in probabilistic sense, where the probabilistic responses, equivalent extreme value distributions and failure probabilities are extracted. Numerical results demonstrate that the seismic performance of the shell structure can be greatly improved by arranging the viscoelastic dampers with the proposed placement.

Lili Sui, Shiyong Fan, Zhenyu Huang, Wei Zhang, Yingwu Zhou and Jianqiao Ye, “Load transfer mechanism of an unwelded, unbolted, grouted connection for prefabricated square tubular columns under axial loads”,


ABSTRACT: This study develops a novel unwelded, unbolted, ultrahigh-performance fibre-reinforced concrete (UHPFRC) grouted connection for prefabricated square tubular composite columns. Herein, eight full-scale columns with UHPFRC grouted connections are tested to investigate their ultimate tensile and compressive resistance. The test results show that the novel connections exhibit good tensile and compressive resistance and structural stiffness. The primary failure modes are punching shear of the end plate, welding fracture at the inner tube, tube yielding and local buckling of the steel tube. The test specimens are simulated using finite element (FE) analysis in ABAQUS. The experimental and simulated results are in good agreement, indicating that the FE simulations can capture the observed failure modes and ultimate tensile and compressive resistance. Thereafter, existing analytical design formulas are evaluated to assess their suitability to predict the compressive and tensile resistance of prefabricated tubes with/without the novel grouted connections. A good agreement between the formula predictions and the test results are observed. These analytical formulas have the potential to be used in the design of the novel unwelded, unbolted, UHPFRC grouted connections for prefabricated steel, reinforced concrete and steel–concrete composite columns.

ABSTRACT: Welded hollow spherical joints with H-beam (H-WHSJ), as a new connection pattern in space lattice structures, have been applied in practical engineering. This study aims to investigate the residual mechanical properties of H-WHSJ after loading in elevated-temperature environments and provide an important basis to evaluate the performance of space lattice structures after the occurrence of fire. The effects of temperature history, plastic residual deformation, sizes of WHSJ and H-beam, type of steel, and stiffening rib arrangement on the residual mechanical performance of H-WHSJs after exposure to elevated temperatures are determined via axial compression test by using 28 specimens and finite element (FE) parametric study. The major conclusions are as follows. (1) The residual characteristics of H-WHSJ after elevated temperature are rarely affected by temperature history, but mainly determined by the residual deformation at elevated temperature when the temperature is lower than 700 °C. (2) Plastic residual deformation can considerably reduce the residual bearing capacity ($N_r$) of the loaded H-WHSJ. In particular, $N_r$ decreases by approximately 20% when the residual deformation is 6% of the hollow sphere diameter. (3) The formula to calculate the residual bearing capacity of H-WHSJ after loading in elevated-temperature environments has been proposed, and its prediction are in good agreement with the test and FE results.

ABSTRACT: To address the dilemma of structures constructed with seawater and sea sand concrete (SWSSC), including insufficient durability and high cost, an innovative composite column, named SWSSC-filled reactive powder concrete (RPC) tube (SFRPC tube), is proposed and studied. This hybrid system is composed of a prefabricated RPC thin-wall hollow tube with fiber reinforced polymer (FRP) hoops and infilled SWSSC. In order to understand the basic compressive performance of the proposed composite structure, a total of 24 short columns, with 300 mm outer diameter and 600 mm height, were tested in axial compression. SFRPC tube columns exhibited a multi-crack failure mode on the surface of tube without obvious peeling-off of the RPC cover. The RPC tube can serve as the permanent formwork, and maintain its own integrity in the whole loading process, carrying considerable axial load acting on the composite column, due to its super-high compressive strength. The results reveal that the SFRPC tube system effectively utilizes the ultra-high mechanical properties of RPC and FRP confinement effect. Compressive performance of SFRPC tube columns can be further improved as the volumetric FRP hoop ratio in RPC tube increases. It is found that overlapping joint methods for single FRP hoop in RPC tube and the thickness of RPC tube have no significant effect on the mechanical performance of SFRPC tube columns under the current testing conditions. A special confinement model was also proposed for assessing the axial load carrying capacity of SFRPC tube columns.

ABSTRACT: Thirty specimens of built-up double-box columns consisting of four cold-formed steel channels were experimentally tested under concentric and eccentric axial compression. The test specimens had varied cross-sectional dimensions (outside dimensions equal to 89 mm × 147 mm or 86 mm × 96 mm), different effective lengths (3200 mm, 1700 mm, 210 mm, or 135 mm), and different thicknesses (1.2 mm or 1.5 mm). The load vs. displacement curves and the measured compression strength of specimens were obtained and the failure modes were analyzed. The test results showed that the failure mode of the long specimens (L/r between 103 and 108, where L is the calculated length of the column, r is the minimum radius of gyration) was flexural buckling about the weak axis. The typical failure modes of medium length specimens (L/r between 53 and 57) and short specimens (L/r between 4 and 8) subjected to concentric axial compression were deformation concentration caused by large local buckling. The failure mode of the medium length specimens under eccentric axial compression was flexural buckling, except for the specimens whose web height was 147 mm and the eccentricity direction was along the minor axis, for which the failure mode was deformation concentration. Then, finite element (FE) models considering geometric, material, and contact nonlinearity were developed, compared to experimental results, and used to explore a wider design space. The FE analysis results showed that the slenderness ratio of the column and the web height-to-thickness ratio have an important influence on the strength of these columns. Finally, the applicability and effectiveness of calculating compression strength for this type of built-up column using methods such as “Effective Ratio of Width-to-Thickness Method” in Chinese code, “Effective Width Method” in AISI and “Direct Strength Method” in AISI, were evaluated by comparison with the test and FE results. For all the columns analyzed with slenderness ratio greater than 105, it is reasonable to use these methods to calculate the eccentric axial compression strength of columns. The methods in China and AISI S100-16 were found to be conservative for calculating the eccentric axial compression strengths of these built-up double box columns.


ABSTRACT: A single-layer reticulated steel (SRS) cooling tower consists of members and joints. Joint stiffness is an important component of SRS cooling towers, as it significantly influences the overall behavior of the structure. A new semi-rigid joint system consisting of H-shaped and C-shaped rolled steel, known as an HCR joint, has been developed for application in SRS cooling towers. In this study, a finite element (FE) model of an HCR joint under bending conditions is established and verified by joint tests. Then, HCR joints subjected to different loading combinations, including bending and shear forces, bending and certain axial forces, and eccentric forces, are numerically analyzed. The bending moment-rotation (M-Φ) curves and change rules for the stiffness and ultimate bending capacity are obtained. Next, the stability of SRS cooling towers with semi-rigid HCR joints is analyzed based on the M-Φ curves of the HCR joints under various eccentric forces. Two FE models of the structures are established. In FE Model-1, the stiffness of the HCR joints under a bending load is used for all of the joints in the structure. In FE Model-2, the stiffness of the HCR joints under different eccentric forces are used based on the different ratios of bending force to axial force in the joints at different locations in the structure. During the analysis, the structural height, grid size, and joint stiffness are considered, and the effect of the parameters on the critical load and buckling mode of the structure is determined.


ABSTRACT: In a seismic assessment context, wind turbine blades are often excluded from numerical studies mainly due to their complex shape and lack of sufficient data. This tends to suppress their modal effect from the global dynamic response and can potentially influence the reliability of the seismic vulnerability of wind
turbines, determined in a traditional manner, i.e., employing the lumped mass approach. This study aims to provide a closed-form solution for deriving the cross-sectional properties of a typical airfoil to further calculate the flapwise, edgewise, and torsional stiffness of a typical wind turbine blade. A genetic algorithm (GA)-based modeling optimization is performed to evaluate the geometric and material parameters that are representative of realistic blades. These parameters are used to achieve the target blade mass, stiffness, and frequencies. The proposed approach results in design solutions (DS) as different combinations of these parameters. Each DS leads to mechanical and modal characteristics that are equivalent for all blade configurations, such as blades with or without webs, with or without structural twist and varying pitch axis locations. These solutions are employed to develop the blades of the RNA in a wind turbine model to test the efficiency of the method. It is suggested that blades should be realistically considered for reliable seismic assessment of wind turbines.


ABSTRACT: This study attempted to explore the effects of initial self-stress in concrete and steel fibre on the compressive behaviour of concrete-filled steel tube (CFST) columns. A total of 36 CFST columns with a radial self-stress ranging between 3.31 MPa and 6.66 MPa and a steel fibre volume percentage of 0, 0.6% and 1.2% were tested under axial compression. The steel tube thickness of 2.5 mm, 3.5 mm and 4.25 mm was used to achieve different confining stiffness to the expansion of concrete core. The concrete strength grade of C40, C50 and C60 was used to obtain different expansion deformations. The failure mode, axial load-axial shortening curve, ultimate load and ductility of CFST columns were investigated. Experimental results showed that all specimens exhibited shear failure, and neither self-stress nor steel fibre had obvious influence on the failure mode. Self-stress in concrete enhanced the ultimate load of the CFST columns by 9.8%–27.6%, but decreased their deformability significantly. Adding steel fibres could enhance the ultimate load and slightly improve the post-peak behaviour and ductility of CFST columns with self-stress. Based on the results of this study and literature, an optimum self-stress level (the ratio of radial self-stress and concrete strength) of 0.10 is proposed. Finally, formulas are proposed to predict the load carrying capacity of FSS-SCCFST columns under axial compression, and the predictions agree well with the test results.


ABSTRACT: The seismic performance of flexible pipes significantly affects the resilience of seismically isolated buildings after an earthquake. However, the unqualified design or installation of flexible pipes is a critical issue in China and may also be observed in other countries due to the lack of corresponding design code. To investigate the performance of flexible pipes, 27 metal flexible pipes (MFPs) and 24 rubber flexible pipes (RFPs) with an expected deformation capacity of 400 mm were tested. The schemes recommended by the code and used previously in real engineering practices are compared comprehensively for two types of flexible pipes. The effects of critical parameters (i.e., the nominal inner diameter, installation length, and design length) on the damage evolution mode, deformation capacity, and failure mode are investigated. The test results indicate that 1) for previous MFPs designed with an installation length, two damage states are experienced, and the rupture of the outer net results in failure before 400 mm. However, water leakage is not observed owing to the strong deformation capacity of the inner bellows. 2) The cap of seismic performance of the previous MFPs considering maximum manufacturing redundancy is identified. Such an MFP with the smallest diameter ruptured before 400 mm, while a pull-out with a maximum length of 4 mm of the outer net is observed for other MFPs, and the function is generally well. 3) For previous RFPs, two damage states are experienced before 400 mm, but water leakage is observed along with rupture. A better deformation capacity is achieved for the RFP with a smaller diameter and longer design length. 4) Regarding the MFP and RFP designed according to the code, they can completely perform well under 30 cycles of 400 mm and function well after an earthquake. The research outcome can provide an important reference for the vulnerability research and seismic design of flexible pipes in seismically isolated buildings.

ABSTRACT: Structural artist Félix Candela pioneered the 8-sided hyperbolic paraboloidal (hypar) umbrella by introducing a parabolic discontinuity bisecting each quadrant of the classical 4-sided form. While artistically striking, such structures have never been rigorously examined from a structural engineering perspective. This paper formulates equations governing the geometry of 8-sided hypars, facilitating the in-depth analysis and comparison against their more common 4-sided variants via finite element modeling. A parametric investigation based on two historical case studies identified that 8-sided umbrellas exhibit larger deflections and stresses relative to 4-sided renditions, thus rebuking Candela’s hypothesis concerning the improvement to structural efficiency offered by the parabolic fold. While corner deflections and principal stresses generally decrease with increasing curvature, the discontinuity present in 8-sided forms disrupt the flow of internal forces, resulting in stress concentrations at the parabolic apex manifesting as large moment demands. However, it was demonstrated that 8-sided hypars exhibit increased resistance to shell buckling over 4-sided variants as revealed through a simplified analytical approach.


ABSTRACT: The AISC 341 (2016) has a more stringent width-to-thickness (b/t) limit for highly ductile hollow box columns (HBCs) than the AIJ (2010) or Taiwan Code (2010), resulting in significant thickness difference in design. Moreover, the cyclic backbone curves based on ASCE 41 (2013) and NIST (2017) underestimate the post-buckling flexural strength of HBCs, particularly in high axial compression force. This paper presents test results of six full-scale, built-up HBCs using SM 570 M steel with the actual yield strength of 460–530 MPa. The lateral cyclic behavior of built-up columns was studied in terms of different b/t ratios, magnitudes of axial compression forces, and lateral drift histories (i.e., cyclically symmetric versus near-fault displacement histories). The built-up box columns were 290–400 mm wide with b/t ratios from 11 to 21, 4000 mm high, and tested laterally with both ends fixed after under a constant axial compression force, 2591–7935 kN. The HBC specimens which were designed based on the highly ductile member requirement in AISC 341 (2016), even under an axial compression force (=40%P), performed satisfactorily at 4% drift and experienced flange and web fracture at 5% drift. However, the HBC specimens that satisfied the most compact b/t requirement in AIJ (2010) or Taiwan code (2010) did not perform well at 4% drift, losing the axial capacity after significant column local buckling and shortening. The gathered test data, supported by more test data in this work, were analyzed by a multiple regression method to obtain empirical formulations for predicting the maximum column moment, plastic rotation and post-yield hardening parameters. The proposed formulation reasonably predicts the first-cycle envelope curves of built-up HBCs, improving prediction results based on ASCE 41 (2013) and NIST (2017).


ABSTRACT: A corotational Lagrangian formulation for nonlinear dynamic analysis of steel planar frames is addressed. This formulation employs the Plastic Zone Method and is capable of considering second-order effects, initial geometric imperfections and residual stresses. The element dynamic equilibrium is derived from the virtual power theorem, and local cubic shape functions are used to deduce the element tangent stiffness and mass matrices. The integration of stresses over the cross-section area is executed based on elastic–perfectly plastic stress-strain curve, which is applied for each slice of the cross-sections located at the Gauss points along the member length. In order to solve the system of dynamic nonlinear equations in time domain, the numerical analysis procedure makes use of the Newmark’s implicit time integration method and the Newton-Raphson technique. The PPLANLEP computational program, which is based on the finite element method, is modified to perform the nonlinear time-history analyses. A good correspondence between the found numerical solutions and
those reported by other researchers and obtained by OpenSees software is observed, indicating that the proposed method is efficient in predicting the nonlinear dynamic behavior of steel structures.


ABSTRACT: Despite the great efforts aimed at modifying nonlinear solution methods, researchers have failed to achieve a single algorithm which can correctly trace the equilibrium path for all problems. It has been proved that the numerical algorithms, such as the Arc-length and Newton-Raphson, cannot easily deal with limit points while tracing the equilibrium path. Moreover, secondary and tertiary paths attained by these methods do not simultaneously appear in the solutions. Verifying these methods requires the exact answers of some structures’ equilibrium equations. In spite of the simplicity of structures, intricate post-buckling behaviors with different critical points are observed under the hypothesis of large displacements. Analyzing the equilibrium paths and their features along with providing exact expressions seem to be very useful. In line with this goal, a family of simple planar and space trusses can be analyzed analytically. Closed-form solution and critical points of these structures are available in detail. Additionally, a parametric study of geometrical bounds for monitoring secondary branches is given, which clarifies the effect of geometry on the truss’ behavior. While these outcomes are beneficial for educational purposes, they may also be utilized to check the computer programs’ developments.


ABSTRACT: The current paper aims to analyze the influence on the critical buckling loads of the non-uniform distribution of the oriented fibers along the thickness direction of three-phase CNT/polymer/fiber functionally graded orthotropic plates. The various plies of the laminated plates are reinforced by both carbon nanotube (CNT) particles and conventional oriented straight fibers. The orthotropic features of such layers are provided by the reinforcing fibers which are functionally graded (FG) along the thickness coordinate. In the literature, CNTs represent generally the sole reinforcing phase and are assumed aligned and graded in the thickness direction. Here, instead, CNTs are randomly oriented and uniformly scattered in the matrix, whose properties are further improved by aligned, graded, straight and oriented fibers. A general power-law function is introduced to define the non-uniform features instead of the usual patterns presented in the literature (such as FG-X and FG-O), which can be included in the proposed approach as particular cases. The current methodology is tested through the comparison with the results available in the literature. The validation procedure is carried out for two-phases composites, considering also CNTs as straight and aligned reinforcing fibers, characterized by both uniform and graded properties. Several boundary conditions are also analyzed and verified. As proven by the numerical results illustrated in the paper, the variation of the through-the-thickness distribution of the fiber volume fraction is able to change noticeably the value of both uniaxial and biaxial critical buckling loads of arbitrarily restrained thin and thick plates. This effect should be considered in the manufacturing process and in the mechanical analysis of these structures.


ABSTRACT: Space grids often exhibit a highly regular structure which is formed by repeated structural units. In the past, various algorithms have been developed to generate more complex structural assemblies using simple commands. In this paper, we explore the innovative use of symmetry groups to create various configurations of space grids, ranging from rectangular grids and their variants, to triangular and hexagonal grids, as well as grid forms of more complex shape. The advantage of this approach is that the generated space grid has pre-determined symmetry properties; this represents a shift in current design philosophy. A second objective is to show how group theory may be used to simplify the vibration analysis of layered space grids. The procedure is applied to the transverse vibrations of triple-layer space grids of D2h and D4h symmetries,
modelled as discrete-parameter systems. A study of the symmetry of subspace basis vectors allows some important predictions to be made on the pattern of the motions and the location of stationary nodes. It is found that the lowest and highest frequencies of space grids of this type occur in the first subspace of the system, a finding that has significant computational importance.

ABSTRACT: The flexural-torsional buckling behaviour and resistances of fixed-ended press-braked S690 high strength steel angle section columns have been studied based on testing and numerical modelling, and reported in this paper. A testing programme, employing four different equal-leg angle section sizes, was firstly conducted, and comprised material tensile coupon tests, initial global and torsional geometric imperfection measurements and twelve fixed-ended column tests. The column test setup and procedures were thoroughly presented, and the key obtained test results, including the failure loads and deformations at the failure loads, load–end shortening curves, load–mid-height torsional rotation curves and failure modes, were fully reported and discussed. This was followed by a numerical modelling programme, where finite element models were initially developed to simulate the experimental responses and then adopted to perform parametric studies to generate further numerical data over a wide range of cross-section dimensions and member lengths. The obtained test and numerical data were then used to evaluate the accuracy of the relevant codified design rules, given in the European code, North American specification and Australian/New Zealand standard, and a recently proposed DSM-based design approach. The results of the evaluation revealed that all the codified design rules yield excessively conservative and scattered flexural-torsional buckling resistance predictions for fixed-ended press-braked S690 high strength steel angle section columns, while the DSM-based design approach leads to substantially improved resistance predictions, owing to the rational consideration of the length-dependent characteristic of flexural-torsional buckling and the interaction of flexural-torsional buckling with minor-axis flexural buckling.

ABSTRACT: Selection of influential geometric imperfections may be crucial for efficient calculations of lower buckling strengths of thin cylindrical shells subject to axial compression by the geometrically/and materially nonlinear FEM analysis with imperfections (GNIA/GNMIA). The imperfections in the shapes of eigenmodes provided by the preliminary linear buckling analysis (LBA) of perfect shells are brought into focus. For categorizing a large set of potentially influential eigenmodes customarily normalized to unit amplitude the strain energy of the shell deformed in the shape of each eigenmode is determined. By the square root of the strain energy an unconventional energy measure of the shell geometric imperfections is defined. Considering the eigenmode imperfections and localized imperfections normalized by the amplitude and by the energy measure the buckling strengths of an imperfect shell are compared. A preference is given to the normalization of the geometric imperfections by the energy measure. Nevertheless, for the currently revised Structural Eurocodes, particularly for the standardization of GNIA/GNMIA FEM design of shells based on amplitudes of geometric imperfections an amendment is suggested.

ABSTRACT: The sustainability of spatial structures, where the main bearing members are steel tubes, is becoming more and more prominent. In order to investigate the effect of local corrosion on the mechanical properties and ultimate compressive strength of circular steel tubes, outdoor accelerated corrosion tests on 11 steel tubes were conducted considering the effects of different corrosion locations and corrosion degrees. The experimental results showed that the ultimate bearing capacity of the specimens was significantly affected by local corrosion, and the corrosion in the middle of the tube was more unfavorable than that in the end. Moreover, local corrosion can change the failure phenomenon of circular steel tubes. Finite element analysis on
the bearing capacity of circular steel tubes after local corrosion was carried out, and the reliability of the simulation method was verified by comparison with experimental findings. The stress evolution on different sections during axial compression was also analyzed. Finally, the effect of different corrosion conditions on the bearing capacity was studied using parametric analysis. The analysis results demonstrated that the circumferential corrosion ratio and corrosion depth are important indices to evaluate the corrosion effect. Meanwhile, it was found that the corrosion location has a significant impact on the residual bearing capacity of tubes; however, the impact decreases with the increase in circumferential corrosion ratio and corrosion depth. The research results of the present work can provide a technical reference for the study of the mechanical properties of building components, such as round steel tubes, after corrosion.


ABSTRACT: Performance-Based Seismic Design (PBSD) procedures require adequate estimation of the global cyclic force–displacement (F-D) behaviors of the primary lateral load-resisting elements. As reinforced concrete (RC) walls constitute one of the most widely used lateral load elements in building construction, several nonlinear analytical modeling approaches have been developed over the past several decades to numerically simulate the hysteretic behavior of these structures. However, comparisons between these models have often provided few details on the model input parameters, have not used consistent model discretization, and have assessed hysteretic predictions more qualitatively than quantitatively. Accordingly, the objectives of this paper are to: 1) provide detailed information on the modeling parameters used to simulate the cyclic lateral F-D behavior of a set of planar RC walls with flexure-dominant as well as shear-dominant behaviors, 2) evaluate the sensitivity of the F-D curves to different wall model discretizations applied consistently between different models, and 3) propose and use a new quantitative approach to assess the hysteretic behaviors predicted by the numerical models. The considered models are PERFORM 3D, MVLEM, SFI-MVLEM, and BTM. To represent the information that is typically known during the design of a structure, the nonlinear modeling parameters were limited to the wall geometry, reinforcing layout, concrete compression strength, and reinforcing steel yield strength, with no calibration of the material behaviors to the reported test results. A total of 2,300 analyses were performed to simulate four slender and four squat previously-tested RC walls. Results of the cyclic lateral F-D predictions were evaluated based on commonly used measures of effective stiffness, maximum strength, and ultimate displacement. Additionally, the hysteretic response of the numerical simulations was assessed by proposing, validating, and using the Modified Nash-Sutcliffe Efficiency (NSE-sub-m) metric. Comparisons between the computing times for the models were also made, as well as comparisons of the local nonlinear behavior of a slender wall. Results show that the discretization used in the PERFORM 3D, MVLEM, and SFI-MVLEM simulations did not significantly affect the predicted global response, whereas the discretization did affect the F-D curves from the BTM model. The values of NSE-sub-m agreed with qualitative evaluations of the F-D curves and were able to properly evaluate complex cyclic behaviors of RC walls including pinching and stiffness deterioration. The results of this investigation are expected to be used as modeling guidelines of RC walls when conducting PBSD.


ABSTRACT: To investigate the triaxial compressive response of engineered cementitious composite (ECC), the method of providing passive confinement by steel tubes was adopted. Eight groups of circular steel tube confined ECC (STCE) and two groups of steel tube confined concrete (STCC) were prepared and tested by monotonic axial compression. The effect of ECC compressive strength and diameter-to-thickness ratio of steel tube on the failure mode, axial load versus displacement curves and strain development in steel tube of the specimens were analyzed. The test results revealed that the peak load and the corresponding displacement of STCE increased with the decrease of the diameter-to-thickness ratio of the steel tubes. For STCE specimens with identical diameter-to-thickness ratio of steel tube, the axial displacements corresponding to the peak loads decreased with the increase of ECC compress strength. The transverse confining mechanism of STCE is different from that of STCC because the fiber bridging effect in ECC results in the “self-confining” effect. Furthermore, a modified Richart mode was proposed to predict the axial carrying capacity of STCE.
ABSTRACT: Recycled aggregate concrete (RAC) was mainly limited to the nonstructural uses in practice due to its inferior properties. To expand the range of application of RAC, a novel structure type of concrete-encased concrete-filled steel tube (CFST) has attracted great interest due to its excellent performance. Since little literature about the behavior of the RAC-encased RACFST, it is imperative to conduct research about the new type of member for practical application to meet the requirement of the large market and sustainable development. This paper presents experimental and analytical studies on the mechanical behavior of RAC-encased, RAC-filled steel tube (RACFST) composite columns under combined compression and bending. In the experiments, sixteen specimens were tested under axial or eccentric compression to investigate the effects in the recycled coarse aggregate (RCA) replacement ratio (0%, 25%, 50%, 75%, 100%), eccentricity ratio (e/h = 0, 0.2, 0.4, 0.6), steel ratio (2.72%, 2.11%), and slenderness (l/h = 3, 6, 9) on their mechanical performance. The results indicated that the replacement ratio of RCA had little effect on the failure mode of the RAC-encased RACFST composite columns. Compared with the specimens under axial compression, reductions of 23.1%, 63.9%, and 72% were observed in the compressive strength for specimens with eccentricities of 0.2h, 0.4h, 0.6h, respectively. Both the increase in the steel ratio and the reduction in the slenderness significantly improved the compressive strength of the specimens. A finite-element model of the specimens was developed to predict the load-deformation relationship and failure mode. The ultimate bearing capacity was predicted using existing design codes and the test result were compared. The values predicted by the design codes EC4, AISC360 PSD, and CECS188 showed deviations <15% (relative to the experimental values), which could be considered overconservative for the bearing capacity of RAC-encased RACFST composite columns.

ABSTRACT: The seismic behavior of fire-exposed concrete-filled steel tubular (CFST) columns was investigated based on a verified finite element analysis (FEA) model in this paper. Coupling effects of the fire exposure and sustained axial load on CFST columns were considered. Existing test data was employed to verify the feasibility of the model, where the temperature field tests, fire resistance tests, cyclic tests of CFST columns under ambient temperature and cyclic tests of CFST columns after fire exposure without coupling effects were considered. Further analysis was carried out based on the verified model. It was found that the coupling effects of fire exposure and sustained axial load could cause structural failure of CFST columns during fire exposure. However, if the CFST columns did not fail due to coupling effects, the residual deformation, residual stress, hysterical curves, and ultimate strengths after fire were similar to the CFST columns subjected to fire and axial load sequentially. The interactions between steel tube and concrete were studied. It was shown that the bond strength did not influence the behavior of CFST columns under and after fire exposure significantly. On the other hand, the contact stress was influenced by the lateral deflection and fire duration time of CFST columns. The deformation curves of CFST columns with low shear span ratios after fire exposure were generally similar to those without fire exposure. Lastly, it was found that the strength degradation of CFST columns with lower shear span ratios was more significant after fire exposure.

ABSTRACT: Laplace transform operator only accepts initial values at zero in evaluating derivative functions. This limits its use in vibration analysis of beams as a tool for merely finding analytical solutions and coefficients. By extending Laplace transform’s capacity to take non-zero initial conditions, a novel operational method for developing dynamic beam elements is proposed. The method avoids integration and differentiation, which are traditionally used in developing dynamic vibration elements. The ease of application of this operational method is demonstrated by developing dynamic stiffness elements of Euler-Bernoulli beams under various boundary conditions. The proposed technique also allows for easy handling of coupled differential equations, such as the ones applied to bending-torsion vibration of beams, as well as discontinuous functions
which appear in elastic support modelling. MATLAB software has been used as graphing tool and for the mathematical calculations in this research.


ABSTRACT: A consistent design approach, performed by second-order inelastic analysis using beam finite elements with strain limits, is proposed for web-tapered steel members. In the proposed design approach, a geometrically and materially nonlinear analysis with imperfections (GMNIA) of the tapered steel member is carried out and the ultimate strength of the member is signified by reaching either the strain limit defined according to the Continuous Strength Method (CSM) or the peak load factor, whichever occurs first. To consider the beneficial effect of strain gradients along the length of the members on local cross-section resistances, the strains are averaged over the local buckling half-wavelength. The accuracy of the proposed design approach is verified against results from nonlinear shell finite element modelling as well as a number of experiments on tapered members considering various taper ratios, loading conditions and member slenderness values. The proposed method provides more accurate and consistent ultimate strength predictions than EN 1993-1-1 [1], because the following aspects, which are ignored in traditional design methods, are captured: (1) the interaction between cross-section elements for the consideration of local buckling, (2) the influence of local moment gradients on cross-section resistance, (3) the partial plastification of cross-sections and (4) strain hardening.


ABSTRACT: A method for evaluating the mechanical integrity of open-top cylindrical storage tanks subjected to a differential settlement is given. The settlement profile underneath the bottom circumference of the tank shell can be transformed into different harmonic components using the Fourier transformation. The existing method in American Petroleum Institute’s standard API 653, which is currently used by the industry in North America, does not differentiate the effect of different harmonic components. Nevertheless, the proposed method evaluates a cumulative damage factor by considering the effects of first five harmonic components individually. The paper further discusses other limitations of the existing method in API 653 document. Numerous finite element analysis (FEA) simulations are conducted to formulate and validate the proposed method by employing geometric nonlinear algorithm with nonlinear plastic material properties (GMNA) in ABAQUS finite element software. The trend for limiting settlement values with respect to different harmonic components under consideration and different tank geometries are discussed. The proposed method is validated by performing FEA using four actual settlement data profiles on different tank geometries. Lastly, the comparison is drawn between the FEA results, the existing API 653 method and the proposed method. The results of the allowable settlement indicate that the existing method is not consistent with the FEA findings. For some of the actual settlement data, the existing method results in overly conservative values and for others it gives non-conservative values. Thus, the existing method may not capture the true behavior of tanks under settlement and needs modifications. The results of allowable settlement from the proposed method are found to be consistent with the FEA results for all different settlement data and tank geometries. Therefore, it is recommended that the new method is used instead of the existing method.


ABSTRACT: This paper presents a finite-element (FE) investigation on the flexural capacities of H-section high-strength steel beams with web openings. A non-linear finite-element model (FEM) was developed for H-section high-strength steel beams with web openings, which included initial geometric imperfections. The FEMs were validated against the test results available in the literature for H-section high-strength steel beams with web openings. The validated FEMs were then used to conduct a parametric study comprising 180 FEMs to investigate the effects of different cross-sections, the opening diameter, the number of opening and the type of
loadings on flexural capacities of H-section high-strength steel beams. The flexural capacities predicted from the finite-element analysis (FEA) were also used to study the performance of the current design guidelines for steel structures. A comparison of numerical strengths and design strengths found that the American National Standard (AISC) is over-conservative by as much as 61%, whereas the North American Specification (NAS) and Chinese Code (CC) are conservative by 34% on average, when predicting the flexural capacities of H-section high-strength steel beams with web openings. In addition, the Steel Design Guide Series 2 (SDGS-2) and Continuous Strength Method (CSM) for cold-formed steel (CFS) members with openings are generally appropriate for H-section high-strength steel beams with web openings subjected to flexural failure. Moreover, the design rules from Direct Strength Method (DSM) were found to be over-conservative by around 40%. Accordingly, this paper proposes modified design equations over the existing design rules of SDGS-2. The proposed design equations have predicted closely the flexural capacities of H-section high-strength steel beams with web openings, being only 1% conservative to the FEA strengths.

ABSTRACT: This paper investigates the complex nonlinear vibrations and internal resonance of the rotating blade subjected to the aerodynamic force, which is simplified to a pretwisted rotating cantilever rectangular plate with the varying cross-section and varying rotating speed. Considering the effects of the cross-section warping, pretwisted and presetting angles, the nonlinear partial differential governing equations of motion are established based on the third-order shear deformation theory, von Karman large deformation theory and Hamilton principle. Two-degree-of-freedom nonlinear ordinary differential equations of motion are obtained by using Galerkin method. The method of multiple scales is applied to obtain the averaged equations under the case of the primary parametric resonance-1/2 subharmonic resonance and 1:2 internal resonance. Numerical simulations are performed to portray the amplitude-frequency response and amplitude-force response curves, bifurcations and chaotic dynamics of the pretwisted rotating cantilever rectangular plate by discussing the influences of the aerodynamic force and rotating speed perturbation. The bifurcation diagrams, maximum Lyapunov exponents, phase portraits, waveforms and Poincare maps are utilized to illustrate the complex nonlinear vibrations of the pretwisted rotating cantilever rectangular plate.

ABSTRACT: The flexural behaviour of I-section steel-reinforced concrete-filled steel tubes (SRCFSTs) was investigated via finite-element (FE) analysis. Different behaviours of the SRCFST beams were compared in terms of moment vs. midspan deflection curves, stress distribution in concrete, contact pressure, and flexural strength. The results indicated that the I-section steel delayed the movement of the neutral axis and the propagation of concrete cracks in bending. The simulation results of the FE model were validated by experimental results with regard to the moment vs. midspan deflection curves, moment vs. curvature curves, moment vs. ultimate tensile strain curves, and flexural strength of the tested specimens. Additionally, a parametric analysis of the verified FE model was performed for various parameters, such as the area of the I-section steel, yield strength and thickness of the outer steel tubes, yield strength of the I-section steel, and concrete strength. The parametric analysis revealed that the yield strength and thickness of the outer steel tubes and the areas of I-section steel were the key parameters influencing the flexural strength of the SRCFST beams. Furthermore, design equations for the flexural strength of SRCFST beams were derived according to Han’s method and the AISC specification, and both methods provided a safe and conservative prediction for the flexural strength of the SRCFST beams.

ABSTRACT: Composite structures are commonly analysed using the Finite Element Method (FEM). However, new accurate and efficient discrete numerical techniques have appeared recently – the meshless methods. Thus,
this work uses a meshless method – the Natural Neighbour Radial Point Interpolation Method (NNRPIM) – to perform an elasto-static analysis of composite laminated plates. Meshless methods only require an unstructured nodal distribution to discretize the problem domain. In order to numerically integrate the integro-differential equation from the Galerkin weak formulation, a background integration mesh is constructed using the Voronoï diagram. Then, the nodal connectivity is enforced using the ‘influence-cell’ concept and the shape functions are obtained. In this work, laminated composite plates are analysed using distinct equivalent single layer theories, considering different transverse high-order shear deformation laws. Thus, several third-order, exponential and trigonometric transverse shear deformation theories are combined with the NNRPIM to analyse the structural response of composite laminated plates. In the end, composite laminated plates are numerically analysed and the meshless solutions are compared with the analytical solution available in the literature. Therefore, this work contributes with new solutions for classic composite symmetric cross-ply laminated plates and provides a comparative study on the accuracy of some high-order shear deformation theories (HSDTs).


ABSTRACT: Cold-formed steel (CFS) framed buildings have shown potential towards innovative and efficient building design in high seismic regions. The objective of this study is to expand the knowledge and breadth of design options of CFS construction into higher capacity lateral force resisting systems; as such, the lateral performance of CFS shear walls sheathed with fiber cement board (FCB) and composite steel-gypsum (SG) panels are the focus of this work. Three-dimensional finite element shell modeling is used by focusing on the impact of sheathing type, screw type and fastener pattern. The computational method includes fastener-based modeling which necessitates the use of experimentally-derived connection behavior. An experimental program of monotonic and cyclic fastener testing was conducted to provide shear response of CFS-to-sheathing connections with various sheathings (FCB, SG), screws, and screw spacing. Monotonic connection means are derived from the experiments and introduced in the finite element model. The numerical results demonstrate significant capacity benefits and different failure modes from traditional wood-sheathed shear walls. This work not only aims to provide an innovative and accurate computational tool for FCB- and SG-sheathed shear walls to the research community, but also to expand CFS practice through higher capacity design options. To enable adoption by practitioners, prescriptive design recommendations are provided. As the developed finite element model is computationally expensive, Pinching4 parameters from the cyclic testing are also provided to aid in the development of reduced-order models.


ABSTRACT: The nonlinear dynamic response of laminated composite cylindrical shell under external periodic force with forcing frequency varied in the spectral vicinity of first and second natural frequency is presented. The governing equations of motion are solved to obtain the state vector representing the periodic response using Newmark time marching based shooting approach and arc length/pseudo-arc length continuation techniques. The main contributions of the paper is to explore the parameters influencing the transition between softening and hardening nonlinear behavior of cylindrical shell. In addition the nonlinear restoring force dynamics leading to differences in the positive and negative half cycle response amplitude have been explained using strain/stress distribution. Further, the upper and lower surfaces of the shell are subjected to tensile and compressive stresses for unequal time within a cycle. The periodic variation of the steady state stresses and its FFT reveal significantly large higher harmonic contributions detrimental to fatigue design of structures. Symmetric laminated shell depict greater response amplitude compared to antisymmetric ones owing to increase in restoring forces due to laminating scheme induced bending-stretching coupling for antisymmetric laminates. The deformed configuration of the shell corresponding to primary and secondary peak reveal modal interaction between first and higher modes.

References listed at the end of the paper:
1 Reissner E., Non-linear effects in vibrations of cylindrical shells. Ramo-Wooldridge Corporation, Guided Missile Research Division, Aeromechanics Section; 1955.
ABSTRACT: Semi-analytical solution for critical buckling load and nonlinear load-deflection relationship of I-section laminated composite curved beams with elastic end restraints is presented. The governing differential equations of thin-walled curved beams are derived from the principle of virtual displacement with full
consideration of curvature effect. The elastic end restraints of laminated curved beams for practical engineering is adopted, and the characteristic displacement functions of pinned-pinned and clamped-clamped are linearly combined to describe the stability behavior of end-restrained curved beams. The Galerkin method is used to solve the governing differential equations for stability analysis of laminated curved beams. Accuracy of the present semi-analytical solution for predicting critical buckling load is verified with available solutions in the literature, and its effectiveness for nonlinear stability analysis is illustrated in comparison with the finite element method using ABAQUS. The in-plane and out-of-plane behaviors of laminated composite curved beams are compared. Finally, the effects of geometry of section, initial imperfection, central angle of curved beam (the ratio of arc length to radius), layup in flange and web, and stiffness of elastic end restraints are evaluated to shed light on nonlinear stability behavior. The present semi-analytical solution for nonlinear stability analysis of thin-walled I-section laminated composite curved beams can be used effectively and efficiently in design analysis and optimization of thin-walled curved beam structures.

References listed at the end of the paper:
12 C.H. Yoo, P.A. Pfeiffer, Buckling of curved beams with in-plane deformation, J Struct Eng, 100 (2) (1984), pp. 291-300
29 R.H. Plaut, Buckling of shallow arches with supports that stiffen when compressed, J Eng Mech, 116 (4) (1990), pp. 973-976
and minimum thicknesses are varied. Selective laser melting method of additively manufactured functionally graded thickness thin-walled composite beams with the locations of maximum gradient along their perimeter.

Ahmad Baroutaji (1), Arun Arjunan (1), Mark Stanford (1), John Robinson (1) and Abdul Ghani Olabi (2,3)
(1) School of Engineering, University of Wolverhampton, Telford Innovation Campus, TF2 9NT, UK
(2) Dept. of Sustainable and Renewable Energy Engineering, University of Sharjah, P.O. Box 27272, Sharjah, United Arab Emirates
(3) School of Engineering and Applied Science, Aston University, Birmingham B4 7ET, UK


ABSTRACT: Functionally graded thickness (FGT) is an innovative concept to create light-weight structures with better material distribution and promising energy absorption characteristics suitable for vehicle crashworthiness applications. Accordingly, this paper suggests innovative circular tubes with in-plane thickness gradient along their perimeter and assesses their crashworthiness behaviour under lateral loading. Three different designs of circular tubes with thickness gradient were considered in which the locations of maximum and minimum thicknesses are varied. Selective laser melting method of additive manufacturing was used to...
manufacture the different tubes. Two different bulk powders including titanium (Ti6Al4V) and aluminium (AlSi10Mg) were used in the manufacturing process. Quasi-static crush experiments were conducted on the laser melted tubes to investigate their crushing and energy absorption behaviour. The energy absorption characteristics of the different FGT tubes were calculated and compared against a uniform thickness design. The results revealed that the best crashworthiness metrics were offered by FGT titanium tube in which the maximum thickness regions were along the horizontal and vertical directions while the minimum thickness regions were at an angle of 45° with respect to the loading direction. The aforementioned tube was found to absorb 79% greater energy per unit mass than its uniform thickness counterpart. Finally, with the aid of numerical simulations and surrogate modelling techniques, multi-objective optimisation and parametric analysis were conducted on the best FGT tube. The influences of the geometrical parameters on the crashworthiness responses of the best FGT structure were explored and the optimal thickness gradient parameters were determined. The results reported in this paper provide valuable guidance on the design of FGT energy absorption tubes for lateral deformation.

References listed at the end of the paper:
2 A.A.A. Alghamdi, Collapsible impact energy absorbers: an overview, Thin-Walled Struct, 39 (2001), pp. 189-213, 10.1016/S0263-8231(00)00048-3
3 A.G. Olabi, E. Morris, M.S.J. Hashmi, Metallic tube type energy absorbers: A synopsis, Thin-Walled Struct, 45 (2007), pp. 706-726, 10.1016/j.tws.2007.05.003
5 A. Baroutaji, E. Morris, A.G. Olabi, Quasi-static response and multi-objective crashworthiness optimization of oblong tube under lateral loading, Thin-Walled Struct, 82 (2014), pp. 262-277, 10.1016/j.tws.2014.03.012
6 T. Tang, W. Zhang, H. Yin, H. Wang, Crushing analysis of thin-walled beams with various section geometries under lateral impact, Thin-Walled Struct, 102 (2016), pp. 43-57, 10.1016/j.tws.2016.01.017
7 Z. Li, H. Yang, X. Hu, J. Wei, Z. Han, Experimental study on the crush behavior and energy-absorption ability of circular magnesium thin-walled tubes and the comparison with aluminum tubes, Eng Struct, 164 (2018), pp. 1-13, 10.1016/J.ENGSTRUCT.2018.02.083
10 A. Baroutaji, M.D. Gilchrist, A.G. Olabi, Quasi-static, impact and energy absorption of internally nested tubes subjected to lateral loading, Thin-Walled Struct, 98 (2016), pp. 337-350, 10.1016/j.tws.2015.10.001
11 A. Baroutaji, A.G. Olabi, Lateral collapse of short-length sandwich tubes compressed by different indenters and exposed to external constraints, Materwiss Werksttech, 45 (2014), p. n/a-n/a, 10.1002/mawe.201400236
14 X. An, Y. Gao, J. Fang, G. Sun, Q. Li, Crashworthiness design for foam-filled thin-walled structures with functionally lateral graded thickness sheets, Thin-Walled Struct, 91 (2015), pp. 63-71, 10.1016/j.tws.2015.01.011
54 T. Tran, A. Baroutaji, Crashworthiness optimal design of multi-cell triangular tubes under axial and oblique impact loading, Eng Fail Anal, 93 (2018), pp. 241-256, 10.1016/j.engfailanal.2018.07.003

ABSTRACT: In this study, nonlinear finite element (NLFE) analysis is conducted to determine the maximum shear capacity (V(max)) of stiffened steel plate shear walls (SSPSW) with rectangular openings. Results of a wide range of parametric study are presented using developed response surface method (RSM), which quantified the effect of prominent input variables on the predicted shear capacity of SSPSW. The studied parameters, which evaluated by different aspect ratios of the infill plate (L/h), are thickness of the infill plate (t), yield stress of the steel used in the infill plate (F-sub-γ), and the ratio of opening area to the total area of the infill plate (A-sub-0/A-sub-p). RSM is utilized to propose equations to predict the maximum shear capacity of SSPSW with different rectangular opening ratios, which can assist in optimum designing of SSPSW. Results show that, RSM is an accurate method to predict the shear capacity of specimens. Furthermore, by having characteristics of the specimens, the optimum size of openings and thickness of the infill plate can be calculated to achieve the target V(max). Evaluating the results also indicated that shear capacity has linear relationship with variations of the steel infill plate thickness. Besides, by increasing in the thickness and aspect ratio of the infill plate, V(max) is strongly influenced by opening ratio.

References listed at the end of the paper:
3 S. Sabouri-Gholami, C.E. Ventura, M.H. Kharrazi, Shear analysis and design of ductile plate steel walls, J Struct Eng, 131 (2005), pp. 878-889
4 M. Bypour, M. Gholhaki, M. Kioumarsi, B. Kioumarsi, Nonlinear analysis to investigate effect of connection type on behavior of steel plate shear wall in RC frame, Eng Struct, 179 (2019), pp. 611-624
6 Y. Qi, Q. Gu, G. Sun, B. Zhao, Shear force demand on headed stud for the design of composite plate shear wall, Eng Struct, 148 (2017), pp. 780-792
10 T.M. Roberts, S. Sabouri-Gholami, Hysteric characteristics of unstiffened perforated steel plate shear panels, Thin Wall Struct, 14 (1992), pp. 139-151
11 D. Vian, Steel plate shear walls for seismic design and retrofit of building structures, State University of New York at Buffalo (2005)
15 M. Meghdadian, M. Ghaelhnoi Effects of the opening on the behavior of Composite Steel Plate Shear Wall (CSPSW), J Rehabilitation Civ Eng, 7 (2019), pp. 139-152
17 Bypour M, Kioumarsi M, Zucconi M., Effect of stiffeners on behavior of steel plate shear wall with rectangular openings. In: 17th international conference of numerical analysis and applied mathematics, Greece; 2019
18 E. Alavi, F. Nateghi, Experimental study on diagonally stiffened steel plate shear walls with central perforation, J Constr Steel Res, 89 (2013), pp. 9-20
https://doi.org/10.1016/j.engstruct.2020.111376

ABSTRACT: This paper presents analytical investigations on the free vibration and static bending of functionally graded graphene-reinforced nanocomposite (FG-GPLRC) spherical shells. The GPL nanofillers are dispersed into polymer matrix uniformly and un-uniformly in the thickness direction with a piece-wise type, and UD, FG-O, FG-X, FG-V and FG-A types of GPL distribution patterns are taken into account. The effective material properties of graphene-reinforced nanocomposites are estimated by using the modified Halpin-Tsai multi-scaled model and the rule of mixtures. Governing differential equations for free vibration and bending of the FG-GPLRC spherical shells are derived based on the three-dimensional elasticity theory with the aid of the state space method, and the layer-wise model is employed to obtain the analytical solutions. The validity of the present method is first examined, followed by the illustrative parametric studies to further scrutinize the free vibration and static bending behaviors of the FG-GPLRC spherical shells with the various reinforcement schemes, including the distribution pattern, the weight fraction, and geometric parameter of GPLs in details. References listed at the end of the paper:

12 C. Feng, S. Kitipornchai, J. Yang, Nonlinear bending of polymer nanocomposite beams reinforced with non-uniformly distributed graphene platelets (GPLs), Compos Part B: Eng, 110 (2017), pp. 132-140
13 C. Feng, S. Kitipornchai, J. Yang, Nonlinear free vibration of functionally graded polymer composite beams reinforced with graphene nanoplatelets (GPLs), Eng Struct, 140 (2017), pp. 110-119
14 M. Song, S. Kitipornchai, J. Yang, Free and forced vibrations of functionally graded polymer composite plates reinforced with graphene nanoplatelets, Compos Struct, 159 (2017), pp. 579-588
17 B. Yang, S. Kitipornchai, Y.F. Yang, J. Yang, 3D thermo-mechanical bending solution of functionally graded graphene reinforced circular and annular plates, Appl Math Model, 49 (2017), pp. 69-86
18 B. Yang, J. Yang, S. Kitipornchai, Thermoelastic analysis of functionally graded graphene reinforced rectangular plates based on 3D elasticity, Meccanica, 52 (2017), pp. 2275-2292
19 D. Liu, S. Kitipornchai, W. Chen, J. Yang, Three-dimensional buckling and free vibration analyses of initially stressed functionally graded graphene reinforced composite cylindrical shell, Compos Struct, 139 (2018), pp. 560-569
21 Y. Wang, C. Feng, Z. Zhao, F. Lu, J. Yang, Torsional buckling of graphene platelets (GPL) reinforced functionally graded cylindrical shell with cutout, Compos Struct, 197 (2018), pp. 72-79
22 Y. Wang, C. Feng, Z. Zhao, J. Yang, Eigenvalue buckling of functionally graded cylindrical shells reinforced with graphene platelets (GPL), Compos Struct, 202 (2018), pp. 38-46
23 Y. Wang, C. Feng, Z. Zhao, J. Yang, Buckling of graphene Platelet Reinforced Composite Cylindrical Shell with Cutout, Int J Struct Stab Dyn (2018;18.)
26 Y. Kiani, Buckling of functionally graded graphene reinforced conical shells under external pressure in thermal environment, Compos Part B: Eng, 156 (2019), pp. 128-137
31 A. Wang, H. Chen, W. Zhang, Nonlinear transient response of doubly curved shallow shells reinforced with graphene nanoplatelets subjected to blast loading considering thermal effects, Compos Struct, 225 (2019), Article 111063

ABSTRACT: The paper presents stress analysis in a circular axially symmetrical plated perforated plate comprising two layers, i.e. the base layer in the form of S355J2 steel and the applied layer in the form of titanium, freely supported and loaded normally to its surface. Calculations were carried out according to analytical relations and using finite element method in ANSYS program. The tested plate with a diameter of \( D = 300 \text{ mm} \) had holes on five circles. On the first outer circle the plate had holes \( d = 20.5 \text{ mm} \) in diameter, whereas on the inner circle the plate had holes \( d = 9.5 \text{ mm} \) in diameter. Experimental research was also carried out, and the results were used to verify the results obtained by the finite element method using the ANSYS program and derived by the analytical method.


ABSTRACT: A modified method is proposed for the consistent imperfection method, which introduces the shape of the first-order linear buckling mode of a spatial structure as the imperfection pattern to estimate the non-linear buckling load of an imperfect structure. By adjusting the magnitudes of the joint deflection component and the member deformation component, the imperfection pattern calculated by the modified method is shown to be more reasonable to represent the construction and fabrication errors in reality. It is also found that the imperfection pattern calculated by the first-order linear buckling mode may not be the most adverse one to the structure, and the non-linear buckling load of the imperfect structure is highly associated with the similarity between the imperfection pattern and the deformation of the structure, which is described by the Euclidean distance between the imperfection pattern and the incremental displacement vectors. Subsequently, a prediction method of the non-linear buckling load of an imperfect structure is proposed using machine learning techniques, including the artificial neural network and the support vector regression (SVR), which avoid the computation cost of multiple non-linear buckling analysis for imperfect structures. Finally, the performance of the prediction method is verified, and a simplified formula is given for the design of reticulated shells based on the SVR with the linear kernel.

References listed at the end of the paper:

3 Q. Wu, H. Wang, H. Qian, K. Han, F. Fan, Effect of insufficient screwing depth of bolt on mechanical behavior of bolt-ball joint and stability of single-layer reticulated shell, Eng Struct, 213 (2020), Article 110590
5 J.M.T. Thompson, G.W. Hunt, A general theory of elastic stability, John Wiley (1973)
ABSTRACT: Stirrup-confined concrete-filled square steel tubular (CFSST) columns with spiral stirrup alleviates the local buckling of square steel tube, thereby improving both ultimate bearing capacity and ductility. This paper presents an experimental study on compressive behavior of spiral stirrup reinforced concrete-filled square steel tubular (SSRCSST) columns. Twenty-nine axial compression specimens and eighteen eccentric compression specimens were tested for experimental investigation of the effects of the sample size, the concrete strength, the thickness of steel tube, the ratio of diameter to width, the spacing of spiral stirrup and the steel ratio. In addition, the effect of eccentricity ratio on the eccentric compression specimens was also investigated. The test results show that the spiral stirrup has excellent cooperation ability with square steel tube and concrete, can effectively improve the non-uniform confine of square steel tube and enhance the confine effect on concrete. Furthermore, decreasing the spacing of spiral stirrup can enhance the axial bearing capacity and ductility of SSRCSST columns, but has little effect on the eccentric bearing capacity. A composite model confined by square steel tube and spiral stirrup is established, the calculation formulas to estimate the bearing capacity of SSRCSST columns are developed and close correlations are found between the calculated results and the experimental results.

ABSTRACT: The paper adequately presents an analysis of thin-walled functionally graded straight and curved beams for general non-uniform polygonal cross-sections. In order to mathematically model a complex beam which property information in both material distribution and geometric continuity need to be collected from multiple patches through blade thickness and each cross-section, a higher-order approach has been adopted. Subsequently, the higher orders of warping, coupling distortion including bending, torsion as well as Poisson’s distortion were fully taken into account. The anisotropy of materials with its effects are then also included. Beam frame modal which each edge on a cross-section is generally considered as multi-separated beams has found to be extremely compatible that well captures all behaviors of the beam. As a result, the study allows a blended coupling of closed-section beam-shells on different curvatures. Various examples were conducted to illustrate the performance and accuracy also the computational efficiency of the method where several compared results coming from ABAQUS modeling.


ABSTRACT: This study develops a novel double-layer steel-lightweight high ductility cement composite (LHDCC)-steel sandwich composite panels with hybrid shear connectors. Two interventions are included compared to the traditional single-layer steel–concrete–steel panels: (1) material intervention: using ultra lightweight high ductility cement composite; and (2) structural intervention: using double layers to replace the single layer. The experimental program tests two full-scale single-layer sandwich panels and eight full-scale double-layer sandwich panels subjected to concentrated punching load. The specimens vary with different layer numbers, shear span-to-depth ratios, steel contribution ratios, types and spacing of shear connectors, and loading areas. The effects of these parameters on the load–displacement curve and failure mode of the composite sandwich panels are discussed in detail. Compared to the single-layer sandwich panels with comparable steel contribution ratio, the double-layer sandwich panels exhibit larger ultimate resistance and residual resistance. The punching cone model is established to illustrate the failure mechanisms of the double-layer sandwich panels, the failure sequence of which follows: (1) punching shear failure of concrete; (2) punching shear fracture of top plate; and (3) punching shear fracture of middle plate. Based on corresponding failure mechanisms, this study develops analytical models, taking into account of the above parameters, to evaluate the ultimate resistance of the composite panels. The developed models provide close predictions of each peak resistance of the single- and double-layer sandwich panels, which provides reference for the design of multilayer SCS composite panels.


ABSTRACT: The concrete confinement induced by the steel tube of a concrete-filled steel tubular (CFST) column depends on its cross-sectional shape. The mechanism of confinement in octagonal CFST columns differs considerably from that in circular or square CFST columns. It is therefore important to ascertain the confinement effect in octagonal CFST columns to accurately quantify their behavior. In this paper, a numerical modeling method employing the theory of fiber analysis is presented that can simulate the axial behavior of short octagonal CFST columns that are loaded axially to failure. New constitutive laws of concrete including lateral confining stress model and the residual strength factor for compressive concrete in CFST octagonal columns are developed by interpreting the available test data. The concrete material model is implemented in the computational procedure of nonlinear analysis. The accuracy of various models of lateral confining stresses including the proposed one in this paper is evaluated against test data. The behavior of octagonal CFST stub
columns including salient parameters is examined by using the computer program developed. A design equation is suggested for estimating the capacities of octagonal CFST stub columns considering confinement effects. The codified design methods in several international standards for circular CFST columns are evaluated against the test results to investigate their applicability to octagonal CFST columns. The developed material models and computational and design methods are shown to yield computations which are compared well with experimental results of octagonal CFST columns. The current design codes considerably underestimate or overestimate the strengths of octagonal CFST columns.

References listed at the end of the paper:

15. W. Xu, L.H. Han, W. Li, Performance of hexagonal CFST members under axial compression and bending, J Constr Steel Res, 123 (2016), pp. 162-175
ABSTRACT: Experimental work on steel H-section fully encased by high strength concrete showed the occurrence of premature failure due to concrete cover spalling. This failure mode limits the utilization of full material strength and hence impedes the attainment of anticipated load-carrying capacity. This paper proposes an analytical model to predict the full range axial load-displacement behaviour of concrete encased steel composite section made from concrete grade up to C130 and steel section grade up to S690. The analytical model captures the compression behaviour of concrete encased steel composite section at the constitutive level including premature cover spalling, concrete confinement from stirrups and steel section. Concrete fracture energy is used to estimate the cover spalling strain, and a confinement model is proposed to evaluate the confining pressure provided by the steel section. Good agreement is observed between the analytical predictions and test results in terms of initial stiffness, peak load, residual strength, and the full range of load-displacement response. Based on the findings, recommendations are put forward for practical design of high strength concrete encased steel composite columns.
ABSTRACT: A circular concrete-filled double steel tubular column (CFDST) with a square hollow section (SHS) as an inner tube is introduced as a new form of a composite column in the paper. A series of axial compression tests that are carried out on this new type of composite column is reported in this study. Three-dimensional models based on the finite element (FE) program ABAQUS are also developed for such columns employing a modified confined concrete constitutive model for the core concrete. The accuracy of the model is verified by comparing the FE model with the experimental results. The effects of various parameters on the load-axial strain response of CFDST short columns are studied by using the validated FE model. The suggested formulas based on the confined concrete model for calculating the bearing capacity of CFDST short columns are proposed.


ABSTRACT: In this paper, strength and buckling behavior analysis of a ring-stiffened cylindrical shell for the sightseeing submersible subjected to mechanical and thermal loads are studied. Based on the Donnell’s assumption and classical shell theory, the governing equations of strength analysis for the ring-stiffened cylindrical shell are established, and the problems are solved by finite difference method (FDM) and Newmark-\(\beta\) method. Meanwhile, the governing equations of buckling behavior for the ring-stiffened cylindrical shell are set up in view of the energy method, which are resolved by the Ritz method. The research shows that the external load has the most significant influence on the strength of ring-stiffened cylindrical shell. Moreover, compared with other factors, the external load has a great influence on its strength, and the effect of shell thickness on the buckling load of ring-stiffened cylindrical shell is most obvious. The research work can provide theoretical basis for the design and optimizing of underwater equipment such as tourist submarines.


ABSTRACT: A concrete-filled double-skin steel tubular (CFDST) column incorporating an outer stainless-steel tube and a high-strength inner carbon steel tube exhibits high corrosion resistance and load-carrying capacity. This paper presents the axisymmetric analysis technique for simulating the structural response of short circular CFDST columns loaded concentrically. The double-skin confinement mechanism for modeling the sandwiched concrete is explored and implemented in the analysis. The significant strain hardening response of stainless steel in axial compression is recognized in the analysis technique. The benefits of axisymmetric analysis over the full three-dimensional simulation are highlighted for the analysis of a member which is symmetric about its rotation vertical axis. The comparison of axisymmetric analysis results is made with the experimental results given in the previous independent studies. The parametric investigation on the structural response of CFDST columns is performed by means of using the verified axisymmetric model. The analysis results indicate that the inner tube diameter-to-thickness ratio less than 40 should be selected to prevent its local buckling from occurring and the inner tube should have yield stress higher than the 0.2% proof strength of the outer stainless steel tube. The outer stainless-steel with proof stress of 195 MPa should be filled with high-strength concrete of 120 MPa to ensure the strain compatibility. Liang’s design model closely estimates the ultimate axial strengths of the CFDST columns composed of an outer stainless-steel tube and a high-strength inner carbon steel tube.


ABSTRACT: The 3D deployable frames studied in this work are structures composed of elastic beam elements connected by complex joints. During transformation a controlled snap-through allows the instantaneous stabilization of the structure in an open and in a closed, compact configuration. The mechanics of the transformation is highly nonlinear, since it relies on finite rotations of the structural elements. It is also strongly influenced by geometrical features required for a manufacturing-ready design, such as the finite size of structural elements and sufficient spacing between the beams. These features are generally disregarded in the
usual wireframe-based design, but they are taken into account in this work by applying a tailor-made
corotational 3D joint finite element, developed to incorporate naturally finite joint size, finite nonlinear joint
stiffness and friction effects. The formulation of the proposed joint FE is presented and the performance of the
numerical implementation is verified using computational benchmarks. The joint FE is then applied to the
numerical investigation of the transformation response of bistable deployable structures from a single module
case to large, complex structures. Among other findings, it is shown that the incorporation of finite joint size
and beam spacing in the numerical model leads to a different snap-through mechanism that significantly
reduces the peak force required for transformation, which could be a basis for future design strategies.
Additionally the performance of structures applying the bistable structural pattern on the whole structure or
following an entirely modular design (interconnected single modules) is also compared, as a function of the
structural size.

Engineering Structures, Vol. 227, Article 111387 15 January 2021,

More papers published in the journal, Composite Structures (2019 and on):
http://www.sciencedirect.com/science/journal/02638223

plates and profiles under low-velocity impact load”, Composite Structures, Vol. 207, pp 1-12, 1 January 2019,
https://doi.org/10.1016/j.compstruct.2018.09.005

ABSTRACT: The effect of impact load with low velocity in thin-walled plates and profiles has been
investigated. The paper deals with the relation between damage propagation, size and shape as a function of
boundary conditions, layer arrangements and impact energy. The structures under consideration were made of
eight-layer Glass Fiber Reinforced Polymer (GFRP) laminate with a quasi-isotropic, quasi-orthotropic and
angle ply arrangement of layers. The standardised plates predefined to CAI tests and channel section profiles
have been subjected to impact load. Based on the performed tests, the impact characteristics have been obtained
and compared with the theoretical model (one degree of freedom mass-spring system). Further, despite it not
being mentioned in the ASTM 7136 standard, characteristic curves were identified. It was noted that the
impacts introducing matrix damages and the partial fracture of the fibres significantly change the course of the
Force-Time histories, particularly after the maximum impact force is reached.

References listed at the end of the paper:
1 Standard Tests for Toughened Resin Composites, NASA Reference Publication 1092, ACEE Composites Project Office, Langley
Research Center (Hampton, Va.), 1982.
2 Advanced Composite Compression Tests, Boeing Specification Support Standard BSS 7260, Rev. C, The Boeing Co. (Seattle,
3 V.V. Silberschmidt, Dynamic Deformation, Damage and Fracture in Composite Materials and Structures, Woodhead Publishing,
Great Britain (2016)
5 X.C. Sun, S.R. Hallett, Barely visible impact damage in scaled composite laminates: Experiments and numerical simulations, Int J
6 E.V. González, P. Mainí, P.P. Camanho, C.S. Lopes, N. Blanco, Effects of ply clustering in laminated composite plates under low-
7 A.A. Nassr, T. Yagi, T. Maruyama, G. Hayashi, Damage and wave propagation characteristics in thin GFRP panels subjected to
impact by steel balls at relatively low-velocities, Int J Impact Eng, 111 (2018), pp. 21-33
8 W.J. Cantwell, Geometrical effects in the low velocity impact response of GFRP, Compos Sci Technol, 67 (2007), pp. 1900-1908
9 A. Wagih, P. Mainí, N. Blanco, J. Costa, A quasi-static indentation test to elucidate the sequence of damage events in low velocity
impacts on composite laminates, Compos Part A, 82 (2016), pp. 180-189
10 D.J. Bull, S.M. Spearling, I. Sinclair, Investigation of the response to low velocity impact and quasi-static indentation loading of
11 H. Abdulhamid, Ch. Bouvet, L. Michel, J. Aboissière, C. Minot, Influence of internally dropped-off plies on the impact damage of
asymmetrically tapered laminated CFRP, Compos Part A, 68 (2015), pp. 110-120
12 T.W. Shyr, Y.-H. Pan, Impact resistance and damage characteristics of composite laminates, Compos Struct, 62 (2003), pp. 193-203
13 E. Panettieri, D. Fanteria, M. Montemurro, C. Froustey, Low-velocity impact tests on carbon/epoxy composite laminates: a
benchmark study, Compos B, 107 (2016), pp. 9-21
ABSTRACT: Predicting the honeycomb sandwich’s response to impact loading is a major challenge in the aeronautical industry. Several papers demonstrated the possible use of non-linear springs to model Nomex’s impact behavior. On the other hand, the authors show that the lack of transverse shear consideration constitutes a real limitation. The aim of this study is to overcome this limitation by introducing a compression/shear coupling to take into account the transverse shear. In this approach, the modelling of a low velocity impact test is performed on a sandwich composite with CFRP skins and Nomex® honeycomb. Composite skins are modeled as an elasto-plastic-damage material using a user field subroutine (Abaqus®). The Nomex core is modeled with non-linear springs integrating a compression/shear coupling behavior. Then, the sandwich response under low speed impact is realized and compared with experimental data leading to a good correlation.

References listed at the end of the paper:


References listed at the end of the paper:


direction are taken into consideration. Unlike the classical analytical treatment which relies on trial functions, the

---

**ABSTRACT:** Exact solutions for thermo-electro-mechanical free vibration of a piezoelectric fiber-reinforced composite cylindrical shells, Composite Structures, Vol. 207, pp 292-303, 1 January 2019,

https://doi.org/10.1016/j.compstruct.2018.08.076

Unlike the classical analytical treatment which relies on trial functions, the
governing equations in the Hamiltonian form can be directly solved through a rigorous way. Free vibration of PFRC cylindrical shells is reduced into a symplectic eigenproblem which has five kinds of explicit eigenfunctions. Analytical frequency equations and vibration mode shapes are derived simultaneously. In numerical examples, a comparison study is performed to verify the validity of the proposed solution. A detailed discussion is presented to reveal the effects of key influencing factors on the expression of eigenfunctions.

Some new results which can be used as benchmarks for the approximate approach are given also.

References listed at the end of the paper:
4 A. Kumar, D. Chakraborty, Effective properties of thermo-electro-mechanically coupled piezoelectric fiber reinforced composites, Mater Des, 30 (2009), pp. 1216-1222
5 P. Tan, L.Y. Tong, D.C. Sun, Dynamic characteristics of a beam system with active piezoelectric fiber reinforced composite layers, Compos Pt B-Eng, 33 (2002), pp. 545-555
6 M.C. Ray, N. Mallik, Active control of laminated composite beams using a piezoelectric fiber reinforced composite layer, Smart Mater Struct, 13 (2004), p. 146
16 M.C. Ray, J. Shivakumar, Active constrained layer damping of geometrically nonlinear transientsvibrations of composite plates using piezoelectric fiber-reinforced composite, Thin-Walled Struct, 47 (2009), pp. 178-189
17 H.S. Shen, A comparison of buckling and postbuckling behavior of FGM plates with piezoelectric fiber reinforced composite actuators, Compos Struct, 91 (2009), pp. 375-384
18 X.K. Xia, H.S. Shen, Nonlinear vibration and dynamic response of FGM plates with piezoelectric fiber reinforced composite actuators, Compos Struct, 90 (2009), pp. 254-262
29 H.S. Shen, D.Q. Yang, Nonlinear vibration of anisotropic laminated cylindrical shells with piezoelectric fiber reinforced composite actuators, Ocean Eng, 80 (2014), pp. 36-49
33 C.W. Lim, X.S. Xu, Symplectic elasticity: theory and applications, Appl Mech Rev, 63 (2010), Article 050802
40 J.B. Sun, X.S. Xu, C.W. Lim, Accurate symplectic space solutions for thermal buckling of functionally graded cylindrical shells, Compos Pt B-Eng, 55 (2013), pp. 208-214
41 J.B. Sun, X.S. Xu, C.W. Lim, Buckling of functionally graded cylindrical shells under combined thermal and compressive loads, J Therm Stresses, 37 (2014), pp. 340-362
46 B. Liu, Y.F. Xing, M.S. Qatu, A.J.M. Ferreira, Exact characteristic equations for free vibrations of thin orthotropic circular cylindrical shells, Compos Struct, 94 (2012), pp. 484-493
50 M. Pietrzakowski, Piezoelectric control of composite plate vibration: effect of electric potential distribution, Comput Struct, 86 (2008), pp. 948-954
53 K. Dong, X. Wang, Wave propagation characteristics in piezoelectric cylindrical laminated shells under large deformation, Compos Struct, 77 (2007), pp. 171-181


ABSTRACT: It is generally acknowledged that the indentation resistance or hardness of auxetic materials is higher than that of their conventional counterparts under elastic deformation. However, this property of the auxetic material may not always be superior to that of the non-auxetic materials when the deformation is relatively large with plasticity considered. In this study, we come up with an index to quantitatively depict the indentation resistance of the hexagonal honeycombs under large deformation. The indentation resistance of both the auxetic and non-auxetic hexagonal honeycombs is compared and discussed. Results show that in the premise of honeycombs possessing the same relative density, the indentation resistance of auxetic hexagonal honeycombs is not always higher than that of the non-auxetic honeycombs. This phenomenon is verified by the numerical simulations. Further analysis shows that there is a critical value of the absolute value of Poisson’s ratio, which is determined by the cell-wall length ratio, to estimate the higher indentation resistance between the
auxetic and non-auxetic hexagonal honeycombs. The influence of indentation velocity is also analyzed based on numerical simulations. This present work is supposed to shed light on the design and evaluation of the indentation resistance for both auxetic and conventional honeycombs.

References listed at the end of the paper:
1 R. Lakes, Foam structures with a negative Poisson’s ratio, Science (80-), 235 (1987), pp. 1038-1040, 10.1126/science.235.4792.1038
5 W. Miller, C.W. Smith, K.E. Evans, Honeycomb cores with enhanced buckling strength, Compos Struct, 93 (2011), pp. 1072-1077, 10.1016/j.composites.2010.09.021
7 J. Ju, J.D. Summers, Compliant hexagonal periodic lattice structures having both high shear strength and high shear strain, Mater Des, 32 (2011), pp. 512-524, 10.1016/j.matdes.2010.08.029
16 A. Alderson, A triumph of lateral thought, Chem Ind, 10 (1999), pp. 384-391
18 R.S. Lakes, K. Elms, Indentability of conventional and negative Poisson’s ratio foams, J Compos Mater, 27 (1993), pp. 1193-1202, 10.1177/002199839302701203
20 N. Chan, K.E. Evans, Indentation resilience of conventional and auxetic foams, J Cell Plast, 34 (1998), pp. 231-260, 10.1002/1521-9559(9803)00304
29 W. Liu, N. Wang, T. Luo, Z. Lin, In-plane dynamic crushing of re-entrant auxetic cellular structure, Mater Des, 100 (2016), pp. 84-91, 10.1016/j.matdes.2016.03.086
30 D. Li, J. Yin, L. Dong, R.S. Lakes, Strong re-entrant cellular structures with negative Poisson’s ratio, J Mater Sci, 53 (2018), pp. 3493-3499, 10.1007/s10853-017-1809-8

ABSTRACT: The porous materials become a new class of advanced engineering material due to their excellent advantage such as low specific weight, efficient capacity of energy dissipation, reduced thermal and electrical conductivity, enhanced recyclability and machinability. In this study, the nonlinear vibration of piezoelectric sandwich nanoplates with functionally graded (FG) porous core under electrical load is presented. The piezoelectric effect, flexoelectric effect and von Karman type large deformation are simultaneously taken into account. Results show that the piezoelectric and flexoelectric effects of the material reduce the vibration frequency of the sandwich nanoplate even there is no applied voltage on the piezoelectric layer. The natural frequency of the sandwich structure with porous core can be adjusted by controlling the porosity distribution and porous coefficients of the porous material, and the applied voltages on the piezoelectric layer.

References listed at the end of the paper:
5 T.R.C. Chuaqui, C.M.C. Roque, Analysis of functionally graded piezoelectric Timoshenko smart beams using a multiquadric radial basis function method, Compos Struct, 176 (2017), pp. 640-653, 10.1016/j.compstruct.2017.05.062
11 D. Chen, J. Yang, S. Kitipornchai, Elastic buckling and static bending of shear deformable functionally graded porous beam, Compos Struct, 133 (2015), pp. 54-61, 10.1016/j.compstruct.2015.07.052
12 D. Chen, S. Kitipornchai, J. Yang, Nonlinear free vibration of shear deformable sandwich beam with a functionally graded porous core, Thin-Walled Struct, 107 (2016), pp. 39-48, 10.1016/j.tws.2015.06.025
13 A.S. Rezaei, A.R. Saidi, Exact solution for free vibration of thick rectangular plates made of porous materials, Compos Struct, 134 (2015), pp. 1051-1060, 10.1016/j.compstruct.2015.08.125
14 A.C. Eringen, Nonlocal polar elastic continua, Int J Eng Sci, 10 (1972), pp. 1-16
21 A.G. Arani, M.H. Zamani, Nonlocal free vibration analysis of FG-porous shear and normal deformable sandwich nanoplate with piezoelectric face sheets resting on silica aerogel foundation, Arab J Sci Eng, 43 (2018), pp. 4675-4688, 10.1007/s13369-017-3035-8
33 Z.D. Zhou, C.P. Yang, Y.X. Su, R. Huang, X.L. Lin, Electromechanical coupling in piezoelectric nanobeams due to the flexoelectric effect, Smart Mater Struct, 26 (2017), Article 095025, 10.1088/1361-665X/aa7936
35 M.S. Majdoub, P. Sharma, T. Cagin, Enhanced size-dependent piezoelectricity and elasticity in nanostructures due to the flexoelectric effect, Phys Rev B, 77 (2008), Article 125424, 10.1103/PhysRevB.77.125424
44 J.N. Reddy, N.D. Phan, Stability and vibration of isotropic, orthotropic and laminated plates according to a higher-order shear deformation theory, J Sound Vib, 98 (1985), pp. 157-170, 10.1016/0022-460X(85)90383-9


ABSTRACT: The results of geometrically nonlinear analyses on 43 built-up Pultruded Fibre-Reinforced Polymer (PFRP) columns with closely spaced chords and intermittent interconnections are presented. A comparison between columns with the end sections entirely loaded and columns loaded at the end battens only is reported, showing no appreciable difference in the P-δ response. The effects due to variations of column
length and battens spacing are then investigated. It is found that stocky columns with small battens spacing attain pre-buckling failure at the web-flange junctions of the chords for loads approximately equal to 70% of the crushing load. Slender columns fail by global buckling, whereas intermediate-slenedness columns may experience interaction between local and global buckling. A design method is finally proposed.

References listed at the end of the paper:
1 T. Keller, Recent all-composite and hybrid fibre-reinforced polymer bridges and buildings, Prog Struct Mat Eng, 3 (2001), pp. 132-140
4 Y. Bai, T. Keller, C. Wu, Pre-buckling and post-buckling failure at the web-flange junction of pultruded GFRP beams, Mater Struct, 46 (2013), pp. 1143-1154
5 J.A. Sobrino, M.D.G. Pulido, Towards advanced composite material footbridges, Structural Engineering International, 12 (2) (2002), pp. 84-86
8 S. Russo, Experimental and finite element analysis of a very large pultruded FRP structure subjected to free vibration, Compos Struct, 94 (3) (2012), pp. 1097-1105
12 G. Boscato, C. Casalegno, S. Russo, Performance of built-up columns made by pultruded FRP material, Compos Struct, 121 (2015), pp. 46-63
13 S. Russo, Bucklings interactions in columns made by built-up thin, open, pultruded FRP shapes, J Reinf Plast Compos, 34 (12) (2015), pp. 972-988
14 S. Russo, Shear and local effects in All-FRP bolted built-up columns, Adv Struct Eng, 18 (8) (2015), pp. 1227-1240
17 American Society of Civil Engineers. Pre-standard for load & resistance factor design of pultruded FRP structures, 2012.
19 L.C. Bank, J. Yin, Failure of web-flange junction in postbuckled pultruded I-beams, J Compos Constr, 3 (4) (1999), pp. 177-184
22 F. Laudiero, F. Minghini, N. Tullini, Buckling and postbuckling finite element analysis of pultruded FRP profiles under pure compression, J Compos Constr, 18 (1) (2014), p. 04013026
23 F. Laudiero, F. Minghini, N. Tullini, Postbuckling failure analysis of pultruded FRP beams under uniform bending, Compos B Eng, 54 (2013), pp. 431-438
24 F. Bleich, Buckling Strength of Metal Structures, McGraw-Hill Book Company, New York (1952)
25 E.J. Barbero, J. Tomblin, A phenomenological design equation for FRP columns with interaction between local and global buckling, Thin-Walled Struct, 18 (2) (1994), pp. 117-131
26 A. Zureick, D. Scott, Short-term behavior and design of fiber-reinforced polymeric slender members under axial compression, J Compos Constr, 1 (4) (1997), pp. 140-149

ABSTRACT: A three-dimensional element-free Galerkin method (EFG) based on the Strain-Rotation (S-R) decomposition theorem, named 3D-SR-EFG, is developed to investigate the nonlinear bending behavior of functionally graded carbon nanotube reinforced composite (FG-CNTRC) plates. Due to its overcoming the deficiencies of classic finite deformation theories, S-R decomposition theorem can provide a reliable theoretical support for the geometrically nonlinear simulation. The incremental variational formulation based on the S-R decomposition theorem for three-dimensional static large deformation problems is derived from the updated co-moving coordinate formulation and principle of potential energy rate. Global weak-form EFG is adopted to obtain the discrete form of the formulation. Convergence and comparison studies are conducted to validate the numerical stability and accuracy of the proposed 3D-SR-EFG. The influences of volume fraction and distributions of CNTs, plate’s aspect ratio and width-to-thickness ratio, boundary conditions on the nonlinear bending response of the CNTRC plates are numerically analyzed and discussed in parametric studies. Results demonstrate that the 3D-SR-EFG can effectively predict the nonlinear bending behavior of the CNTRC plates. This work also further extends the applications of the S-R decomposition theorem.


ABSTRACT: This paper applied the modified Fourier series method to investigate the sound-vibration characteristics by establishing a composite laminated thin sector plate-cavity coupled model for the first time based on the classical plate theory (CPT) and Rayleigh-Ritz energy technique. The coupled system consists of an annular sector or circular sector plate backed by an acoustic cavity filled with air or water. Ignoring the influence of boundary conditions, displacements admissible functions of laminated sector plate and sound pressure admissible functions of cavity can be set up as a Fourier series superposition, whose composition are the superposition of Fourier cosine series and supplementary functions. The addition of these supplementary polynomials can effectively eliminate the discontinuity or jump phenomenon on the boundary. The correctness of the established analytical model has been validated by being compared with the results achieved by the finite element method (FEM). On this basis, the coupling mechanism of the weakly coupled system and the strongly coupled system are discussed in detail. In addition, some new results and discussions are given, including the cavity depth, plate thickness, anisotropic degree, varying boundary conditions and so on, which could provide reference for future research.

ABSTRACT: The free vibration of a deploying laminated beam in hygrothermal environment with a constant axial velocity is studied. The model of this system is given within the framework of the Euler-Bernoulli beam theory and von Karman nonlinear strain theory. The nonlinear dynamic equilibrium equation with generalized boundary conditions is established based on the Hamilton’s principle with considering the combined effects of the axial motion, transverse vibration and hygrothermal environment. Based on the Galerkin method, a set of ordinary differential equations is obtained. The numerical results of the discretization equation are performed adopting the eigenvalue method and Newmark method. In addition, the dynamic stability is discussed, and extensive numerical calculations are performed to illustrate the effects of varying extension velocities, temperature, humidity and ply angles on frequencies.

ABSTRACT: Bistability in doubly curved and twisted (helical) composite slit tubes is investigated for the first time. This work establishes a natural extension in this area which has been focused on straight and until more recently, doubly curved (toroidal) tubes with positive Gaussian curvature. The model developed introduces longitudinal and transverse curvature, and twist into strips of laminated composite material. The composite is engineered to be bistable and the second stable state determined via strain energy minimisation using the Rayleigh-Ritz method. The strain energy is formulated as a function of curvature strains, longitudinal stretching and a variable middle ply fibre angle of the laminate. The second stable state forms a compact and untwisted cylindrical coil with the latter engineered by tailoring the middle ply fibre angle. A new manufacturing process capable of producing helically curved tubes using glass-fibre/polypropylene-matrix composite is presented to verify the hypothesis of this work. An untwisted coil enables the efficient stowage and deployment of new forms of bistable composite tube which adhere to similar form factors as straight and toroidal ones. By embedding electrical conductors, helical bistable composites enable new lightweight, compact and multifunctional structures for communication and sensing applications.

References listed at the end of the paper:
This work addresses the design optimization of ceramic–metal composite plates with functionally graded material properties, varying through the thickness direction, subjected to thermo-mechanical loadings. Constrained multiobjective optimization is performed for mass minimization and material cost minimization as well as the minimization of stress failure criteria or maximization of natural frequency. The optimization problems are constrained by stress based failure criteria among other structural response constraints and manufacturing limitations. The design variables are the index of the power-law distribution in the metal-ceramic graded material and the thicknesses of the graded material and, eventually, also the metal and ceramic faces. A finite element plate model based on a higher order shear deformation theory, accounting for the transverse shear and transverse normal deformations and considering the temperature dependency of the material properties, is applied for the optimal design of ceramic-metal functionally graded plates. The optimization problems are solved with two direct search derivative-free algorithms: GLÖDS (Global and Local Optimization using Direct Search) and DMS (Direct MultiSearch). A few multiobjective optimization problems are studied and the results are presented for benchmarking purposes.
ABSTRACT: Cylindrical lattice structures are types of lightweight structures and can utilize the orthotropy of fiber-reinforced composite materials. Maximization of the buckling loads is important because they dominate the strength of the structures. On the basis of the fact that a hyperboloidal shape deviation increases the buckling loads of cylindrical homogeneous shells, the changes in the buckling loads of cylindrical lattice structures with a hyperboloidal shape deviation are discussed. Further, the buckling loads of both conventional cylindrical lattice structures and shape-deviated hyperboloidal lattice structures with respect to the compressive, bending, and torsional loads are calculated using a finite element method. The results show that the shape deviation decreases the buckling loads, while the change in mass is negligible. The effects of the shape deviation on the buckling loads differ between homogeneous shell structures and lattice structures.

References listed at the end of the paper:

1. V. Vasiliev, A.F. Razin, Anisogrid composite lattice structures for spacecraft and aircraft application, Compos Struct, 76 (1–2) (2006), pp. 182-189
2. V. V. Vasiliev, V. A. Barynin, A. F. Razin, Anisogrid composite lattice structures – Development and aerospace applications, Compos Struct, 94 (3) (2012), pp. 1117-1127
6. A. V. Lopatin, E. V. Morozov, A. V. Shatov, Bending of the composite lattice cylindrical shell with the midspan rigid disk loaded by transverse inertia forces, Compos Struct, 150 (2016), pp. 181-190
8. E. V. Morozov, A. V. Lopatin, V. A. Nesterov, Buckling analysis and design of anisogrid composite lattice conical shells, Compos Struct, 93 (12) (2011), pp. 3150-3162
12. G. Totaro, Local buckling modelling of isogrid and anisogrid lattice cylindrical shells with hexagonal cells, Compos Struct, 95 (2013), pp. 403-410
17. G. Totaro, F. De Nicola, Recent advances on design and manufacturing of composite anisogrid structures for space launchers, Acta Astronaut, 81 (2) (2012), pp. 570-577


ABSTRACT: First time, an analytical three-dimensional elasticity solution is proposed for bending analysis of composite laminated cylindrical shell panels having arbitrarily end-support conditions which were unavailable hitherto. Governing partial differential equations are obtained in terms of displacements and stresses by employing Reissner mixed variational principle in the cylindrical coordinate system. Further employing extended Kantorovich method, governing partial differential equations are reduced to sets of non–homogeneous first order ordinary differential equations (ODEs). The set of ODEs with variable coefficients (along radial direction) is ingeniously solved through a new modified power series method whereas the set with constant coefficients (along circumferential direction) is solved using Pagano’s approach. After thorough validation, some new benchmark results are presented for single layer and multilayered laminated composites under
various boundary conditions. This development will help to revisit/develop solutions for many classical problems of arbitrarily supported shell structures.

References listed at the end of the paper:
7 T. Kant, A critical review and some results of recently developed refined theories of fiber-reinforced laminated composites and sandwiches, Compos Struct, 23 (4) (1993), pp. 293-312
10 C.P. Wu, K.H. Chiu, Y.M. Wang, A review on the three-dimensional analytical approaches of multilayered and functionally graded piezoelectric plates and shells, Compat Mater Continua, 8 (2) (2008), pp. 93-132
13 H.T. Thai, S.E. Kim, A review of theories for the modeling and analysis of functionally graded plates and shells, Compos Struct, 128 (2015), pp. 70-86
14 C.P. Wu Liu YC., A review of semi-analytical numerical methods for laminated composite and multilayered functionally graded elastic/piezoelectric plates and shells, Compos Struct, 147 (2016), pp. 1-5
17 T.K. Varadan, K. Bhaskar, Bending of laminated orthotropic cylindrical shells—an elasticity approach, Compos Struct, 17 (2) (1991), pp. 141-156
32 E. Asadi, M.S. Qatu, Static analysis of thick laminated shells with different boundary conditions using GDQ, Thin Wall Struct, 51 (2012), pp. 76-81
33 S. Maleki, M. Tahani, A. Andakhshideh, Static and transient analysis of laminated cylindrical shell panels with various boundary conditions and general lay-ups, ZAMM-Z Angew Math Me, 92 (2) (2012), pp. 124-140
The effect of different types of load, span to thickness ratio, grading index on the response is studied. Some new methods have been proposed for the analysis of Functionally Graded Material (FGM) plate. A Governing differential equation (GDE) of the FGM plate is developed using energy principle. Wendland radial basis function (RBF) based meshfree method is implemented for discretizing the GDE. A MATLAB code is developed to obtain the desired results. The normalized deflection and stresses are obtained and compared with other published results.


ABSTRACT: A new dynamic model based on the shell theory is presented to investigate the vibration behavior of a rotating composite laminated blade with a pre-twisted angle. The effects of the Coriolis and centrifugal forces due to the rotation motion of the blade are considered in the formulation. Based on the Rayleigh-Ritz method and continuous algebraic polynomial functions satisfying the boundary conditions of a cantilever, the natural frequencies and mode shapes of a rotating pre-twisted blade are obtained. The convergence analysis is performed and the accuracy of the proposed model is verified by comparing the non-dimensional frequencies obtained by the present method with those in literature. The frequency loci veering and crossing phenomena along with the corresponding mode shape variations are presented and discussed in detail. A comprehensive parameter investigation of the effects of aspect ratio, pre-twisted angle, stagger angle, rotation velocity and hub radius on variations of the modal characteristics of the blade is conducted. It is demonstrated through the results of this paper that the developed model is effective to evaluate the dynamic behavior of rotating pre-twisted blades, which would be useful for improvement in design and optimization of the material and geometry dimension of the blades.


ABSTRACT: Two new higher order transverse shear deformation theories (NHSDTs) with five variables have been proposed for the analysis of Functionally Graded Material (FGM) plate. A Governing differential equation (GDE) of the FGM plate is developed using energy principle. Wendland radial basic function (RBF) based meshfree method is implemented for discretizing the GDE. A MATLAB code is developed to obtain the desired results. The normalized deflection and stresses are obtained and compared with other published results. The effects of different types of load, span to thickness ratio, grading index on the response are studied. Some new results for patch loading are also obtained.

ABSTRACT: This paper presents a multi-level aeroelastic tailoring framework for the optimisation of composite aircraft wings. The framework is capable of structural sizing and produces detailed composite ply configurations through robust and reliability-based design optimisation, and is demonstrated on a representative regional jet airliner finite element wing box model. The optimisation procedure is divided into two levels. The first level optimises the wing structure for minimum weight subject to multiple constraints including strain, buckling, aeroelastic stability and gust response. These first level solutions are then fed into the second level to be further optimised for robustness or reliability by considering uncertainties in material properties at ply level. Both the principles of robust and reliability-based design optimisation can also be used in combination to ensure a balance between the robustness and reliability of the structural performance. In order to keep computations to an acceptable cost, the second level optimisation employs the Polynomial Chaos Expansion method to approximate the effect of probabilistic uncertainty on structural performance. In comparison to the original benchmark wing, the framework produces an overall weight reduction of 32.1%, despite a 1.5% increase from the first to the second level optimisation that accounts for stochastic design variations.


ABSTRACT: Wrinkling is one of the main flaws that can appear during forming processes of textile composite reinforcements. When the forming is carried out on a multi-layered fabric the wrinkle development is strongly increased if the plies have different orientations. This phenomenon has been observed in previous experimental studies and is confirmed by a set of forming tests on multi-layered reinforcements. Beyond these experiments, a multilayered fabric forming process numerical simulation based on stress-resultant textile shell elements is presented. It is shown that this simulation is able to accurately describe multi-layered fabric forming processes and in particular the development of wrinkles. In the case of multi-layered reinforcements where the neighboring plies are oriented differently, the numerical simulations shows the development of zones where the fibers in one direction are subjected to compression which gives rise to wrinkles. The analysis of the forming for different friction coefficients confirms the major role of the friction between the plies in wrinkling. The influence of the pressure imposed by the blank holder has also been studied.


ABSTRACT: As a first endeavor, the full layer-wise method is presented for elasto-up to yielding analysis of a functionally graded cylindrical panel with different boundary conditions and under steady state thermal and nonuniform mechanical loads. Static load and thermal field are applied in large and nonuniform scales which are acted on the inner and outer layers of the panel. Treca and von Mises yield criteria are compared together and with TTO (Tamura–Tomota–Özawa) model to find the yielded regions in the panel. The results of the used method are compared with a simulation using the commercial ABAQUS. The stress and temperature fields were expressed on the basis of an analytical solution using trigonometric terms for the full simply supported boundary conditions and simply-free boundary conditions and the derived results are presented graphically. Yielded areas vary by changing the geometry of boundary conditions and are closer to the supports. Both von Mises and Treca criteria predicted same yielded region with the distinction that von Mises criterion is more conservative compared to Treca criterion. Yield modes vary in different layers of the panel through its thickness and according to von Mises and Treca yield criteria and the TTO model in this analysis, yield begins from the inner layer of the panel. By increasing the temperature, yield stress in the panel increased and by increasing FGM index and thickness of the panel, yield stress decrease in the panel.

ABSTRACT: Flexible hybrid electronic (FHE) material systems embody the intersection of compliant electrical networks and functional material architectures. For a wide variety of future applications, FHE material systems will be subjected to dynamic mechanical stresses, such as for motion monitoring or for vibration isolation. Consequently, an understanding is required on how these new classes of material systems may respond mechanically and electrically when under states of high-cycle and high-frequency loads. Here, conductive silver microflakes Ink is interfaced with elastomeric geometries programmed with specific strain responses. Changes in electrical resistance under cyclic displacements are shown to depend on the heat generated by electrical current flow and on the thermal heat generation promoted by the pre-strain on the material system. Configurations subject to high static pre-strains and large strain rates exhibit greater increases in temperature and resistance, whereas a near constant conductivity is manifest in FHE material systems with compositions that reduce static local strains despite high engineering pre-strain application. These results may guide future efforts to understand the resistance change in conductive Ink networks and expand the use of flexible hybrid electronic material systems into myriad dynamic application environments.


ABSTRACT: Pyramidal lattice sandwich structure (PLSS) exhibits high stiffness and strength-to-weight ratio which can be effectively utilized for designing lightweight load bearing structures for ranging from ground to aerospace vehicles. While these structures provide superior strength to weigh ratio, their sound insulation capacity has not been well understood. The aim of this study is to develop numerical and experimental methods to fundamentally investigate the sound insulation property of the pyramidal lattice sandwich structure with solid trusses (PLSSST). A finite element model has been developed to predict the sound transmission loss (STL) of PLSSST and simulation results have been compared with those obtained experimentally. Parametric studies are then performed using the validated finite element model to investigate the effect of different parameters in pyramidal lattice sandwich structure with hollow trusses (PLSSHT), revealing that the pitching angle, the uniform thickness and the length of the hollow truss and the lattice constant have considerable effects on the sound transmission loss. Finally a design optimization strategy has been formulated to optimize PLSSHT in order to maximize STL while meeting mechanical property requirements. It has been shown that STL of the optimal PLSSHT can be increased by almost 10% at the low-frequency band. The work reported here provides useful information for the noise reduction design of periodic lattice structures.


ABSTRACT: This paper is concerned with the numerical analysis of structural and acoustic behaviors of composite laminated plates under the action of moving loads. The plate is assumed to be immersed in a compressible inviscid fluid. The moving loads may traverse on the surface of the plate along arbitrarily-shaped curved trajectories. The structural model of the plate is formulated using a modified variational principle combined with a multilevel partitioning procedure (i.e., individual layer and layer segment). The exact 3-D theory of elasticity is employed for the structural modeling in order to accommodate the analysis of arbitrarily thick composite plates, and the displacement field of each layer segment is approximated by Chebyshev orthogonal polynomials. A time-domain boundary element method based on Kirchhoff integral formulation is adopted to couple with the structural model of the plate to evaluate the radiated sound pressure of the fluid. Assessment of the accuracy of the present method is made by comparing the solutions attained from the coupled finite element/boundary element method. The effects of the velocities and trajectories of the moving loads on the dynamic responses of composite sandwich plates as well as the far-field radiated sound are investigated. The modal contributions to the vibro-acoustic responses of the plates are also discussed.


ABSTRACT: In this article, the effect of active constrained layer damping (ACLD) on the linear frequency response characteristics of skew magneto-electro-elastic (SMEE) plates has been evaluated. The constraining and the constrained layer of ACLD treatment are considered to be made of 1–3 piezoelectric composite (PZC)
and viscoelastic layer, respectively. The advantage of incorporating smart materials such as PZC in attenuating the vibrations of the SMEE plates is thoroughly investigated. In this regard, a three-dimensional finite element (FE) formulation is derived with the aid of the principle of virtual work considering the coupling between magnetic, electric and elastic fields. The SMEE plate kinematics is governed by layer-wise shear deformation theory. The Complex modulus approach is adopted in order to model the constrained layer of the ACLD patch. A special emphasis is placed on investigating the effect of various skew angles on the frequency response of SMEE plates with ACLD treatment. Meanwhile, an exhaustive parametric study is carried out to analyze the influence of control gain, stacking sequence, patch position, fiber orientation angle of PZC, aspect ratio, and coupling effects. The results confirm that these parameters in association with ACLD treatment and skew angle significantly affect the damping characteristics and hence the controlled frequency response of SMEE plates. Moreover, the numerical results of this research lay a strong platform in the field of vibration and control. Also, it encourages the optimized design and analysis of smart SMEE structures for the application of sensors and actuators.


ABSTRACT: The thermo-elastic behaviour induced by temperature in composite structures has become a significant factor in structural design. In this paper, a three-dimensional thermo-elastic theory for composite cross-ply laminated plates was discretized by a differential quadrature hierarchical finite element method (DQHFEM). The DQHFEM is a weak-form differential quadrature method using hierarchical bases that can provide highly accurate results using only a few sampling points. Flexible and efficient wedge (triangular prism) and hexahedron elements were constructed and applied to three-dimensional (3D) analyses of cross-ply laminated plates and shells for the first time. Compared with various models in literatures, the DQHFEM showed very good agreements with exact solutions based on 3D elastic theory. The thermo-mechanical analyses of cross-ply laminated plates and shells based on 3D theory indicate that the DQHFEM is an effective method for high accuracy analyses with low computational costs, because the DQHFEM can provide results with high accuracy by using only several nodes on the thickness direction.


ABSTRACT: This work investigates the aeroelastic stability boundary of curved composite panels with embedded Macro Fiber Composite (MFC) actuators in the supersonic airflow. Prescribed voltages are statically applied to the MFC actuators, inducing a pre-stress field which results in an additional stiffness effect on the curved panels, thus changing the aeroelastic stability boundary of curved composite panels. The principle of virtual work is applied to develop the equations of motion for the nonlinear flutter of curved composite panels with embedded MFC actuators. The Von Karman large deflection panel theory and the first order quasi-steady piston theory are adopted in the formulation. The Newton-Raphson method is employed to determine the static aeroelastic deflection under the applied voltages, and an eigenvalue solution is adopted to predict the aeroelastic stability boundary of the curved panels. Numerical results show that the influence of the applied voltages is distinct for the curved composite panels with different curvatures. In addition, the lamination angles of the MFC actuator and the temperature elevations will also significantly affect the aeroelastic stability boundary of curved composite panels in the supersonic airflow.


ABSTRACT: As a promising strengthening solution, carbon fiber reinforced polymer (CFRP) sheets have been used to improve the structural response of concrete-filled steel tubes (CFSTs) in service loads, owing to the durability and high strength-to-weight ratio provided by CFRP. Despite the wealth of knowledge available in the literature on how CFRP sheets contribute to strengthening CFSTs under static loads, there is a research gap regarding how the strengthened structural components respond to lateral impact loads, due to vehicle and vessel collision, as well as wind and water-borne debris impact. This was the motivation of the current study to
establish a computational framework supported by experimental tests to evaluate the performance of CFST beams with and without CFRP under a set of impact scenarios. For this purpose, a range of influential aspects related to CFRP, concrete, and steel, as well as impact energy, are investigated. Such a holistic assessment provides unique information to answer fundamental and practical questions regarding the use of CFRP for strengthening of CFST beams against impact loads. To further assist with the proper configuration of CFRP-strengthened CFST beams, a section analysis method is developed and validated as the outcome of this study.

ABSTRACT: This study aims to detect the influence of material uncertainties on the free vibration of nonlocal piezoelectric nanoplates. The size-dependent governing equations are derived based on the nonlocal theory and Hamilton’s principle, and Navier method is used for the solution. Considering inadequate experimental data, uncertain-but-bounded parameters are used to quantify the uncertain nanomaterial properties. Based on the interval analysis theory, a novel hull iterative algorithm (HIA) is proposed to evaluate the thermo-electro-mechanical vibration behavior of piezoelectric nanoplates. The presented method is compared with Monte Carlo method and sensitivity based interval analysis method, and well agreements are achieved. A sensitivity analysis is performed to identify the most dominant uncertain parameters. Using the HIA, parametric studies are carried out to explore the combined effects of material uncertainties and temperature change, external electric voltage, biaxial force as well as nonlocal parameter on the natural frequency of piezoelectric nanoplates.

ABSTRACT: This paper mainly concerns effects of the auxetic structure on the crash performances in terms of the axial crash force, specific energy absorption, and deceleration, which are evaluated with the conventional and honeycomb structures. Based on the systematic design procedure, the re-entrant units for the auxetic structure are regularly arranged in the tube wall, which are produced by the additive manufacturing with SUS316L metal powder. Under the low impact condition, the auxetic does not only exhibit higher specific energy absorption, but also demonstrate substantially low deceleration due to effect of the densification during the axial crash compared with the conventional tube. Furthermore, while the honeycomb tube demonstrates oscillating behavior in the deceleration, the auxetic tube tends to maintain steady deceleration after the first peak during the axial crash, which is able to guarantee enhanced damping performances under the low impact condition.

ABSTRACT: The increasing need for automatic mesh generation has led to the development of efficient triangulation algorithms that are able to discretize any 2D or 3D domain. Modern finite element formulations based on strain smoothing techniques (SFEM) provide enhanced convergence properties, preventing yet the stiffening behavior of triangular meshes. Recent research has shown that meshless methods based on triangular mapping of the integration domain can be used to produce even better convergence properties than SFEM. The present study explores the Edge-based Smoothed Point Interpolation Method (ES-PIM) as a meshless solution to investigate linear buckling on variable angle tow (VAT) laminates. Such advanced composite structures show a heterogeneous distribution of constitutive properties and thickness, presenting additional challenges to the numerical solution. Important aspects related to the transverse shear correction herein adopted are investigated, leading to interesting conclusions regarding the possibility to use the ES-PIM for conservative estimates of the critical buckling load of VAT laminates.

ABSTRACT: Damage severity of sandwich panels to underwater explosion load depend not only on the shock factors, but also on the fluid behind the structure. Underwater explosion tests were performed on water-backed sandwich panels to examine the deformation and failure of such composite structure. The dynamic blast response of water-backed sandwich panel was investigated using the LS-DYNA software. An analytical three-stage model was developed for the deformation history of water-backed sandwich panel subjected to shock loading in water. Blast resistance of water-backed sandwich panel was compared with monolithic plate of equivalent areal mass and air-backed sandwich panel with the same configurations. Water-backed sandwich panel exhibited the best deformation/damage resistant capability. Compared with air-backed sandwich panel, core material exhibited greater volumetric strain when the sandwich structure wetted on both sides. Overpressure in the water behind structure was reduced to about 7% by using sandwich structure over monolithic plate of equivalent thickness. Present study led to the apprehension of dynamic response of water-backed sandwich structure to underwater blast load, thereby developed useful guidelines for the design of blast-resistant structural systems.


ABSTRACT: Pultruded glass fiber reinforced polymer (GFRP) sections face a critical issue of premature web crippling failure when loaded in the transverse direction. However, limited research on the web crippling behavior of asymmetric sections like channel section was reported in the literature. In addition, the effect of specimen length on the web crippling behavior has not been explicitly investigated. This paper presents an experimental study on the web crippling behavior of pultruded GFRP channel sections under transverse bearing load. Four channel sections with various dimensions were tested under two transverse loading conditions, i.e. interior-two-flange (ITF) and exterior-two-flange (ETF). For each section, two specimen lengths were adopted to study the effect of specimen length on the web crippling behavior. Therefore, three variables including sectional dimensions, specimen length and loading conditions were considered in the experimental program. Two failure modes, namely web-flange junction failure and web buckling failure, were observed. The load-displacement curves and web crippling capacities of all specimens were reported and compared. Finally, design equations were proposed considering the failure mechanisms. The predicted web crippling capacities generally agreed well with the experimental results.


ABSTRACT: Research on carbon-fiber-reinforced plastic (CFRP) composite laminates shows that advanced pseudo-ductility can be obtained using a cut-ply approach. This study investigates the energy absorption capability of CFRP square tubes with overlapping discontinuous plies. The cutting-angle, α, which can be used as a design variable, is considered and controlled to cut both spacing and density. Quasi-static axial compression tests were conducted to investigate the failure process, crashworthiness and the corresponding energy-absorption mechanism. The results indicate that the cutting angle has a significant effect on the energy absorption. Increasing the cutting angle increases the specific energy absorption from 50.8 J/g to 74.1 J/g. Compared to one sample (56.2 J/g), the specific energy absorption increases by 32%. This study also indicates that the energy absorption of composite tubes can be tailored by adjusting the position of the cuts.


ABSTRACT: A meshfree radial point interpolation method is presented for static and buckling analysis of thick laminated plates, taking into account the continuity of interlaminar transverse shearing stresses and zigzag variation of the displacement field through the plate’s thickness. The kinematics of the deformation field is based on the refined theory of Wang and Shi (2015). The corresponding weak-form for static bending and buckling analyses of plates based on the Wang and Shi’s theory are derived through minimum potential energy principle. The discretized systems of equations for static bending and buckling analyses are derived and the
associated numerical integration is performed by the novel CTM quadrature. This integration method can exactly model the problem geometry and thus is very fast and accurate. Several numerical examples are solved to demonstrate the accuracy and efficiency of the plate theory adopted in this paper. Additionally, the examples are also analyzed using the FSJT, TSJT and Shi’s plate theory (2007). Because the four theories considered in this paper use five field variables and they also have some other similarities, the influence of higher order terms of the displacement field, transverse shearing strain energy consistency, and imposition of transverse shearing stress continuity on results is investigated.


ABSTRACT: In this study, sandwich panels with carbon/epoxy composite skins and an magnetorheological elastomer (MRE) honeycomb core in different proportions of magneto/elastomer (w/w%) are manufactured and studied numerically and experimentally. Test specimens in the beam form are subjected to free and forced vibrations and evaluated with and without the presence of an external (until 120 kA/m) magnetic field, positioned on the free end and on the center of the beam. The experimental results showed good performance in the attenuation of vibration level, especially on the fundamental vibration mode of the structures in question. The applied magnetic field on the free end of the test panel was capable of reducing until 37.45% their first natural frequency value. It can be noted from numerical and experimental results that sandwich panel with MRE honeycomb shifted the natural frequencies due to the increase of an induced magnetic field, especially for the first mode shape.


ABSTRACT: A layerwise B-spline finite element formulation is used to study the stability and first-ply failure of composite plates with embedded delaminations and subjected to localized thermal heating over the plate surface with uniform temperature rise through its thickness. The step functions are used to represent jump discontinuities in displacement fields at the zone of delamination between layers of composite plates. As the applied thermal loading is nonuniform, in the first step the prebuckling stress distribution within the plate is evaluated by solving the thermoelasticity problem. Subsequently, thermal buckling temperature is computed using the plate prebuckling stress distribution. Postbuckling response of the plate is obtained considering the von Kármán type geometric nonlinearity. In the delaminated region, virtual springs are added to prevent interpenetration of lower and upper sublaminates. The localized thermal load at which the first-ply failure of the lamina occurs has been detected by Tsai-Wu quadratic interaction criterion. The effects of the area of heating region, delamination size and its position in the thickness direction and plate boundary condition on the composite plate critical buckling temperature and on first-ply failure load are reported. The present model can capture global, local and combined global–local buckling mode shapes.


ABSTRACT: In this paper, a general vibration analysis of functionally graded porous (FGP) structure elements of revolution with general elastic restraints is performed for the first time. Under the basic framework of the first order shear theory, the moderately thick and thin FGP structure elements of revolution are considered. The specific FGP structure elements include the cylindrical shell, conical shell, spherical shell, cylindrical panel, conical panel and spherical panel. In order to simulate general elastic restraints, the artificial spring boundary technique is adopted this paper. And the modified series solution composed of a standard cosine Fourier series and two auxiliary terms is introduced in the Rayleigh-Ritz method to express the admissible function. A series of numerical examples are conducted, which show that the current model has superior convergence characteristics, computational accuracy and stability. On this basis, a series of innovative results are also given in the paper, which may provide basic data for other algorithm research in the future.

ABSTRACT: The damage detection of composite material structures is one of the major concerns in aerospace field, given their even more frequent use. In this work, the failure of an aerospace omega stiffened CFRP panel subject to compressive load is experimentally and numerically studied. The specimen is characterised by a 0° oriented notch damage, with respect to the load direction, located in the middle of the bay. A compressive mechanical test has been performed to determine the global buckling phenomenon and the progressive fibre-matrix damage development induced by the compressive load acting on the panel. The panel has been instrumented with back-to-back strain gauges in skin and stringers locations. Non-destructive techniques, such as lock-in thermography and ultrasounds, have been used to detect the damage status. Numerical analyses have been carried out by means of the FE software ABAQUS and the results have been compared against the experimental data. Finally, an un-notched configuration has been numerically tested and the results have been compared against the notched configuration, in order to assess the influence of the pre-existent damage on the mechanical and failure behaviour of the structure during service loading conditions.


ABSTRACT: Because of their superior mechanical and environmental properties compared to traditional metals, fiber-reinforced composite materials have earned a prevalent acceptance for different structural applications. The tailoring potential of composites to achieve high specific stiffness and strength has promoted them as promising candidates for constructing lightweight structures. From that aspect, designers have tackled the problem of designing composite laminates, which is inherently challenging due to the presence of non-linear, non-convex, and multi-dimensional problems with discrete and continuous design variables. Witnessing new manufacturing technologies also granted engineers the capability of exploiting the full potential of composites by using nonconventional laminates leading to more complex design problems. To circumvent this difficulty, designers have used lamination parameters as intermediate variables to achieve global optimization. This literature review aims to demonstrate the use of lamination parameters for efficient multi-level optimization of robust and manufacturable nonconventional laminates by integrating the optimization process with manufacturing constraints and industry design guidelines.


ABSTRACT: In this paper, we present some advanced shell models for the analysis of orthotropic multilayered structures in which the mechanical and physical properties may change in the thickness direction. The finite element method showed successful performances to approximate the solutions of the advanced structures. In this regard, two variational formulations are available to reach the stiffness matrices, the principle of virtual displacement (PVD) and the Reissner mixed variational theorem (RMVT). Here we introduce a strategy similar to MITC (Mixed Interpolated of Tensorial Components) approach, in the RMVT formulation, in order to construct an advanced locking-free finite element. Moreover, assuming the transverse stresses as independent variables, the continuity at the interfaces between layers is easily imposed. We show that in the RMVT context, the element exhibits both properties of convergence and robustness when comparing the numerical results with benchmark solutions from literature, even for higher span to thickness ratios, and both interlayer continuity conditions and boundary conditions are fully satisfied.


ABSTRACT: The paper focuses on the nonlinear dynamic response of a thermally loaded thin composite plate subjected to harmonic excitation. A theoretical formulation is derived in terms of assumed modes and an Airy stress function, which incorporates an initial global geometric imperfection. Contributions of in-plane boundary
constraints due to surrounding thermal sealing materials are taken into account by giving equivalent in-plane boundary stiffness. The effects of the temperature, equivalent in-plane boundary stiffness and initial geometric imperfection on the dynamic behavior are investigated through a detail parametric study. It is shown that the critical buckling temperature of a perfect plate decreases with increasing the equivalent in-plane boundary stiffness significantly. A secondary stable equilibrium branch exists for an imperfect plate. The presence of the global imperfection postpones the onset of the critical state. The nonlinear dynamic response of the plate is a hardening-spring type in the pre-critical region due to one equilibrium state, and is a softening-type in the post-critical region because of two stable equilibria. The strain frequency response is dominated by the superharmonic frequency components for the plate at ambient temperature, and the subharmonic frequency components in the thermal environments.

ABSTRACT: The nonlinear dynamic responses of laminated plates consisting of graphene reinforced composite (GRC) layers in thermal environments are studied in this paper. The effect of visco-elastic foundation is also considered in the analysis. All layers in an FG-GRC laminated plate are assumed to have the same thickness, whereas the graphene volume fractions for the layers are assumed to be linearly varying in a piece-wise pattern along the plate thickness direction. The material properties of GRC are estimated by a extended Halpin-Tsai model. To include the effect of small scale, the efficiency parameters for graphene are introduced in the model and determined from the results of molecular dynamics (MD) simulations. The plate is modeled based on the Reddy’s higher order shear deformation plate theory and the effects of the von Karman geometric nonlinearity and the initial loading are included in the derivation of the motion equations. Once the applied load is determined, the deflection as the function of time can be solved by the fourth-order Runge-Kutta numerical method. The impacts of functionally graded (FG) pattern, visco-elastic foundations, temperature change and applied load type on the dynamic behaviors of the FG-GRC plate are presented and discussed.

ABSTRACT: In the present work, the static response of symmetric and anti-symmetric laminated composite and sandwich plates is investigated for elevated temperature and moisture conditions. Analysis is carried out using recently developed zigzag model which is based on a trigonometric (secant) shear deformation in the plate. The theory incorporates inter-laminar shear stress continuity along with the traction free boundary conditions at the top and bottom surfaces. The finite element method is employed for analysis, using the eight noded isoparametric serendipity element, accounting for the C continuity. Numerous examples covering the various features such as effect of thermal and moisture coefficients, material anisotropy, boundary and loading conditions and span to thickness ratio are solved for symmetric as well as anti-symmetric plates. Results in the form of deflection and stresses are presented and validated with the available results in the existing literature. Further, few new results are also provided in this work, to set a benchmark study for the future research.

ABSTRACT: To meet the growing demands for structural lightweight and safety, metal-foam-composite hybrid tubular sandwich structures which combine low-cost metallic materials and high-strength composites with low-density cellular materials, have been recently introduced to be a class of energy absorber configurations for automotive engineering. This study proposed four different hybrid sandwich tubes and investigated their crashworthiness and performance to cost ratio under quasi-static axial condition. For a comparative purpose, individual carbon fiber reinforced plastic (CFRP) tube, aluminum tubes and aluminum foam were also tested here. From the energy absorption perspective, it is found that all the hybrid specimens exceeded the sum of the individual components. Of different configurations, specimen C-F-C (i.e. outer CFRP tube + aluminum foam + inner CFRP tube) had the highest energy absorption capacity (in energy absorption): 6.70 kJ, specific
energy absorption (SEA): 37.32 kJ/kg, improvement of energy absorption: 39.1%, and material cost: 6.877 £, respectively. The specimen C-F-A (i.e. outer CFRP tube + aluminum foam + inner aluminum tube) exhibited the highest crushing force efficiency (0.87) and value-added performance of energy absorption (0.325 kJ/£). The specimen A-F-A (i.e. outer aluminum tube + aluminum foam + inner aluminum tube) exhibited the lowest peak crushing force (63.56 kN) and lowest material cost (2.227 £). Further, the finite element (FE) model was established to analyze the crashworthiness characteristics of hybrid sandwich tubes through validating the simulation results with the experimental data, which provided a basis for further parametric analysis and structural optimization.

ABSTRACT: This work deals with the optimum design of variable angle-tow (VAT) composites in the theoretical framework of B-Spline surfaces. The design problem is formulated as a constrained optimisation problem in the context of the multi-scale two-level (MS2L) optimisation methodology. The proposed approach aims at optimising all parameters characterising the VAT laminate at each pertinent scale (mesoscopic and macroscopic ones). In particular, this study focuses on the first level of the MS2L optimisation strategy that aims at determining, at the VAT laminate macroscopic scale, the optimum distribution of the laminate mechanical properties over the structure. At this stage, the behaviour of the VAT composite is described by means of the polar formalism and the spatial distribution of the polar parameters is represented through a set of suitable B-Spline surfaces. The expression of the gradient of objective and constraint functions is determined in a closed form by exploiting the properties of the B-Spline surfaces. Moreover, the effect of the discrete variables tuning the shape of the B-Spline surfaces (mainly the number of control points) on the quality of the optimum solution is investigated. The effectiveness of the proposed approach is tested through some meaningful benchmarks taken from literature.

ABSTRACT: A novel carbon fiber reinforced plastics-aluminum alloy (CFRP/AA6061) hybrid tube with five-cell-round-der-corner (C5C) profile was presented in this paper. Different from the available hybrid tubes, the novel structure consisted of a C5C-profile aluminum alloy tube wrapped by CFRP cloths. Numerical simulations and experiments of the C5C hybrid tubes subjected to axial compression were performed. The parameters of modelling CFRP and modelling the interface between CFRP and AA6061 tube were validated. Two multi-objective optimizations aiming to obtain the optimal dimensions of the C5C profile and the optimal angles of the CFRP plies were conducted. The energy absorption and the peak force of the C5C hybrid tube were compared with that of the tubes with common profiles. The effect of wrapping on the energy absorption and the peak force was discussed. The results showed that the novel hybrid tube had excellent energy absorption performance. It could avoid the unstable cracking and early cracking that often occurred to the tubes with common profiles. The specific energy absorption (SEA) of the C5C CFRP/AA6061 tube was 16.7% larger than the SEA sum of the constituent tubes. Wrapping could produce a coupling amplification effect and CFRP/Al hybrid tubular structures manufactured by wrapping were promising materials in lightweight.

ABSTRACT: The vibration and buckling of the coating-FGM-substrate conical shells (CFGSCSs) with mixed boundary conditions (MBCs) under the hydrostatic pressure are studied. The basic equations of CFGSCSs are displayed based on the Donnell-type linear shell theory and solved using by Galerkin’s method. The novelty of current study is to obtain formulas for the critical hydrostatic pressures (CHPs) and the cyclic frequencies (CFs) of CFGSCSs with the MBCs. Finally, the influences of FGM cores and variation of the material gradient index on the CFs and CHPs for CFGSCSs are studied.

ABSTRACT: A rational new plate theory must meet specific guidelines and cannot be proposed by merely choosing a different function for the transverse variations of the displacement components. In the present research, a novel hyperbolic global-local plate theory is proposed based on 8 criteria, for the first time and implemented in a new formulation that takes into account the potential energy of the contact region, for behavior analysis of biaxially preloaded sandwich plates with unevenly-distributed SMA wires and soft cores under impulsive/impact loads. The proposed theory contains both odd and even functions and consequently, is more appropriate for asymmetric lamination schemes; in addition to satisfying the continuity condition of the interlaminar stresses. It is the first time that stress-strain asymmetry and anisotropy of the SMA is incorporated in the impact response analysis. Modified micro-macro-mechanical and bridging models are employed to relate the apparent properties to the local ones and vice versa. Effects of the uniform, double-linear, and double-sinusoidal distributions of the SMA wires are compared. The localized time variations of phases evolutions of the anisotropic SMA wires are predicted based on a particular algorithm, employing an iteration-based updating solution procedure for the resulting finite element formulation within each time step.


ABSTRACT: This paper presents the quasi-static energy absorption of open section monolithic carbon-epoxy specimens for a range of environmental test conditions. Experimental observations showed that the test temperature influenced the failure mode; elevated temperatures (>23 °C) resulted in the specimens exhibiting a spaying failure mode whilst reduced test temperature (~35 °C) resulted in a brittle failure mode. Despite the difference in failure modes, the reduced and elevated test conditions both resulted in lower energy absorption compared with the baseline result at ambient temperature. In addition to the temperature effect, introducing moisture further reduced the energy absorption. The results show that an un-conditioned specimen tested at ambient temperature may not necessarily represent the worst case and care must be taken when using ambient temperature tests to inform the design of crushworthy structures and the influence of environment should be accounted for during the design phase.


ABSTRACT: Geometrically nonlinear dynamic analysis of functionally graded carbon nanotube reinforced composite (FG-CNTRC) rectangular plates subjected to blast loads is conducted based on Reddy’s higher-order shear deformation theory using the weak form quadrature element method. The von-Kármán strain terms are introduced to consider the geometrically nonlinear effects. The polymer composite plate is reinforced by single-walled carbon nanotubes (SWCNTs) with the uniform and functionally graded distribution in the plate thickness direction. The effective material properties of the FG-CNTRC plates are estimated with the extended rule of mixture. The Newmark-β time integration scheme and the Newton–Raphson iteration technique are adopted to solve the nonlinear incremental dynamic equilibrium equation in temporal domain. Comparative and convergence studies are carried out to validate the accuracy, efficiency and numerical stability of the presented weak form quadrature element formulation. The effects of the carbon nanotube distribution and volume fraction, plate width-to-thickness ratio, plate aspect ratio, load type and boundary condition on the dynamic response of the FG-CNTRC plates under blast loads are systematically investigated through the parametric studies.


ABSTRACT: This paper deals with the buckling behavior of corrugated thin plates made of multilayer functionally graded (FG) graphene nanoplatelets (GPLs) reinforced nanocomposites (FG-GPLRC) within the
framework of classical plate theory. The GPLs are uniformly dispersed in each individual layer with its weight fraction following a layer-wise variation along the thickness direction. The effective Young modulus of each layer is determined by the modified Halpin-Tsai model while the Poisson’s ratio is predicted based on the rule of mixture. It is assumed that the plate is subjected to either compression or shear or both on the edge. Analytical critical buckling solutions are obtained for both unilateral buckling when the plate is resting on a rigid foundation and bilateral buckling without the constraint of the foundation. A parametric study is conducted to investigate the influences of distribution pattern, geometry, size, and weight fraction of GPL nanofillers as well as the corrugated profile and rigid foundation on the buckling performance of the plate. It is found that the buckling resistance of the corrugated plate can be effectively enhanced by adding a small amount of GPLs into the matrix according to FGX distribution pattern and when the inclination angle is 45 degrees.


ABSTRACT: In this work, postbuckling response of bi-directional functionally graded (FG) beams with porosities is investigated. The transverse shear deformation is taken into account based on a novel third-order shear deformation theory in which the kinematic of displacements is derived from an elastic formulation. Porosities owing to the technical issue during the preparation of functionally graded materials (FGMs) with even and uneven distributions are considered. Material properties of bi-directional FG beams vary smoothly along the thickness and axial directions simultaneously based on the power law distribution. Geometric nonlinearity is described by employing the von Kármán nonlinear theory. Equations of motion are derived utilizing the principle of minimum potential energy. Nonlinear partial differential equations are solved numerically to obtain the critical buckling loads and the postbuckling equilibrium paths under different boundary conditions using the generalized differential quadrature method (GDQM) and the Newton-Raphson iteration. Numerical results demonstrate that FG and axially FG (AFG) indexes, porosities distribution, boundary condition, Young’s modulus ratio, aspect ratio, and plane strain and plane stress states have significant influences on the buckling and postbuckling responses of bi-directional FG beams.


ABSTRACT: A novel porous crochet-sintered metal (PCSM) is fabricated by rolling a crocheted porous cloth and subsequent vacuum sintering using a continual single super-fine soft 304 rope twisted by 49 fibers as raw material. This work investigates the quasi-static and dynamic axial crushing response of PCSMs and their filled composite tubes. The pore structures of PCSMs are formed by inter-crocheted and multiple inter-locked rope skeletons and metallurgical bonds. The PCSMs have almost no initial impact effects with a high crushing force efficiency. Filling the PCSMs changes the deformation model of 6063 tube, improves the static crushworthiness parameters of 6063 tube by 8–25% with almost no increasing initial impact effect, and doesn’t always play a positive role in dynamic absorption. Porosity has obvious influence on the quasi-static and dynamic behavior and crushworthiness of PCSMs and their filled composite tube, and the effect of porosity on dynamic crushworthiness of composite tube is greater than that on quasi-static crushworthiness of composite tube. The PCSMs and their composite tubes show great potential for application in energy absorbers. The method of filling PCSM into bare tube is possible to improve the energy absorption ability of thin-walled tube with almost no increase in the initial peak force.


ABSTRACT: Wind turbine blades are exposed to numerous impact risks throughout their lifetimes. The impact risks range from bird collisions during operation to impacts with surrounding structures at the time of transportation and installation. Impact loads on the fibre composite blades can induce several complex, simultaneously interacting and visually undetectable damage modes and have a high potential to reduce the local and global blade stiffness. An assessment of such impact-induced damages is therefore necessary and usually involves high computational costs using numerical procedures, especially when analysing large
composite components. To minimise this computational expense, different numerical impact modelling techniques are utilised, primarily shell-element-based approaches and multiscale-modelling-based global-local approaches. In this article, a comparison between (1) pure shell, (2) shell-to-solid coupling, and (3) submodelling finite element modelling techniques using Abaqus/Explicit is presented for a case where an impactor hits the leading edge of a blade. A high-fidelity local solid finite element model is developed for the leading edge of a DTU 10 MW blade at the region of impact and its stiffness is compared with baseline. A user material subroutine VUMAT for the intralaminar damage mode based on the Hashin failure criterion is formulated and then validated via an experiment from the literature. Finally, based on different numerical modelling techniques, impact investigations are performed, and the impact responses, damage to the blade and computational analysis durations are compared. It is found that the submodelling-based global-local approach is the most efficient analysis technique for this case, capturing failure modes including delamination, core crushing and local surface indentation in the blade. The findings of this study can be used to develop accurate and computationally efficient tools for modelling impact-induced damage to a blade.


ABSTRACT: In this study, bending, free vibration, and buckling response of functionally graded porous micro-plates are investigated using the classical and first-order shear deformation plate theories. The Navier solution technique is utilized to obtain analytical solutions to simply supported rectangular plates. A power-law distribution is used to model the variation of two material constituents through the plate thickness. Three different porosity distributions are considered and assumed to take forms of cosine functions. The microstructure-dependent size effects are captured using the modified couple stress theory. Numerical results of bending, free vibration, and buckling are presented to determine the effects of constituent material variation, microstructure-dependent size effects, and porosity distributions on the mechanical response of functionally graded porous micro-plates.


ABSTRACT: The vibration characteristics and dynamic responses of a rotating composite non-uniform beam based on Rayleigh beam theory considering the combined influence of hygrothermal environment and elastically restrained root are investigated in this paper. The influence of temperature, humidity and other parameters on the natural frequencies and dynamic responses of the rotating composite non-uniform beam is discussed. Firstly, the Hamilton’s variational principle is employed to establish the governing equation of a rotating composite non-uniform beam. Then, the upper and lower bounds of the fundamental bending frequency are obtained according to the Rayleigh’s and minimum principle. A semi-analytical solution of the governing equation is obtained on the basis of the power series method. Finally, numerical results are performed to analyze the effects of the rotating speed, hub radius, temperature variation, moisture concentration, fiber orientation angle, taper ratio and elastic restrained root on the natural frequencies and dynamic responses.


ABSTRACT: Towards improving the numerical efficiency in the analysis of multi-layered shell structures with the finite element (FE) method, an adaptable two-level mathematical refinement approach is proposed for refined curvilinear shell elements. Based on Carrera Unified Formulation (CUF), the approximation of displacement functions of shell elements can be improved by refining the through-the-thickness assumptions and enriching the shape functions. By using the hierarchical Legendre polynomial expansions (HLE) as shape functions, the element capabilities can be enhanced conveniently without re-meshing. To further increase the numerical efficiency of shell FE models, Node-Dependent Kinematics (NDK) is utilized to implement local kinematic refinements on the selected FE nodes within the domain of interest. The conjunction of NDK with the two-level refinements of the shell FE models leads to an adaptable refinement approach in the analysis of shell
structures, which can be used to build FE models with optimal efficiency and high fidelity. The competence of the proposed approach is investigated through numerical studies on laminated shells.


ABSTRACT: Increasing awareness of environmental concerns is leading a drive towards more sustainable structural materials for the built environment. Natural fibres such as flax and jute have increasingly been considered for fibre-resin composites, with a major motivation for their implementation being their notable sustainability attributes. This paper is part of an ongoing effort by the author to demonstrate the structural properties of primary structural elements and members fabricated from natural fibre composites of flax and jute. Previously the structural properties of flat plates, plain channel sections and channel sections with complex stiffeners were investigated under pure compression. This paper presents investigations of channel sections with complex stiffeners under pure bending. A series of sixteen channels with varying geometries, complex stiffener arrangements and composite thicknesses were tested in pure flexure. Material tests indicated that the mean tensile elastic stiffness and strength values were 6386 MPa and 55.1 MPa for flax, and 6941 MPa and 62.1 MPa for jute. The experimental results indicated that flexural failure of the channel sections was governed by tensile fracturing. The ultimate moment capacities varied from 1.043 to 1.501 kNm for four-layered composites, and 2.184 to 2.511 kNm for six-layered composites. The analytical models predicted the experimental ultimate moment capacities well, with a mean and coefficient of variation of the test to predicted ratio of 0.97 and 0.06, respectively. Finite element models used progressive damage analysis via stress-based damage initiation models and damage evolution laws, to replicate the tension fracture failure mode of the channels. The numerical models predicted the experimental ultimate moment capacities well, with a mean and coefficient of variation of the test to predicted ratio of 0.99 and 0.06, respectively.


ABSTRACT: The result of an experimental programme investigating a novel technique to strengthen web plates of steel plate girders against breathing fatigue due to shear buckling deformations is presented. An experimental test series is present in which six specimens were manufactured to simulate the end panel of a plate girder; these were strengthened with an optimized FRP retrofit panel that was developed in an earlier phase of the research project, and tested for plate girder web shear buckling deformation mitigation under repeated cyclic loading, as well as ultimate load capacity enhancement. Test results and non-linear finite element modelling demonstrated the efficiency of this technique for stiffening the web against these deformation and thus reducing the critical stresses, consequently increasing the fatigue life of the girders by a factor ranging between three and seven, depending on the applied stress range and the fatigue resistance assessment method. The research demonstrates the applicability of this novel FRP strengthening technique to prolong and extend the fatigue life of existing plate girder bridges.

https://doi.org/10.1016/j.compstruct.2018.11.044

ABSTRACT: This paper was dealt with buckling and post-buckling behavior of short thin-walled Z-columns made of a carbon-epoxy laminate, subjected to eccentric compressive load. The buckling mode and the buckling load of real structures versus load eccentricity were discussed. The study involved both experimental tests were carried out on real laminated structures and numerical simulations by the finite element method. The buckling load of real structures was determined by approximation methods on the basis of experimental and numerical post-buckling equilibrium paths of the structure. Additionally, in numerical simulations, the bifurcation load value was determined by solving an eigen problem. In all cases, experimental findings and numerical results show high agreement. The study determined the quantitative influence of the direction and value of compressive load eccentricity on the buckling load and rigidity of the structure in the post-buckling state.

ABSTRACT: Chiral auxetic cellular structures were fabricated from Ti6Al4V alloy using the Selective Electron Beam Melting method, and tested experimentally under quasi-static and dynamic compression loading conditions. The experimental results were used to validate built computational models of auxetic cellular structure in LS-DYNA. The models were used to study the geometry effect on the Poisson’s ratio of the analysed chiral auxetic structure. The response of sandwich composite panels with auxetic core under blast loading was studied extensively computationally, where the maximum panel displacement and the Specific Energy Absorption (SEA) of the composite panel were evaluated. Three different methods for blast loading (ConWep, Smooth Particle Hydrodynamic, Multi-Material Arbitrary Lagrange-Eulerian) were compared and validated based on the experimental data. It was determined that larger thickness of the cover plate lowers the panel maximum displacement, while the SEA is larger when thinner cover plates are used. Also, it was shown that the chiral unit cell amplitude effect on the maximum displacement and SEA is, in most analysed cases, negligible in comparison to the cell length effect, which is more prominent. The presented study illustrates great potential of using sandwich structures with designed auxetic cellular cores to improve the response of modern composite structures to blast loading.


ABSTRACT: Although the stability of the sandwich structures under in-plane excitation has been reported, few of them focus on the functionally graded materials (FGM) sandwich doubly curved shallow shells. Moreover, for the study of static bifurcation, stability and dynamic stability analysis, it is common to ignore the effect of thickness tension or compression. The purpose of this paper is to explore the bifurcation and stability of the FGM sandwich doubly curved shallow shell which is subjected to the in-plane excitation in thermal environment. By introducing the secant function to the transverse displacement, a new displacement field based on the Reddy’s third order shear deformation theory is derived. It is assumed that the material properties of sandwich doubly curved shallow shell are temperature dependent. The distribution of component materials in FGM layer obeys the rule of power law in the radial direction. Considering the geometric nonlinear, using an energy approach and the Galerkin’s method, a two-degree-of-freedom non-autonomous nonlinear dynamic equation with parametric excitation is derived. The threshold of the bifurcation and the stability of the structure are investigated. The instability regions are plotted by dynamic load factor against excitation frequency in alpha1-Omega plane.


ABSTRACT: Curved beams such as arches find ubiquitous applications in civil, mechanical and aerospace engineering, e.g., stiffened floors, fuselage, railway compartments, and wind turbine blades. The analysis of free vibrations of curved structures plays a critical role in their design to avoid transient loads with dominant frequencies close to their natural frequencies. One way to increase their applications and possibly make them lighter without sacrificing strength is to comprise them of Functionally Graded Materials (FGMs) that are composites with continuously varying material properties in one or more directions. Here, we study free vibrations of FGM circular beams by using a shear deformation theory that incorporates through-the-thickness logarithmic variation of the circumferential displacement, does not require a shear correction factor, and has a parabolic through-the-thickness distribution of the shear strain. The radial displacement of a point is assumed to depend only upon its angular position. Thus the beam theory generalizes the Timoshenko beam theory. Equations governing transient deformations of the beam are derived by using Hamilton’s principle. Assuming a time harmonic variation of displacements, and by utilizing a generalized differential quadrature method (GDQM), the free vibration problem is reduced to solving an algebraic eigenvalue problem whose solution provides frequencies and corresponding mode shapes. Results are presented for different spatial variations of the material properties, boundary conditions, and the beam aspect ratio. It is found that frequencies of the FGM beam are bounded by those of two geometrically identical homogeneous beams composed of the two
constituents of the beam. Keeping other variables fixed, the change in the beam opening angle results in very close frequencies of the first two modes of vibration at a critical value of the opening angle, a phenomenon usually called mode transition. The critical opening angle is essentially the same for radially graded, bidirectionally graded and monolithic beams. It equals about 80° (60°) for clamped-clamped (hinged-hinged) beams.


ABSTRACT: Matrix behavior is expected to widely influence the impact response of composites, but detailed conclusions in the case of thermoplastic laminates are still needed. In this paper, we investigated the effect of using either ductile homopolymer PP or less-ductile impact copolymer PP matrices on the low-velocity impact responses of continuous glass fiber-reinforced polypropylene (PP) laminate. These PP types represent two variants in the same family of thermoplastic matrix. A thorough experimental campaign was first performed to provide the tensile properties (for PP and glass/PP) and fracture toughness (Mode-I and Mode-II, glass/PP only) of the employed materials. Then, low-velocity impact tests where the energy levels are ranging from 12 to 30 J were performed. Using ductile PP in glass/PP laminates reduces the energy dissipated during impact as well as the impact damage area. The effect of selected stacking sequences on the resistance to impact was also studied as a way to reveal the difference between ductile and less-ductile glass/PP. Stacking sequence with thin plies shows better impact properties than other sequences regardless of the matrix ductility, which can be explained by micromechanics for both grades of material. Finally, as quasi-static indentation (QSI) is usually used to quickly access the resistance of laminates towards out-of-plane impact, we systematically compared our impact results with QSI results. We found that the prospective use of QSI in forecasting impact properties and damage is very limited in glass/PP composite due to strain-rate sensitivity.


ABSTRACT: Design of materials and structures with quite low coefficient of thermal expansion (CTE), even zero or negative CTE is important for industrial application where drastic temperature changes are encountered. In this paper, making use of the bending of bi-material beam and the unique deformation mechanism of chiral lattice structures, five sets of chiral lattice composite structures with tailorable CTEs are proposed, where synergic effects of rigid node rotation and bi-material ligament bending deformation are responsible for giant range of structural deformation due to temperature change, from positive CTE to negative CTE through adjusting the geometrical parameters of composite bi-material chiral unit cell, and the relationship between unit cell geometric parameters and CTEs of the structure are studied systematically through finite element analysis. Finally, design of bi-material cylindrical shells consisting of anti-tetra chiral unit cells are proposed, and its axial CTEs with different number of the unit cells along the circumferential are studied systematically, demonstrating the robust range of CTEs can be generated through adjusting the geometrical parameters of chiral bi-material unit cells. The proposed chiral structures demonstrated promising application potentials in industrial fields, such as: aerospace and microelectronics, where extremely high structural accuracy is required during harsh working temperature environment.


ABSTRACT: The purpose of the paper is to predict the electromechanical behavior of composite shell structures with embedded piezoelectric layers using 3D-shell model based on a discrete double directors shell element. The implementation is applicable to the analysis of isotropic and functionally graded shells with integrated piezoelectric layers. The third-order shear deformation theory is introduced in the present method to remove the shear correction factor and improve the accuracy of transverse shear stresses. The present results were compared with reference solutions from literature in order to verify the accuracy of the present
formulation and excellent agreement was found. A parametric study is carried out to highlight the influence of material composition and curvature radius on the deflection and axial stress along the thickness.


ABSTRACT: This paper is dedicated to study the elastic buckling behavior of isotropic, laminated composite and sandwich beams subjected to various axially varying in-plane loads and boundary conditions (BCs). The formulation of the problem is derived by using the Ritz method with the displacement field based on a shear and normal deformable beam theory (SNDBT). Polynomial functions are employed to present the displacement field. The convergence studies are performed and then obtained results are compared with those of reported works. Results from extensive analysis are presented for different BCs, aspect ratios, orthotropy ratios, fiber angles and loading conditions. It is observed that the type of the axially variable in-plane load significantly affects the critical buckling loads and mode shapes of the beams depending on the BCs. The normal deformation effect depends on not only the aspect ratio but also BCs and the fiber orientation angles.


ABSTRACT: The ability to steer carbon fibre tapes, varying the tow angle, can widen the designs possibilities of cylindrical shells that are one of the main components of aerospace structures. This research presents experimental and numerical investigation of two carbon fibre reinforced plastic cylindrical shells – a cylinder with conventional layup made of unidirectional prepreg and a variable-stiffness cylinder manufactured by applying fibre placement technology. The shells were tested in compression until buckling and later subjected to a vibration analysis. Load-shortening curves and buckling shapes were acquired during the compression tests, while the natural frequencies and the mode shapes were measured during the vibration tests. Both tests provide a useful data set of the mechanical response of the cylinders which can be applied for further validation of models. The acquired experimental results were compared to a simple, approximated numerical model of the variable-stiffness cylinder showing good correlation with the test results.


ABSTRACT: A finite element model for predicting the nonlinear aeroelastic behavior of composite panels undergoing intralaminar and trans laminar progressive damage in supersonic flow is presented. The classical plate theory in conjunction with the von Kármán nonlinear strains is used for structural modeling, and the linear piston theory is used to model the aerodynamic loads. Progressive damage is modeled by a smeared cracking formulation in which stress-based, continuum damage mechanics and fracture mechanics approaches are combined. No modal reduction is performed and an iterative form of the Newmark method is used for the numerical direct integration in time of the nonlinear equations. Simulations considering different lay-ups are conducted, in which the influence of progressive damage on the aeroelastic behavior of the panels is investigated, and damage extent and failure mechanisms are assessed. The results obtained in the analyses consist in important insights concerning the flutter-induced damage in composite panels.


ABSTRACT: Damage tolerance is of critical importance to laminated composite structures. In this paper, we present a new semi-analytical method for predicting the strain at which delamination propagation will initiate following sublamine buckling. The method uses a numerical strip model to determine the thin-film buckling strain of an anisotropic sub-laminate created by delamination, before evaluating the strain energy release rate for delamination propagation. The formulation assumes that all energy is available for propagation in a peeling mode (Mode I); avoiding an approximate mixed-mode criterion. Results are compared with twelve experimentally obtained propagations strains, covering a variety of laminates each containing a circular PTFE
delamination. Comparison shows agreement to within 12% for balanced sublaminate tests in which delamination propagation occurred before intra-ply cracking. The method can be used to significantly improve the damage tolerance of laminates, opening up new opportunities for structural efficiency using elastic tailoring, non-standard ply angles and material optimisation.


ABSTRACT: One of the main methods for improving the strength of the notched laminates, which are commonly used in the engineering structures, is to employ a stringer in a proper configuration. To optimize the design of these perforated laminates under compression loading, accurate characterization of the effects of various parameters on the instability behavior plays a significant role. For this purpose, after a review on the main previous researches, a semi-energy finite strip method (SE-FSM) is developed in the framework of nonlinear deformation to analyze the buckling behavior of stiffened/unstiffened laminated composites having a circular notch. The developed SE-FSM is based on the semi-analytical solution of von Karman’s equations via Airy stress function and has the advantage of great versatility like the finite element method (FEM) and good economy like the Rayleigh-Ritz method. To verify the developed method and to examine the influence of various parameters (the thickness of specimen, the diameter of the hole and the thickness of stiffener) on the buckling behavior, a detailed experimental parametric study is performed and the extracted results are compared with those of the developed SE-FSM, the full-energy FSM and FEM. High accuracy and fast convergence of the developed method show its computational efficiency for prediction of stability behavior of composite laminates.


ABSTRACT: Sandwich structures with carbon fibre reinforced plastic (CFRP) facesheets are widely used in aerospace and marine structures because they have high strength, stiffness and light weight. However, debonds between the facesheets and the core can reduce greatly the stiffness and the strength of the structures, whilst affecting the vibration behaviours. Hammer impact tests and finite element simulations were conducted to analyse the vibration behaviours of sandwich structures with single and double debonded regions, different matrix modifiers and facesheet stacking orientations. The debonded regions reduced the natural frequencies of sandwich structures, an 80 mm debonded region reduced the natural frequency by 57%. The natural frequencies in bending modes of the structures with [0]4 facesheets were more sensitive to debonds; while structures with [+45/-45]s facesheets were more sensitive in torsion modes. When the debonds were present in the same location for both upper and lower facesheets, there was a greater reduction in the natural frequencies of the bending modes than for other debond arrangements. Reductions in the natural frequency can cause a structure to vibrate at resonance and cause structural failure, therefore understanding of how debonded regions affect the vibration of sandwich structures is critical.


ABSTRACT: A numerical and experimental investigation of the natural frequencies and frequency response of a cantilevered three-layer sandwich beam carrying a tip-mass is presented. The tip-mass is such that its center of mass is offset from the point of attachment. The higher-order sandwich panel theory (HSAPT) and the Hamilton’s principle are employed in deriving the system governing equations of motion and boundary conditions, which are solved using the generalized differential quadrature (GDQ) method. The obtained results are compared with those obtained from the use of commercial finite element software ANSYS, and they are both experimentally validated. The results are generally in good agreement. Parametric studies are conducted to examine the influence of some design variables on system vibrational behavior.
ABSTRACT: (none given)

ABSTRACT: This work presents the highly accurate closed-form solutions for free vibration and eigenbuckling of isotropic rectangular nanoplates with arbitrary homogeneous boundary conditions based on Eringen’s nonlocal theory and classical thin plate theory. The iterative separation-of-variable (iSOV) method based on the Rayleigh quotient, which is the most accurate closed-form solution method among all separation-of-variable methods, is used to obtain the highly accurate solutions, including the exact well-known Navier and Levy types of solutions. The highly accurate closed-form solutions for free vibration of rectangular nanoplates and for eigenbuckling of different scale rectangular plates with arbitrary homogeneous boundary conditions are achieved for the first time, and all solutions are presented in excellent explicit forms. The present solutions coincide well with analytical and numerical solutions in literature, verifying the accuracy of the present method. The influences of nonlocal parameters, boundary conditions and lengths of nanoplates on frequencies and critical buckling loads are studied, and nonlocal effects are explained in physical sense. The present solutions can be taken as the benchmarks for the validation of numerical methods, a guide in parametric design of structure, and the basis of constructing new numerical methods.

ABSTRACT: Analytical solutions are presented for the torsion of bi-directional functionally graded (FG) linearly elastic truncated conical cylinders for six functional forms of the shear modulus varying in both the radial and the axial directions. Furthermore, for an arbitrary variation of the shear modulus along the two directions, we employ a weighted residual approach (WRA) to obtain accurate numerical solutions for the linear elastic boundary value problem. The influence of the variation of the shear modulus and of the cone angle on the stress distribution in the cylinder is discussed through numerical examples. The analytical solutions presented herein can serve as benchmarks for ascertaining the accuracy of approximate or numerical solutions. The WRA combined with an optimization algorithm can be used to find the shear modulus variation to maximize the torsional stiffness.

ABSTRACT: Sandwich panels with truss cores (SPTCs) are a class of novel structures with superior load bearing performance. In recent years, many efforts have been made in designing the SPTCs. However, the
ABSTRACT: Here, the thermo-elastic buckling characteristics of variable stiffness composite shells, viz., cylindrical and spherical shell panels, subjected to uniform/non-uniform thermal fields are investigated based on finite element approach introducing higher-order theory accounting through thickness effect. The variable stiffness in the composite laminate is spatially created introducing curvilinear fibers that continuously changes the fiber orientation within the lamina. The critical buckling temperature is evaluated solving the governing equations developed through the principle of minimization of total potential energy by adopting the eigenvalue approach. To select the appropriate structural model, the thermal buckling of such curved panels subjected to thermal fields are initially examined using different structural theories. To predict the buckling temperature, the thermal stress resultants are firstly evaluated using the displacement fields of pre-buckling of the laminated shells under the assumed temperature. The formulation is tested against considering problems for which analytical/numerical solutions available in the literature. A comprehensive study based on various design factors such as curvilinear fiber angular variation, lay-up, length-to- and radius-to-thickness ratios, and boundary conditions on the thermoelastic stability of laminated composite shell panels is made.

ABSTRACT: In this article, an analytical model is derived to investigate the in-plane homogenized stress-strain relationship of an adhesively bonded commercial hexagonal honeycomb core under large deformation. The model incorporates some advanced features of the core cell such as cell wall curvatures, node bond adhesive layers, and adhesive fillets at the cell wall intersections in the analysis. Nonlinear homogenized results of the fiberglass/phenolic honeycomb core predicted by the analytical model are compared with test data as well as predictions from finite element models (FEMs) of both real and idealized (without modeling the node bond adhesive) core cells to investigate the effects of the node bond adhesive. Predictions of the analytical model are in good agreement with the test data and predictions of the FEM of the real core cell. Homogenized properties of the honeycomb core obtained from the analytical model at infinitesimal strains are compared with several analytical models from the literature. Adhesive peel stress is also calculated by the analytical model and compared with the FEM.

ABSTRACT: A new shear-corrected Reissner-Mindlin model is presented. The method reduces the modeling error of the classical model without affecting the form of the classical plate equations. Therefore, implementation on an existing software for the Reissner-Mindlin plate model is simple. The principle of virtual work and an explicit set of kinematic and kinetic assumptions is used in derivation. There, displacement assumption of the classical model is enhanced by a warping part which is eliminated to end up with equations
for the classical part only. The equations differ from the classical ones in shear correction factors, modification in the source term, and stress expressions.


ABSTRACT: Understanding axial compressive failure mechanisms and estimating the related strength in continuous fibre composites is of paramount importance in the design of their parts. The mechanism at stake is the micro-buckling instability of fibres, which is contained by the matrix. In experimental measurements, compressive strength in bending is consistently higher than in axial compression. Indeed, the induced strain gradient provides an additional containment, namely structural effect. The characterisation of all geometrical and materials properties is usually lacking for models describing these combined mechanisms. A comprehensive experimental protocol is proposed in this paper to measure all the input parameters involved in a design oriented failure criterion. An epoxy matrix/high-modulus carbon fibre composite material illustrates this protocol. The influence of some key parameters, including the initial misalignment of the fibre, is discussed, thanks to additional experimental results.


ABSTRACT: Glass structures are often used in industries utilising large structural topologies. These structures are typically manufactured by post-curing subcomponents together, using a chopped strand mat layer at the interface. To predict failure of these joints requires an accurate assessment of the material and fracture properties. In this paper two industrially manufactured top-hat stiffened panels are tested to determine the fracture behaviour at the component level. This highlights that the variability seen in fracture properties at coupon level is less evident in structural component response. Then a previously developed set of material properties is used to accurately model the structural response, crack initiation and debonding of the panels under four point bend using Finite Element Analysis which gives final failure at 6.2 kN and a 4.4% error compared to the experimental results which exhibits final failure at 5.94 kN. The specific fracture properties tested and R curve are shown to be critical in assessing crack initiation and propagation with considerable error, 14.5%, provided by data assumed from the literature.


ABSTRACT: The purpose of this study is to provide an exhaustive review of the literature on the vibration and buckling of functionally graded materials (FGMs), functionally graded conical shells (FGCSs), functionally graded layered conical shells (FGLCSs), and functionally graded sandwich-conical shells (FGSCSs). The methodological solutions for various problems encountered in pure FGCSs and FGSCSs in the design, for example, linear and non-linear (NL) vibration and stability under various loads and the influences of the different environment are presented. The examples of FGM structures included in the review cover a wide range of applications in nuclear, space and marine engineering, electronics and biomedical fields.


ABSTRACT: This paper provides an efficient method for performing global layup optimization of composite laminates with buckling and manufacturing constraints. The optimization problem is divided into two stages and is based on the use of lamination parameters. During the first stage, exact finite strip analysis and continuous optimum design are employed for buckling optimization of the lamination parameters and laminate thickness. In the second stage, a logic-based procedure combining the branch and bound method with a global
layerwise technique is employed to find the optimal stacking sequences to match the optimized lamination parameters obtained in the first stage. In order to ensure the optimized layup can be used in practice, four manufacturing constraints are added into the logical search process, and the feasible region for the lamination parameters with a manufacturing constraint which requires at least 10% of each of four possible ply orientations are examined. It is found that the laminated GRC beam with graphene distribution pattern X has the smallest deflection and largest fundamental frequency at high length-to-thickness ratios, but it has largest deflection and smallest fundamental frequency at a very low length-to-thickness ratio due to its reduced transverse shear stiffness.


ABSTRACT: By assuming the plane-stress state in each layer, a two-dimensional elasticity model is proposed for laminated graphene-reinforced composite (GRC) beams. It is assumed that the graphene disperses uniformly in each layer but the graphene volume fraction may vary from layer to layer. For an arbitrary individual layer, the governing partial differential equations and boundary conditions are given directly from the two-dimensional elasticity theory. Then, the multi-term Kantorovich-Galerkin method is employed to build a state-space equation for the layer, in which the axial and transverse displacements are expressed as products of trial function matrix and unknown function matrix. Eventually, a global equation for the laminated beam is established by virtue of the displacement and stress continuity conditions at the interfaces. Non-dimensional displacements, stresses and natural frequencies are obtained for laminated GRC beams with different boundary conditions. The effects of graphene distribution patterns, boundary conditions, length-to-thickness ratios, layer fraction increments and the number of layers are examined. It is found that the laminated GRC beam with graphene distribution pattern X has the smallest deflection and largest fundamental frequency at high length-to-thickness ratios, but it has largest deflection and smallest fundamental frequency at a very low length-to-thickness ratio due to its reduced transverse shear stiffness.


ABSTRACT: In this article, performance of the elliptical patches of smart constrained layer damping (SCLD) treatment is investigated for controlling vibrations of smart laminated composite plates. A three dimensional mesh free model (MFM) has been implemented for the first time based on the element free Galerkin (EFG) method and layer wise displacement theory for studying the dynamic behavior of the composite plates integrated with the SCLD treatments. Symmetric/antisymmetric cross-ply and general angle-ply laminates are considered for the substrate of the smart composite plates. Circular and regular rectangular type patches are also considered for the analysis. It is observed that the elliptical SCLD patches are more efficient in attenuating the amplitude of vibration in the laminated composite plates as compared to the circular and square type patches. The results from numerical analysis also reveal that the elliptical patches have the maximum performance index followed by the circular and the square type SCLD patches in enhancing the active damping characteristics of smart composite plates. The performance of the elliptical patch is sensitive to the piezoelectric fiber orientation angle and becomes maximum if the piezoelectric fiber orientation is vertical irrespective of the types of SCLD patches considered as well as the lamination sequence.


ABSTRACT: The current study deals with thermal postbuckling behavior of graphene-reinforced composite (GRC) laminated cylindrical panels resting on elastic foundations. The GRC layers of the panel are arranged in a piece-wise functionally graded (FG) distribution along the thickness direction, and each layer of the panel contains different volume fractions of graphene reinforcement. The temperature dependent material properties of GRCs are estimated by the extended Halpin–Tsai micromechanical model with graphene efficiency parameters being calibrated against the GRC material properties obtained from the molecular dynamics simulations. The nonlinear governing equations for the thermally-loaded GRC laminated cylindrical panels are
derived based on the higher order shear deformation theory and include the geometric nonlinearity effects in the sense of the von Kármán nonlinear kinematic assumptions. The panel-foundation interaction and thermal effects are also considered. The thermal postbuckling equilibrium paths for the perfect and geometrically imperfect GRC laminated cylindrical panels are obtained by applying a singular perturbation method in conjunction with a two-step perturbation approach. An iterative scheme is developed to obtain the numerical thermal postbuckling solutions of the panels. We observe that the piece-wise functionally graded distribution of graphene reinforcement can enhance the thermal postbuckling strength of the GRC laminated cylindrical panel under a uniform temperature field.


ABSTRACT: A damage identification method, based on structural time domain dynamic responses and Teager energy operator, is presented for sandwich panels with truss core in the paper. The dimensionless structural dynamic responses, i.e., dimensionless velocity and displacement, are combined to construct damage index. Application of the method on sandwich panels in the cases of single damage and multiple damages with different extents are conducted. Effects of some factors on the method are discussed, including excitation location, excitation frequency, boundary condition, number of points N in Poincare maps. Numerical and experimental results show that the proposed method is effective in detecting both single damage and multiple damages with different extents. Excitation location plays a very important role in affecting the effectiveness of the method. Excitation frequency has little effect on the method, and there is a great selection space of excitation frequencies. Increasing the boundary condition constraint is beneficial for damage identification.


ABSTRACT: Experimental and numerical studies were conducted to analyze the low-velocity impact response of orthogrid stiffened panels reinforced with short alfa fibers. Tensile specimens and orthogrid panels were fabricated with two types of epoxy resins and different fractions of crushed and sieved alfa fibers (fiber volume fraction (Vf) from 10% to 50%). Impact tests were conducted on the orthogrid panels to investigate their low-velocity transverse impact behavior. The resistance to damage increased with an increase in fiber content and improvement in the mechanical properties of the composites (measured in static). Bending tests carried out on pre-impacted and non-impacted panels revealed a change in the linearity of the initial bending behavior, which could be justified by the small cracks generated by impact. A numerical model of impact on the orthogrid stiffened composite panels was developed using the nonlinear Hertz’s contact model. To simulate the failure mechanism and load-time history, a standard Tsai-Wu failure criterion was used on ANSYS explicit dynamic software. The simulations show a good correlation with the experimental data. The dominant stresses for damage evolution are found to be normal stresses. The presence of a stiffener reduces the stress, which confirms that stiffeners limit the propagation of damage.


ABSTRACT: The triangulation method has been an effective tool for estimating the source locations of various acoustic emissions (AE). However, it is hard to guarantee high accuracy in composite structures due to their anisotropy. Also, the conventional methods basically require the precise arrival time data of AE signals. Because most of commercial fiber optic sensing systems applicable to real structures have limited measurement performance, the arrival times cannot be clearly identified. In this paper, the magnitudes of fiber optic sensor signals were used for estimating the distances between each sensor and impact location. In order to obtain higher correlation between the magnitude and distance, the signal near the roughly estimated arrival time was
used for calculating the magnitude. Then, through the neural network training, the accuracy of estimating the distances from the signal magnitudes could be enhanced. Finally, the triangulation method was applied for localizing the impact sources. As a result, our suggested triangulation method showed the acceptable localization results about the non-trained impact points. Because the input data for this method could be reliably obtained from the commercial fiber optic sensing system, it can be useful for constructing a simple impact monitoring system for the real composite structures.


ABSTRACT: A semi analytical method is employed to analyze free vibration behaviors of functionally graded (FG) doubly-curved shells of revolution subject to general boundary conditions. The analytical model is established on basis of multi-segment partitioning strategy and first-order shear deformation theory. The displacement functions are made up of the Jacobi polynomials along the axial direction and Fourier series along the circumferential direction. In order to obtain continuous conditions and satisfy general boundary conditions, the penalty method about spring technique is adopted. The solutions about free vibration behaviors of FG doubly-curved shells were obtained by approach of Rayleigh–Ritz. The convergence study and numerical verifications for FG doubly-curved shells with different boundary conditions, Jacobi parameters, spring parameters and truncation of permissible displacement functions are carried out. Through the comparison and analysis, it is obvious that the proposed method has a good stable and rapid convergence property and the results of this paper closely agree with those obtained by published literatures, FEM and experiment. In addition, some interesting results about free vibration characteristics of FG doubly-curved shells are investigated.


ABSTRACT: The present article includes the modal analysis of laminated composite structures under thermal effect. Experiments are conducted to study the influence of temperature change on natural frequencies of glass fibre reinforced polymer (GFRP) composites. GFRP laminated plates are prepared in the laboratory using vacuum bagging by resin infusion. The specimens are thermally conditioned to obtain temperature variation ranging from −10 ◦C to 120 ◦C. A Green–Lagrange nonlinear finite element (FE) model based on third order shear deformation theory (TSDT) has been developed for the analysis. The FE solutions in terms of natural frequencies are compared with experimental data and an extensive parametric study is carried out. The free vibration modal analysis of a hollow stiffened laminated panel is also carried out to identify the effect of temperature change with respect to temperature distribution within the stiffened structures using 1D heat conduction model and the solutions may be used as benchmark.


ABSTRACT: In this study, a finite element (FE) model is proposed to study the thermal transverse vibrations of cracked nanobeams resting on a double-parameter nonlocal elastic foundation. Hamilton’s principal is employed to derive the governing equations for the free vibrations of the nanobeam. The cracked section of the beam is modelled by dividing the cracked element into two classical beam sections connected via a rotational spring positioned at the crack. The Galerkin method of weighted residuals is used to solve the equations of motion and calculate the natural frequencies. The effect of the crack length, crack position, the temperature gradient, the boundary conditions and the foundation stiffness, on the vibration response of the cracked nanobeams supported by elastic foundations is considered by including thermal effects. The FE results are compared to the available benchmark studies in the literature.

ABSTRACT: In this paper, some methods to determine the absolute frequencies of traveling waves in a rotating cross-ply laminated cylindrical shell with elastic supports are investigated. Based on the Sanders’ shell theory and by taking into account the Hamilton principle, the governing equations of motion are derived in the rotating coordinate system, which considers the effects of initial hoop tension, the centrifugal and the Coriolis forces due to the rotation as well. The constraint equations of elastic supports are modelled by using artificial distributed elastic springs in the possible directions. By substitution of mode shape profile functions into equations and using the differential quadrature method, the eigenvalue equations of the rotating shell are derived in both rotating and fixed systems. To make more comparison, the eigenvalue equation of synchronous critical speeds is also derived. Convergence and comparison of the proposed method is investigated through comparing its results with available literature. The comparison results shows that the direction of the corresponding traveling waves and the graphical determination of critical speeds are determined by a more convenient criteria with easier physical interpretation in the fixed system, specially by using the direct method which is more efficient in computation than the converting method.


ABSTRACT: In the present paper, a methodology for determination of an approximate value of the lowest buckling load of the thin-walled column under compression and with an arbitrary cross-section, affected by initial imperfections, whose amplitude does not exceed half the thickness of the wall, using a load-axial shortening plot, is presented. It has been shown that the load corresponding to an alternation in rigidity of the real structure on the load-axial shortening plot determines the buckling load with high accuracy. The attained results have been compared to the values corresponding to the bifurcation load and the lowest buckling loads determined with commonly used methods based on post-buckling equilibrium paths (i.e., P-w method, P-w method, inflection point method). The formulated problem of nonlinear buckling has been solved with the analytical-numerical method and the FEM. An influence of the imperfection amplitude on an approximate value of the lowest buckling load of laminated thin-walled structures has been analysed on the determined post-buckling equilibrium paths and the load-axial shortening plot. Non-symmetric configurations of laminate layers that additionally exhibit various types of the membrane and bending state coupling have been selected. Detailed computations have been conducted for short angle sections (i.e. angle columns) under uniform compression.


ABSTRACT: In the present study, an accurate Bezier based multi-step method is developed and implemented to find the nonlinear vibration and post-buckling configurations of Euler-Bernoulli composite beams reinforced with graphene nano-platelets (GnP). The GnP is assumed to be randomly and uniformly dispersed in the composite mix-proportion, with a random checkerboard configuration. Therefore, a probabilistic model together with an efficient simulation technique is proposed to find the effective moduli of a matrix reinforced GnP. It is worth noting that the presented micro-mechanics model found by the employed Monte-Carlo simulation matches exactly the experimental data and predicts the composite elastic constants more accurate than that found from other common methods, including the Halpin-Tsai theory. Also, for mathematical simplification, the composite beam in-plane inertia is neglected. The presented multi-step method is based on Burnstein polynomial basis functions while shows interesting potential to provide robust solutions for various initial and boundary value problems. It is found that adding a relatively low content of GnP would drastically increase the composite elastic constants, particularly in the transverse direction to fiber. In addition, the numerical results are compared with those provided by exact analytical solutions, where the stability of results suggests the effectiveness of the presented methodology.

ABSTRACT: Composite precast concrete sandwich panels made with diagonal FRP bar connectors have increasingly been used in the last few decades mainly due to their excellent thermal insulating properties. However, there is a lack of standards, design guidelines and reliable models that can be used for their analysis and design. In this paper, a finite element model is developed for investigating their structural behaviour, which aims to clarify their response and to provide a basis for establishing design guidelines. The model accounts for cracking and tension stiffening, material nonlinearity of concrete in compression, and geometric nonlinearity. The modelling challenges and assumptions are investigated, and the model is validated by comparing with other models and test results from the literature. The results explain the structural behaviour of these panels, which exhibit a partial composite action. The results also show that the failure mode of typical panels is ductile and dominated by yielding of the flexural steel reinforcement. A preliminarily investigation of the thermal effects shows that temperature gradients can lead to significant arching action in the panel and can affect its stability. The influence of the diameter and shape of the shear connectors and the stiffness of the insulation are investigated.


ABSTRACT: This paper investigates the nonlinear bending behavior of sandwich beams with functionally graded (FG) negative Poisson’s ratio (NPR) honeycomb core in thermal environments. The novel constructions of sandwich beams with three FG configurations of re-entrant honeycomb cores through the beam thickness direction are proposed for the first time. The temperature-dependent material properties of both face sheets and core of the sandwich beam are considered. 3D full scale finite element analyses are conducted to investigate the nonlinear bending behavior and the variation of effective Poisson’s ratio (EPR) of the sandwich beam in the large deflection region. The numerical simulations are carried out for the sandwich beams with FG-NPR honeycomb core, from which results for the same sandwich beam with uniform distributed NPR honeycomb core are obtained as a comparator. Finite element results showed that the thickness change of sandwich beams with NPR honeycomb cores are distinctly out of ordinary, and the NPR sandwich beams have significantly lower load-bending moment curves compared with those with positive Poisson’s ratio cores. The effects of functionally graded configurations, load distribution types, boundary conditions, temperature changes and length-to-thickness ratios on the bending load-deflection curves and EPR-deflection curves of sandwich beams are discussed in detail.


ABSTRACT: The subject of the paper is the stability and strength analysis of Fibre Metal Laminate thin-walled members subjected to axial loading. This study concerns specifically angle-ply multi-layered Glass Reinforced Aluminium (GLARE) composite type wherein the main focus is on the top-hat open cross-section profiles. Specimens were prepared by autoclave technique that provided a high-quality manufacturing. Symmetrical 3/2 lay-ups were analysed for which 7 stacking sequences were distinguished based on the fibres alignment in the composite layer. Composite specimens were axially compressed in laboratory tests by means of static testing unit that provided displacement control loading. The behaviour of thin-walled GLARE members was investigated with the main attention to post-buckling response together with various failure modes. First Ply Failure (FPF) analysis was carried out simultaneously by Tsai-Wu, Hashin and Puck failure criteria in order to detect a first failure occurrence. FEM analysis included also an attempt to estimate particular regions of laminate’s damage in post-buckling state. Application of various failure criteria allowed to track failure initiation and predict collapsed mode shapes of GLARE top-hat members that were found to be in a good agreement with experimental evidences.

ABSTRACT: In this study, sandwich structures with commercial-grade aluminium alloy skins and bio-inspired core (mycofoam) were fabricated and tested to obtain the axial compression response in terms of in-plane deformation measures and stress. The ensuing spectrum of response data from experimental tests were then fed into three different data driven models that include simple linear regression (SLR), artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS). The performance of the models is compared in estimating the compressive response of sandwich panels with the mycofoam. To assess the performance of models, coefficient of determination (R²), root mean squared error (RMSE) and mean absolute error (MAE) are used. Eleven different training algorithms are tested in ANN and Bayesian Regularization backpropagation with 9 hidden neurons is found to be the optimum ANN structure. In ANFIS model, triangular-shaped membership function (MF) with 20 rules gives the highest performance among 8 different MFs. All three models are found to be capable in estimating the compressive response. ANFIS model has the highest performance, followed by ANN model then SLR model with R², RMSE and MAE being 0.9999, 0.0818, 0.0415 for the training dataset; 0.9999, 0.1626, 0.0491 for the testing dataset and 0.9999, 0.0943, 0.0437 for the validation dataset, respectively.


ABSTRACT: The aim of this experimental investigation is to assess the response to low velocity impacts of green sandwich structures made of agglomerated cork encapsulated between two thin flax/epoxy face sheets. Three different cork densities were considered to assess their role on the response to impulsive loading, both in low and high strain rate conditions by Split Hopkinson Pressure Bar (from 90 to 238 l/s). The performance of these structures has been compared to that obtained with similar specimens using a traditional synthetic foam core. Despite the lower quasi-static mechanical properties of high-density cork (modulus and collapse stress of 117.65 ± 4.04 MPa and 4.29 ± 0.06 MPa, respectively), the cork-based structures exhibited a higher perforation threshold (94.41 ± 2.37 J) than synthetic foam-based sandwiches (79.71 ± 2.24 J) for impacts at room temperature. Finally, the material performance was evaluated under different temperatures, namely −40 °C and +80 °C, where perforation thresholds were found to be higher for cork-based structures (113.98 ± 6.04 J and 101.05 ± 2.42 J) compared to synthetic foam-based sandwiches (94.39 ± 2.20 J and 77.64 ± 1.70 J). The results show that the distinctive deformation mechanisms of cork allow to tailor the response to impulsive loading with a tunable damage extension through-the-thickness, despite a pronounced temperature dependent behaviour compared to synthetic foam.


ABSTRACT: In this work, finite element formulations based on higher order shear deformation theories are used for the nonlinear static analysis of Functionally Graded Material plate-shell type structures. Linear and geometric nonlinear behaviour of the plate-shell type structures are considered. For the nonlinear analysis, the incremental equilibrium path is obtained using the updated Lagrangian procedure and Newton-Raphson incremental-iterative method, incorporating the automatic arc-length method for the cases of snap-through occurrence. The finite element models are based on a non-conforming triangular flat plate/shell element with 3 nodes and 8 or 11 degrees of freedom per node. The solutions of some illustrative plate-shell examples are performed, and the results are presented and discussed with numerical alternative models.

Tao Yu, Hongchao Zhao, Ting Ren and Alex Remennikov (School of Civil, Mining and Environmental Engineering, Faculty of Engineering and Information Sciences, University of Wollongong, Northfields Avenue, Wollongong, NSW 2522, Australia), “Novel hybrid FRP tubular columns with large deformation capacity:
ABSTRACT: Extensive studies have been conducted on the use of fibre-reinforced polymer (FRP) as a confining material in hybrid tubular columns for civil construction, where the design of columns is often controlled by the stiffness and/or strength requirements. By contrast, the capacity of sustaining large deformation without losing structural integrity can be critical in some applications such as the standing supports for underground mines. This paper presents the conceptual development of a novel column form with large deformation capacity. The novel column consists of an outer FRP tube, and an infill made of coarse lumps/aggregates, which can be from coal rejects or other waste/recycled materials, as well as calcium sulfoaluminate (CSA)-based cementitious material with high water content. In addition to its large deformation capacity, the new column allows the extensive, direct and easy use of waste materials and eliminates the need for mixing concrete on site or transporting commercial concrete. This paper also presents the results from a series of compression tests on the new columns as well as two similar column forms. These tests demonstrate the very large deformation capacity of the new column and show that an existing stress-strain model for FRP-confined normal concrete can be used to provide reasonable predictions of the behaviour of the confined infill material in the new column. The potential applications of the new column and the needs for future research are also discussed.


ABSTRACT: The composite materials used at sea are today nearly all based on thermoset resins (polyester, epoxy). However, there is an increasing number of thermoplastic matrix polymers available on the market (PP, PA, PPS, PEEK…), which offer possibilities for forming by local heating, attractive mechanical properties and the potential for end of life recycling. The aim of this study was to design, manufacture and test thermoplastic composite pressure vessels for 4500 m depth, in order to establish a technical, economic and ecological assessment of the use of these materials to replace traditional composites underwater. First, finite element calculations have been carried out to optimize the stacking sequence with respect to the external pressure and buckling resistance. Thick thermoplastic cylinders were then manufactured and tested until implosion, their behaviour showed a good agreement with calculations. Overall, the results show that it is possible to use Carbon/Polyamide 6 (C/PA6) thermoplastic composite cylinders for deep sea applications, as implosion pressures higher than 600 bar (6000 m depth) were achieved.

Farzad Pashmforoush (Faculty of Engineering, Department of Mechanical Engineering, University of Maragheh, P.O. Box 55136-553, Maragheh, Iran), “Statistical analysis on free vibration behavior of functionally graded nanocomposite plates reinforced by graphene platelets”, Composite Structures, Vol. 213, pp 14-24, 1 April 2019, https://doi.org/10.1016/j.compstruct.2019.01.066

ABSTRACT: In this paper, a statistical analysis was performed on free vibration characteristics of functionally graded graphene reinforced composite (FG-GRC) plates. The effective mechanical properties of the graphene based polymer nanocomposite plates were estimated based on the modified Halpin-Tsai micromechanical model to account for the weak load transfer between the matrix and the reinforcement. Free vibration analysis was performed using higher order shear deformation theory. Then, analysis of variance (ANOVA) was carried out for comprehensive investigation of the parameters effect on vibration behavior of nanocomposites. The parameters under investigation were thickness ratio, volume fraction of graphene nanoplatelets (GPLs), distribution pattern of GPLs and boundary condition. The importance degree and contribution percentage of these parameters on natural frequency were calculated based on the ANOVA results. Followed by statistical analysis, an empirical/mathematical model was developed to express the natural frequency of the FG-GRC plates as a function of input parameters. The obtained results revealed that boundary condition and volume fraction of GPLs were the most significant parameters affecting the vibration characteristics of GPL/polymer nanocomposite plates, followed by thickness ratio and distribution pattern of GPLs, respectively. The regression models showed a quadratic relationship between the natural frequency and the involved input parameters.

ABSTRACT: The study investigates the effect of eccentric load on the stability and postcritical states of thin-walled CFRP channel section columns under compression. Test specimens are subjected to compression on a testing machine provided with a fixture for applying eccentric compressive loads. Loading forces, deflection and strains of the column walls and web are measured. The experiments also involve examination of the operating performance of a structure undergoing buckling and determination of its postcritical equilibrium paths describing the relationship between load and deflection. Based on experimental results, numerical models of composite structures are designed and verified by the FEM. The scope of the numerical analysis involves performing a linear analysis of stability, which allows for determining the buckling mode depending on the amplitude of compressive load eccentricity and corresponding critical loads. The next stage of the analysis involves performing a nonlinear analysis of the structures with implemented geometric imperfections reflecting the lowest buckling modes. Based on obtained results, postcritical equilibrium paths of the developed FEM models are determined. Obtained equilibrium paths are then compared with experimental characteristics of real structures. The numerical results and experimental findings show a satisfactory agreement.


ABSTRACT: This research presents a detailed experimental and numerical study on the compressive failure of woven fabric reinforced thermoplastic composites, with an open-hole and with a pinned open-hole. The experimental evaluations are performed on the composite specimens using the Combined Loading Compression (CLC) evaluation method. Experimental results, including load response and damage morphology, are obtained and analysed. A novel meso-scale damage model is developed, based on Continuum-Damage-Mechanics (CDM), for predicting damage in woven fabric reinforced composites. The developed model, which can capture fibre fracture and matrix cracking, as well as the nonlinear response within the woven composite materials, is employed to conduct virtual Combined Loading Compression (CLC) tests. Numerical simulation results are compared with the extracted experimental results for model validation. Good correlation is achieved between experimental and computational results for both the open-hole and the pinned open-hole, with a two-stage failure process being observed for the pinned open-hole.


ABSTRACT: This work is devoted to investigate the effects of moisture and temperature on the bending analysis of functionally graded porous plates resting on two parameters elastic foundation. The effects of transverse normal and shear strains are taken into account. The governing equations are determined via the principle of virtual work. Analytically Navier’s method is utilized to solve the governing equations for simply-supported FG porous plate. The determined results are verified by comparing the results obtained for the FG non-porous and porous plates with the available ones in the literature. The effects due to exponent graded and porosity factors, moisture and thermal loads, foundation stiffnesses, aspect ratio and side-to-thickness ratio on FG porous plate are all investigated.


ABSTRACT: This paper deals with the transient response of a glass-epoxy composite submersible hull subjected to underwater explosive shock and bubble. The physical process of the underwater explosive shock and the subsequent bubble evolution in the fluid is simulated by using the Multi-Material Arbitrary Lagrange Euler (ALE) formulation. The interaction of the composite submersible hull with the complex fluid is handled
ABSTRACT: In this paper, the wave based method (WBM) is presented to analyze the free vibration of composite laminated cylindrical shells with general classical and elastic restrained boundaries. The Reissner-Naghid’s theory is adopted to establish the equations of the motion force and moments, the displacement functions of composite laminated cylindrical shells are extended to wave functions which can accurately satisfy the equations of motion and boundary conditions. According to the kinetic relationship of the composite laminated cylindrical shell, the final equation of the composite shell will be obtained to calculate the free vibration results. To validate its accuracy, the vibration results of composite laminated cylindrical shells subject to various boundary conditions including the classical cases, elastic restraints and their combinations by WBM are compared with those published in the literature. The numerical values of the errors are used to prove the high precision and wide application of WBM. Furthermore, the effects of several important parameters, including boundary conditions, length to radius ratio, and elastic modulus on natural frequencies are discussed. Compared with other existing numerical methods, the present solution has the characteristics of complete matrix assembly and high calculation accuracy. When the boundary conditions change, only the initial parameters of the matrix need modifying to adapt.

ABSTRACT: The scaled boundary finite element method (SBFEM) coupled with the finite element method (FEM) for the simulation of the interaction problem between the elastic plate structure and the multi-layered unbounded elastic soil is first developed in this paper. First, the whole system is subdivided into three sub-domains, including the semi-infinite far-field system, the near-field sub-domain, and the plate structure. The far field of the soil is modeled by utilizing the modified scaled boundary finite element method with a scaling line instead of the scaling center used in the traditional SBFEM. In the traditional SBFEM, only the boundary is discretized with surface elements, so the spatial dimension is reduced by one, and the final governing equation can be solved analytically in the radial direction of the scaled coordinate system, and it can exactly meet the infinite domain problem. The stiffness matrix of the three-dimensional (3D) near field is obtained using the standard FEM. The SBFEM is also applied in order to simulate the deformation characteristics of the plate structure based on the 3D elastic equation without introducing any assumption of the thin plate theory, and the high-order spectral element is introduced in order to discretize the middle surface of plate so that the complicated curved boundaries can be better represented. Then, according to the principle of the degree of freedom matching at the same node, the global stiffness matrix of the plate-soil system can be obtained by coupling the stiffness matrices of the sub-domains at the far-field/near-field interface, as well as at the plate/near-field interface. Thus, the response of the whole system under the external load can be solved naturally. Four numerical examples, consisting of a square plate resting on an isotropic soil, multi-layered soil with weak and thin interlayer, a plate with a different geometrical shape and a square plate with a hole, are provided in order to validate the accuracy and versatility of the proposed formulations.

ABSTRACT: In this study the nonlocal bond-based peridynamic (PD) theory was applied to simulate Lamb wave transmission in 2D bimaterial plates. Plates of unlike materials were jointed end-to-end to make a bimaterial plate. The surface of the plate was then excited tangentially by single-frequency and multi-frequency force signals. The influence of changing material properties on travelling of the symmetric and antisymmetric Lamb waves were studied in detail. The phase and group velocities of travelling wave in bimaterial plates were calculated and it was found that dissimilar material properties of two joint plates can significantly alter the amplitude and arrival time of the wave. Moreover, Fast Fourier Transform (FFT) of the time history of symmetric Lamb wave velocity was calculated and verified. Accuracy and consistency of PD wave model was confirmed entirely using Spectral Finite Element Method (SFEM). The comparison between the results of two applied methods shows a good agreement.


ABSTRACT: Aluminum foam sandwich (AFS) structures are suitable for impact protection in lightweight structural components due to their specific energy absorption capability under compression. However, tailoring the deformation patterns of the foam cells is a difficult task due to the randomness of their internal architecture. The objective of this study is to analyze the effect of embedding aluminum pins into an AFS panel (Z-pinning) to better control its deformation pattern and improve its energy absorption capability. This study considers a closed-cell AFS panel and analyzes the effect of multi-pin layout parallel to the direction of the uniaxial compressive loading. The results of the experimental tests on the reference (without Z-pinning) AFS are utilized to develop numerical models for the reference and Z-pinned AFS structures. Physical experiments and numerical simulations are carried out to demonstrate the advantages of Z-pinning with aluminum pins. The results exhibit a significant increase in elastic modulus, plateau stress and energy absorption capability of the Z-pinned samples. Also, the effect of the pin size and Z-pinning layout on the mechanical performance of the Z-pinned AFS is also investigated using numerical simulations.


ABSTRACT: This paper is devoted to examining the nonlinear vibrational behaviors of functionally graded (FG) sandwich nanobeams in the presence of initial geometric imperfection. Based on the nonlocal strain gradient theory, the governing equation of the FG sandwich nanobeam with consideration of the Von-Karman nonlinearity and initial geometric imperfection is derived. The nonlinear oscillator frequency is obtained with the aid of He’s variational principle. Three types of nanobeams, i.e., FG nanobeam (Type A), sandwich nanobeam with homogeneous core and FG skins (Type B), and sandwich nanobeam with FG core and homogeneous skins (Type C) are taken into account. A cosine function similar to the mode shape form is employed to describe the geometric imperfection mode. Firstly, the present theoretical model is verified by comparing with previous perfect FG sandwich beams. Then, several key parameters such as the power-law exponent, the amplitudes of the nonlinear oscillator and the geometric imperfection, as well as the nonlocal and material characteristic parameters are investigated in detail. Finally, apart from the structural types, the influence of thickness distribution scheme is also thoroughly elucidated. The results obtained in this paper are helpful for exploring the FG sandwich design to enhance the mechanical performance of nano-devices.


ABSTRACT: The vibration characteristics, including fundamental frequencies and loss factors, of a sandwich conical shell with constrained viscoelastic layers is presented. The mechanical properties of viscoelastic core is modeled using Zener fractional order model. The equations of motion are derived employing Donnell representation of classical shell theory and solved using Rayleigh-Ritz method. The results are compared with other investigations and the effects of geometric parameters including the length to radius, radius to thickness and core to facing thickness on fundamental frequencies and loss factors are studied.

ABSTRACT: Functionally Graded (FG) structures are a novel design through which the material properties vary smoothly and this feature leads these structures to have better mechanical or thermal performances. They are mostly constituted from two or more materials with gradually varying volume fraction distribution. Most of the publications on the optimization of laminated composite structures were investigated in the first part of the authors’ review paper (Nikbakht et al. 2018) [1]. In this research which acts as the second part, the majority of publications on optimization of FG structures are reviewed. In addition to FG beams, plates and shells, various structures such as tubes, implants, rotating disks, sport instruments, etc. are investigated. Furthermore, the key outputs of each publication are represented to make this article an asset source for mechanical engineers since there has not been any comprehensive review article on optimal designs of FG structures in the literature.


ABSTRACT: C/SiC composite lattice-core sandwich panels combined with thermal insulation and load-bearing capacities are considered as the most promising candidates for thermal protection system (TPS). In this study, C/SiC pyramidal lattice-core sandwich panel with different inclination angles were fabricated using a compression molding and precursor infiltration and pyrolysis (PIP) method. In-plane compressive experiments are conducted to study the failure behavior of these sandwich panels. The analytical failure modes including elastic buckling, face sheet wrinkling, face sheet crushing and interlayer delamination are established to construct the mechanism maps. The effect of geometrical parameters on failure modes are symmetricaly and analytically studied. Due to the limits of the cost, virtual tests are supplemented by finite element method (FEM). Face sheet crushing is experimentally observed for almost all specimens with different inclination angles, which is in good agreement with analytical predictions. Numerical simulation results show that interlayer delamination occurs at the attachment between face sheet and lattice core after elastic buckling and core shear buckling. This paper gives us some fundamental understanding of the mechanical response and failure mechanism of C/SiC composite lattice-core sandwich panels.


ABSTRACT: This work addresses the problem of the three-dimensional free vibration behavior of skew magneto-electro-elastic plates under the framework of a higher order shear deformation theory. To this end, the finite element method was adopted considering the Hamilton’s principle. The results obtained from the present finite element model are verified with the simulation results of COMSOL software. Further, a parametric study is carried out to evaluate the influence of boundary conditions, stacking sequence, aspect ratio, and the length-to-width ratio. A special emphasis has been given to the natural frequency characteristics of multiphase skew magneto-electro-elastic plates as well. The results from the present analyses allow concluding on the significant influence that the geometrical skewness has on the free vibration behavior of these plates.


ABSTRACT: In this study, we for the first time present an isogeometric Bézier finite element formulation for bending and transient analysis of functionally graded porous (FGP) plates reinforced by graphene platelets (GPLs) embedded in piezoelectric layers. We name it as PFGP-GPLs for short. The plates are constituted by a core layer, which contains the internal pores and GPLs dispersed in the metal matrix either uniformly or non-uniformly according to three different patterns, and two piezoelectric layers perfectly bonded on the top and bottom surfaces of host plate. The modified Halpin–Tsai micromechanical model is used to estimate the
effective mechanical properties which vary continuously along thickness direction of the core layer. In addition, the electric potential is assumed to vary linearly through the thickness for each piezoelectric sublayer. A generalized Co-type higher-order deformation theory (Co-HSDT) in association with isogeometric analysis (IGA) based on Bézier extraction is investigated. Our approach allows performing all computations the same as in the conventional finite element method (FEM) yet the present formulation shows more advantages. The system of time-dependent equations is solved by the Newmark time integration scheme. The effects of weight fractions and dispersion patterns of GPLs, the coefficient and distribution types of porosity as well as external electrical voltages on structure’s behaviors are investigated through several numerical examples. These results, which have not been published before, can be considered as reference solutions for future works.


ABSTRACT: Gradation along the plate thickness is considered in plate structures in practice. It concerns especially issues of linear and non-linear stability of functionally graded (FG) structures. In the present work, a square in-plane FG plate made of a step-variable gradation material was assumed. A five-strip FG plate with two cases of boundary conditions: simply supported on all edges and clamped on longitudinal edges was considered. A stability problem of the FG plate subjected to compression and shear load and a non-linear issue of stability of the compressed plate was solved. To compare the results, the calculations were carried out with three methods.


ABSTRACT: This paper presents an investigation of the free vibration of annular sector sandwich plates with carbon nanotube reinforced face-sheets and various edges boundary conditions. It is assumed that carbon nanotubes are radially aligned and distributed uniformly (UD) or functionally graded (FG) in the thickness direction. The effective material properties of CNT reinforced face-sheets are estimated using the extended rule of mixture, which contains efficiency parameters to consider the size-dependent material properties. A variable kinematic model which has been utilized for FGM cases is extended to FG-CNTs to describe the continuous variation of properties through the thickness. In this paper, the Carrera’s Unified Formulation (CUF) is developed for the analysis of asymmetric sector plates for the first time. The governing equations and associated boundary conditions are obtained employing the Principle of Virtual Displacements (PVDs) based on the CUF and solved using the generalized differential quadrature (GDQ) method. Numerical results for some special cases are presented and validated by comparison with available results in the literature. Some numerical results are tabulated to show the effects of the volume fraction of carbon nanotubes, boundary conditions and geometrical parameters on the free vibration behavior of the annular sector sandwich structures with CNTRC face-sheets.


ABSTRACT: The study investigated thin carbon/epoxy composite plate elements with a central cut-out of regular shape, under uniform compression. The aim of the study was to investigate the possibility of using these elements as elastic elements whose stiffness depends on tailoring the cut-out geometry and laminate ply orientation. To ensure stable operation of the structure in the postbuckling range, the plate was assigned the properties of an unsymmetrical lay-up with extension-twisting and extension-bending couplings. The structure was analysed numerically by the finite element method. The scope of numerical simulations included linear analysis of an eigen problem using procedures for geometrically nonlinear analysis and the commercial simulation software ABAQUS. The aim of the analysis was to determine a laminate ply orientation generating
methods, the ANN model showed the highest accuracy. Among the utilized methods including artificial neural networks (ANN), group method of data handling (GMDH), and genetic algorithms, the use of soft computing has been expanded due to good national problems. In this study, three methods including Artificial neural networks, Group method of data handling and Gene expression programming are utilized to predict the compressive strength of columns confined with FRP. Total of 95 experimental data were selected to form the model. The height of the column, the compressive strength of unconfined concrete, the elastic modulus of FRP, the area of longitudinal steel, the yield strength of longitudinal steel and confinement pressure provided by FRP and transverse steel were considered as input parameters, while the compressive strength of FRP-confined columns was considered as the target. The proposed methods are compared with the existing models and provide great accuracy in predicting the results. Among the utilized methods, the ANN model showed the highest accuracy.

ABSTRACT: An integrated design approach of laminated composite structures actuated by piezocomposite materials is presented for active shape control. The primary purpose is to maximize static shape control authority of a piezo-actuated laminated plate by simultaneously optimizing the substrate laminates and the actuators. The design variables include thickness, ply angles of the substrate plate and locations, PZT fiber orientations of the actuators. Frequency constraints are implemented to obtain acceptable solutions. General genetic algorithm (GA) and NSGA-II are used to obtain the optimal designs. The results indicate that enhanced control authority must be achieved by simultaneously optimizing the substrate laminates and actuators. The bending-twisting coupling effect of the composites and anisotropic actuation effect of the piezocomposite actuators are conducive to produce improved static control performance. More shape control authority is available due to the presence of more actuators. Larger deformation can be produced with a low mass of the host composites without constraints but the structure would be too flexible. A series of Prato-optimal results can be obtained by considering trade-off between shape control authority and mass of the whole structure while considering constraints. Reasonable, practical designs can be obtained by imposing frequency constraints in the integrated design.


ABSTRACT: Experiment in literature has shown the aggregation phenomenon in carbon nanotube (CNT) reinforced polymeric composites. In this paper, considering the aggregation effect of CNTs and porosity in both polymeric matrix and aggregated CNT clusters, a mechanical model to investigate the coupled conduction of temperature and moisture as well as the hygrothermal mechanical behaviors of a porous functionally graded CNT reinforced composite (FG-CRC) rotating annular plate with variable thickness is built. Numerical results of the temperature and moisture fields as well as the hygrothermal mechanical responses are achieved by combining the differential quadrature method (DQM), the Runge-Kutta method and the Newmark method. Several useful conclusions as follow are obtained through numerical examples and discussions. In the numerical examples, influences of the aggregation effect of CNTs, coupled effect of temperature and moisture, material property (graded index and porosity parameters), geometric parameters as well as the rotating conditions to the hygrothermal mechanical responses of the porous FG-CRC annular plate are studied in detail. The theoretical process and conclusions will be helpful to the design and manufacture of novel porous graded materials and structures applying in hygrothermal environment and conditions.


ABSTRACT: Thin-walled beams are widely adopted as the key frontal energy absorption component in automotive body. This work focused on the numerical modelling of a CFRP hat-shaped thin-walled beam under axial-crushing load, which was well validated against testing data as well as experimentally observed fracture behaviour. CFRP hat beam was manufactured with prepreg IM7/8552 through hot-press moulding, and then bonded with a base plate using structural adhesive. The adhesively bonded CFRP beam was loaded under axial crushing to investigate the fracture behaviour in CFRP as well as adhesive layer. The crushing process of CFRP beam was numerically modelled, where the strength-based Chang-Chang failure criterion was adopted to determine the fracture property of CFRP, while Tiebreak was attached in the adhesive and matrix to simulate the interfacial and interlaminar failure. Experimental work revealed that obvious interlaminar failure was observed in CFRP beam, with the outer layers curving outward and inner layers bending inward. Numerical modelling showed good agreement with the experimental data in the aspects of initial peak load and energy...
absorption. Based on the developed modelling technique, the fracture behaviour in CFRP beam as well as the interfacial failure in adhesive layer and composite matrix can be well predicted and evaluated.


ABSTRACT: Recent research has been devoted to thin laminates as a result of aeronautic industries shifting to thinner and lighter structures. In an attempt to improve the out-of-plane response and reduce manufacturing costs considerably, airplane manufacturers are exploring (apart from unidirectional tapes) textile fabrics of different fabric architectures. Within the framework of thin laminates, this paper investigates the impact and compression after impact (CAI) of two types of aerospace graded spread-tow fabrics, namely non-crimp fabrics and woven fabrics, where stitching and weaving, respectively, govern the architecture. The study also comprises two different ply thicknesses (thin and intermediate ply grades) for both fabrics. Experimental results reveal that while woven fabrics display higher damage resistance, non-crimp fabrics ensure higher damage tolerance. The intermediate ply grade performed better than thin plies in terms of damage resistance and CAI strength for both fabrics, as thin ply non-crimp fabric laminates exhibited early and extensive fibre damage.


ABSTRACT: Free vibration behavior of bidirectional-functionally graded, double-tapered rotating micro-beam is investigated. An improved mathematical model based on Timoshenko beam theory and modified couple stress theory is developed that includes the effects of geometric non-linearity, spin-softening, Coriolis acceleration and high operating temperature. The problem is formulated in two steps. In the first step, the problem involving time-invariant inertia force due to rotation of the beam with constant angular speed is formulated using minimum potential energy principle and the governing non-linear equations are solved employing an iterative algorithm. In the next step, the free vibration problem is formulated employing Hamilton’s principle and using the tangent stiffness of the deformed configuration induced due to time-invariant inertial loading. The governing equations for free vibration are transformed to state-space to formulate an eigenvalue problem. The governing equations are solved by approximating the displacement fields following Ritz method. The model is successfully validated with the available results. Extensive sets of results are presented for the first two chord-wise and flap-wise modes of vibration in non-dimensional speed versus frequency plane. The effects of different parameters such as size-dependent thickness, axial and thickness gradation indices, taperness parameters, hub parameter, length-thickness ratio, operating temperature and FGM composition are reported.


ABSTRACT: This study presents the efficient manufacturing of rectangular wood-cored GFRP sandwich components by pultrusion process. Unlike the traditional pultruded sections by use of the roving, three types of mats (strand mat, uni-axial fabric and tri-axial fabric) were adopted to improve the web-flange junction integrity of GFRP hollow-section (HS) and sandwich section (SS) specimens. The mechanical behavior of glue-laminated Douglas-fir (DF), HS, and SS specimens under four-point bending was investigated. The test results showed that DF and HS specimens failed by tensile rupture and web buckling, respectively. The SS specimens exhibited excellent ductility and load-carrying capacity resulting from three main reasons: a) the step-by-step wrinkling of GFRP web, b) the plastic deformation capacity of the timber under the local compression parallel and perpendicular to the grain and c) the bond-slip between the timber core and the GFRP inner surface. Meanwhile, the acoustic emission (AE) system was applied to detect the damage signals. Comparisons between failure progresses and AE signal analysis suggest that cumulative AE energy was more effective than hits to
characterise the damage stages. A 2-D damage location model was also developed. The predicted damage locations agreed well with the experimental failure modes.


ABSTRACT: The recent advancement in the manufacture and analysis of Carbon nanotubes (CNT) has persuaded many researchers to use them as the reinforcing phase of a polymer matrix. Nevertheless, it should be recalled that polymers show a viscoelastic behavior, so that their mechanical properties are functions of time due to the intrinsic nature of the material. In this paper, a Maxwell rheological model is employed to describe the time-dependency of the mechanical properties of the matrix in the framework of linear viscoelasticity. The viscoelastic matrix is enriched by both CNTs and oriented fibers to obtain the so-called three-phase composite materials. Such materials represent the main constituents of the plates investigated in this paper by means of the Reissner-Mindlin theory. The transient response, which is analyzed through the Newmark’s scheme, is expressed in terms of central deflection and mechanical parameters for several configurations. The effect of the mass fraction of both reinforcing phases is discussed. The solutions are achieved numerically by means of a Finite Element (FE) code which implements the viscoelastic model and the proper homogenization technique in order to deal with three-phase composites.


ABSTRACT: The work aims to investigate the capability of a vertical tail leading edge to withstand bird strike and to provide general considerations on the improvement of such capability with respect to the mass saving and to the required structural performances by considering different material systems. The assessment of the numerical models was ensured by a double check, and therefore considering the two test cases, aimed to calibrate and validate the numerical models against experimental data, coming from literature: 1) bird strike on metallic flat square plate; 2) bird strike on wing leading-edge with the skin made in metallic sandwich structure (both the honeycomb core and the outer and inner face was in aluminum). Finally, the crashworthy design of several leading-edge configurations, modifying the material and thickness of the skins and the central core of the leading edge, without changing its external geometrical shape, was investigated by adopting the numerical procedures used for the validation test cases. Actually, unidirectional fiber-reinforced composite material systems were considered for the outer and inner face of the skins, while different materials were adopted for the core. A comparison among the developed configurations, in terms of requirement fulfillment, global deformation parameters and weight, was performed.


ABSTRACT: Current challenges in the automotive industry are the reduction of fuel consumption and the CO₂ emissions of future car generations. These aims can be achieved by reducing the weight of the car, which further improves the driving dynamics. In most currently mass-produced cars, the body accounts for one of the largest parts by weight, and hence designing a lightweight car body assumes great importance for reducing fuel consumption and CO₂ emissions. Extremely lightweight designs can be achieved by using purely composite materials, which are very light but also highly cost intensive and not yet suitable for large scale production due to the necessity of manual processing. A promising approach for the automated, large-scale production of lightweight car structures with a high stiffness to weight ratio is the combination of high strength steel alloys and CFRP prepregs in a special hybrid material/fiber metal laminate (FML) – which can be further processed by forming technologies such as deep drawing. In current research work at the Chair of Forming and Machining Technology (LUF) at the University of Paderborn, innovative manufacturing processes are being developed for the production of high strength automotive structural components made of fiber metal laminates. This paper presents the results of technological and numerical research that is currently being performed at the LUF into
the forming of hybrid fiber metal laminates. This paper focuses on the results of basic research and the individual measures (tool, process and material design) necessary for achieving the desired part quality.


ABSTRACT: The influence of various homogenization models is studied on the free vibration behavior of a functionally graded material (FGM) curved microbeam which is modeled using the modified strain gradient theory of elasticity as well as the first-order shear deformation theory. Different homogenization models (such as Voigt, Reuss, Hashin-Shtrikman bounds, and cubic local representative volume elements (LRVE) schemes) are used to predict the effective material properties of a two-phase particle composite as a function of the volume fraction of particles which are continuously varying along the thickness of a functionally graded microbeam. Employing Hamilton’s principle, the governing equations of motion and boundary conditions are derived. Finally, the numerical results are presented to determine the effect of homogenization models on the vibrational behavior of FGM curved microbeams corresponding to different continuum models for over a wide range of material composition, opening angle, dimensionless length scale parameter and aspect ratio. It is shown that the common used Voigt model overestimates frequencies and the Mori-Tanaka model also overestimates frequencies but provides smaller error in comparison with the Voigt model. In terms of theoretical analysis, LRVE model creates a good compromise between estimation accuracy and the ease of implement, especially for the FGM with a relative high stiffness ratio. The difference of various homogenization models can be raised when considering the decrement in aspect ratio or the increment of opening angle and mode number.


ABSTRACT: In this article, the deformation characteristics of sinusoidally-corrugated laminated composite panels are examined under uniform and sinusoidally distributed transverse loads. The sinusoidal corrugation in laminate structure is achieved using the general curvature method. The displacement field is based on the third-order shear deformation mid-plane kinematics theory with nine degrees-of-freedom. The minimum total potential energy method is employed to obtain the governing equation. The solutions are obtained using two-dimensional finite element approximation via nine-noded isoparametric quadrilateral Lagrangian element. The convergence and comparison studies reveal the consistency and accuracy of present model. The new numerical illustrations reflect the significance of corrugation ratios, edge constraints, side-to-thickness ratios and aspect ratios on the deformation behavior of the corrugated and non-corrugated laminated composite panels.


ABSTRACT: Multi-stable composite laminates have been widely investigated for morphing applications due to distinct geometrical characteristics about each stable configuration. Recently, a mechanism for realizing on-demand stiffness adaptation in compliant structures has been proposed exploiting the stiffness variation from switching between the stable states of embedded bi-stable laminates. This allows for reducing the coupling between loading and morphing deformation modes, broadening the overall design space for morphing structures. However, the design of such embeddable laminates requires the study of multiple lamination domains to allow embedding within larger compliant structures. This process is currently done by computationally expensive simulations. We present an analytical model to predict the stable shapes and structural characteristics of multi-section, multi-stable composite laminates subject to two clamped boundary conditions. The analysis is conducted employing the Rayleigh-Ritz method using polynomial approximations of the displacement fields. The structural characteristics are predicted while constraining the laminate edges, thus extending previous models designed to account mainly for free edge boundary conditions. Our model is subsequently applied to explore the design space for characterizing the stability and variable stiffness properties
of two different classes of bi-stable laminates. The presented model allows for the efficient design of multi-stable laminates embeddable within compliant structures.


ABSTRACT: Over the past decades, a vast number of theories for numerical modeling of laminated composite plates and shells has been developed by various researchers and for diverse reasons. Three-dimensional elasticity theory, equivalent single-layer theories, zig-zag theories and layerwise theories are notable examples. In general, computing 3D elasticity solutions require huge computational time, the ESL theories cannot furnish satisfying results for thick laminates or laminates with distinct properties between layers, and the zig-zag theories cannot directly obtain the transverse stress fields from the constitutive model. The layerwise theory treats each layer individually and Co-sub-z continuity is satisfied from the beginning; therefore, it yields results comparable to 3D elasticity solutions. These attributes and advantages have driven the prosperity of layerwise theories for analysis of composite laminates and structures. The main aim of this review is to provide the recent development of layerwise theories, their numerical implementation, and application in the analysis of composite laminated structures. The main conclusions and possible future research trends are presented. We expect this review will provide a clear picture of layerwise theory for modeling of composite laminated structures and serve as a useful resource and guide to researchers who intend to extend their work into these research areas.


ABSTRACT: Three-dimensional (3D) exact hygrothermal elasticity solutions are developed to study the behaviour of simply supported rectangular multilayered composite plates, considering any combination of orthotropic and/or isotropic layers, under hygro-thermo-mechanical loadings. In agreement with the 3D exact elasticity solutions derived by Pagano in the early 1970s, the form of the through-thickness exact solutions of any given layer depends, in fact, on whether the layer material is isotropic or (at most) orthotropic. The 3D exact thermoelastic solutions found, already available, consider either only isotropic layers or only (at most) orthotropic composite layers. This work aims to be all-inclusive, in addition to a further development by considering hygrothermal elasticity. The results here presented consider composite laminates, fibre metal laminates and sandwich plates with different side-to-thickness ratios under a series of hygro-thermo-mechanical loadings. A transverse mechanical load and/or thermal load and/or hygroscopic load are imposed on the multilayered plate top and bottom surfaces to study the effects of hygrothermal environments in the multilayered plate behaviour. These effects are demonstrated by the through-thickness distributions of displacements, stresses, temperature and weight percent moisture content for the selected multilayered plates under different hygro-thermo-mechanical loadings, which may serve as 3D benchmark exact solutions.

Armagan Karamanli and Metin Aydogdu (First author is from: Faculty of Engineering and Natural Sciences, Department of Mechatronics Engineering, Bahcesehir University, 34353 Istanbul, Turkey), “On the vibration of size dependent rotating laminated composite and sandwich microbeams via a transverse shear-normal deformation theory”, Composite Structures, Vol. 216, pp 290-300, 15 May 2019, https://doi.org/10.1016/j.compstruct.2019.02.044

ABSTRACT: In this paper, the eigenfrequencies of rotating laminated composite (LC) and sandwich microbeams with different boundary conditions (BCs) are studied. The size-dependent variational formulation of the problem is obtained based on the Modified Couple Stress Theory (MCST) by employing a transverse shear-normal deformable beam theory and finite element method (FEM) formulation. The convergence and verification studies of the developed code are carried out and computed results in terms of dimensionless fundamental frequencies (DFFs) are compared with the available ones in the open literature. Various BCs, aspect ratios, fiber orientation angles, thickness to material length scale parameter (MLSP) ratios, core thickness to face layer thickness ratios, dimensionless rotation speeds (DRSs) and hub ratios are employed for the
extensive analyses. It is found that the DFFs of the LC microbeams are highly affected by the small size effect accompanying with the orthotropy ratios, DRSs, hub ratios and fiber orientation angles. The effect of the small size on the DFFs of the rotating clamped-clamped LC microbeams is more pronounced than on those of the rotating clamped-free LC microbeams. The hub ratio has a significant effect on the DFFs of the rotating LC microbeams than the rotation speed.

ABSTRACT: In this paper, an experimental study on the dynamic of cylindrical shells made of Polyethylene terephthalate (PET) is presented; a thermic gradient has been applied on a specimen of the present work to obtain a functionally gradient material (FGM) equivalent properties: the PET shell had been exposed at a thermal temperature gradient in the range of its glass transition temperature of 79 °C. A complex setup has been specifically designed and built to characterise, with dynamic tests, the structural properties of the specimen on temperature change from −10 °C up to about 90 °C and under thermic gradient with different forcing load. Predicting the mechanical properties of shells, panels and plates is one of the main concerns of structural engineers; since shell elements present complicated stability behaviours, rich linear vibration spectra (high modal density), high sensitivity to perturbations and strong interactions with surrounding elements. The linear and dynamic behaviour have been investigated. The shell behaviour is also investigated by means of a finite element model, in order to enhance the comprehension of experimental results.

ABSTRACT: The aim of the present study was to initiate an investigation based on the design of a thin sandwich panel with an auxetic (i.e. exhibiting negative Poisson’s ratio) lattice core using wood composites and 3D print technology. The sandwich panels were fabricated by attaching the 3D LayWooden pyramidal truss structures to HDF face sheets with the PVCa adhesive. The mechanical strengths and failure mechanisms under bending load were estimated experimentally, analytically and numerically. The results showed that the mechanical properties of beams increase with an increasing inclination angle of struts and/or relative density of the core. No signs of damage were observed, such as face sheet crushing (FC) or wrinkling (FW), core member crushing (CB, CC) (delamination or fracture). Damage to the composites occurred due to shearing in the struts of the cells. The greatest rigidity was recorded for beams with a D-core. The data could provide insight into the design of optimized or near-optimized sandwich panels.

ABSTRACT: The buckling and post-buckling behaviors are analyzed for the multilayer functionally graded graphene platelets reinforced piezoelectric (FG-GRP) plates. The FG-GRP plates are subjected to the external electric potential and axial forces, including the uniaxial loading and biaxial loading. The graphene platelets (GPLs) disperse uniformly and parallelly in each graphene platelets reinforced piezoelectric composite (GRPC) layer, but they spread grading across the thickness of the FG-GRP plates. The effective Young’s modulus of each layer for the FG-GRP plates is calculated by the Halpin-Tsai parallel model. The rule of the mixture is employed to predict the Poisson’s ratio, effective mass density and piezoelectric properties of each layer of the FG-GRP plates. The governing equations of motion for the FG-GRP plates are obtained by the first-order shear deformation plate theory, von Karman nonlinear theory and principle of virtual displacements. To obtain the buckling and post-buckling behaviors of the FG-GRP plates with different boundary conditions, the differential quadrature (DQ) method and a direct iterative technique are combined to solve the governing equations of
motion for the FG-GRP plates. The impacts of the external electric voltage, distribution pattern, volume fraction, piezoelectric properties, length-to-thickness of the GPLs and geometry of the plates on the critical buckling load and post-buckling equilibrium paths of the FG-GRP plates are discussed in detailed. It is clearly illustrated that the GPLs have a significantly enhancing influence on the buckling and post-buckling strength of the FG-GRP plates.


ABSTRACT: The buckling load parameters of the graded nanotube sandwich structure reported in this article under the influence of uniform thermal loading. The corresponding properties of the graded nanotube sandwich evaluated via the extended rule of mixture including temperature dependent properties of each constituent. The nanotube structural model derived mathematically using a higher-order polynomial displacement to maintain the required shear stress continuity and thermal distortion via Green-Lagrange strain. Further, the variational technique is adopted to obtain the governing equilibrium equation of the sandwich structural panel and the subsequent algebraic form achieved using the isoparametric displacement finite element steps. The computational buckling load parameter predicted using the own MATLAB code with the help of the current mathematical model. The model accuracy and the consistency are established through simultaneous convergence and validity study with available published results. Finally, the detail applicability of the current higher-order model is highlighted through a series of numerical examples and corresponding inferences.


ABSTRACT: This paper experimentally investigates the effect of Carbon Fibre Reinforced Polymer (CFRP) on the axial capacity of concrete-filled steel tubes with different timber cores. The stub columns were designed having the size of the infill and the CFRP as the main two variables. The structural response including failure, ductility, stiffness and structural efficiency were evaluated and discussed. It was found that the effect of timber core is significant in lightening the weight of the composite, although the total capacity of the composite depends upon the material properties of the core versus the grade of concrete and steel employed in the composite columns. For the structural applications, where the weight reduction and ductility are crucial, the development of this innovative composite is highly recommended. To quantify this, the ratio of ductility index to weight is introduced including these two crucial parameters in the seismic design. An equation is also developed to estimate the axial capacity of timber-concrete-filled steel tubes. Furthermore, the environmental and sustainability assessment are touched on briefly to pave a path for the future work aiming at possibly reducing the contribution of the concrete in the construction.

Nam Vu Hoai, Duc Hong Doan, Nguyen Minh Khoa, thom Van Do and Hong Thi Tran (First author is from: Division of Computational Mathematics and Engineering, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Viet Nam), “Phase-field buckling analysis of cracked stiffened functionally graded plates”, Composite Structures, Vol. 217, pp 50-59, 1 June 2019, https://doi.org/10.1016/j.compstruct.2019.03.014

ABSTRACT: A finite element method and phase-field model used by authors have been firstly extended to the buckling analysis of stiffened functionally graded (FG) plate with cracks. The finite formulation of the plate is based on the first order shear deformation theory (FSDT). The material properties of the FG plate change from the bottom surface to the top one by a power-law function, the stiffener is full of the material, which is the same as the bottom surface, where the stiffeners are attached to. Firstly this work studies on the accuracy of our results with reference solutions available in the literature. Then, the exploration of the interaction between the stiffeners and cracks under compressive buckling is investigated. The numerical results show much useful information for readers, scientists, designers, especially the smallest of the stiffener depth needs to add to the cracked FG plate to have a cracked one with stiffeners, which has the same buckling strength as the uncracked FG plate with no stiffeners.

ABSTRACT: In this paper Discrete Material and Thickness Optimization (DMTO) is used to optimize sandwich composite structures subject to both displacement and linear buckling constraints. Using a new thickness formulation where density design variables scale ply thicknesses rather than constitutive properties, it is possible to size both core and face sheet plies simultaneously. This makes it possible to have different ply thicknesses for core and face sheet layers while also covering ply-drops. Furthermore, separating core and face sheets allows enforcing a symmetric lay-up which can be important to avoid warping during curing. The approach is demonstrated in three numerical examples of increasing complexity.


ABSTRACT: In this paper, the interlaminar stresses in open-hole laminates subjected to compressive loads are analysed using a numerical model. This model implements the Serial/Parallel Mixing Theory (S/PMT) and a Continuum Damage Mechanics (CDM) approach. The S/PMT estimates the global stiffness in the laminate from fibre and matrix properties. The CDM model approximates the damage initiation due to fibre microbuckling. The global response estimated by the model was verified with experimental data from the literature. The model predicts that the damage initiates in the laminate middle-plane where the thickest block of plies oriented in the load direction is located, and progressively propagates to the nearest block of layers with the same orientation. Two laminate stacking sequences were analysed. The interlaminar stresses around the hole presented symmetry with respect to the load direction and the perpendicular axis, being located the maximum and minimum values in different angular positions for each stress component and laminate.


ABSTRACT: Large composite structures, such as composite wind turbine blades, may exhibit multiple failure modes that challenge the modeling strategies and methodologies designers adopt in finite element (FE) analysis. This study develops a comprehensive and general FE modeling method to simulate interactive failure process of composite box beams used in wind turbine blades. The composite box beams are the primary loading-carrying members and could show different failure modes due to competing failure mechanisms. A continuum-damage mechanics based progressive failure analysis approach is developed in three-dimensional stress/strain domain to simulate failure behavior of the box beams. Structural nonlinearities associated with geometry, materials and contact are included. The material failures considered in this study are composite failure with three material failure modes, foam core crushing and adhesive failure. The in-plane shear stress versus strain relation of unidirectional composites is included in the material damage model. Comprehensive comparisons are made between numerical simulations and experimental observations with respect to strain response, ultimate loads, failure modes and failure progress. The modeling approach is found to be capable of predicting both strength and failure of box beams with reasonable accuracy and it exhibits great potential to predict failure response of composite wind turbine blades.

Peng Feng and Lili Hu (First author is from: National Engineering Laboratory for Green and Safe Construction Technology in Urban Rail Transit, Department of Civil Engineering, Tsinghua University, Beijing 100084, China), “Steel columns strengthened/reinforced by prestressed CFRP strips: Concepts and behaviors under axial compressive loads”, Composite Structures, Vol. 217, pp 150-164, 1 June 2019, https://doi.org/10.1016/j.compstruct.2019.03.038

ABSTRACT: A novel strengthening method using prestressed (PS) carbon fiber reinforced polymer (CFRP) strips was proposed. This method can be used for repairing existing steel columns or constructing new columns for high-rise buildings, power transmission towers and other buildings. Specifically, a prestressing system (PS
 system) can be used to prestress CFRP strips without using a hydraulic jack. A steel column, PS CFRP strips and the PS system comprise a self-balanced system that offers much greater stiffness against overall buckling than a pure steel column. To verify this strengthening method, axial compression tests are conducted. The results show that the buckling load of the PS-strengthened specimen is 2.5 times greater than that of an unstrengthened specimen, and the failure mode ranges between the first order symmetric and the second order asymmetric overall buckling mode. In addition, finite element analysis (FEA) was adopted to obtain the optimal prestress value, which can also be used as a guide in design. Finally, a simple calculation method of axial bearing capacity was proposed.


ABSTRACT: Wrinkles are known to have a strong knock-down on the mechanical performance of structures made from composite materials. Here, static tensile tests were conducted to investigate the effect of wrinkle features on the strength of a wind turbine blade sub-structure, representative of a blade root feature. A pultruded tapered insert is embedded in each sub-structure and the wrinkle is in close vicinity to the termination of the tapered insert. Each of the tested sub-structures was then numerically modelled using finite element simulations. The numerical representations of the wrinkle geometries were constructed based on measurements of the actual structures, and an automatic fitting of the four chosen wrinkle features; angle, depth, wash out, and location. There is less than 5% deviation between the simulation and experimental results for all tested sub-structures. The numerical model was able to predict when the failure mode changed from a delamination at the tapered insert to a delamination in the wrinkle area. The average wrinkle angle was found to be a better metric than the maximum wrinkle angle to characterise the severity of the wrinkles in the vicinity of a tapered insert.


ABSTRACT: The paper presents the influence of PU foam with an addition of glass fiber on the buckling resistance of an I-beam. Three beam types were considered: an aluminum beam (AA), a composite AA-PU beam and a composite AA-PU-CFRP beam. Each beam was made with two C-profiles connected by webs. The flanges were reinforced by flat bars. Channels were made by bending 0.08 mm thick aluminum alloy 6061-T6 sheets. Flat bars were made from aluminum alloy 6061-T6 2.0 mm in thickness. The metal sheets components were connected by RFSSW and Resistant Spot Welding RSW technologies. The composite AA-PU beam additionally has the stiffening of the web by polyurethane foam with the addition of glass fiber. The PU foam filled up the I-sections in such a way that rectangular cross-sections were obtained. The composite belka AA-PU-CFRP beam was made like the composite AA-PU beam, but with CFRP plates glued to the flanges. The beams were subjected to three-point bending tests. The load-bearing capacity for a buckling resistance was analyzed. The results from experimental tests were used in numerical analysis carried out by the ADINA System program based on the Finite Element Method.


ABSTRACT: Out of plane wrinkle defects are a major cause of strength reduction in structural composites. Therefore, this paper presents the numerical modelling of a wind turbine blade sub-structure with a tapered beam and a wrinkle. The model is validated against preliminary static tensile tests of a sub-structure without a wrinkle. There is a very good correlation between the predicted and experimentally obtained load at final delamination. A parametric study is then performed using the validated model to determine which wrinkle features are the most important to measure and include when determining the strength of a wrinkled wind
turbine blade sub-structure. From the study, it is concluded that the maximum wrinkle angle is the most important feature, but the depth and wash out degree are also important under the right conditions.

Kadir Mercan, Engin Emsen and Oemer Civalek (Akdeniz University, Faculty of Engineering, Civil Engineering Department, Division of Mechanics, 07058 Antalya, Turkey), “Effect of silicon dioxide substrate on buckling behavior of zinc oxide nanotubes via size-dependent continuum theories”, Composite Structures, Vol. 218, pp 130-141, 15 June 2019, https://doi.org/10.1016/j.compstruct.2019.03.022
ABSTRACT: This paper aims to highlight the effect of SiO$_2$ substrate on the buckling behavior of Zinc Oxide (ZnO) nanotube. ZnO nanotube is modeled in various length and diameter to show the effect of size on buckling loads. Silicon Dioxide (SiO$_2$) is the material on which Zinc Oxide (ZnO) is grown and used as gas/chemical sensor. In present paper, SiO$_2$ substrate is modeled as two parameters elastic layer. In order to consider the elastic substrate, Winkler and Pasternak foundation models are used. Different values of elastic foundation parameters are taken into consideration to see the effect of these parameters on buckling loads of Zinc Oxide (ZnO) nanowire. Additionally, to take the size effect into consideration on calculating buckling loads, nonlocal elasticity, surface elasticity, modified couple stress, modified strain gradient theories are used. Some benchmark results have been depicted. Some detailed results are also given and compared in figures and tables.

ABSTRACT: In this study, stress analysis of laminated composite beams is carried out by using Refined Zigzag Theory (RZT) and Peridynamic Differential Operator (PDDO). The PDDO replaces local differentiation with nonlocal integration. This makes the PDDO capable of solving the local differential equations accurately. RZT is suitable for both thin and thick beams eliminating the use of the shear correction factors. Also, RZT ensures a constant number of kinematic variables regardless of the number of layers in the beam. The governing equations of the RZT beam and the boundary conditions were derived by employing the principle of virtual work. The capability of the present approach was assessed by considering various beams for different boundary conditions and aspect ratios. It provides robust and accurate predictions for the displacement and stress components in the analysis of highly heterogeneous laminates.

Ramesh Talreji and Nam Phan (First author is from: Department of Aerospace Engineering, Department of Materials Science and Engineering, Texas A&M University, College Station, TX 77843, USA), “Assessment of damage tolerance approaches for composite aircraft with focus on barely visible impact damage”, Composite Structures, Vol. 219, pp 1-7, 1 July 2019, https://doi.org/10.1016/j.compstruct.2019.03.052
ABSTRACT: Industry practice in composite aircraft damage tolerance, as reported in the open literature, is reviewed and examined in view of the current knowledge in the field of damage and failure of composite materials. Particular attention is paid to the challenging regime of damage tolerance when barely visible impact damage (BVID) is of concern. The validity of the compression after impact (CAI) testing as a means of assuring safety against failure from BVID is critically assessed. The role of in-field nondestructive evaluation (NDE) for quantifying the damage severity is considered as an integral part of the damage tolerance assessment. Finally, recommendations are made toward exploring other avenues for improving the current damage tolerance approaches as they apply to the case of BVID in composite structures.

Weili Wu and Wei Li (College of Textiles, Donghua University, No. 2999, Northern Renmin Rd, Songjiang District, Shanghai 201620, China), “A novel material for simulation on compaction behavior of glass fiber non-crimp fabric”, Composite Structures, Vol. 219, pp 8-16, 1 July 2019, https://doi.org/10.1016/j.compstruct.2019.03.006
ABSTRACT: In this paper, compaction behaviors of glass fiber non-crimp fabrics (NCFs) were investigated via finite element analysis (FEM). Firstly, the compaction mechanism of NCFs was analyzed, it suggested the compaction process is mainly characterized by the decrease of macro pores and micro pores, a novel and reasonable constitutive model (porous elastic) was proposed. Then, the feasibility of modeling the compaction process for NCFs with the porous elastic material via FEM was explored. A macroscale model of NCF was established firstly, the simulation complies well to the experimental results. Then, the mesoscale models were
attempted, and the effect of model parameters on simulation results were investigated, including the model size, platen location, warp cross-sectional shape. Results show that the size of mesoscale model and compaction platen position have little effect on the compaction behavior, while the cross-sectional shape of the warp yarn has a slight influence on the simulation results. Finally, compared the warp yarn cross-section changes of simulation with experimental data, it was revealed that variations in yarn cross sections in the model have a good agreement with experimental results, except that the macro-porosity differs slightly.

Masood Danesh and Abbas Ghadami (First author is from: Khoy School of Civil Engineering, Urmia University, 58159-14853 Khoy, West Azerbaijan, Iran), “Sound transmission loss of double-wall piezoelectric plate made of functionally graded materials via third-order shear deformation theory”, Composite Structures, Vol. 219, pp 17-30, 1 July 2019, https://doi.org/10.1016/j.compstruct.2019.03.040

ABSTRACT: According to the third-order shear deformation assumption, this paper analytically investigates the sound transmission loss (STL) through a rigidly baffled finite rectangular double wall piezoelectric plate structure made of functionally graded materials (FGMs) with enclosed acoustic cavity, under harmonic plane sound excitation and initial external electric voltage. The effective piezoelectric material properties of each plate are supposed to be continuously variable across the thickness direction using a power law model in terms of the volume fractions of the material phases. The coupled vibroacoustic governing equations are achieved utilizing Hamilton’s principle and then solved analytically by applying the sound velocity potential method in conjunction with double Fourier series expansions to determine STL equation. Numerical studies are performed to illustrate the effects of the acoustic cavity depth, initial external electric voltage, incident elevation angle, gas type used in acoustic cavity, and material gradient on the changes of STL curves of simply supported double wall FGM piezoelectric plate. The profound effect of these factors on sound isolation performance is clearly shown.


ABSTRACT: This paper studies experimentally the structural behavior of channel steel reinforced concrete-filled glass fiber-reinforced polymer (GFRP) tubular stub columns. To understand their structural performance, we examined 27 specimens which subjected to axial compression. The variables of the specimen are concrete strength grade, diameter-to-thickness ratio of GFRP tube and steel ratio. The displacement-load curve, strain-load curve, ultimate load, axial compressive stiffness and failure characteristics of the specimens were analyzed. The results of the test show that the specimens’ ultimate bearing capacity increases as the concrete strength increases. And those specimens with higher concrete strength grade have greater initial stiffness and better deformation capacity than those with lower concrete strength grade. The varieties of the steel ratio have no significant effect on the specimens’ axial deformation property. The confinement coefficient is proposed to evaluate the constraint effect of the GFRP tube on both the inner channel steel and the core concrete. There was a negative correlation between the restraint effect and the diameter-thickness ratio of the GFRP tube. A simplified formula for calculating the axial bearing capacity of the composite columns is proposed.

Atteshamuddin S. Sayyad and Yuwaraj M. Ghugal (First author is from: Department of Civil Engineering, SRES’s Sanjivani College of Engineering, Savitribai Phule Pune University, Kopargaon 423601, Maharashtra, India), “Static and free vibration analysis of laminated composite and sandwich spherical shells using a generalized higher-order shell theory”, Composite Structures, Vol. 219, pp 129-146, 1 July 2019, https://doi.org/10.1016/j.compstruct.2019.03.054

ABSTRACT: In this article, higher-order closed-form solutions are obtained for static bending and free vibration analysis of laminated composite and sandwich spherical shells using a generalized higher-order shell theory. A theory is independent of the choice of shearing stress function (polynomial/non-polynomial) which eventually results in a theoretical unification of most of the classical and higher-order shear deformation theories. The present theory yields an accurate distribution of transverse shear stresses through the shell thickness; therefore, it does not require problem dependent shear correction factor. Governing equations and associated boundary conditions of the theory are derived by employing Hamilton’s principle. Navier type higher-order closed-form solutions are obtained for simply supported boundary conditions. Displacements,
stresses and natural frequencies are presented for laminated composite and sandwich plates as well as shallow and deep spherical shells. The results of parabolic, trigonometric, hyperbolic, and exponential models are compared with each other and previously published results to verify the accuracy and efficiency of the present generalized shell theory.

References cited at the end of the paper:
[34] Sayyad AS, Ghugal YM. A new shear and normal shear theory for isotropic, transversely isotropic, laminated composite

ABSTRACT: A novel cell-based smoothed finite element method is proposed for thin and thick plates based on Reissner-Mindlin plate theory and assumed shear strain fields. The domain is discretized with arbitrary polygons and on each side of the polygonal element, discrete shear constraints are considered to relate the kinematical and the independent shear strains. The plate is made of functionally graded material with effective properties computed using the rule of mixtures. The influence of various parameters, viz., the plate aspect ratio and the material gradient index on the static bending response and the first fundamental frequency is numerically studied. It is seen that the proposed element: (a) has proper rank; (b) does not require derivatives of shape functions and hence no isoparametric mapping required; (c) independent of shape and size of elements and (d) is free from shear locking.

ABSTRACT: Compared with traditional composite panels, the modeling, analysis and design of variable-stiffness panels with curvilinear fibers are much more complicated. Although the design flexibility is greatly enhanced, the design of variable-stiffness structures must meet manufacturing constraints to ensure that the designed structures can be fabricated finally. In order to design variable-stiffness composite panels that is very challenging due to its nonlinearity and non-convexity, a novel multi-stage design method for variable-stiffness panels is developed based on lamination parameters. First, lamination parameters are taken as design variables, and the stiffness distribution is obtained efficiently by few iterations. Next, the lamination parameters are transformed into actual layups. Finally, the realistic fiber path is regenerated by considering manufacturing constraints. In addition, the isogeometric analysis, which is more suitable for variable-stiffness structure, is used instead of the traditional finite element analysis to improve the analysis accuracy. Illustrative example demonstrates the high computational efficiency and optimization capacity of proposed method, compared to gradient-based algorithm and evolutionary algorithm.

Pruthul Kokkada Ravindranath, Samit Roy, Vinu Unnikrishnan, Xuemin ang, Tingge Xu, Ray Baughman and Hongbing Lu (First author is from: Aerospace Engineering and Mechanics Department, University of Alabama, Tuscaloosa, AL, USA), “A multiscale model to study the enhancement in the compressive strength of multi-walled CNT sheet overwrapped carbon fiber composites”, Composite Structures, Vol. 219, pp 170-178, 1 July 2019, https://doi.org/10.1016/j.compstruct.2019.03.065
ABSTRACT: The high tensile strength of polymer matrix composites is derived primarily from the high strength of the carbon fibers embedded in the polymer matrix. However, their compressive strength is generally much lower due to the fact that under compression, the fibers tend to fail through micro-buckling well before compressive fracture occurs. In this work, we consider multi-walled carbon nanotube (MWNT) sheets wrapped

ABSTRACT: This paper presents a theoretical model that allows to calculate the acoustic transmission loss through laminated composite pyramidal sandwich structure consisting of two parallel plates connected by trusses. First-order shear deformation theory is adopted to model the vibration of such a structure, accounting for in-plane motion and coupling between extension and flexure of the different components, and taking into account elastic anisotropy. The interaction between the structure and the surrounding fluid is taken into account by imposing a velocity continuity condition at the interfaces. The displacement and stress fields are calculated in Fourier domain by solving the set of boundary condition equations at the connecting points. The theoretical predictions for the acoustic transmission through the structure show satisfactory agreement with experimental results of a standing wave tube experiment on specimens that were fabricated by cutting trusses from carbon fiber reinforced composite plates and snap-fitting them to plates made of the same material. Numerical simulations are used to verify, the influence of the stacking geometry and material parameters on the acoustic transmission for different frequencies and angles of incidence. Conclusions are presented that are helpful for practical design.

H.N.R. Wagner (1), H. Koeke (2), S. Daehne (2), S. Niemann (2), C. Huehne (1,2) and R. Khakimova (3)

(1) Technical University Braunschweig, Institute of Adaptronic and Functional Integration, Braunschweig, Germany
(2) German Aerospace Center (DLR), Institute for Composite Structures and Adaptive Systems, Braunschweig, Germany
(3) Fraunhofer Institute, Open Hybrid LabFactory e.V., Wolfsburg, Germany


ABSTRACT: Launch-vehicle primary structures like cylindrical shells are increasingly being built as monolithic composite and sandwich composite shells. These imperfection sensitive shells are subjected to axial compression due to the weight of the upper structural elements and tend to buckle under axial compression. In the case of composite shells the buckling load and imperfection sensitivity depend on the laminate stacking sequence.

Within this paper multi-objective optimizations for the laminate stacking sequence of composite cylinder under axial compression are performed. The optimization is based on different geometric imperfection types and a brute force approach for three different ply angles. Decision tree-based machine learning is applied to derive general design recommendations which lead to maximum buckling load and a minimum imperfection sensitivity.

The design recommendation are based on the relative membrane, bending, in-plane shear and twisting stiffnesses. Several optimal laminate stacking sequences are generated and compared with similar laminate configurations from literature. The results show that the design recommendations of this article lead to high-performance cylinders which outperform comparable composite shells considerably. The results of this article may be the basis for future lightweight design of sandwich and monolithic composite cylinders of modern launch-vehicle primary structures.

References listed at the end of the paper:

from: https://www.nasa.gov/offices/nesc/home/Feature_ShellBuckling_Test.html [cited 2017-11-05-2017].
ABSTRACT: With aeronautic industries focussing on thinner structures and reducing manufacturing costs, recent research has been dedicated to the impact and post impact response of thin laminates (<2 mm) made of textile fabric composites. A recent study revealed that thin laminates based on thin plies exhibit extensive fibre failure and a reduced compression after impact strength. To mitigate this weakness, we propose a novel laminate concept based on combining plies of different thicknesses in an unsymmetrical configuration (intermediate grade plies are located only at the bottom of the laminate, i.e., the non-impacted face). C-scan inspection on impacted and quasi-statically indented specimens, allowed the damage sequence of the proposed unsymmetrical hybrid laminate to be compared with that of the thin-ply baseline. The hybrid laminate with intermediate plies at the bottom, delayed and reduced the fibre damage, decreased the projected delamination.
area and led to a 30% increase in the compression after impact strength in contrast to the thin-ply baseline laminate.


ABSTRACT: The critical local buckling of simply-supported sinusoidal panels subjected to uniaxial compression using the Rayleigh-Ritz method is investigated. With increased applications of thin-walled composite structures in engineering, these corrugated panels are especially popular due to their high stiffness to weight ratio and high out-of-plane rigidities. Failure of such thin-walled panels occurs mainly in buckling rather than material failure; thus, it leads to the importance of buckling failure analysis. Conventional methods are limited when analyzing these panels in local buckling because of its unique geometries. Hence, a semi-analytical solution is developed to predict the local buckling based on classical shell theory with a unit cell approach, and it shows excellent correlation with the results based on the numerical finite element analysis. A parametric study is conducted to evaluate the effects of the thickness, aspect ratio, and the corrugated amplitude of the panel on buckling. It is revealed that the derived solution can accurately capture the local buckling behavior at high thickness/radius of curvature ratios, any aspect ratios, and high corrugated amplitudes. Additionally, the effects of orthotropy, Poisson’s ratios and twisting capacities on the buckling behavior are explored. The proposed semi-analytical solution can be effectively used to aid in the efficient and accurate design analysis and optimization of corrugated panels.


ABSTRACT: Nonlinear and post-buckling behaviors of internally cracked functionally graded plates subjected to uniaxial compressive loading have been presented in this paper. A general nonlinear mathematical model for cracked functionally graded plates has been developed based on the first order shear deformation theory within the framework of von-Karman nonlinearity. To approximate the primary variables, Legendre polynomials are used in the current research. The crack is modelled by decomposing the entire domain of the plate into several sub-plates and therefore, a plate decomposition technique is applied. In this study, the penalty technique is used to enforce interface continuity between the sub-plates. The integrals of the potential energy are numerically computed by Gauss-Lobatto quadrature formulas to get adequate accuracy. Finally, the obtained non-linear system of equations is solved by the well-known Newton-Raphson technique. Results are presented to show the influence of crack length, various locations of crack, crack direction, boundary conditions and volume fraction index in nonlinear behavior of functionally graded plates.


ABSTRACT: In this study, nonlocal strain gradient theory (NSGT) is applied to examine the dynamic instability of embedded viscoelastic graphene sheet under periodic axial load including thermal effects. The foundation is simulated by visco-Pasternak model containing springs, dampers and a shear layer. The motion equations are derived according to the four-variable refined shear deformation plate theory and via Hamilton’s principle. The equations are converted into a linear system of Mathieu-Hill equations by means of Navier’s method. Afterwards, Bolotin’s approach is utilized to determine the principle unstable region of graphene sheet. The influences of nonlocal parameter, structural damping coefficient, length scale parameter, static load factor, temperature variation, foundation type as well as aspect ratio on the dynamic stability of graphene sheet are investigated. Based on the numerical results, it is indicated that with enlarging the nonlocal parameter, static load factor and temperature change, the excitation frequency decreases and so, instability region shifts to left side while the effect of length scale parameter is on the contrary. Additionally, it is indicated that when the
length scale parameter enhances, the effects of temperature and foundation on the instability region of graphene sheet reduce.


ABSTRACT: This paper presents an experimental investigation of compression on pristine specimens and the compression after impact (CAI) response of wood-based sandwich structures. Nine different types of sandwiches, made with plywood core and different aluminum or composite (carbon or glass or flax fiber) skins, are studied. Impact energy levels were fixed at 5 J, 10 J and 15 J in order to create significant defects. Failure modes and damage scenarios are analyzed. The influence of different skins with plywood core is explained in terms of residual strength, residual stiffness, and specific properties. It is shown that this type of structure exhibits very interesting compression properties in terms of specific strength, which is superior to a reference sandwich used for aircraft flooring, and in terms of behavior, with large plateau areas that can be useful for crash issues.


ABSTRACT: Accurate modeling of the complete stress-strain relationship of confined concrete is of vital importance in predicting the structural behavior of confined concrete columns under combined axial compression and bending. Although the axial stress-strain behavior of confined concrete under concentric loading is well established, the behavior under eccentric loading when axial and bending loads are combined is not well understood. This paper presents an experimental study on the behavior of carbon fiber-reinforced polymer (FRP)-confined high-strength concrete (HSC) columns under eccentric compression loading. 31 short concrete columns with circular and square cross-sections were tested under compression with different load eccentricities. The equivalent axial stress-strain curves of FRP-confined HSC under eccentric loading are obtained through sectional analysis conducted on the recorded experimental data. The results indicate that load eccentricity significantly affects the axial stress-strain behavior of FRP-confined HSC. In both circular and square cross-section specimens, an increase in the load eccentricity results in an increase in the ultimate axial strain but a decrease in the second branch slope of the axial stress-strain curve, which translated to a reduced ultimate axial stress in the specimens of the current study. The analysis of the results has shown that the ultimate axial strain increased and ultimate axial stress and second branch slope of the axial stress-strain curve decreased almost linearly with increasing eccentricity.

Mohammed Sobhy and Ashraf M. Zenkour (First author is from: Department of Mathematics and Statistics, Faculty of Science, King Faisal University, P.O. Box 400, Hofuf 31982, Saudi Arabia), “Porosity and inhomogeneity effects on the buckling and vibration of double-FGM nanoplates via a quasi-3D refined theory”, Composite Structures, Vol. 220, pp 289-303, 15 July 2019, https://doi.org/10.1016/j.compstruct.2019.03.096

ABSTRACT: This study is devoted to illustrate the mechanical buckling and free vibration analyses of double-porous functionally graded (FG) nanoplates embedded in an elastic foundation. A new quasi-3D refined plate theory is presented to model the displacement field. This theory contains only five unknown functions and considers the shear strain as well as thickness stretching. Based on the modified Mooney-type exponential relation, a new exponential law is presented to govern the materials variation and porosities distribution through the thickness of the nanoplates. The two porous nanoplates are bonded together by a set of parallel elastic springs and surrounded by Pasternak medium. The nonlocal strain gradient theory containing the nonlocal parameter and gradient coefficient is utilized to study the size-dependent effects. Based on Hamilton’s principle, the equations of motion are drawn including the material parameters, elastic foundation reaction and biaxial compressive forces. An analytical approach for simply-supported and clamped bilayer porous FG nanoplates is implemented. The obtained results are compared with those available in the literature. Additional numerical
calculations are introduced to show the influences of the material length scale parameters, inhomogeneity parameter, porosity factor and other parameters on the critical buckling and frequencies of the double-porous FG nanoplates.


ABSTRACT: The subject of the paper is a rectangular plate with symmetrically varying mechanical properties in the thickness direction. The nonlinear hypothesis of deformation of the straight line normal to the plate neutral surface is assumed. The field of displacements of the plate is formulated assuming this hypothesis. Based on the Hamilton’s principle three differential equations of motion are obtained. The system of equations is analytically solved. The critical loads and fundamental natural frequencies for exemplary plates are derived. Moreover, the FEM model of the plate in the ABAQUS system is developed, and analytical calculations for exemplary plates are carried out. The calculation results of these two methods are compared.


ABSTRACT: The dynamic response and structural damage of liquid-filled cylindrical shell composite structures, with different wall thicknesses and at varying stand-off distances, under repeated explosion loading were studied experimentally. The explosion resistance of liquid-filled cylindrical shell composite structures influenced by the wall thickness and stand-off distances was clarified, and the resistance thickness and critical distance were determined. The effect of internal liquid filling enhance the ability of the cylindrical shell to resist explosion loading was verified by experimental data. A stronger explosive load and greater deformation result in a more obvious enhancement effect of liquid filling on the cylindrical shell structure.

The deformation and damage results of the liquid-filled cylindrical shell composite structures were divided into five typical modes. Three major modes were analysed numerically. By means of numerical simulation, the deformation and damage processes of the liquid-filled cylindrical shell composite structures subjected to repeated explosive loading were studied. The energy transformation directions of the three major modes were investigated in their respective deformation processes.


ABSTRACT: This paper presents experimental and analytical studies on impact and compression after impact (CAI) responses of sandwiches with glass fiber reinforced polymer (GFRP) skins and synthetic foam cores under low-velocity impacting. The impact test results showed that the penetration depth of GFRP panels with synthetic foam is much smaller than that of bare synthetic foam panels. The edgewise compression test results indicated the facesheet debonding dominates the failure mode of the sandwich panels without lattice webs, while the failure mode of the sandwich panels with lattice webs is predominated by the wrinkling and delamination of the facesheets and the crushing of foam core. The influences of applied impact energy, GFRP lay-up, synthetic foam density and the existence of webs on the impact and post impact behavior of sandwich panels are discussed herein. Analytical models are proposed to predict the residual ultimate edgewise compressive load capacity of sandwich panels with lattice webs after impacts, using energy principles and variational methods in applied mechanics. The influences from impact damage, the local buckling of the facesheets and the confined strength of the foam core are measured and compared well with proposed analytical models.

Rui Ren, Jianlin Zhong, Guigao Le and Dawei Ma (School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing 210094, China), “Research on intralaminar load reversal damage modeling

ABSTRACT: Despite abundant finite element analysis (FEA) of low velocity impact (LVI) performance of composite laminates, the questions regarding the effects of different load reversal damage laws on predicted impact responses of composite laminates and which one is preferred for more physically-sound simulation of laminate LVI responses remain unresolved. In this paper, an elasto-plastic progressive damage model based on three load reversal damage laws including coupled tension-compression law, semi-stiffness recovery law and full-stiffness recovery law, were numerically implemented in predicting laminate LVI responses. By comparisons between simulations and available experimental data, the influences of different load reversal damage laws on predicted delamination threshold load, impact force, laminate central deformation, dissipated impact energy as well as damage status were analyzed. More accurately predicting laminates’ LVI responses, the semi-stiffness recovery law was concluded as the preferred intralaminar load reversal damage law.


ABSTRACT: Aim of the paper is to develop and to assess a class of plate finite elements for the analysis of multilayered composite and sandwich structures. The adopted model is the mixed Refined Zigzag Theory (RZT-), based on the kinematics of the Refined Zigzag Theory (RZT) and on the assumption of transverse shear stresses coming from integration of indefinite equilibrium equations. A triangular and quadrilateral flat finite element are developed by means of the Reissner’s Mixed Variational Theorem and an interpolation strategy to eliminate shear locking. Several numerical examples are discussed to demonstrate the accuracy of RZT- and related finite elements for static response, free-vibrations and critical load problems of sandwich structures.


ABSTRACT: Composite structures containing lithium-ion polymer (LiPo) batteries are being developed for electrical energy storage in motor vehicles and other applications. This paper presents an experimental and numerical study into the effect of embedding (LiPo) batteries into carbon fibre laminates and sandwich panels on the vibration and acoustic properties. The vibration responses (modal frequencies, damping) were measured experimentally using Laser Doppler vibrometry and calculated numerically using finite element modal analysis. The results reveal that careful placement of LiPo batteries within composite structures is needed to control the vibration properties. Embedding batteries at the nodal points increases the vibration bending damping ratio for modes II and III, with improvements of up to 220% (mode II) and 310% (mode III) for the laminate and sandwich composite, respectively. LiPo batteries also improve the acoustic performance by increasing the coincidence frequency and decreasing the wavenumber amplitude at frequencies above the first vibration bending mode. The results indicate that the judicious placement of embedded LiPo batteries can improve the vibration damping properties of both carbon fibre laminates and sandwich composites.


ABSTRACT: In this work, the low velocity impact behaviour of thermoplastic fibre metal laminates (FMLs) made of aramid fibre reinforced polypropylene and aluminium alloy Al 5052-H32 is presented. The impact behaviour of these FMLs and their constituent materials was determined using a drop-weight impact tower. Force-time curves were used to obtain the absorbed energy for each tested material at different impact energies. The results showed that the FML configuration based on a 3/4 layering arrangement (3 layers of aluminium and 4 layers of composite) exhibited the highest specific absorbed energy for the first damage and perforation
threshold when compared to the other laminates and constituent materials here studied. Optical analysis showed that the plastic deformation and the tearing of the aluminium layers, as well as fibre breakage and delamination were the main impact energy-absorption mechanisms. These findings warrant further research to fully understand the low velocity impact behaviour of these thermoplastic FMLs for engineering applications.

ABSTRACT: The free vibration of different kinds of stepped coupled doubly-curved shell structures with elastically constrained edges are investigated by adopting the Jacobi-Ritz method for the first time. Coupled structures are comprised of substructures, where paraboloidal, hyperbolical, elliptical, and cylindrical stepped shells are typical ones. The Flügge’s thin shell theory is utilized to construct the analytical model, together with the multi-segment partitioning strategy. For each shell segment, despite of various boundary conditions, the displacement components along the meridional directions are expressed by Jacobi polynomials and those along the circumferential directions are represented by Fourier series. Then the unknown coefficients of the displacements are obtained by introducing the Rayleigh-Ritz method. The solutions proposed here for coupled structures have two main advantages: first, there is no need to vary the displacement or the motion equations; and secondly, the efficiency of modeling can be notably enhanced. By comparison with (Finite Element method) FEM and others’ results, the reliability of current method can be validated. At last, the free vibrations of different kinds of coupled structures containing stepped shell are analyzed by presenting several numerical examples, the results of which may be served as reference data.

ABSTRACT: Sandwich panel with Honeycomb Filled with Circular Tubes (HFCT) as core is numerically investigated by using ABAQUS/Explicit in this study. To calibrate the numerical model, the panels equipped with conventional hexagon honeycomb cores are modeled. Good agreement between numerical and experimental results is achieved. The sandwich panels with HFCT are compared with the sandwich panels with Honeycomb and Multi-tube cores of identical mass subjected to vertical and oblique impacts. The maximum displacement of face-sheets, plastic energy absorption, boundary reaction forces and impact load time history are calculated to assess the impact resistant capacity. The panel with HFCT core has smaller rear face-sheet displacement and higher energy absorption capacity as compared to the panels with the Multi-tube and Honeycomb core. Under oblique impact, both HFCT and Multi-tube panels have superior impact resistant capacity than the Honeycomb panel. In addition, the impact resistances of four types of multi-arc tube filled Honeycomb (HFMT) are also analysed. Their performances under vertical and oblique impacts are compared with those of HFCT.

ABSTRACT: In this study, a NURBS formulation based on the four-variable refined plate theory (RPT) for free vibration, buckling and static bending analyses of multilayer functionally graded graphene platelets reinforced composite (FG GPLRC) plates, for the first time, is proposed. The distributions of graphene platelets (GPLs) in the polymer matrix either uniformly or non-uniformly including different patterns are considered. The Young’s modulus of the nanocomposites is predicted by the modified Halpin–Tsai model, while the Poisson’s ratio and density mass are implemented by the rule of mixtures. Governing equations are derived and the NURBS formulation is employed to obtain natural frequencies, critical buckling loads and deflections of multilayer FG GPLRC plates. Thanks to continuous higher-order derivatives of NURBS basis functions in isogeometric
analysis (IGA), the present approximation is easy to satisfy the C-continuity requirement of the RPT model. In addition, a rotation-free technique is applied to eliminate the bending and shear slopes in the case of clamped boundaries. Effects played by GPLs weight fraction, GPLs distribution patterns, number of layers, thickness-to-length ratio are investigated. Numerical results indicate that the inclusion of GPLs can significantly improve the stiffness of plates.


ABSTRACT: Slamming is a dynamic phenomenon in which a high magnitude pulse peak pressure occurs in a short time duration when the bottom structure of a ship impacted against the sea surface. This phenomenon can cause damage in the structure due to fluid-structure interaction (FSI) thus, plays a vital role in designing and manufacturing of ships for naval applications. In this paper, high performance sandwich structure, having many opportunities and challenges for the marine structural design, were studied experimentally using a high-speed shock test machine to examine the water entry problem. In addition, a velocity control system was used to calibrate and preserve the approximately uniform velocity throughout the slamming impact. Sandwich panels with different thicknesses i.e. 27 mm and 37 mm therefore, having different stiffness’s were exposed under constant impact velocities of 6 and 8 m/s at the deadrise angle 10°. Experimental results were then compared and verified by the numerical investigation based on explicit Smoothed Particle Hydrodynamics (SPH) method. This study focuses on the overall structural response, deformation, and hydrodynamic response of the structure during the dynamic impact designed for naval applications.


ABSTRACT: In this paper, a semi-analytical approach is proposed to investigate the dynamic buckling behavior of functionally graded carbon nanotubes reinforced composite (FG-CNTRC) cylindrical shell under dynamic displacement load. Five types of carbon nanotubes (CNTs) distribution are considered, in which the uncertainty of CNTs distribution is also taken into account. Combining with the first-order shear deformation theory and von-Kármán strains, the nonlinear governing equations for dynamic buckling analysis of FG-CNTRC cylindrical shell considering the thermal effects are derived. Then, Galerkin method and the fourth-order Runge-Kutta method are employed to solve the governing equations. And the dynamic critical buckling condition of FG-CNTRC cylindrical shell is determined by the Budiansky-Roth criterion. Compared with the published literatures, the feasibility and accuracy of proposed analysis approach are validated. Finally, the parametric studies are systematically carried out to analyze the effects of CNTs distribution type, CNTs volume fractions, the uncertainty of CNTs distribution, the loading rate and form of dynamic displacement load, structural characteristics and temperature on the dynamic buckling behavior of FG-CNTRC cylindrical shell.


ABSTRACT: A numerical study of the effect of uncertainties in ply angles and thicknesses on the flutter speed of a cantilevered composite plate wing was conducted in this paper. Reduction of the number of uncertain parameters was possible thanks to the use of the polar method, which also enabled a systematic analysis of the influence of material symmetries. From the polar domain of orthotropic laminates, several stacking sequences were reconstructed in order to propagate parametric uncertainties. Typical fabrication uncertainties on ply thicknesses and angles were considered in order to quantify their influence on the probabilistic aeroelastic response. The reduction of the set of stochastic parameters by the polar method enabled the use of a polynomial-chaos approach which was combined with machine-learning techniques in order to deal with the
correlation and with discontinuities in the response surface. Results reveal that possible manufacturing tolerances cause significant deviations in the critical flutter speed from the nominal value, especially when mode switches occur. As these deviations surpass classical dimensioning margins, uncertainty quantification approaches can provide added safety.

ABSTRACT: Because the fiber composite approach can provide significant improvement in specific strength and stiffness over conventional metal alloys, the consuming demand is getting more increase. Moreover, the composite material structures are more effective in economic point of view due to great reduction of number of parts and manufacturing processes relatively to the conventional metal structure. However the composite structures has an disadvantage for instance, very weak for impact damage due to foreign object damage such as, sand, rock, birds, tool, etc. Especially the damage due to low velocity impact rather than that by high velocity impact cannot be visually found. Such the low velocity damage can be divided into some types such as matrix cracking, fiber fracture, delamination, etc. In this study low velocity impact behaviors of monolithic laminate plate were investigated and sandwich composite plate compared using a commercial FEM Code.

ABSTRACT: In this paper, a general approach is provided for the free vibration analysis of rotating functionally graded carbon nanotube reinforced composite (FG-CNTRC) cylindrical shells with arbitrary boundary conditions. General formulations are derived based on the first-order shear deformation theory, the Donnell-type kinematic assumptions, and the artificial spring technique. Coriolis and centrifugal effects due to rotation are taken into account in the shell model. By employing Chebyshev polynomials as admissible functions, the Rayleigh-Ritz method is employed to derive the equations of motion for rotating FG-CNTRC cylindrical shells. The approach proposed is validated by comparing the present results with those reported in literature. The traveling wave motions of rotating FG-CNTRC shells are investigated. The effects of geometric parameters, volume fraction of carbon nanotubes, and boundary conditions on shell vibrations are also evaluated.

Hadi Babaei, Yaser Kiani and M. Reza Eslami (First author is from: Mechanical Engineering Department, South Tehran Branch, Islamic Azad University, Tehran, Iran), “Large amplitude free vibrations of long FGM cylindrical panels on nonlinear elastic foundation based on physical neutral surface”, Composite Structures, Vol. 220, pp 888-898, 15 July 2019, https://doi.org/10.1016/j.compstruct.2019.03.064
ABSTRACT: In the current investigation, the small and large amplitude free vibration characteristics of long cylindrical panels made of FGMs is investigated using the higher order shear deformation theory and Donnell kinematic assumptions. The interaction of the panel with a nonlinear hardening/softening foundation is also included into the formulation. The properties of the panel are assumed to be graded across the thickness of the panel and assumed to be temperature dependent. Using the neutral surface concept, the three coupled motion equations of the shell are established and solved for the case of long panels which are immovable simply supported on straight edges. The solution method is based on the two step perturbation technique which results in a closed form expression for the frequencies of the panel as a function of the midpoint deflection. Numerical studies are first validated for the case of long FGM plates. Afterwards novel numerical results are given to show the effect of geometrical parameters, power law index, foundation stiffnesses and temperature elevation. As shown, temperature elevation results in the reduction in natural frequencies and enhancement of the frequency ratio of the panel. Also temperature dependency reduces the natural frequencies and frequency ratios of the panel.

Erfan Shafei, Shirko Faroughi and Timon Rabczuk (First author is from: Faculty of Civil Engineering, Urmia University of Technology, Urmia, Iran), “Isogeometric HSDT approach for dynamic stability analysis of

**ABSTRACT:** Due to wide application of anisotropic composite plates in modern engineering structures and they were studied rare in literature, the main goal of this work is to study dynamic stability analysis of general anisotropic composite plates. To this end, here, we use the advantages of isogeometric analysis (IGA) to develop a higher-order shear deformation theory (HSDT) framework. In this work, force-frequency curves are obtained for general anisotropic composite plates using novel IGA-HSDT approach which have been previously presented using conventional finite element for specially orthotropic plates. Based on observation, the developed method is higher-order accurate, stable for wide spectral frequency range of anisotropic plates, and efficient in capturing the mode-converging phenomenon. IGA-HSDT model affirmed that the thick plates are more sensitive to frequency convergence prior to divergence with respect to thin ones. Furthermore, C3 NURBS capture the discrete spectrum accurately which is important for explicit dynamic applications of anisotropic plates. Specifically, anisotropic plates with clamped boundaries and low slenderness ratios have mode-converging phenomenon in dynamic stability curves prior to fundamental mode divergence which is not detected in previous works.

Yingjie Zhang and Yongqiang Li (College of Science, Northeastern University, Shenyang 110819, China), “Nonlinear dynamic analysis of a double curvature honeycomb sandwich shell with simply supported boundaries by the homotopy analysis method”, Composite Structures, Vol. 221, 110884, 1 August 2019, https://doi.org/10.1016/j.compstruct.2019.04.056

**ABSTRACT:** Dynamics of a double curvature honeycomb sandwich shell with simply supported boundaries are studied in this paper. The nonlinear governing equations of the double curvature honeycomb sandwich shell subjected to transverse excitations are derived by using Hamilton’s principle and Reddy’s third-order shear deformation theory. Based on the homotopy analysis method, the average equations of the primary resonance and harmonic resonance are obtained. The influence of structural parameters, the transverse exciting force amplitude and transverse damping to the double curvature honeycomb sandwich shell are discussed by using the analytic approximation method. The amplitude-frequency response curves demonstrate softening nonlinearity in primary resonance (no internal resonance), hardening nonlinearity in 3 order superharmonic resonance and no jump phenomenon in 1/3 subharmonic resonance. The variation of nonlinear strength, multivalued jump point and multivalued region are detailed and discussed.


**ABSTRACT:** We analyze mechanical behavior of porous beams by an effective computational approach based on isogeometric analysis (IGA). The quasi-3D theory is employed to take into account not only both normal and shear deformations without any shear correction factor, but also the thickness stretching effect, while the use of NURBS basis functions within the IGA framework can directly meet the first-order derivative demand of the quasi-3D theory. To demonstrate the accuracy and performance of the quasi-3D theory-based isogeometric analysis, mechanical static bending and natural frequency of porous beams are investigated via the proposed method. In porous beams, porosities are assumed to vary along the thickness direction and to distribute in uniform, symmetric, and asymmetric configurations. The effects of porosity distribution, volume fraction of porosity, boundary condition, length-to-height ratio, etc., on deflections, stresses, and fundamental frequencies of porous beams are systematically analyzed. Numerical results indicate that the porosity distribution significantly alters the deflection and natural frequency of porous beams with large thickness and high volume fraction of pores. The present study, thus, provides an incisive approach for investigation on mechanical responses of porous structures and useful insights into the porosity design to achieve appropriately natural frequency and deflection responses.

Cuong-Le Thanh, Loc V. Tran, Tinh Quoc Bui, Hoang X. Nguyen and M. Abdel-Wahab (The first author is from: Faculty of Civil Engineering and Electricity, Open University, Ho Chi Minh City, Viet Nam), “Isogeometric analysis for size-dependent nonlinear thermal stability of porous FG microplates”, Composite Structures, Vol. 221, 110838, 1 August 2019, https://doi.org/10.1016/j.compstruct.2019.04.010
ABSTRACT: In this article, we present for the first time a research analysis for the size-dependent effects on thermal buckling and post-buckling behaviors of functionally graded material micro-plates with porosities (imperfect FGM) using isogeometric analysis. A seventh-order shear deformation plate theory associated with the modified couple stress theory (MCST) is particularly imposed to capture the size-dependent phenomenon within imperfect FGM micro-plates. The material properties of imperfect FGM micro-plates with three different distributions of porosities including even, uneven and logarithmic-uneven varying across the plate thickness are derived from the modified rule-of-mixture assumption. The nonlinear governing equation for size-dependent imperfect FGM micro-plate under uniform, linear and nonlinear temperature rise is derived using the Von-Kármán assumption and Hamilton's principle. Through numerical example, the effect of temperature rise, boundary conditions, power index, porosity volume fraction, porosity distribution pattern and material length scale parameter on thermal buckling and post-buckling behaviors of FGP micro-plates are investigated.

H. Salehipour, A. Shohsavar and O. Civalek (The first author is from: Department of Mechanical Engineering, Ilam University, Ilam 69315-516, Iran), “Free vibration and static deflection analysis of functionally graded and porous micro/nanoshells with clamped and simply supported edges”, Composite Structures, Vol. 221, 110842, 1 August 2019, https://doi.org/10.1016/j.compstruct.2019.04.014

ABSTRACT: The static deflection and free vibration problem of functionally graded porous (FGP) cylindrical micro/nanoshells are analyzed using the concept of the modified couple stress theory. The governing equations of first order shear deformation theory (FSDT) are employed and solved by generalized differential quadrature (GDQ) solution method. Using the power low for the FG properties, and incorporating pore content effect, a modified power function is considered for modelling FGP material properties. The transverse deflection under transverse loading and free vibration are numerically presented for a cylindrical micro/nanoshell with simply and clamped edges. The influences of porosity type, porosity volume fraction, material properties, size scale parameter, and type of the boundary conditions on the static bending and free vibration of FGP micro/nanoshells are investigated.


ABSTRACT: A new multifunctional lattice sandwich structure consisting of a lattice sandwich beam, a nonlinear energy sink (NES) and a giant magnetostrictive material (GMM) is proposed in this research. This structure exhibits excellent self-vibration suppression and aeroelastic energy harvesting performance. The dynamic equations of the whole structure are established using Hamilton principle and Newton’s second law, and the Runge-Kutta algorithm is used to obtain the amplitude response of the beam coupled with NES and without NES, which can indicate the vibration control effect of NES. Moreover, the energy harvest effect of the structure with GMM is also analyzed through numerical simulation. And a comparative analysis of relevant parameters such as NES mass, spring stiffness and damping coefficient is also implemented. The results show that this new multifunctional lattice sandwich structure can achieve the desired effect of vibration suppression and energy harvesting, and proper adjustment of parameters will improve the effect. This study provides a new idea for related research on vibration control and energy harvesting.

Haitao Ye, Jiayao Ma, Xiang Zhou, Hai Wang and Zhong You (First author is from: School of Aeronautics and Astronautics, Shanghai Jiao Tong University, China), “Energy absorption behaviors of pre-folded composite tubes with the full-diamond origami patterns”, Composite Structures, Vol. 221, 110904, 1 August 2019, https://doi.org/10.1016/j.compstruct.2019.110904

ABSTRACT: Carbon fiber reinforced plastics (CFRP) has demonstrated significant promise to improve the performance-to-weight ratio in automotive and aerospace sectors. Nevertheless, traditional thin-walled CFRP tubes still have several defects such as a high initial peak force with a relatively low mean crushing force and unstable collapse mode, which significantly reduce their performance when used as energy absorption devices. In this study, the full-diamond origami pattern was introduced to thin-walled CFRP tubes. The effect of the origami patterns on the energy absorption properties and collapse modes of these tubes subjected to quasi-static axial loads was investigated both experimentally and numerically. A comprehensive parametric study on the geometrical parameters and ply stacking sequence of pre-folded CFRP tubes was conducted. Moreover, a
comparison between the pre-folded CFRP tube and the metal counterpart was performed, which shows that CFRP pre-folded tube can effectively reduce the initial peak forces while increasing the overall energy absorption capacity.


ABSTRACT: In this paper, the bending, vibration and buckling characteristics of functionally graded porous graphene-reinforced nanocomposite curved beams are studied based on a trigonometric shear deformation theory. The effect of various theories deduced from the proposed formulation on the static and dynamic behavior of curved nanocomposite beams is also studied. The governing equilibrium equations are formed by applying Lagrangian equations of motion coupled with the finite element approach employing a 3-noded C-continuous curved beam element. The methodology developed here is tested for problems having known solutions in the open literature. A detailed investigation involving various parameters such as coefficient of porosity, type of distribution pattern for the porosity and graphene platelets, radius of curvature of curved beam, length-to-thickness ratio, the platelet geometry, and boundary conditions on the static bending, free vibration and elastic stability behavior of nanocomposite curved beams is conducted. New results for certain boundary conditions of graphene reinforced curved beams are presented. Participation of various types of in-plane and transverse bending modes responsible for yielding the lowest critical buckling loads/natural frequencies are also highlighted.


ABSTRACT: This paper aims to investigate the performance of pultruded glass fiber reinforced polymer (pGFRP) I-section columns subject to short-term concentric compression, bringing up a discussion on the relevant parameters affecting their local buckling behavior and the interpretation of tests results. An experimental program was carried out, including a detailed material characterization and twenty-nine compression tests on short I-columns made of either polyester or vinyl ester matrices, with variable flange width-to-section depth ratios \((b/d)\), column lengths and local end conditions. The theoretical critical loads predicted using generalized beam theory (GBT) and finite element method (FEM) were compared to experimental results obtained by Southwell and Koiter techniques, with better agreements obtained for the latter. It is shown that, besides the length and local end conditions for loaded edges, post-buckling with associated non-linear elastic strains distribution throughout the cross-section and damage prior to buckling have relevant influence on the measured critical loads. On the other hand, the influence of the rotational stiffness of web-flange junctions were considered small for the material and cross-sections studied. Finally, results have shown that the usual boundary condition adopted in literature approaches a clamped condition instead of simply-supported one.


ABSTRACT: Carbon fibre reinforced plastics (CFRP) are characterized by lightweight, high specific strength and stiffness, superior energy-absorbing capacity, and excellent design flexibility. Thus, use of CFRP thin-walled structure as crashworthy application can improve fuel economics and crashworthiness characteristics compared with their metal counterparts. In this study, we reported crushing behavior of several CFRP tapered tubes with various cross-sectional profiles and tapered angles under multiple load cases through numerical simulations. The influences of cross-sectional profiles, tapered angle and loading angle on crashworthiness of all configurations were explored by comparing their failure modes, load-displacement curves, crashworthiness indicators and energy-absorbing mechanisms. It was found that a positive correlation between total energy-absorbing capacity and the edge number of cross section profile was demonstrated, and the tapered tubes with circular profile showed the best total energy-absorbing capacity under both axial and oblique loadings. Besides, it was indicated that the energy-absorbing capacity of the tubes reduced in different degrees with increasing
impact angle, and raising tapered angle of the tube was capable to mitigate this reduction degree. Further, the complex proportional assessment method (COPRAS) was adopted to effectively pick up the optimal configuration from all configurations concerned. It was found that H-6, which is the CFRP tapered tube with hexagonal profiles and tapered angle of 6°, was the best configuration, indicating its superiority in crashworthiness characteristics under multiple load cases. Finally, the CFRP tapered tube H-6 was further optimized by using a discrete optimization method to improve its crashworthiness characteristics, and the results showed that the SEA-sub-alpha was improved by 4.35% from the initial design. This study demonstrated that the proposed two-step process (firstly select the best optimal configuration based on COPRAS; then perform the discrete optimization) was fairly effective to obtain an optimal configuration for crashworthiness design of CFRP tapered tubes under multiple load cases.

ABSTRACT: In this work, the large-amplitude free and forced vibrations of functionally graded carbon nanotube reinforced composite (FG-CNTRC) conical shells are investigated based on the higher-order shear deformation theory. In order to obtain the governing equations, the metricized energy functional of the structure is presented based on the higher-order shear deformation theory (HSDT) and von-Karman geometric nonlinearity. Then, the variational differential quadrature (VDQ) method is adopted to present the discretized energy functional. The numerical time differential operators together with the arc-length continuation scheme are utilized to solve the governing equations and find the free and forced vibration responses. In order to evaluate the influences of reinforcement factors and geometrical parameters on the nonlinear vibration behavior, various numerical results are reported. The numerical results reveal that the increase of semi-vertex angle of the shell increases the nonlinear to linear frequency ratio.

ABSTRACT: We present in this note a new derivation for a Fourier transform-based fundamental solution for the coupled bending-stretching problem of laminated composite plates. The classical laminated plate theory is used for the description of the kinematics of the plate.

ABSTRACT: This study investigates the in-plane localised crushing responses and progressive damage mechanisms of CF/EP composite sandwich panels under both quasi-static and dynamic loadings. The effect of the indenter shape on the damage mechanisms of the CF/EP composite sandwich panels under both quasi-static and dynamic in-plane localised crushing were investigated. It was found that the specimens were prone to lamina bending under quasi-static compression irrespective of indenter shapes, whilst the specimens failed mostly with fronds fracturing with different extents of transverse shearing under dynamic crushing. The specific energy absorptions of the CF/EP composite sandwich panels under dynamic impact are 20% lower than those under quasi-static compression. An energy balance model was adopted to analyse failure mechanisms and energy dissipation. To the model, the geometry of the debris wedge was predicted using an inverse calculation with experimental validation. The results show that the crush energy is mainly consumed by friction work and bending at about 55% and 35%, respectively.

ABSTRACT: Fiber steering is an outstanding capability for producing composite structures with spatially tailored properties. The ability of tailoring the reinforcement arbitrarily in the space generates laminate with
variable-stiffness, possessing substantial scope for outperforming traditional constant-stiffness laminates. This investigation presents a methodology to optimize composite cylinders with a variable-axial (also known as variable angle-tow and variable-stiffness) layout under axial compression for the adopted design space, loads and boundary conditions, using a novel optimization concept based on the manufacturing characteristics of the Tailored Fiber Placement (TFP) process. Next, a post-buckling analysis is carried out in order to make a first assessment of the imperfection sensitivity of the cylinders. The current approach locally optimizes both thickness and fiber angle of each finite element (FE), where thickness accumulation is reached through a smooth overlapping of rovings, a typical characteristic of TFP process. The optimized cylinders have significantly higher linear buckling loads than the corresponding initial layouts and are less sensitive to affine initial geometrical imperfections. The current work on optimization of the linear buckling behavior of variable-axial (VA) shells shows both the potential of using VA-configurations to exploit their tailoring ability and the capabilities of the current optimization framework to improve and optimize the behavior of VA structures.


ABSTRACT: This research paper presents the dynamic and aeroelastic analysis of functionally graded carbon nanotube reinforced (FG-CNTRC) laminated composite plates with damage in the subsonic regime. First order shear deformation theory (FSDT) is applied to develop finite element code in MATLAB environment for structural analysis. The anisotropic damage formulation based on the concept of stiffness reduction is introduced into the finite element formulation to include the damage in the plate. To implement aeroelastic analysis through PK-method, the required aerodynamic force matrix coefficients, are generated in MSC.Nastran by supplying modal parameters (obtained from structural analysis) through direct matrix abstract program (DMAP) using doublet-lattice-method (DLM). The accuracy of the present model has been analyzed by tackling the various numerical illustrations and validated with some of earlier published literature. Further, the effect of various parameters like CNT fiber volume fraction, lamination sequence, damage location and orientation on flutter characteristic are studied.


ABSTRACT: In this work novel unconventional core architectures are presented which are able to induce flexural band gaps while not being detrimental for structural bending stiffness of the sandwich structures. Two different core schemes are examined with both of them exhibiting low-frequency stop bands. While unconventional, the designs of the core offer a novel solution which can be easily manufactured in high volume parts using two-dimensional automated cutting machine. A hybrid finite element and periodic structure theory scheme is employed for the calculation of the stiffness and mass matrices, and periodic structure theory is used to obtain the wave propagation of the beams. Having acquired the wave dispersion curves and the finite element analysis’ results, two specimens are manufactured using carbon fibre cured plates and commercially available PVC foam as core material. Experimental measurements of the dynamic performance of the structures are conducted using a laser vibrometer and electrodynamic shaker setup.


ABSTRACT: This study presents an isogeometric plate element, IG-RZT based on the refined zigzag theory (RZT) to model bending behavior of blade stiffened and unstiffened thick or thin laminates. This element is free of shear-locking and shear correction factors due to the use of Non-Uniform Rational B-Splines (NURBS) functions which satisfy the requirement of C1 continuity in the computation of transverse shear stresses. Comparison of the predictions with IG-RZT element with the previous benchmark solutions reveals fast convergence and high accuracy for general laminate layups under different loading and boundary conditions. Thus, the IG-RZT element can be adopted for computationally efficient and accurate analysis of unstiffened and stiffened flat laminates.

References listed at the end of the paper:


[36] Di Sciuva M, Gherlone M, Iurlaro L, Tessler A. A class of higher-order C0 composite and sandwich beam elements based on the


ABSTRACT: The scaled boundary finite element method (SBFEM) incorporated with the precise integration technique (PIT) is further extended to present the semi-analytical analysis of static bending and free vibration behaviors of laminated magneto-electro-elastic composite plates. It is applicable to thin and thick multilayered magneto-electro-elastic plates. The basic equations are formulated by only using the two dimensional model, which helps to make sure that the computation is efficient. The discretization is carried out in terms of spectral elements. Only three displacement components, electric and magnetic potentials are selected as the basic variables. Characterized by the important features of the SBFEM, the elastic displacements, electric and magnetic potentials along the thickness direction can be solved analytically. Differing from most plate models taking a priori assumptions on distributions of the mechanical, electric and magnetic variables, the derivation of governing SBFEM equations strictly follows the 3D theory of magneto-electro-elastic materials without introducing any assumptions on multiphysics fields. By virtue of the scaled boundary coordinates and the principle of virtual work, the key partial differential equations are simplified into the governing ordinary differential matrix equation. To increase the accuracy of the SBFEM governing equation, the PIT is utilized, which ensures that any desired accuracy of the results can be reached. Static and dynamic numerical examples show that variations of mechanical, electric, magnetic fields and natural frequencies predicted by the proposed approach are in excellent agreement with the elastic solutions of other methods. Therefore, the versatility and perfect accuracy of the present technique is fully validated. Furthermore, the influences of aspect ratios, boundary conditions and stacking sequences on the cross-thickness distributions of displacements, stresses, electric potential, electric displacements, magnetic potential, magnetic induction and vibration frequencies in the multilayered magneto-electro-elastic plate are discussed.


ABSTRACT: In this paper, a new solution approach based on Lagrange multipliers is developed for aeroelastic panel flutter analysis of rectangular composite plates sandwiched by two Macro Fiber Composites (MFCs). The smart panel has general stacking sequences and subjected to the elastic edge restraints. By utilizing the assumed mode technique, the displacements and electric potentials are expanded using formerly determined mode shapes. Afterward, the potential and kinetic energies of the problem are achieved and by employing the Lagrange equation, the discretized equations of the motion are obtained. The supersonic aerodynamic load is modeled through the well-known piston theory and included within the equations by means of the non-conservative force term of the Lagrange equation. Deriving the equations is more simplified thanks to the
orthogonality of the Legendre polynomials. Finally, the input voltage of the MFC actuator is determined through the proportional or velocity feedback control algorithms based on the sensor output. The capability and credibility of the proposed approach are confirmed by comparing the results with those achieved by the FEM. The method is used to investigate the effects of MFCs orientations on the panel flutter boundaries of smart plates.


ABSTRACT: In this research, a novel three-dimensional (3D) exact solution for the dynamic analyses of functionally graded (FG) cylindrical structures with arbitrary boundary conditions is put forward. In accordance with the power law distribution of constituents volume, the material properties vary consecutively along the length of the FG cylindrical structures. The theoretical model is derived based on the 3D elasticity theory. The displacements of the FG cylindrical structures are expanded as a 3D cosine series accompanied with auxiliary functions. In comparison with traditional Fourier series, these complementary functions can be helpful to remove the discontinuities of the displacements and the correlated derivatives at the edges. The advantage of the present method compared with others is that it is able to be extended to arbitrary boundary conditions without peculiar procedures. The present results are compared with those from other literature to validate its reliability. Several numerical examples are exhibited for FG cylindrical structures (open cylindrical shell, open cylindrical solid, cylindrical shell and cylindrical solid) with different types of boundary conditions (both classical and elastic boundary conditions). In addition, the effect of gradient index on the FG cylindrical structures is also reported.


ABSTRACT: In this paper, the nonlinear resonance behaviors of bi-directional functionally graded (BDFG) microbeams are investigated. The material properties including the material length scale parameter vary along both thickness and axial directions. Employing Hamilton’s principle, the differential equations are derived based on von-Karman geometric nonlinearity and Timoshenko beam theory. The modified couple stress theory is adopted to capture the size effects. The continuous system dynamics model is discretized by method of Galerkin scheme along with appropriate eigenfunctions, resulting in the reduced order model which is a coupled large-dimension system of nonlinear ordinary differential equations. The nonlinear resonance behaviors of two type of BDFG microbeams are explored by performing one- and two-parameter bifurcation analyses. In one-parameter bifurcation analysis, the frequency- and force-response curves are constructed by tracing the period motion of microbeam using the pseudo-arclength continuation technique. Cyclic-fold bifurcation which indicates jump phenomenon is detected in the period motion. The trajectories of cyclic-fold bifurcation points are achieved by implementing the two-parameter bifurcation analysis. The cusp bifurcation of periodic motion implies the occurrence of CF bifurcation. Numerical simulations are performed to examine the influences of the system parameters, e.g. gradient indexes, dimensionless length scale parameter, damping coefficients and aspect ratio on the nonlinear resonance of BDFG microbeams.


ABSTRACT: This paper is concerned with the numerical analysis of nonlinear flutter of composite laminated panels with local non-smooth friction interfaces and exposed to supersonic airflow. The Reddy’s third-order shear deformation plate theory with zig-zag effects and the nonlinear von Kármán strains are employed to formulate the structural model of the panel. A series of macro-slip friction models are adopted to impose the friction boundaries, which can describe the non-smooth characteristics of the friction interface. The discretized governing equations of motion of the panel with non-smooth friction boundary are established using the nonlinear finite element method. The effects of the physical parameters of the friction interface including the normal force, the coefficient of friction and the length of the friction interface, on the flutter behaviors of the laminated panel are examined. It is found that the critical flutter dynamic pressure of the panel may increase due
to the constraints of the friction boundary. As the dynamic pressure increases, an abrupt variation in the flutter response of the panel may appear due to the coexistence of the stick and slip motions of the friction interface. In addition, the friction boundary has little effects on the location of the maximum deformation of the panel.

ABSTRACT: New hyperelastic orthotropic models are proposed for the simulation of textile membranes used in civil engineering applications. In contrast to published models, part of the new models is polyconvex and ensures thereby a physically meaningful and mathematically sound formulation. The models are adjusted to uniaxial tension tests performed in warp and fill direction, where not only the stress-strain response in tension direction is accounted for but also the lateral contraction. Thereby, the crosswise interaction between the warp and fill direction is captured. In a series of different boundary value problems the new models as well as a competitive formulation given in literature are compared with respect to the accuracy to represent the experimental data, the mathematical properties as well as the numerical robustness. As it turns out, most formulations including the model from the literature show a loss of material stability and non-converging Newton iterations in structural simulations. Only one of the proposed polyconvex formulations works robustly in numerical simulations of realistic structural engineering problems. Thereby, this new orthotropic model enables realistic simulations of textile membranes in a fully geometrically nonlinear setting, which does not require simplifications based on linearized strains, which are currently used as standard in engineering practice.

ABSTRACT: To investigate the shearing effect and size effect of micro-beams, a new Timoshenko beam model based on the modified gradient elasticity (MGE) is developed by using the variational principle. The new model can be simplified to the MGE Bernoulli-Euler beam model when the shearing effect is neglected, also can be simplified to the classical Timoshenko beam model when two internal length scales vanish. To solve this new model, a central finite difference method with virtual nodes is developed. Three numerical examples of the homogeneous beams and axially functionally graded (AFG) beams are considered in this paper. The size effect can be captured by the new model, i.e. the deflection, rotation angle and shearing angle decrease with the internal length scales increasing. The shearing effect, which plays an important role in deflection for a micro-beam, cannot be neglected even for the slender beam.

Xintao Huo, Guangyong Sun, Haiyang Zhang, Xiaojian Lv, Qing Li, “Experimental study on low-velocity impact responses and residual properties of composite sandwiches with metallic foam core”, Composite Structures, Vol. 223, Article 110835, 1 September 2019, https://doi.org/10.1016/j.compstruct.2019.04.007
ABSTRACT: Performances of lightweight sandwich panels can be enhanced by proper combination of facesheets and core. To promote sandwich structures for automobile applications, this study aimed to investigate the crushworthiness and residual performance of metallic foam based sandwich panels. Three types of facesheet materials (i.e. aluminum alloy Al6061, glass fiber reinforced plastic (GFRP) and carbon fiber reinforced plastic (CFRP)) with different Young's moduli and ultimate strengths were considered; and the effects of skin thickness, core density and core height were evaluated under both low-velocity off-panel pre-impact and in-panel post-compression. The compression after impact (CAI) tests were conducted in a full range of impact energy up to structural penetration of sandwich panel. The loading process and failure mechanism were scrutinized based upon the internal damage and external deformation modes, acquired by computerized tomography (CT) scan as well as in-situ 3D digital image correlation (DIC) techniques, respectively. Under the low-velocity pre-impact, two typical load-displacement responses, namely double-peak and triple-peak patterns, were observed. It was found that impact resistance of the sandwiches with Al6061 facesheets was higher than that with fiber reinforced plastic (FRP) laminated facesheets, meaning that ductile materials could be a better choice for sandwich facesheets when the impact resistance is a primary concern. For the in-panel post-compression test, it was found that the Al6061 facesheet failed in a collapse mode due to buckling; while the FRP laminated facesheet damaged in a form of fracture. Besides, the experimental results revealed that the specimens with Al6061 facesheets exhibited advantages in terms of peak load, energy absorption and the
specific energy absorption (SEA). Nevertheless, the sandwiches with the FRP laminated facesheets demonstrated better structural integrity and residual performance of mechanical responses after the pre-impact.


ABSTRACT: Shape memory polymer composites (SMPCs) demonstrate the advantages of light weight, high strain rate, high strength, high stiffness, self-locking and self-deployment. In this study, the mechanical properties and deformation performance of SMPC-based lenticular tube are studied. Dynamic mechanical analysis (DMA) tests and three-point bending tests were carried out to determine thermomechanical properties, and +45°/−45° fiber layout was chosen as the optimum layout. Tensile tests were conducted to investigate the mechanical properties of SMPC at different temperature. The strain distribution during recovery process was obtained by digital image correlation (DIC) experiment. Bending and recovery process were simulated by finite element analysis, the stress distribution of curved state of lenticular tube were obtained. Comparing with traditional lenticular tube, SMPC-based lenticular tube exhibits the advantages of controllability and stability in deploying process, and they still work well after folding 30 deformation cycles. Due to its above advantages, several potential applications are proposed for deployable space structures and will be validated in near future.


ABSTRACT: Composite structures in a thermal environment may suffer from buckling failures due to thermally induced compressive forces, leading to concerns over their application in environmentally aggressive conditions. This issue is addressed by proposing a novel approach to the design of tow paths for enhancing thermal buckling performance, and it can also overcome the problems of tow gaps and overlapping. A level set function, such as defined by signed distance function, for representing a series of equidistant tows throughout the laminate, is adopted here to formulate an optimization problem that seeks to maximize the buckling load under thermal loading, and the level set values are thus the design variables. Sensitivities of thermal buckling eigenvalues with respect to tow paths, i.e. level set values, are derived through the adjoint method, and they are used to solve the optimization problem through the Hamilton-Jacobi equation. In this study, numerical examples are presented to demonstrate the effectiveness of the proposed method, where laminated plates made of various materials under different boundary conditions are considered. Results show that the proposed approach can provide efficient solutions with enhanced buckling performance.


ABSTRACT: Together with fiber breakage and matrix cracking, delamination is one of the common damage mechanisms occurring in laminated fiber-reinforced composite structures. Delamination initiates due to the relatively low interlaminar strength of adjacent plies. Delamination onset and propagation can be induced by various combinations of loads and usually leads to a significant reduction of the load-carrying capacity of the structure. For this reason, an efficient and reliable progressive failure analysis capability is required. In this work, the delamination process is simulated by means of a two-way global-local coupling approach. In particular, within this novel global-local approach a method is introduced that ensures the preservation of the dissipated energy when switching between the global and local level. This approach is tested and illustrated under single-mode I and II, and mixed-mode loading in the double cantilever beam (DCB), the end-notched flexure (ENF) and the mixed-mode bending (MMB) benchmark tests, respectively, and the results are compared to available analytical solutions. Finally, the developed method has been applied to a one-stringer stiffened panel and a good agreement was attained compared to the solid model reference solution.
ABSTRACT: In the study presented, active and passive vibration control techniques for a thin-walled composite beam were developed and experimentally analysed. An MFC (Macro Fibre Composite) actuator was used, together with the magnetic forces between two permanent cuboidal magnets (passive vibration control) for vibration damping applications. After the experiments conducted with active vibration control (MFC actuator), it was found that in all cases, the vibration damping of the analysed system was much higher at its resonant frequency. Nevertheless, due to the experimental results, it could be concluded that active and passive vibration control systems were efficient for thin-walled composite beam vibration amplitude control. Methodology for thin-walled composite beam vibration control analysis was developed and presented in the article.

ABSTRACT: This paper presents a study on the stresses caused by transverse shear force on corrugated laminates that complements existing work having addressed stresses caused by bending moment. It recalls recent theory for simulating transverse-force effects, provides fundamental insights on the peculiar effects of corrugation on shear stress distributions, and illuminates the effects of geometric parameters and laminate design on inter- and intralaminar shear-stress distributions. At the end, a critical distance between clamping and transverse-force introduction is identified at which the internal bending moment and the transverse force compete in providing failure conditions.

ABSTRACT: Laminated carbon fibre reinforced composite materials are very susceptible to delamination, which is one of the most serious failure modes in composite laminates. According to the requests of damage tolerance evaluation, to completely evaluate the buckling responses and failure behaviors of delaminated composites under uniaxial compression, an analytical model was established. Based on the principle of minimum potential energy and brittle damage mechanics, the analytical model incorporated both the delamination propagation and failure evaluation into the buckling analysis. Uniaxial compression tests of three specimens containing embedded delaminations were conducted. The predicted results are highly consistent with the experimental outcomes, thus validating the applicability and accuracy of the proposed analytical model. It is found that the out-of-plane deflections and energy release rate of the delaminated laminate are closely related to the buckling states; the choice of Gc in a range from G1c to Giic has little effect on the predicted results with the proposed model.

ABSTRACT: A robust design optimization algorithm is proposed for variable angle tow composite structures in the presence of uncertainties in the constituent material properties and applied loads. The proposed algorithm uses a stochastic perturbation method to propagate these uncertainties through to the simulated structural response, measured in terms of buckling load. The expected value plus a selected number of standard deviations of the response in the form of a bi-criteria problem. To describe the curvilinear fibres, two types of fibre path function, namely linear- and nonlinear-variation formulae, are adopted to illustrate the proposed methodology. A comparison between the resulting robust designs and deterministic designs is made, and changes to the final designs of fibre tow paths arising from the inclusion of uncertainty are discussed. It is shown that the robust designs out-perform the deterministic designs under real-world situations that include uncertainties.

ABSTRACT: Preload in a cast-in-situ concrete-filled steel tube (CFST) structure is an important parameter that has been studied and considered in design and construction. However, the impact of a preload on fire resistance of CFST has not been taken into account in the existing design method of CFST under fire. In this paper, twelve CFST columns with and without preload in the steel tubes are experimentally studied to investigate their heating process, failure modes, thermal and structural responses. The test results show that preload of the steel tube has significant impact on the fire resistance of some of the columns. Further investigations on this important observation will be done numerically in a companion paper [24] to carry out a more comprehensive parametric study.


ABSTRACT: Cast-in-situ concrete-filled steel tube (CFST) structures are inevitably subjected to preload that are developed in the steel tube during the construction process. These preloads may have detrimental effects on the overall performance of a CFST component, such as a CFST column, especially when the column is subjected to elevated temperature. However, existing design methods of CFST exclude the impacts of preload in fire resistance design. In this paper, a three-dimensional finite element model for predicting fire resistance of CFST with preload is developed and validated by experimental tests. The model is then used to predict fire resistance time of CFST columns with different slenderness, load and preload ratios. The results show that preload of the steel tube have little influence on the fire resistance of short CFST columns, while the influence of preload on the fire resistance can be significant when the slenderness ratio is greater. Further increase of the slenderness ratio exceeding a certain range, however, reduces the effect of preload. It can be generally concluded that fire resistance of slender CFST columns decreases with increase of preload ratios and the effect of preload on fire resistance of CFST columns is more prominent when the load ratio is greater. In addition, formulas for calculating fire resistance of cast-in-situ concrete-filled steel tubes (CFST) with preload are proposed.


ABSTRACT: In this research, the post-buckling behaviors of doubly curved composite shells in hygro-thermal environment are investigated by employing multiple scales perturbation method. Three-phase composites shells with polymer/Carbon nanotube/fiber and polymer/Graphene platelet/fiber (PGF) and Shape Memory Alloy (SMA)/matrix according to Halpin-Tsai model are taken into consideration. The displacement-strain of laminated doubly curved shells via third-order shear deformation theory (TSSTDT) and using von-Kármán nonlinear shell theory is obtained. The governing equations of shallow shell are derived by implementing Hamilton's principle. For investigating correctness and accuracy, this paper is validated with other previous researches. Finally, different parameters such as volume fraction of SMA, temperature rise, various distribution patterns, aspect and curvature ratios are considered in this article. It is found that these parameters have significant effect on the thermal buckling loading.


ABSTRACT: The natural frequency and transient response of FGM cylindrical shells under arbitrary boundary conditions are performed in present work. A novel semi-analytical method, which integrates Durbin’s inverse Laplace transform and the differential quadrature method, is developed to analyze the dynamical behavior of cylindrical shells. Durbin’s numerical inversion method is selected to gain time domain solutions. The trigonometric series expansion is used in the circumferential direction whereas the use of differential quadrature method provides numerical solutions in terms of axial direction. Comparisons show that the calculated natural frequencies are in good agreement with results in the literature. Convergence study illustrates that the developed
method is rapidly convergent with the increase of sampling points, and the calculated transient response of the cylindrical shell is validated by comparing with Navier’s solution. The influences of boundary conditions, material graded indexes, temperature changes, elastic foundation coefficients and geometric parameters on transient response are analyzed. Numerical results indicate that the peak displacement of cylindrical shells increases with the increase of temperature changes and length-radius ratios or the decrease of elastic foundation coefficients and thickness-radius ratios.


ABSTRACT: In this paper, an extended first order shear deformation theory is proposed for Reissner-Mindlin laminated composite panels with internal delamination. The distinctive feature of the present theory is that a contact mechanism is involved in the governing equations based on FSDT by introducing a constitutive relation between the contact force and the transverse deflection and are expressed in terms of the displacements and the rotation functions. The proposed theory is applied to investigate the structural failure of a delaminated Reissner-Mindlin composite panel subjected to in-plane compression. Numerical solutions are computed by developing MATLAB program for different values of thickness-to-width ratio, material properties, aspect ratio and delamination conditions and are compared with those obtained from the modified classic laminated plate theory established in previous works and with ABAQUS results. Both theories and ABAQUS analysis predict a consistent global buckling mode without opening in between the delamination. The comparisons of the two solutions not only validate the efficiency and accuracy of the proposed M-FSDT but also evidence that neglecting the transverse shear strain may lead to the overestimation of the load capacity of the panel up to more than 35% when the thickness-to-width ratio is greater than 0.15.


ABSTRACT: In this paper, the non-linear mechanical behavior of shear deformed woven composite was predicted using a representative volume element (RVE) model based on multi-scale progressive failure analysis. The micro-scale RVE model, consisting of single fiber and a matrix, was employed to determine the stress amplification factor and distinguish the failure of each fiber and the matrix constituent. Then, a meso-scale RVE model of shear deformed twill woven composite was developed to predict non-linear behavior using micro-stress transferring with finite element simulation. Fiber yarn shapes were observed with respect to the shear angle of the twill fabric. Based on the observed yarn geometry, shear deformed twill composite was modeled by using the open source software TexGen. To prove validity of the proposed model, shear deformed twill woven composite was fabricated using a picture frame, followed by a vacuum assisted resin transfer molding process. Mechanical tests were conducted and the failure progress during the tests was observed to determine their failure analysis. As a result, a good correlation between the multi-scale progressive damage model and experimental results such as mechanical properties, the non-linear stress-strain curve, and failure modes were achieved.


ABSTRACT: In this paper, the mechanical behavior of aluminum foam sandwich plate (AFSP) subjected to repeated impact loadings is investigated. Firstly, the method to achieve repeated impacts of AFSP in the numerical simulation is proposed. Then dynamic responses obtained from repeated impact tests are compared with those of numerical simulations, and the results show good agreements. Besides, the mechanism of energy absorption of the AFSP under repeated impacts is examined. Results show that the elastic deformation energy of AFSP increases with the impact number, but the increment declines. On the contrary, the plastic deformation energy decreases with the impact number. In addition, the effects of thickness distribution of face sheets on impact resistance of AFSP under repeated impacts are investigated. It can be found that as the thickness of front

**ABSTRACT:** This study aims to optimize fabric architecture of soft armour panel in order to improve ballistic performance without increasing weight. Finite Element (FE) analysis, in conjunction of ballistic test, was used to investigate ballistic responses of fabrics with different weave parameters under ballistic impact. In an individual layer, the yarn crimp effect on energy absorption exhibits significant in the consideration of yarn count, weave density and areal density of fabric. FE results indicate that the stress on the high crimp fabric fluctuated more severely at the crossover and fail earlier than that of the fabric with low crimp. In a multi-layer panel, the yarn crimp is still influential on energy absorption of each fabric layer, Backface Signature (BFS) and perforation ratio of the whole panel. The panel combining low crimp fabrics shows that the energy absorption efficiency of each layer is higher than that of the panel composed of high crimp fabrics. However, the panel with low crimp fabrics possesses enlarged BFS and increased perforation ratio. These findings are greatly meaningful for the design of soft armour panel.


**ABSTRACT:** Over the years, Composite Overwrapped Pressure Vessels (COPV) have been utilized in the aerospace and automotive industries. In the present work, a novel approach has been adopted in designing the liner and test the feasibility of adopted manufacturing and joining techniques. The selection of winding angle and thickness distribution of composite along the meridional direction of the pressure vessel is derived by using an analytical approach based on classical laminate theory. Further, Finite Element Modelling (FEM) software ABAQUS-6.14 is utilized and tested for minimum burst pressure load to account the effects of composite winding angle layup and effective thickness of liner and composite at the pole, dome and equator regions of COPV. Among the various failure criterion of COPV, liner buckling and bond failure between the liner and composite overwrap resulting in the creation of the debond region are considered. These failures are concerned with contact issues and can be minimised by proposing to include a hyperelastic elastomer layer between the liner and composite overwrap. The analytical and FE analysis approach towards predicting the strength response of composite under applied load showed good agreement. At minimum burst pressure load findings showed that overall behaviour, stress-strain distributions and effect of elastomer thickness on liner were found satisfactory. A critical study involving Finite Element Analysis (FEA) based liner alone burst pressure test, and credibility of joining techniques employed in assembly of liner is analysed and found acceptable.


**ABSTRACT:** The current research reported the thermal free vibration characteristics of the debonded composite shell structure considering the large geometrical deformation. The delaminated composite panel structural model is derived using two different higher-order polynomial kinematics. The nonlinear structural geometry has been modeled via Green-Lagrange relations in conjunction with temperature loading. The separation between the adjacent layers of the composite has been incurred through a sub-laminate approach and the corresponding displacement continuity imposed at the boundaries (laminated and delaminated). Moreover, the isoparametric Lagrangian type of element (eighty-one and ninety degrees of freedom) is adopted for the discretization of the physical shell structure. The nonlinear governing equation of motion of heated shell (healthy and debonded) structure derived using Hamilton principle and the nonlinear frequency responses computed using the direct iterative technique for the computational purpose. The solution (numerical) stability and the accuracy have been established as a priori by solving a series of examples available in the literature. The conclusions regarding the model applicability for debonded (size, location and position) structural analysis represented with or without temperature effect.

ABSTRACT: The damage of fiber reinforced polymer matrix composite materials induced by impact load is one of the most critical factors that restrict extensive use of these materials. The behavior of composite structures under transient impact loading and the ways to enhance their characteristics to withstand this type of dynamic loading might be of specific significance in the aerospace sector and other applications. This paper critically reviews the important parameters from the published literature influencing the impact resistance and the damage mechanics of fiber-reinforced composite materials. Firstly, the paper reviews the influence of impact velocity on various failure modes. Following this, a comprehensive review on the four key parameters specifically material, geometry, event and the environmental-related conditions that affect the structural behavior of fiber reinforced polymer matrix composites to impact loading is discussed. The review further outlines areas to improve the impact damage characteristics of composites and then conclude with a summary of the discussion on the future work relating to the most influencing parameters.


ABSTRACT: In this paper, static bending, buckling, free and forced vibration of functionally graded (FG) nanobeams are studied within the framework of the recently proposed nonlocal strain gradient theory and the Euler-Bernoulli beam theory. The material properties of nanobeam are presumed to be graded in the thickness direction according to a simple power-law distribution in terms of the volume fraction of the constituents. The governing equation and the related boundary conditions are derived via the principle of the calculus of variation. In order to eliminate the axial displacement in the formulation, the concept of the neutral surface is adopted. Some analytical solutions are obtained for the static displacement, critical buckling load, free vibration frequencies and the dynamic displacement for the case of the simply-supported end condition. In the dynamic analysis, three different loading cases, a moving load with constant velocity, point and distributed harmonic loads, are considered, and Duhamel’s integration is utilized for obtaining the corresponding dynamic deflections. Several numerical examples are presented in figures and tables in order to examine the effects of the strain gradient and the nonlocal parameters, the gradient index, the excitation frequency and the moving load velocity on the mechanical behavior of FG nanobeam.


ABSTRACT: This study aims at exploring buckling behavior of multilayered composite plates including functionally graded material (FGM) layer in thermal environments by using a mesh-free method. The thermal buckling of the composite plate laminated with FGM layer is formulated by an improved Moving Kriging (MK) meshless method based on an nth-order shear deformation theory which enables the optimal order number to provide the best prediction to be chosen. In the improved MK mesh-free method, the covariance basis function is presented in a compactly supported form to build the shape functions with no fitting parameters. Four types of multilayered composite plates with FGM layer subjected to in-plane and through-thickness temperature changes are considered, and the material properties are both position and temperature dependent. Performance accuracy of the proposed mesh-free method is first confirmed by comparing the computed results with the reference solutions available in the literature, followed by the detailed parametric studies in which the effects of the ingredient fraction, FGM constituents, composition scheme, plate geometric parameter and boundary condition are scrutinized focusing on temperature dependency of the material properties.


ABSTRACT: Elastoplastic thermal buckling characteristics of ceramic-metal functionally graded material (FGM) beams subjected to transversely non-uniform temperature rise are investigated by symplectic method in Hamiltonian system. Based on TTO model, the linear hybrid hardening elastoplastic model is used to simulate
the elastoplastic material properties and establish thermal elastoplastic constitutive equations of FGM beams. Then, the canonical equations are established to transform critical loads and buckling modes into symplectic eigenvalues and eigensolutions in symplectic space. The main contributions of this study are that complete buckling mode space and critical thermal axial forces for elastoplastic thermal buckling of the FGM beams are obtained by analytical solutions; meanwhile, buckling temperatures and elastoplastic interfaces of the bucked FGM beams are obtained by inverse solutions. Numerical examples of buckling behaviors varying with thermal load, slenderness ratio and power law index are presented. The effects of elastoplastic material properties on critical temperatures and plastic zone are analyzed and discussed.

ABSTRACT: We consider a sandwich plate with face sheets made of unidirectional fiber-reinforced composite with fibers being either glass, or carbon or aramid and the core made of balsa wood loaded by a blast pressure, and find optimal geometries and materials for maximizing the first failure load. While analyzing the problem, we assume that the areal density is fixed and use the Nest-Site Selection optimization algorithm, a third-order shear and normal deformable plate theory, a one-step stress recovery scheme, and the Tsai-Wu failure criterion. We also delineate the effect on the first failure load of inertia forces and uncertainties in values of various parameters. For a sandwich plate optimally designed for the first failure load, we find the ultimate load by progressively degrading elasticities of failed elements. We find that the optimal single-core sandwich designs are symmetric about the mid-surface with thick face sheets and the optimal two-core sandwich designs have a thin middle face sheet, and thick top and bottom face sheets. The first failure load of the optimal clamped single-core (two-core) design is approximately 20% (30%) more than that of the corresponding simply-supported plate. For simply-supported (clamped) sandwich structures, the failure initiates at the centroid (center of the clamped edge) of either the top or the bottom surfaces. It is also found that the first failure occurs in a face sheet (core) due to the in-plane transverse axial stress (transverse shear stress) exceeding its critical value. The collapse load of a clamped (simply-supported) sandwich structure is approximately 15%–30% (0%–17%) higher than the first failure load. The maximum deflection of the collapsed structure may be in a direction opposite to that of the applied load. A novelty of the work is in considering inertia effects in ascertaining the first and the ultimate failure loads and quantifying the benefits, if any, of two-core over one-core sandwich structures, and determining effects of uncertainties in values of parameters.

ABSTRACT: Longitudinal compressive strength of common engineering FRP is known to possess large stochastic variation which highlights the importance of accurate prediction on the compressive failure behaviour. This study employs non-linear 3D FE modeling to investigate the influence of spacial fibre waviness and non-uniform fibre packing on the compressive strength of UD FRP. Cuboid shaped FE model is constructed, and a region of sinusoidal fibre waviness is introduced in the model. Fibre is considered as materially linear-elastic but geometrically non-linear, while matrix is considered as elastic perfectly plastic. The results highlight that in the fibre kinking process fibre rotation may not necessarily occur in the plane with largest preliminary fibre misalignment angle (or fibre waviness plane). The compressive strength of FRP not only depends on fibre misalignment angle but also on fibre waviness direction, while non-uniform fibre packing seems to have insignificant influence on the compressive strength.

ABSTRACT: The hot-press molding method was developed to fabricate a novel composite Y-frame core sandwich panel in this paper. The shear experiments were conducted to investigate the shear mechanical response of the composite Y-frame core sandwich panels with different relative densities. The impact of relative density on the failure behavior, shear stress-strain curves and shear properties were discussed. The shear tests indicated that the shear mechanical response of the composite Y-frame core sandwich panels was significantly
influenced by the relative density. It was observed from the tests that the delamination failure at the web of the Y-frame core was the dominant failure mode. The shear stress-strain curves of the composite Y-frame core sandwich panels with different relative densities were featured by three typical stages and two peak stresses. The shear strength and stiffness of the composite Y-frame core sandwich panels were predicted, which were in good agreement with the experimental results.


ABSTRACT: Considering the design of aerospace structures, an experimental campaign is essential for validating the sizing methodology and margins of safety. Particularly for buckling-critical cylindrical shells, the traditional buckling test could lead the specimen to permanent damage. Therefore, the validation of nondestructive experimental procedures for estimating the buckling load of imperfection-sensitive structures from the prebuckling stage is receiving more attention from the industry. In this context, this paper proposes an experimental verification of the robustness of a vibration correlation technique developed for imperfection-sensitive structures. The study comprises three nominally identical unstiffened composite laminated cylindrical shells. Each specimen is tested 10 times for buckling at DLR and, the reproducible results — within a small range of deviation between them — corroborate the equivalence of the cylinders. For the robustness assessment of the vibration correlation technique, two different buckling test facilities are considered. Furthermore, the material properties are recalculated through composite composition rules and the influence of enhanced theoretical buckling loads on the VCT predictions is verified. The experimental campaigns corroborate that the vibration correlation technique provides appropriate estimations representing the influence of the different test facilities; moreover, enhanced theoretical buckling loads can improve the predictions for some of the test cases.


ABSTRACT: This work analyses the thermal vibration of a double curved sandwich panel (DCSP) with embedded pre-strained shape memory alloy (SMA) wires hybrid composite face sheets and soft core. The von Karman nonlinear displacement–strain relationships are here applied to handle large deflections due to a thermal loading. The equations of motion are derived by applying the Hamilton’s principle and the first order shear deformation theory (FSDT) for the composite face sheets and core layer. This last one features the displacement field of the Frostig’s second model here, used to model the DCSP. The material properties of the DCSP are assumed to be both temperature-dependent (TD) and/or temperature-independent (TI). The effect of the SMA wires is captured by adding a stress recovery within the formulation. This term is determined by using a one-dimensional Brinson’s model in the constitutive equations of the SMA composite face sheets during the phase transformation of the pre-strained SMA wires. It is verified that SMAs can play a key role within DCSPs subjected to a thermal loading condition, whereby the proposed formulation is validated comparatively against the available literature. We also explore the sensitivity of the vibration response for a varying SMA activation temperature, volume fraction, and pre-strain, as well as for different curvature ratios, thickness ratios and different sequences in composite layers.


ABSTRACT: Dynamic stability characteristics of variable stiffness composite rectangular panels subjected to non-conservative compressive or shear follower loads are investigated here using the shear-deformable finite element method. At the beginning, the veering of modal frequencies are studied by the eigenvalue analysis to classify the divergence and flutter type of instabilities and evaluate the critical loads for isotropic and variable stiffness composite plates under both types of follower forces. Thereafter, the governing finite element equations are reduced into a set of Mathieu-Hill equations employing the modal transformation technique and the method of multiple scales is used to determine the regions of instability of composite laminates under pulsating follower forces. Limited numerical examples are presented to demonstrate the simple and combination
(additive/difference) type of parametric instabilities of edge supported and cantilever panels with curvilinear fibers under compressive or shear pulsating follower forces.


ABSTRACT: Telephone cord blisters (TCBs) are frequently observed in film/substrate material systems. They nucleate and propagate forward with wavy boundaries between the film and the substrate. The current study views the problem from a completely new angle: It is discovered that the spontaneous formation and morphology of TCBs in thin films under biaxial compressive residual stresses can be accurately explained and determined by assuming the existence of a pocket of energy concentration (PEC) instead of the existence of a separation of critical size. For the first time, completely-analytical formulae—the ‘Ω formulae’—are derived for the two local morphology parameters of TCBs of any shape, that is, width and height, and for the two global morphology parameters of TCBs of sinusoidal shape, that is, the wavelength and transverse amplitude. Mechanical conditions are also given for the first time for the formation of TCBs. Predictions for the four morphology parameters of the developed theory agree very well with extensive experimental results. In addition, by reversing the calculation, the residual stress and the film/substrate interface fracture toughness are also accurately determined from measurements of the TCB morphology parameters.


ABSTRACT: Composite structures are extensively used in many industries, where they are subjected to a variety of loads and may undergo large deformations. Reliable utilisation of such structures requires prior knowledge of their failure response. In order to predict failure loads and modes, accurate, yet computationally efficient, evaluation of three-dimensional (3D) stress fields becomes important. In this paper, we present a modelling approach, based on the Unified Formulation, that accounts for geometric nonlinearity in laminated composites and predicts 3D stress fields for subsequent failure analysis. The approach builds upon the hierarchical Serendipity Lagrange finite elements and is able to capture high-order shear deformation, as well as local cross-sectional warping. A total Lagrangian approach is adopted and the classic Newton-Raphson method is employed to solve the nonlinear governing equations. A key novelty of the proposed formulation is its completeness and its applicability to fully anisotropic structures. In other words, using the Green-Lagrange strain components within the Unified Formulation framework, the explicit form of the tangent stiffness matrix is derived including general stiffness properties. This new model is benchmarked against 3D finite element solution, as well as other formulations available in the literature, by means of static analyses of highly nonlinear, laminated composite beam-like structures. Significant computational efficiency gains over 3D finite elements are observed for similar levels of accuracy. Furthermore, to show the enhanced capabilities of the present formulation, the postbuckling response of a composite stiffened panel is compared with experimental results from the literature. The 3D stress fields computed in the postbuckling regime are used to detect failure of the stiffened panel. The corresponding failure mode, as obtained by the new model, is shown to match with the experiment.


ABSTRACT: At present plywood structures are used in the loading area of utility structures. Low velocity impact studies on these structures showed cracks on its lower surface. Hence, in the current study low-velocity impact of a lighter honeycomb sandwich structure is investigated to satisfy the needs of the utility vehicle segment. To meet this objective, facing sheets are manufactured using the polypropylene matrix and glass fibers. Polypropylene honeycombs are used in the study. Depending on the experimental boundary conditions, a cross-ply laminate set up is used for the facing sheets. An impact energy of 100 J is chosen in the study. This energy caused visible failure on the plywood sample. Hence a lighter sandwich construction which can resist 100 J impact is implemented in this study. Influence of top and bottom facing sheet thicknesses on the amount
of damage inflicted on its surfaces are studied. Experimental histories of absorbed energy and contact force are recorded. A finite element analysis is performed using LS-DYNA and numerical results are compared with the experimental responses. A honeycomb sandwich panel [0/90/90/0/Core/0/90/90/0] meeting the objective of the study is seen as an optimum replacement for the existing plywood structures.


ABSTRACT: A novel approach which combines isogeometric collocation and an equilibrium-based stress recovery technique is applied to analyze laminated composite plates. Isogeometric collocation is an appealing strong form alternative to standard Galerkin approaches, able to achieve high order convergence rates coupled with a significantly reduced computational cost. Laminated composite plates are herein conveniently modeled considering only one element through the thickness with homogenized material properties. This guarantees accurate results in terms of displacements and in-plane stress components. To recover an accurate out-of-plane stress state, equilibrium is imposed in strong form as a post-processing correction step, which requires the shape functions to be highly continuous. This continuity demand is fully granted by isogeometric analysis properties, and excellent results are obtained using a minimal number of collocation points per direction, particularly for increasing values of length-to-thickness plate ratio and number of layers.


ABSTRACT: The static aeroelastic analysis and optimization of flexible wings are conducted for steady state conditions while both aerodynamic and structural parameters can be used as optimization variables. The system of multidisciplinary design optimization as a robust methodology to couple commercial codes for a static aeroelastic optimization purpose to yield a convenient adaptation to engineering applications is developed. Aspect ratio, taper ratio, sweepback angle are chosen as optimization variables and the skin thickness of the wing. The real-coded adaptive range multi-objective genetic algorithm code, which represents the global multi-objective optimization algorithm, was used to control the optimization process. The support vector regression (SVR) is applied for optimization, in order to reduce the time of computation. For this multi-objective design optimization problem, numerical results show that several useful Pareto optimal designs exist for the flexible wing.


ABSTRACT: An advanced modelling approach is presented for the linear analysis of multilayered cylindrical shells. It relies on the combined use of a sublamine shell formulation along with the Ritz method. The approach is particularly suitable for the analysis of sandwich shells, and can be naturally applied for studying non-conventional configurations characterized by the presence of multiple cores. The formulation relies upon a displacement-based approach and makes it possible the analysis of thin and thick configurations, without restrictions regarding the shallowness of the shell. The quality of the predictions is assessed by comparison against 3D solutions, and the advantages offered by current modeling approach are highlighted in terms of required theory-related degrees of freedom. The flexibility of the formulation is exploited to illustrate the analysis of a triple-core sandwich panel, giving evidence of the advantages offered by the proposed approach for modeling shells characterized by an arbitrary degree of complexity. Novel results are presented for future benchmarking purposes.


ABSTRACT: Multi-layered piezoelectric nanostructures stand as one the most promising candidates for smart nanodevices and nanocomposites which are widely used as sensors and actuators in nano-electromechanical
systems due to their excellent performances in fabrication, design and energy conversion (i.e. electrical and mechanical energy). The inherent nano-sized piezoelectricity properties (e.g. enhanced piezoelectric effect and novel electrical/chemical/physical properties) enable them to be regarded as the next-generation piezoelectric materials. Present study aims to investigate the size-dependent thermo-electromechanical responses of multi-layered piezoelectric nanoplates under heating loads. In the context of nonlocal piezoelectric thermoelastic theory, a composite laminated piezoelectric plate is chosen as the analytical model whilst the coupled governing equations for each layer with size-dependent characteristic lengths of thermal, electric and elastic fields as well as non-idealized interfacial conditions are obtained, and then solved by using Laplace transformation techniques. The transient solutions obtained are applied to bi-layered piezoelectric nanoplates and the effects of size-dependent characteristic lengths and material constants ratio on structural responses are evaluated and discussed to provide a comprehensive understanding and design insights of piezoelectric nanocomposites.


ABSTRACT: Electro-elastic analysis of a cylindrical sandwich pressure vessel including a porous core and two integrated piezoelectric face-sheets are analytically studied in this work. Third-order shear deformation theory is employed for description of displacement field along the thickness direction. The piezoelectric layers are subjected to applied electric potentials. The principle of virtual work is used to derive the governing equation of electro-elastic bending. The governing equation are solved for clamped-clamped boundary condition with short circuit electrical condition. The numerical results including deformation, stress analysis, and electric potential distribution are plotted in terms of porosity coefficient, various types of porosity, applied electric potential, and parameters of Pasternak's foundation. One can see that maximum displacement and stress components are obtained for asymmetry pattern while the minimum displacement and stress components are obtained for symmetry pattern. The numerical results indicate that with increase of porosity coefficient, the radial and axial displacements are increased while all stress components are decreased. Investigation on the effect of applied electric potential indicate that although increase of applied electric potential leads to significant increase of radial displacement and maximum electric potential, it does not change the radial displacement and all stress components.


ABSTRACT: Variable Angle Tow (VAT) composites offer increased freedom for tailoring material properties compared to traditional straight-fibre composites. This increased freedom leads to greater design flexibility for enhanced structural performance but comes at the cost of more complex, spatially-varying displacement, strain and stress fields. To maximise the utility of VAT composites, a computationally efficient, yet accurate, numerical framework is needed. To this end, we employ a modelling approach that builds upon the recently developed, hierarchical Serendipity Lagrange finite elements. Three-dimensional (3D) stress distribution is obtained using the present modelling technique and verified against 3D finite element solutions, as well as other formulations available in the literature. A key advantage of the present approach is the ability to predict accurate 3D stress fields efficiently, i.e. with reduced computational effort, including around local features such as geometric, kinematic or constitutive boundaries. Moreover, the present work concerns the peculiarities of commonly used mathematical expressions for describing spatially varying fibre orientations across VAT laminates. The presence of an absolute value in the function used to describe fibre orientation can lead to discontinuities in fibre angle slope and curvature. In turn, these discontinuities lead to mathematical singularities in the constitutive relations along the laminate. If this singularity is not appropriately modelled as a boundary of the continuum, but rather as an interior point of the continuum, stresses may be predicted inaccurately. Compared to other models in the literature, our method is capable of unveiling detailed 3D stresses readily and accurately also in the vicinity of this singularity.

ABSTRACT: Based on nonlocal strain gradient theory, we present dynamical behaviors of a microtubule subjected to axial load, thermal load and variable transverse load simultaneously. The existing nonlocal strain gradient constitutive relation is adjusted from the perspective of dimensional analysis for better understanding and application, especially when establishing a multi-field coupling model. Subsequently, the strain potential, external potential and kinetic energies are obtained, and the governing equation of motion and corresponding classical and non-classical boundary conditions are derived via Hamilton’s principle, where the traditional nonlocality of strain and strain gradients, and higher-order gradients of nonlocal stress are involved. Variations of frequencies with respect to two intrinsic parameters and change of temperature are presented. The nonlocal effect indicates a softening mechanism while the strain gradient effect implies a hardening rule. By comparison, effect of the change of temperature is not as significant as two intrinsic parameters. In addition, it is observed for the first time that the inverse tendencies for nonlocal and strain gradient effects emerge with a relative large parameter. Such performances are inconsistent with the influence mechanism in nonlocal strain gradient theory. Therefore, the bounds of nonlocal scale and strain gradient parameters for transverse dynamics of microtubules are determined accordingly.


ABSTRACT: A Timoshenko functionally graded (TFG) imperfect microscale beam is considered and the coupled viscoelastic mechanics is analysed in a nonlinear regime. Based on the Timoshenko beam theory, incorporating geometric imperfections, the Kelvin-Voigt method is used for internal viscosity, the rotary inertia is automatically generated due to the Timoshenko theory, and the Mari-Tanaka scheme is used for the mixture. After utilising the constitutive stress/strain relations, Hamilton’s principle is used giving three sets of coupled motion equations. A discretisation is performed using Galerkin’s method and numerical simulations, for mechanical behaviour analysis, are built upon a continuation method.


ABSTRACT: The paper presents an effective approximation for free vibration analysis of axially functionally graded material (AFGM) beams based on the Jacobi polynomial theory. An arbitrary-order derivative of the Jacobi polynomial is expressed as the expression of low-order components, whereas its boundary values are fully defined by the polynomial parameters. The particular feature is used to derive the generalized eigenvalue equation for free vibration analysis of AFGM beams in conjunction with the Euler-Bernoulli, the Timoshenko and the nonlocal strain gradient beam theories. Several numerical examples in the literature are presented to demonstrate potential applications of the Jacobi polynomial approach. A fast convergence of the approximation error for natural frequency results has confirmed high accuracy of the proposed approach. The Legendre and the Chebyshev polynomials are special cases of the Jacobi basis function. This guarantees the flexibility of the presented method for free vibration analysis of AFGM beams with nonuniform geometries and axially varying material properties.


ABSTRACT: This paper theoretically and experimentally investigates the dynamic snap-through phenomena and the nonlinear vibrations of the bi-stable asymmetric laminated composite square panel under the foundation excitation. We propose a new method to describe the dynamic snap-through phenomena of the bi-stable asymmetric laminated composite square panel by using the time-varying principle curvatures. The boundary conditions of the bi-stable asymmetric laminated composite square panel are clamped at the center of the panel and free at four edges. The mode shapes are obtained by employing Rayleigh-Ritz method and Lagrangian
ABSTRACT: The nonlinear hygro-thermal dynamics of a bi-directionally functionally graded beam with coupled transverse and longitudinal displacements are studied. The material properties and hygro-thermal distributions are assumed to gradually change along both thickness and length directions according to the arbitrary functions. The nonlinear coupled dynamic equations governing the transverse and longitudinal motions of the beam are derived using Hamilton’s principle, the von Kármán geometric nonlinearity and Euler-Bernoulli theory, as well as considering uniform, linear and sinusoidal distributed hygro-thermal loads. The generalized differential quadrature method with an iterative technique is applied for the nonlinear analysis. Parametric studies are implemented to explore the impacts of the material gradations, temperature rise and moisture concentration on nonlinear frequencies of the beam for various boundary conditions. Results show that the nonlinear dynamic is highly depended on hygro-thermal effects as well as the material properties, which can be used for designing accurately the multi-directionally functionally graded structures in different environmental conditions.

ABSTRACT: This work applies the first-order shear deformation theory (FSDT) to study of the electro-elastic behavior of cylindrical sandwich pressure vessels with porous core and piezoelectric face-sheets, immersed in a Pasternak foundation. The core material is made of aluminum, whose effective properties are strictly related to different distributions of porosity. The governing equations of the problem are derived from the principle of virtual work and they are solved as a classical eigen-problem under the assumption of clamped-supported boundary conditions. A large parametric investigation aims at showing the influence of some meaningful parameters on the electro-elastic response of the structure, such as the type of distribution and the coefficient of porosity, as well as the Pasternak foundation coefficients. Based on the numerical results, we verify a general increase in deformability for increasing coefficients of porosity, and foundation coefficients. Our outcomes represent a key point for the design purposes, where the optimal performances of the structure are mainly related to a correct selection of the input structural parameters and surrounding environment. For engineering applications as electrical actuators, rollers, or control devices, an interesting control in deflection of the structure is here pursued by tuning the applied electrical potential.

ABSTRACT: Lateral torsional buckling (LTB) and local section distortion of pultruded glass fiber reinforced polymer (GFRP) I-sections subject to flexure are investigated. LTB behavior will dominate longitudinally slender beams having low flange slenderness. However, as the flange becomes more slender and/or the beam
shorter, the effects of local section distortion (LSD) become significant, reducing the LTB capacity of the member. Using the energy method, an analytical study was conducted and explicit equations for predicting the critical LTB buckling moments of GFRP I-sections accounting for the effects of LSD are proposed. The proposed LTB equation was validated using experimental results and finite element analysis. Excellent agreement was observed between the proposed LTB equation and experimental results for sections expected to be dominated by LTB behavior. Extending the study using the same approach, an equation predicting LTB capacity as it is affected by LSD was also validated using experimental results. It is found that the proposed LTB equation captures the capacity reduction due to LSD and therefore, provides more accurate predictions for sections expected to be dominated by LSD behavior; those having small slenderness ratios and large flange slenderness ratios.


ABSTRACT: The nonlinear transient dynamic response of graphene nanoplatelets (GPLs) reinforced composite doubly curved shallow shells with three GPL distribution patterns was investigated under time-dependent blast loads. The thermal effects were explicitly considered in the study, in which a modified Halpin–Tsai model was adopted to estimate the effective Young′s modulus. Rule of mixtures was employed to determine the mass density and Poisson's ratio. The equations of motion were derived from Hamilton's principle and the nonlinear von Karman strain–displacement relationship, based on a higher-order shear deformation theory. A set of second-order ordinary differential equations was obtained using Galerkin’s method. Numerical solutions were based on a fully implicit finite difference scheme in time. The derived nonlinear equations were then solved using the Newton–Raphson method. Further, parametric studies were conducted to consider the influence of the temperature difference between top and bottom surfaces, as well as the GPL weight fraction, distribution type, length-to-thickness ratio, total number of layers, parameters related to blast loading, and the aspect, shallowness, and curvature radius ratios of the doubly curved shallow shell on the nonlinear transient dynamic response of the structure.


ABSTRACT: The present paper concerns the influence of transverse heterogeneity caused by layer stacking sequence in laminated cylindrical panels under compression on their stability and post-buckling behaviour. According to the classical laminated plate theory (CLPT) this inhomogeneity causes not trivial coupling matrix B terms. A method of the modal solution to the nonlinear buckling problem within Koiter′s asymptotic theory, using the semi-analytical method (SAM) and the transition matrix method, was applied in the analysis. Post-buckling behaviour of laminated shallow cylindrical panel within the first- and second-order non-linear approximation were determined when the coupling matrix B was included or neglected. Additionally for model 1D the dimensionless stiffness reduction coefficient values were estimated which already in the phase of composite structure design process makes it easier to assess the influence of coupling matrix on stability. Just like in the case of plate elements, when the value of these coefficients is close to 1, the effect of couplings on stability is negligible. If the value of these coefficients is significantly less than 1, then the effect of the coupling matrix terms on stability increases.


ABSTRACT: The present paper investigates thick-walled composite pipes subjected to simultaneous multi-axial loads common to those experienced in coiled tubing applications. The pipes were assumed to be filament wound carbon fiber-epoxy laminates with multiple layers and variable fiber orientations. MATLAB-based software was used to calculate stresses and carry out failure analyses through the thickness of the pipes when subjected to pressure, axial and bending (spooling) loads. Analyses were performed to determine if the composite tubes could achieve comparable strengths and spooling diameters as equivalent steel tube geometries.
ABSTRACT: Sandwich Composite panels have been proved to be efficient materials for energy dissipation. A new type of sandwich composite panels using 3D-mats with interconnected channels sandwiched between Kevlar® layers have been manufactured in this research work. The core of the panels have been filled with high-performance 600nm silica based Shear Thickening Fluids (STFs) dispersed in polyethylene glycol of molecular weight 200g/mol (PEG-200) to study its effect in improving the energy dissipation of the material. The panels are subjected to ballistic impact using a 9mm diameter projectile. It was found that the STF-incorporated sandwich composite panels could absorb 96.3% of the incident energy which accounts to 67.4% more energy absorbed and also a 61.26% increase in absorbed energy per unit increase in weight in comparison to the hollow sandwich composite panels. This makes the STF-incorporated sandwich composite panels a promising material for enhanced energy absorption.

H.N.R. Wagner, E. Petersen, R. Khakimova, C. Hühne, “Buckling analysis of an imperfection-insensitive hybrid composite cylinder under axial compression – numerical simulation, destructive and non-destructive experimental testing”, Composite Structures, Vol. 225, Article 111152, 1 October 2019,
https://doi.org/10.1016/j.compositesct.2019.111152

ABSTRACT: Thin-walled shells like cylinders are primary structures in launch-vehicle systems. When subjected to axial loading these shells are prone to buckling. The corresponding critical load heavily depends on deviations from the ideal shell shape. In general, these deviations are defined as geometric imperfections and although imperfections exhibit comparatively low amplitudes, they can significantly reduce the critical load. Considering the influence of geometric imperfections adequately into the design process of thin-walled shells poses major challenges for structural design.

An alternative to robust design of thin-walled shell by accurate consideration of geometric imperfections is the development of a robust or imperfection-insensitive shell architecture. In this article a special hybrid cylinder is presented and analyzed. The composite shell design is based on an interstage structure of the Ariane 6 by MT Aerospace and has special CFRP belts which are intended to reduce the imperfection sensitivity of the shell. The shell was tested at the German Aerospace Center in Braunschweig and the corresponding results are presented and described. The hybrid cylinder was analyzed with the Southwell-method and geometrically nonlinear finite element analyzes. The results show that the Southwell-method delivers conservative buckling load estimations and that the CFRP belts reduce the imperfection sensitivity significantly.

A. Loredo, M. D'Ottavio, P. Vidal, O. Polit, “A family of higher-order single layer plate models meeting C0z -requirements for arbitrary laminates”, Composite Structures, Vol. 225, Article 111146, 1 October 2019,
https://doi.org/10.1016/j.compositesct.2019.111146

ABSTRACT: In the framework of displacement-based equivalent single layer (ESL) plate theories for laminates, this paper presents a generic and automatic method to extend a basis higher-order shear deformation theory (polynomial, trigonometric, hyperbolic…) to a multilayer C0z higher-order shear deformation theory. The key idea is to enhance the description of the cross-sectional warping: the odd high-order C1z function of the basis model is replaced by one odd and one even high-order function and including the characteristic zig-zag behaviour by means of piecewise linear functions. In order to account for arbitrary lamination schemes, four such piecewise continuous functions are considered. The coefficients of these four warping functions are determined in such a manner that the interlaminar continuity as well as the homogeneity conditions at the plate’s top and bottom surfaces are a priori exactly verified by the transverse shear stress field. These C0z ESL models all have the same number of DOF as the original basis HSDT. Numerical assessments are presented by referring to a strong-form Navier-type solution for laminates with arbitrary stacking sequences as well for a sandwich plate. In all practically relevant configurations for which laminated plate models are usually applied, the results obtained in terms of deflection, fundamental frequency and local stress response show that the proposed zig-zag models give better results than the basis models they are issued from.
ABSTRACT: Bistable rollable booms are favorable when a low strain energy requirement for the coiled state is imposed and have more controllable deployment when compared to monostable booms. An inextensional analytical model describing the bending deformation mechanics of Collapsible Tubular Mast (CTM) booms was used to determine how design variables induce bistability, or the existence of two strain energy wells in the rolled-up and unrolled states. The effects of varying lamina material, laminate layup, and shell arc geometries between different inner and outer shell segments on the second strain energy well and stiffness properties were determined for boom cross-sections formed by circular segments. The full design space for two-walled composite CTM booms was explored to evaluate the validity of the developed analytical model. Optimized CTM boom designs were experimentally characterized for comparisons against model results. The model under-predicted the stable coiled diameter of the co-cured two-walled booms by up to 8.9% and 23.4% for the individual thin shells wrapped alone.

ABSTRACT: The linear parametric instability (PI) of laminated inhomogeneous orthotropic truncated conical shells (LIHOCSs) under periodic axial load depending on the time, are studied using the first order shear deformation theory (FOSDT). After deriving basic equations for LIHOCSs, the Galerkin method is used to find the ordinary differential equation of motion. The equation of motion is transformed into the Mathieu equation, in which the PI is studied using the Bolotin method. Comparing the concrete cases of current work with the other studies, the validity of the obtained formulas is proved. Finally, the effects of various parameters, such as lay-up, inhomogeneity, and loading factors on the boundaries of parametric instability regions (PIs) for LIHOCSs, have been studied in detail.

ABSTRACT: Low-velocity impact tests and compression after impact (CAI) experiments were conducted on composite foam-core sandwich (FCS) panels. The impact tests revealed that the damage depth of the FCS panels increases with an increase in the impact energy. The CAI experiments revealed that the residual compressive strength of the FCS panels decreased with an increase in the impact energy. The local buckling of the FCS panels without impact damage occurred during compression, which was observed by the strain bifurcation phenomena using electrical strain gauge measurements. However, the large strain gradient and compression failure of the FCS panels with impact damage occurred during compression, as observed by the full-field deformation using three-dimensional digital image correlation (3D-DIC) measurements. The numerical simulations using the finite element method (FEM) were consistent with the observed failure phenomena, i.e., the damage at the impact site weakening the compressive strength of the FCS panels.

ABSTRACT: The paper concerns the progressive failure analysis of laminates with the in-plane shear nonlinearity accounted for. The nonlinear shear response of the layer is described by the constitutive relation treating the stresses as a function of strains. Thus it can be easily incorporated into the displacement-based FEM codes. The brittle failure mechanisms of the fibers and the matrix of the layer are recognized with the use of the Hashin criterion. The model is implemented into the non-commercial FEM program for the analysis of multifold shells which is based on the 6-parameter nonlinear shell theory of the Cosserat type.
ABSTRACT: This paper analyzed the free vibration of functionally graded (FG) doubly-curved shells with un-uniform thickness distribution based on Ritz method. The energy method and first-order shear deformation theory are adopted to derive the formulas. In this paper, the stepped FG doubly-curved shells are divided into their segments in axial direction according to the steps of the structures, and the displacement functions of shell segments are consisted with Jacobi polynomials along axial direction and standard Fourier series along circumferential direction. In addition, the boundary conditions at ends of the stepped FG doubly-curved shells and the continuity conditions at two adjacent segments were enforced by penalty method. Then the final solutions can be obtained based on Ritz method. Finally, to confirm the validity of proposed method, the results with the same conditions are compared by Finite Element Method (FEM) and experiment. The results show that the proposed method has the advantage of fast convergence, high accuracy and simple boundary simulation etc.

ABSTRACT: This paper presents a differential quadrature hierarchical finite element method (DQHFEM) for dynamic analyses of functionally graded material (FGM) sandwich shallow shells in thermal and non-thermal environments. A layer-wise theory based on the first-order shear deformation theory (FSDT) for each layer was adopted. Effective material properties of the FGM are estimated according to Voigt’s rule of mixture (ROM) and/or Mori–Tanaka (MT) scheme. For the shells in thermal environment, a nonlinear temperature distribution in thickness direction is considered and the elastic properties are assumed to be temperature dependent. The results obtained from the proposed formulation are validated with those available in literatures. Natural frequencies obtained from Sander’s, Love’s and Donnell’s shell theories for different geometric and boundary conditions are compared with each other first to assess the performance of different shell theories for FGM sandwich shells under non-thermal environment. Then the effects of volume fraction index, core thickness and temperature gradient on natural frequencies of FGM sandwich shells are investigated. The presented DQHFEM is much like the fixed interface mode synthesis method but does not need modal analysis and is of high accuracy. This work is the first application of the method to functionally graded sandwich shells in thermal environments.

ABSTRACT: The supersonic panel flutter of functionally graded cylindrical shells under thermal loadings is investigated by considering the effects of various axisymmetric and asymmetric geometric imperfections. The problem is formulated using a nonlinear first-order shear deformation theory of shells with the first-order aerodynamic piston theory. The temperature is assumed to vary in the thickness direction according to the steady-state heat conduction equation. The semi-analytical finite element method (FEM), based on the field consistency redistribution approach is used to obtain discretized nonlinear aeroelastic equations. In the process of FEM, the imperfection functions are also discretized and efficiently approximated by the Hermitian polynomials in order to facilitate the required integrations. For analysis purpose, the deformations and stresses induced by the temperature rise are first computed by solving the nonlinear static aerothermoelastic equations using the Newton-Raphson method. The pseudo-arclength continuation method is also employed to detect the possible snap-through of the shell. The linearized stability equation about the equilibrium state is then used for determining the flutter boundaries. Numerous parametric studies are conducted to examine the effects of temperature rise and imperfections on the flutter boundaries, which show considerable effects of imperfections on changing the trend of variation of the flutter pressure with temperature.

ABSTRACT: The main content of this paper is to establish an analysis model for dynamic analysis of composite laminated doubly-curved revolution shell based on the Higher order Shear Deformation Theory (HSDT). Firstly, the energy functional of shell is established based on higher order shear theory. Then, the multi-segment partitioning technique is introduced to segment the shell along the generatrix direction, which is mainly to relax the boundary conditions of shell, and then reduce requirements for the displacement function. At the boundary position, the boundary spring parameters are used to obtain the corresponding boundary conditions. Similarly, the connecting spring parameters are introduced to simulate the continuity conditions between the segmented shells. The parameters of boundary spring and connecting spring can be regarded as the weight parameter. Thirdly, all displacement components of the composite laminated doubly-curved revolution shell are expressed by Jacobi orthogonal polynomials. Finally, the whole dynamic characteristics are obtained by Rayleigh-Ritz method with respect to unknown Jacobian expansion coefficient. The convergence, validity and dynamic characteristics of the analytical model established in this paper are given by a series of numerical examples.


ABSTRACT: Stiffened composite panels are widely used in industry, and their safety requirements have drawn great attention. However, non-destructive testing and evaluation (NDT&E) methods for these panels are still limited. This is due to the fact that the stiffeners induce complex signals during damage detection. This paper presents a new damage detection method for stiffened composite panels based on Lamb waves. The method combines a quantitative wavefront expression for an anisotropic composite and the conventional time-of-flight (ToF) method to detect debonding damage between stiffeners and the composite skin as well as low-velocity impact damage in the skin sheet. Initially, Lamb wave propagation characteristics are evaluated by numerical simulations to obtain mode conversion at the stiffener and delay after transmission through the stiffener. Then the numerical simulations and experiments are implemented in stiffened cross-ply composite laminates to verify the effectiveness and accuracy of the proposed method. Results indicate that the proposed method can accurately locate damage and has potential for industrial application.


ABSTRACT: The concrete-encased-steel filled FRP tube (CSFFT) is a composite that enables taking advantage of combined effects of material properties of FRP, concrete and steel. Such composites outperform the conventional concrete or steel structures, by integrating outer FRP wrapping as lateral confinement and chemical barrier to concrete core and encased steel section, as well as the load-carrying capacity of concrete and steel section. While the CSFFT composites exhibit a great potential for broader applications, the issues associated with concrete shrinkages and stress hysteresis experienced in FRP confinement as observed by previous studies could weaken their performance at some cases. Therefore, to overcome these drawbacks, this study was to investigate active confinement on the CSFFT composites using expansive concrete-generated prestress. A total number of 24 concrete-encased-steel filled square CFRP tube (CSFSCT) specimens were casted and tested under axial compression. The variables studied included the number of CFRP layers (one, two and three layers), and the area of the section steel (type A and B). Test results showed that the CSFSCT failed by the rupture of the CFRP in the hoop direction. For test specimens with the same sectional area of steel and CFRP layer, the normalized ultimate load capacity of the prestressed specimen was 1.03–1.13 times that of the non-prestressed specimen, which indicated that the pre-stress effect made the tube specimens had higher strength enhancement ratio. As the number of CFRP layer increased, the ultimate load capacity and ultimate axial strain increased, and the slope of the second linear segment of the load-strain curve increased. Moreover, it was revealed that the area of the steel was effective in increasing the $P/P$ and strain reduction factor of tube specimens. The models of ultimate stress and axial strain of confined concrete were formulated to account for
both FRP-induced passive confinement and expansive concrete-generated active confinement and were validated by the experimental data.


ABSTRACT: The resulting oscillation of bi-stable hybrid symmetric laminate could enable broadband energy harvesting via piezoelectric transduction. The aim of this work is to investigate its dynamic behaviors to provide the basis for designing broadband energy harvester. This paper proposes the dynamic analysis of this bi-stable laminate, focusing on the intra-well dynamics around its stable states and the inter-well dynamics between two stable states. Two types of stacking sequence are performed for this bi-stable laminate, and experimental testing with different harmonic excitations is carried out for each type of this bi-stable laminate. The strain responses at three positions are monitored to investigate the dynamic responses. A finite element model is also developed to analyze the static strain distribution and capture the dynamics. The results show that the laminates exhibit intra-well response under low-level excitation, and the inter-well response at a particular range frequency appears when excitation level increases. Different types of inter-well response mode involving the snap-through behavior are obtained in experiments, such as intermittent inter-well vibration and chaotic vibration. The presented results essentially highlight the need for considering the stacking sequence associated with the dynamics while designing the hybrid bi-stable symmetric laminate to obtain the desirable nonlinear response.

José S. Moita (1,2), Cristóvão M. Mota Soares (3), Carlos A. Mota Soares (3) and António J.M. Ferreira (4)
(1) IDMEC, Intituto de Engenharia Mecânica, Lisboa, Portugal
(2) ISE-Universidade do Algarve, Campus da Penha, Faro, Portugal
(3) IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
(4) Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal


ABSTRACT: This work presents the formulation for static bending analysis of functionally graded axisymmetric plate/shell type structures under mechanical loading, and considering different structural behaviours: linear, geometric nonlinear and material nonlinear. The implemented model is based on a simple conical frustum finite element model with 2 nodes and 3 degrees of freedom per node, which includes shear deformation effects, and it shows to be extremely efficient in the analysis of axisymmetric shells subjected to axisymmetric loading. The used of reduced numerical integration procedure is essential for its success when applied to thin shells. The formulation accounts for the calculation of displacements and through-thickness stress distribution. The solutions for some illustrative examples involving variation of volume fractions are obtained, and the results are presented and compared with numerical alternative models when available, and discussed.

Tianyu Zhou (1), Pan Zhang (1), Wei Xiao (2), Jun Liu (1) and Yuansheng Cheng (1)
(1) School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
(2) China Ship Development and Design Center, China


ABSTRACT: The performance of sandwich panels with metallic face-sheets and polyvinyl chloride (PVC) foam ungraded/graded cores under air blast loading was investigated experimentally. In present paper, the performance of interest included the permanent deformation, failure modes and the associated mechanisms underlying the overall response. The majority of the paper was concentrated on the effects of geometric parameters and core gradation on the blast performance of panels. Experimental results showed that regardless of the panel configuration considered here, the panels exhibited a localized dishing deformation of front face and a global dome deformation of back face. The way to achieve a more effective design against air blast is to
increase the thickness of the face sheet towards the blast rather than the other sheet. The panel system with a low-density (large thickness) core appeared to be favorable for the mitigation of back face deformation and core cracking failure. Effect of core gradation indicated that placing the low density material at the third core layer and the high density material at the second core layer, thus reducing the momentum transmitted to back face and increasing the crushing deformation of graded core, helped enhance the blast resistance of panel. Furthermore, the comparisons of blast performance between ungraded sandwich panel and graded panels were made. It turned out that overall graded panels did not always outperform the ungraded panel. An optimal core gradation would bring benefits for blast resistance in terms of the face sheet deformation and core cracking failure, but also was required to face the risk of delamination failure.

S. Chandra (1), K. Sepahvand (1), V.A. Matsagar (2) and S. Marburg (1)
(1) Chair of Vibroacoustics of Vehicles and Machines, Department of Mechanical Engineering, Technical University of Munich (TUM), 85748 Garching b. Munich, Germany.
(2) Department of Civil Engineering, Indian Institute of Technology (IIT) Delhi, Hauz Khas, New Delhi 110 016, India.


ABSTRACT: During the service life, laminated composites may be subject to some random thermal environment. Quantification of the uncertainty in static and dynamic response of the composites under such condition is still a challenging issue. This work presents a stochastic dynamic response analysis of a graphite-epoxy composite plate using generalized polynomial chaos (gPC) expansion due to random mean temperature increment. A stochastic finite element method (SFEM) based on the first-order shear deformation theory (FSDT) is used to describe the free and forced vibration response of the graphite-epoxy composite plate. The numerical studies show a reduction in amplitude of the dynamic mean temperature increment, and are compared with the results of the Monte Carlo simulation. The numerical studies show a reduction in amplitude of the dynamic mean displacements with the increment in the time and it increases with the increment in the random mean temperature. The characteristics of loading have also significantly influenced the uncertainty in the time-dependent displacement response.

References listed at the end of the paper:
4 V. Rao, P. Sinha, Dynamic response of multidirectional composites in hygrothermal environments, Compos Struct, 64 (3) (2004), pp. 329-338
5 Mallikarjuna, T. Kant, Dynamics of laminated composite plates with a higher-order theory and finite element discretization, J Sound Vib, 126 (3) (1988), pp. 679-687
6 T. Kant, Mallikarjuna, Non-linear dynamics of laminated plates with a higher-order theory and C^0 finite elements, Int J Non-Linear Mech, 26 (3) (1991), pp. 335-343
7 T. Kant, C. Arora, J. Varaiya, Finite element transient analysis of composite and sandwich plates based on a refined theory and a mode superposition method, Compos Struct, 22 (2) (1992), pp. 109-120
8 J. Kommineni, T. Kant, Large deflection elastic and inelastic transient analyses of composite and sandwich plates with a refined theory, J Reinf Plast Compos, 12 (11) (1993), pp. 1150-1170
11 N. Huang, T. Tauchert, Large deflections of laminated cylindrical and doubly-curved panels under thermal loading, Comput Struct, 41 (2) (1991), pp. 303-312
12 B. Patel, M. Ganapathy, D. Makhecha, Hygrothermal effects on the structural behaviour of thick composite laminates using higher-order theory, Compos Struct, 56 (1) (2002), pp. 25-34
17 P. Ribeiro, E. Jansen, Non-linear vibrations of laminated cylindrical shallow shells under thermomechanical loading, J Sound Vib, 315 (3) (2008), pp. 626-640
21 M. Biswal, S. Sahu, A. Asha, Vibration of composite cylindrical shallow shells subjected to hygrothermal loading-experimental and numerical results, Compos Part B: Eng, 98 (2016), pp. 108-119
27 A.K. Onkar, D. Yadav, Non-linear free vibration of laminated composite plate with random material properties, J Sound Vib, 272 (3) (2004), pp. 627-641
35 C. Soize, A comprehensive overview of a non-parametric probabilistic approach of model uncertainties for predictive models in structural dynamics, J Sound Vib, 288 (3) (2005), pp. 623-652
38 K. Sepahvand, Spectral stochastic finite element vibration analysis of fiber-reinforced composites with random fiber orientation, Compos Struct, 145 (2016), pp. 119-128
40 K. Sepahvand, S. Marburg, Random and stochastic structural acoustic analysis, John Wiley & Sons, New York, USA (2016), Ch. 10, pp. 305–338
41 A. Lal, B. Singh, Stochastic free vibration of laminated composite plates in thermal environments, J Thermoplasf Compos Mater, 23 (1) (2010), pp. 57-77
42 B. Singh, V. Verma, Hygrothermal effects on the buckling of laminated composite plates with random geometric and material properties, J Reinf Plast Compos, 28 (4) (2009), pp. 409-427
45 R. Kumar, Effects of hygrothermomechanical loading and uncertain system environments on flexural and free vibration response of shear deformable laminated plates: Stochastic finite element method micromechanical model investigation, J Front Aerospace Eng, 6 (1) (2017), pp. 39-69
46 R. Kumar, Hygrothermally induced nonlinear free vibration response of laminated composite plates with random system properties: stochastic finite element micromechanical model investigation, J Front Aerospace Eng, 6 (2) (2017), pp. 116-145
48 T. Kant, J. Varaiya, C. Arora, Finite element transient analysis of composite and sandwich plates based on a refined theory and implicit time integration schemes, Comput Struct, 36 (3) (1990), pp. 401-420
50 N. Wiener, The homogeneous chaos, Am J Math, 60 (4) (1938), pp. 897-936
51 C. Chamis, G. Sendeckyj, Critique on theories predicting thermoelastic properties of fibrous composites, J Compos Mater, 2 (3) (1968), pp. 332-358
53 M. Gorji, F. Mirzadeh, Theoretical prediction of the thermoelastic properties and thermal stresses in unidirectional composites, J Reinf Plast Compos, 8 (3) (1989), pp. 232-258


ABSTRACT: Adopting multi-cell sections and composite wrapping are two effective approaches to improve the crashworthiness performance of thin-walled tubes. The axial crushing of single-cell and multi-cell aluminum/carbon fiber reinforced plastic (Al/CFRP) hybrid tubes is investigated in this paper. Quasi-static and dynamic experimental tests are performed for CFRP, Al and Al/CFRP tubes with single-cell, double-cell or quadruple-cell sections. The influences of Al wall thickness and the number of composite layers and sectional cells on the crushing response and energy absorption characteristics of the tubes are analyzed. Results show that the increase of all these factors can improve the load bearing and energy absorption capability of the tubes. The enhancement effect of composite wrapping for the Al/CFRP hybrid tubes is determined by the relative strength/weakness on the energy absorption efficiency of Al and CFRP. The interaction effect between the Al and CFRP on energy absorption of various sections is also investigated and the results show that the interaction effect decreases with the increase of the number of the sectional cells, while it is enhanced by increasing the number of CFRP layers.

Xinwei Xue (1), Chaofeng Zhang (1), Wei Chen (2), Meiping Wu (1) and Junhua Zhao (1)
(1) Mechanical Engineering School of Jiangnan University, Jiangsu Key Laboratory of Advanced Food Manufacturing Equipment & Technology, China
(2) Suzhou Jiangnan Aerospace Mechanical and Electrical Industry Co., Ltd, China


ABSTRACT: The honeycomb sandwich structure is a typical light weight structure that is widely used in transportation and other industries. It is necessary to study the impact resistance of this honeycomb sandwich structure when subjected to low-velocity and heavy mass drops. To improve the impact resistance of the honeycomb sandwich structure under low-velocity and heavy load, the first stage was the development of a high ductility and high strength carbon/glass fibre hybrid composite skin. A further discussion is conducted about the relation between the honeycomb core height and the impact resistance of the honeycomb sandwich structure, according to simultaneous test results and finite element method (FEM) analysis. With the verified accurate
ABSTRACT: The compressive behaviors and failure maps of lightweight all-metallic sandwich cylinders with pyramidal truss cores are studied experimentally and theoretically. Orthotropic truss cores are fabricated through geometric mapping and snap-fit method. Curved facesheets are bonded to the truss cores by two-times vacuum brazing approach to eliminate unbound nodes. The full-field deformation and strain of the sandwich cylinder are measured by using the 3D digital image correlation system. The local buckling of the facesheet, the mode of which is influenced by the truss cores, is observed during the experiment. Theoretical models are developed considering five possible failure modes of the sandwich cylinder under compression, namely, Euler buckling, global buckling of the cylinder, local buckling of facesheet, face yielding and core member buckling. Failure maps are constructed on the basis of the models. The typical failure modes obtained from numerical simulation are consistent with the theoretical prediction.


ABSTRACT: The influence of the gradient of a sandwich structure with graded truss core on bending behavior are investigated in this paper. The single-layer and double-layer composite sandwich structures are formed by alternating width of core bars and stiffening plate. Three different types of sandwich structure with graded truss core are designed and manufactured. The gradient of a sandwich structure is characterized by introducing a gradient ratio $g$. A continuum damage model based on Hashin criteria is developed to predict the strength of these structures. The results from three-point bending tests are used to verify the FE model. Good agreements can be achieved between experimental and numerical results. The numerical model is subsequently used to investigate the influence of gradient ratio $g$ on bending strength, stiffness and damage distribution of these sandwich structures. The results indicate that the gradient ratio $g$ can prominently influence the failure mode of the double-layer sandwich structure. An appropriate gradient ratio $g$ of truss core can promote the sandwich structure with higher strength and stiffness. The stiffening plate can significantly enhance the strength and stiffness of the double-layer sandwich structure.

Xu Liang (1), Yu Deng (1), Zeng Cao (1), Xue Jiang (2), Titao Wang (1), Yongdu Ruan (1) and Xing Zha (1)
(1) Dept. of Ocean Engineering, Zhejiang Univ., 866 Yuhangtang Rd., Hangzhou, Zhejiang Province 310058, PR China
(2) Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, G15AE, UK

ABSTRACT: Nowadays, intelligent piezoelectric materials are widely used in transducer devices and aerospace structures. To investigate the dynamic behaviour of a functionally graded piezoelectric material (FGPM) cylindrical panel, a semi-analytical approach by introducing the Laplace transform, differential quadrature method, state space approach and Durbin’s numerical inversion of Laplace transform is presented. The accuracy of this method is validated by comparing the results with the published literature and by ANSYS under various boundary conditions. Convergence studies showed the proposed approach has a quick convergence rate with growing sample point numbers and increasing layer numbers. The analysis of initial electric potential on the outer surface and bottom surface indicated that when the plus and minus signs of two sides are opposite, the
value of central electric potential will decrease. Under simply supported condition, if FG index $\tilde{\gamma}$ increases, the deflection amplitude of the panel will increase, while the electric potential amplitude decreases. Moreover, the amplitude of displacements along the radial direction becomes larger when the central angle increases, but the period time decreases at the same time. The proposed method fills a gap of 3-D semi-analytical investigations for the dynamic behaviour of FGPM cylindrical panels in different boundary conditions.


ABSTRACT: The behavior of thin-walled short columns (struts) with operating damages subjected to uniform compression were analyzed. The columns section struts made of 8 layer GFRP laminate with four different layer arrangement have been considered. Experimental tests have been performed on intact and pre-damaged short columns to access the influence of impact damages on the behavior of considered structures in full range of load till failure. Impacts with different energies (10J, 20J, 30J) were introduced into webs, flanges and corners of columns. The observed damages have been described and categorized. The influence of the impact on the buckling and failure modes and loads, propagation of initial damages were investigated. The corner impacts have a catastrophic effect on the behavior of the compressed channel section columns in opposition to case when the webs are pre-damaged. Generally, compression after impact of thin walled profiles does not generate propagation of impact damage.

References listed at the end of the paper:
1 A. Gliszczynski, T. Kubiak, L. Borkowski, Experimental investigation of pre-damaged thin-walled channel section column subjected to compression, Compos Part B, 147 (2018), pp. 56-68
5 Y. Chen, J. Wan, K. Wang, S. Han, Residual axial bearing capacity of square steel tubes after lateral impact, J Constr Steel Res, 137 (2017), pp. 325-341
8 N. Li, P. Chen, Experimental investigation on edge impact damage and Compression-After-Impact (CAI) behavior of stiffened composite panels, Compos Struct, 138 (2015), pp. 134-150
9 A. Malhorta, F. Guild, Impact damage to composite laminates: effect of impact location, Appl Compos Mater, 21 (1) (2014), pp. 165-177
13 A. Gliszczynski, T. Kubiak, K. Wawer, Barely visible impact damages of GFRP laminate profiles – an experimental study, Compos B, 158 (2019), pp. 10-17
17 A. Teter, Z. Kolakowski, On using load-axial shortening plots to determine the approximate buckling load of short, real angle columns under compression, Compos Struct, 212 (2019), pp. 175-183
Selim Gürgen (1), Mehmet Alper Sofuoğlu (2)

(1) Eskişehir Vocational School, ESOGU, 26110 Eskişehir, Turkey

(2) Department of Mechanical Engineering, ESOGU, 26480 Eskişehir, Turkey


ABSTRACT: Vibration attenuation performance of structures is significantly important in aerospace, automotive, sport and medical equipment applications. In order to enhance the vibration absorption properties, shear thickening fluid (STF) is a candidate component in the structures due to its viscoelastic behavior. In this study, the vibration characteristics of carbon fiber reinforced polymer (CFRP) tubes were investigated. To compensate the lack of vibration isolation behavior of CFRP tubes, a natural STF was filled into the tubes and thus, the thickening rheology of this smart fluid was benefited in the STF/CFRP structures. The vibrational properties of the structures were investigated with modal analysis and the natural frequencies and damping ratios were calculated for two different boundary conditions (single and double-fixed ends). The results showed that the STF integration into the CFRP tubes significantly enhances the natural frequency of the structures as well as providing higher damping ratio in the STF/CFRP systems.


ABSTRACT: We develop a lattice structure of a desired Poisson’s ratio that is maintained when subjected to finite deformation. Using a gradient-based design optimization in an isogeometric computational framework, the representative unit cell is sophisticatedly tailored to attain the controlled Poisson’s ratio of up to -2. The ligaments of the lattice structure are modeled using geometrically exact beams whose configuration and cross-sectional area are regarded as design variables, which are parameterized by the higher order B-spline basis functions. The obtained optimal design is fabricated using a PolyJet 3-D printing machine and validated by physical experiments. Excellent quantitative agreement is observed between the numerical and the experimental results measured from an optical deformation measurement system.

Jing Bai (1), Jun Wang (1), Liao Pan (1), Lixin Lu (1) and Guoxing Lu (2)

(1) Jiangsu Key Laboratory of Advanced Food Manufacturing Equipment and Technology, Department of Packaging Engineering, Jiangnan University, 1800 Lihu Avenue, Wuxi 214122, China

(2) Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, John Street, Hawthorn, VIC 3122, Australia and School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore


ABSTRACT: The axial crushing of the single wall corrugated paperboard is explored experimentally and analytically. Quasi-static compression experiment is conducted of the single wall corrugated paperboard, and a typical folding element is suggested based on the selection principle of the unit, including two corner elements.
and two panels. Then, a theoretical model is derived to predict the plateau stress of the corrugated paperboard. It is shown that the prediction of plateau stress from the model compares well with the experimental results. Moreover, it is found that the fluted board contributes more to the total energy dissipation than the liner. The results may help to reveal the deformation mechanism and crush resistance of the single wall corrugated paperboard.

Ru-yang Yao (1), Zhen-yu Zhao (2), Wen-qian Hao (3), Guan-sheng Yin (1) and Bei Zhang (4)
(1) School of Science, Chang’an University, Xi’an 710064, China
(2) State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
(3) Department of Engineering Mechanics, Northwestern Polytechnical University, Xi’an 710129, China
(4) School of Information Engineering, Chang’an University, Xi’an 710064, China


ABSTRACT: Circular tube with external wide grooves has been defined as “Type B” grooved tube in the previous research. However, there have been few studies highlighting the effects of aluminum foam filling and material of “Type B” grooved tube. In the present, axial crushing behaviors of aluminum foam-filled 304 stainless steel “Type B” grooved tube are investigated. Quasi-static axial crushing tests are conducted to examine the deformation modes and energy absorption performance of foam-filled uniform/thickness gradient grooved tube with weak/strong thick-walled section. Experimental results show that the foam filling and thickness gradient configuration have a more obvious effect on energy absorption characteristics of grooved tube with weak thick-walled section. A novel analytical model is put forward by taking the strain hardening effect and effective crushing distance into consideration. Compared with the previous researches, the theoretical predictions in this study are in better agreement with the experimental results. Moreover, by comparing the experimental results of 304 stainless steel and 2A12 aluminum grooved tube, it can be concluded that the mean crushing force, crushing force efficiency and structural effectiveness of steel grooved tube are 205%, 56% and 27% on average higher than those of aluminum grooved tube.

Y. Lebaupin (1), J. Friedli (2), B. Caglar (1), M. Piccand (1), R. Pasquier (2) and V. Michaud (1)
(1) Laboratory for Processing of Advanced Composites (LPAC), Institute of Materials (IMX), Faculty of Engineering (STI), Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 12, 1015 Lausanne, Switzerland
(2) Novelis Switzerland SA, Rte des laminoirs 15, CH-3960 Sierre, Switzerland


ABSTRACT: This study investigates the intrusion and crushing performance of hybrid fiber metal laminates based on aluminum and carbon fiber reinforced polymers, in comparison to reference aluminum parts, made from AA6451 or AA7075 automotive grade alloys. A first set of crushing tests and intrusion tests were performed to assess the influence of several parameters: aluminum thickness (0.9, 1.5 and 2.5 mm) and aluminum composition (AA6451 and AA7075), the thickness of carbon composite patch (2 or 3) and the area of composite coverage, patch or strips. Intrusion test results of hybrid structures were correlated to validate and refine a Finite Element Model. Then, a range of configurations was numerically modelled to determine the optimum aluminum-composite lay-up architectures and the ideal locations of the patches leading to the best absorbed energy/weight ratio for a given load. Results demonstrate that localized composite patches improve the intrusion properties of tubes without penalizing the overall part weight.

K. Shiva (1), P. Raghu (1), A. Rajagopal (1) and J.N. Reddy (2)
(1) Department of Civil Engineering, IIT Hyderabad, India
(2) Department of Mechanical Engineering, Texas A&M University, College Station, TX, USA

ABSTRACT: In this work nonlocal buckling analysis of laminated composite plates considering surface stress effects is presented. For computation of critical uniaxial and biaxial buckling loads, both approximate solutions and finite element solutions are presented. Approximate solutions based on Navier’s method for simply supported boundary conditions and based on Levy’s method for other type of boundary conditions are presented. The analysis of laminate is based on Reddy’s third order shear deformation theory (TSDT) (Reddy, 1984). Eringen’s non-local differential material model (Eringen, 1983) has been used in the present work. The surface stress effects are incorporated using the Gurtin Murdoch theory (Gurtin and Murdoch, 1975). Various types of laminates have been considered for the analysis. A parametric study is carried out, considering geometric and material properties to understand the effect of non-locality and surface stress on buckling loads. It is found that the inclusion of non-locality and surface effect has a significant effect on the critical buckling load and this varies with various aspect ratios and span to thickness ratios, and boundary conditions of the laminated plate. The results obtained are compared with those available in the literature for validation.

Roham Rafiee, Amin Ghorbanhosseini and Shiva Rezaee (Composites Research Laboratory, Faculty of New Science & Technologies, University of Tehran, North Karegar St., Tehran 1439957131, Iran), “Theoretical and numerical analyses of composite cylinders subjected to the low velocity impact”, Composite Structures, Vol. 226, Article 111230, 15 October 2019, https://doi.org/10.1016/j.compstruct.2019.111230

ABSTRACT: The main objective of this research is to develop a theoretical solution for predicting the low-velocity impact induced failure in composite cylinders. Observing both in-plane and out-of-plane impact induced failure modes in composite cylinders is demanded of determining all components of the stress and strain fields. Thus, it is necessary to exploit the appropriate theory for this purpose. Layer-wise theory is employed to develop a theoretical solution for extracting stress/strain components in a composite cylinder subjected to low-velocity. Then, proper failure criteria are employed to predict the failure caused by impact. Finally, finite element modeling is performed to analyze the low-velocity impact in composite cylinders. Comparing the results, it is revealed that developed theoretical solution is more accurate than finite element modeling.

Xianfeng Yang (1), Xulong Xi (2), Qifan Pan (4) and Hu Liu (3)
(1) Institute of Solid Mechanics, Beihang University, Beijing 100191, PR China
(2) Aviation Key Laboratory of Science and Technology on Structures Impact Dynamics, Aircraft Strength Research Institute of China, Xi’an 710065, PR China
(3) School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore
(4) JUNHUI Aviation Technology Co., Ltd., Xi’an 710100, PR China


ABSTRACT: Honeycomb structures have attracted much attention in various engineering fields due to its superiorities in high specific strength, high specific stiffness and excellent energy-absorbing characteristics. The light-weight materials with exceptional mechanical behaviors can be achieved by incorporating the reinforced mesostructure into the regular honeycomb structures. In the present work, a novel circular-celled honeycomb was proposed by incorporating the petal-shaped mesostructures into the regular circular cell honeycomb. The 3D finite element models of the petal-shaped honeycombs (PSH) are established to investigate the in-plane crushing behavior and energy absorption capacity under different impact velocities through the nonlinear finite element code LS-DYNA. A comparison between the regular circular-cell honeycomb, the single petal nested circular honeycomb and the PSH was carried out, and the simulation results indicated that the PSH exhibited the best mechanical behavior and energy absorption characteristics compared with the other two types of honeycombs. Three representative deformation modes, namely quasi-static, transition and dynamic mode, were observed from the numerical simulations of the PSH with different geometric configurations and impact loadings, and the failure mode map was also summarized to furtherly clarify the localized deformation characteristics. In addition, the influences of impact velocity and the relative density on the plateau stress and the energy absorption behavior of the PSH were also investigated in this paper. The results showed that the specific energy absorption of PSH can be improved by up to nearly twice than the regular circular honeycomb under the same impact speed.

ABSTRACT: Composite materials are finding increasing application, for example in commercial aircraft. Traditionally fiber angles are constant in a single layer. Currently, so called variable stiffness panels with steered fibres, where the angle is changing within a layer are investigated. These panels are usually manufactured using automated fibre placement machines. Since the fibre angle is changing, and the tow paths are shifted as a whole in a single direction, gaps and/or overlaps between consecutive tows are created. This paper explores the effect of these gaps on the stiffness and buckling load of variable stiffness panels. A methodology is presented using homogenization to account for the gaps in a computational efficient way. The result shows that the stiffness results are on conservative side and are within 5% accuracy. However, the buckling results are on the unconservative side. The computational cost of the pre-processing of the proposed method is 45 times lower than the cost of the defect-ly method presented in the literature.

Atteshamuddin S. Sayyad (1) and Yuwaraj M. Ghugal (2)
(1) Department of Civil Engineering, SRES’s Sanjivani College of Engineering, Savitrribai Phule Pune University, Kopargaon 423601, Maharashtra, India
(2) Department of Applied Mechanics, Government College of Engineering, Karad 415124, Maharashtra, India


ABSTRACT: To the best of the authors’ knowledge, there is no research work available on FG sandwich curved beams in the whole variety of literature. Therefore, the analysis presented on static behaviour of FG sandwich curved beams in this study is the main contribution and the novelty of the present study. A sinusoidal beam theory considering the effects of transverse normal stress/strain is applied for the bending analysis of FG sandwich beams curved in elevation. The beam has functionally graded skins at top and bottom and isotropic core at the middle. Material properties of FG skins are varied through the thickness according to the power law distribution. The present theory accounts for sinusoidal variation of axial strain and cosine distribution of transverse shear strain through the thickness of the beam. Governing equations of equilibrium are derived using Hamilton’s principle. Analytical solutions for simply supported curved beam are obtained using Navier’s solution procedure. The non-dimensional numerical results are obtained for different radii of curvature and various power law coefficients. The present study contributes many new results on the bending analysis of functionally graded sandwich beams curved in elevation for the reference of future research in this area.

M. Vinyas (1,2), K.K. Sunny (2), D. Harursampath (1), T. Nguyen-Thoi (3,4) and M.A.R. Loja (5,6)
(1) Department of Aerospace Engineering, Indian Institute of Science, Bangalore 560012, India
(2) Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology, Bangalore 560064, Karnataka, India
(3) Division of Computational Mathematics and Engineering, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(4) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(6) LAETA, IDMEC – Instituto Superior Técnico – Universidade de Lisboa, Av. Rovisco Pais, 1, 1049-01 Lisboa, Portugal

“At the best of the authors’ knowledge, there is no research work available on FG sandwich curved beams in the whole variety of literature. Therefore, the analysis presented on static behaviour of FG sandwich curved beams in this study is the main contribution and the novelty of the present study. A sinusoidal beam theory considering the effects of transverse normal stress/strain is applied for the bending analysis of FG sandwich beams curved in elevation. The beam has functionally graded skins at top and bottom and isotropic core at the middle. Material properties of FG skins are varied through the thickness according to the power law distribution. The present theory accounts for sinusoidal variation of axial strain and cosine distribution of transverse shear strain through the thickness of the beam. Governing equations of equilibrium are derived using Hamilton’s principle. Analytical solutions for simply supported curved beam are obtained using Navier’s solution procedure. The non-dimensional numerical results are obtained for different radii of curvature and various power law coefficients. The present study contributes many new results on the bending analysis of functionally graded sandwich beams curved in elevation for the reference of future research in this area.”


ABSTRACT: The present article researches the influence of piezoelectric interphase thickness on the coupled frequency response of three-phase smart magneto-electro-elastic (TPS-MEE) plates with the aid of Reddy’s third-order shear deformation theory (RTSDT). A three-phase smart composite constituted of CoFeO, piezomagnetic matrix embedded with carbon fibers in the piezoelectric shell is considered for evaluation. The coupling characteristics of the smart carbon/PZT-5A (PZT-7A)/CoFeO, composites significantly changes with
the interphase thickness of piezoelectric interphase. Thereby the stiffness and the natural frequency of the structure composed of these three-phase MEE materials drastically changes. A finite element (FE) formulation has been derived incorporating Hamilton’s principle. The equations of motion are obtained through condensation technique. The results reveal a significant effect of interphase thickness on the natural frequency of the three-phase smart magneto-electro-elastic plate. Further, a special attention has been paid on evaluating the influence of carbon fiber/piezoelectric volume fraction on the free vibration behaviour of TPS-MEE plate. Also, a parametric study has been performed to investigate the effect of boundary conditions, aspect ratio and length-to-width ratio.

Yufan Tang (1), Fengxian Xin (1) and Tian Jian Lu (2)
(1) State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi’an Jiaotong University, Xi’an 710049, PR China
(2) State Key Laboratory for Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China


ABSTRACT: A combined theoretical and numerical study is carried out to evaluate the sound absorption performance of a micro-perforated sandwich panel with perforated honeycomb-corrugation hybrid core (PHCH) at high temperatures up to 700 K. The theoretical model is established based on the classical Maa theory for micro-perforated panels and the method of electro-acoustic analogy. Validity of the model is checked against direct numerical simulations performed on COMSOL Multiphysics. Sound absorption properties of PHCH and its competitors obtained at different temperatures reveal that temperature affects remarkably their low-frequency performance. Average particle velocity in the perforation hole is numerically calculated as a function of temperature, and good agreement between sound absorption peaks and particle velocity peaks is achieved. To further demonstrate the superiority of PHCH in low-frequency sound absorption, the half-absorption bandwidths of PHCH are compared to those of its competitors at high temperatures. The influence of facesheet and corrugation are also studied, illustrating that the former plays a more significant role than the latter. The proposed sandwich structure shows promising engineering applications not only as a load-bearing structure, but also as a sound absorber, even at high temperatures.


ABSTRACT: Results of an experimental investigation into the low-velocity impact response of carbon fibre reinforced laminates and sandwich structures are presented. Six different impact tests have been performed on the composite laminates and sandwich panels with impact energy levels ranging from 17.13 to 154.18 J. Two types of loading conditions were implemented: (1) impacts by the impactors having the same mass and variable impact velocities resulting in different impact energy levels; (2) impacts with the same level of energy (equivalent energy impacts) and different impactor masses with corresponding (different) velocities. The experiments probed the effects of impactor mass, velocity, and different impact energy levels by analysing the patterns of induced damage, energy absorption, penetration resistance and force-displacement response. Microscopic non-intrusive damage assessment procedures were employed to investigate various damage modes induced by the drop weight impact depending on the impact of velocities and impactor masses.


ABSTRACT: Sandwich structures, which are light but have high strength, are extensively used in automobile, marine and aircraft structures. However, core/facesheet debonding can occur and reduce the stiffness of the structures and hence result in the failure of the structures, whilst affecting the vibration behaviours. Hammer
impact tests and finite element simulations were conducted on flat and curved sandwich structures, which were composed of carbon fibre reinforced polymer (CFRP) facesheets and epoxy cores, to analyse how the vibration behaviours were affected by debonding and other factors. The 15°- and 30°-curved structures showed only slight differences in the natural frequencies of bending and torsional modes. However, significant difference in the lateral modes were found as the mode shape merged with torsional movement and hence the natural frequencies increase. Debonding resulted in the reduction in the natural frequencies, an 80 mm debonded region reduced the natural frequency of the flat and 30°-curved structures by 57.0% and 56.6%, respectively. Change of natural frequencies can make a structure resonate and lead to failure, therefore how the debonded regions affect the vibration of sandwich structures is important for applications.

Xianfeng Wang (1), Huaqiao Wang (2), Cheng Ma (1), Jun Xiao (1) and Liang Li (1) (1) College of Material Science & Technology, Nanjing University of Aeronautics and Astronautics, China (2) School of Mechanical Science & Engineering, Huazhong University of Science and Technology, China “Analysis of vibration reduction characteristics of composite fiber curved laminated panels”, Composite Structures, Vol. 227, Article 111231, 1 November 2019, https://doi.org/10.1016/j.compstruct.2019.111231
ABSTRACT: Firstly, based on modal experiment, this paper analyses composite fiber curve laminates, which includes [0/15°], [15°/30°], [30°/45°], [45°/60°], [60°/75°], [75°/90°], and then gets damping ratio of each laminated plate. After analysis, the results showed that the curve of fiber layer for 30°/45° composite laminated plate damping ratio is the maximum, however, the curve of fiber layer for 60°/75° composite laminated plate damping ratio is the maximum. Secondly, the simple harmonic test of laminated plates with curved layers was carried out. Those plates includes [0/45°/0/15°/-45°], [0/45°/15°/30°/-45°], [0/45°/30°/45°/-45°], [0/45°/45°/60°/45°], [0/45°/60°/75°/-45°], [0/45°/75°/90°/-45°]. It is easy to get the acceleration response maps of each laminated plate. The above simple harmonic test results showed that larger the damping ratio, the better the damping effect and the smaller the amplitude of acceleration. The amplitude of acceleration changes inversely with the change of damping ratio. Finally, the conclusion is that the laminated plate with the best vibration damping effect is [30°/45°], and the laminated plate with the worst vibration damping effect is [60°/75°].

Xing Liu (1,2), Bachir Belkassem (3), Arnaud Jonet (1,3), David Lecompte (3), Danny Van Hemelrijck (1), Rik Pintelon (4) and Lincy Pyl (1) (1) Department of Mechanics of Materials and Constructions, Vrije Universiteit Brussel (VUB), Pleinlaan 2, BE-1050 Brussels, Belgium (2) SIM M3 Program, Technologiepark 935, BE-9052 Zwijnaarde, Belgium (3) Royal Military Academy, Civil and Materials Engineering Department, Renaissancelaan 30, BE-1000 Brussels, Belgium (4) Department of Fundamental Electricity and Instrumentation, Vrije Universiteit Brussel (VUB), Pleinlaan 2, BE-1050 Brussels, Belgium “Experimental investigation of energy absorption behaviour of circular carbon/epoxy composite tubes under quasi-static and dynamic crush loading”, Composite Structures, Vol. 227, Article 111266, 1 November 2019, https://doi.org/10.1016/j.compstruct.2019.111266
ABSTRACT: Carbon/epoxy composites demonstrate significant and promising improvements of the weight-to-performance ratio in the automotive industry. In this paper, their energy absorption performance is thoroughly investigated. Quasi-static and dynamic axial crush tests have been performed on a variety of carbon/epoxy composite tube specimens with different thicknesses, layups and architectures (fabric and unidirectional). It is shown that the frequency response of the drop weight test setup bias the crush load histories and give false peak crush loads which lead to a wrong understanding of the elastic behaviour of the composites. Different filtering processes are adopted to investigate their necessity and influence on the energy absorption performance of carbon/epoxy composites. Comparing the specific energy absorption and crush efficiency of the variety of carbon/epoxy composite tube specimens, the fabric ones perform better than the unidirectional ones. The results show that more energy can be absorbed in the quasi-static conditions.

P.M.G. Bashir Asdaque and S. Roy (Department of Applied Mechanics, Indian Institute of Technology Delhi, New Delhi 110016, India), “Nonlinear dynamic analysis of slender, composite smart-structures under fixed and
ABSTRACT: The present theory is based on an intrinsic, electromechanically coupled mixed variational formulation to study dynamical instability of a two-way coupled electromechanical beam. A computational code is developed based on the present theory, where the coupled equations over space-time are solved by a combined Newton-Raphson and Newmark method. Validation of the dynamic results for sensor applications for fixed and follower loads have been done. Both, linear and nonlinear results have been discussed. The eigenvalue analysis, flutter dynamic instability and the effect of various circuit conditions on instability have been discussed. The computation time comparison between the commercially available software and the present theory shows the efficacy of the analysis presented. The computational platform developed here may be utilized for designing real applications like smart wind turbines and smart laminated airplane wings, which are highly flexible and undergo large displacements and rotations.

Grażyna Ryzińska (1,2), Matthew David (2), Gangadharma Prusty (2), Jacek Tarasiuk (3) and Sebastian Wroński(3)

(1) Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics, Powstańców Warszawy Ave. 12, 35-959 Rzeszow, Poland
(2) ARC Training Centre for Automated Manufacture of Advanced Composites, School of Mechanical & Manufacturing Engineering, UNSW Sydney, NSW 2052, Australia
(3) AGH UST, Faculty of Physics and Applied Computer Science, Poland

ABSTRACT: This paper presents the progressive crushing performance of composite tubes with varied fibre architecture. The effect of lay-up configuration and influence of percentage of unidirectional (UD) and woven fabric (WF) fibre architectures on the specific energy absorption (SEA) is investigated using experiments. Composite tubes with internal diameter 42 mm and wall thickness to diameter of 0.05 were manufactured for a range of specimens with different ratios of axial and hoop fibres. The samples were chamfered at an angle of 70°. Progressive crushing of specimens under quasi-static (20 mm/min) and dynamic (4.48–6.7 m/s) loading were performed. A new factor Axial Fibre Mass Fraction (AFMF) was introduced to describe the mass fraction of axial fibres to reflect upon the SEA response. To investigate the influence of AFMF and loading rate on the crushing mechanism of composite tubes, computer tomography (CT) was additionally. The calculated SEA for different loading conditions indicate a drop of 10%–20% for dynamic cases depending on the fibre architecture of the samples. The CT-scans present a relationship between debris length and AFMF. The average length of debris decreases with the increase of AFMF which indicates more intense fibre breaking, reduced integrity of the ‘petals’ and hence increased SEA.

Mohammad R. Hosseini A. (1), Mohammad R. Forouzan (1) and Ehsan Daneshkhah (2)
(1) Department of Mechanical Engineering, Isfahan University of Technology, Isfahan 84156-8311, Iran
(2) Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

ABSTRACT: Glass-polyester molded grating composites (MGC) are brittle and sensitive to the damage caused by the impact. In this study, a finite element model has been proposed to predict the strength of the molded grating composite panels against low-velocity impact loads. Molded grating composites have unidirectional reinforcement fibers, except in the intersections where behave as a blocked bidirectional reinforced materials. Hashin failure criteria and a proposed sudden degradation model have been employed to distinguish damage initiation and formulate damage evolution, respectively. The proposed degradation rule basically is Tserpes model with a small modification for shear dominant tension-compression degradation. In order to validate the results a series of experimental impact tests were carried out by means of a drop weight tower in different states
of the height and mass of the drop weight. Three-point bending tests on the intact specimen and impacted specimens were performed in order to determine the reduction of strength and stiffness after impact. The results show that the numerical analysis based on the proposed modified Tserpes model predicts the ultimate force and the slope of the load-displacement diagram with a reasonable accuracy that correlate well with the experimental results.

Behrouz Karami (1), Maziar Janghorban (1), and Timon Rabczuk (2)
(1) Department of Mechanical Engineering, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran
(2) Institute of Research and Development, Duy Tan University, Da Nang, Viet Nam
ABSTRACT: We study functionally graded nanoplates made of (hexagonal) beryllium crystals. Therefore, a five-variable refined plate theory in conjunction with the nonlocal strain gradient theory is developed. From the best knowledge of authors, it is the first time that mentioned theories are developed for hexagonal materials.

The governing equations are obtained using Hamilton’s principle where an analytical technique based on Navier’s series is utilized to solve the static problem for simply-supported boundary conditions. To simplify the equations, the number of unknowns and governing equations are reduced by dividing the transverse displacement into bending, shear, and thickness stretching parts. The obtained results of the displacements are compared with those predicted by other 2D and quasi-3D plate theories available in the literature. We show that the bending characteristics of FG anisotropic nanoplates are influenced by the nonlocal parameter, strain gradient parameter, length-to-thickness ratio, length-to-width ratio and exponential factor. This study offers benchmark results for the static analysis of functionally graded anisotropic nanoplates which could for instance be used for other computational approaches. We also quantify the accuracy of replacing an anisotropic model with an isotropic one and show that the differences in the stresses can grow up to 10% in some conditions.

K. Foroutan (1), H. Ahmadi (1) and E. Carrera (2)
(1) Faculty of Mechanical Engineering, Shahrood University of Technology, Shahrood, Iran
(2) Mul Group, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Turin, Italy
ABSTRACT: An analytical approach for the nonlinear vibration analysis of imperfect functionally graded carbon nanotube-reinforced composite (FG-CNTRC) cylindrical panels is presented. The FG-CNTRC cylindrical panel is subjected to external pressure in the thermal environment. The nonlinear temperature distribution in the thickness direction is assumed. The classical thin shell theory with the von-Kármán strain-displacement kinematic nonlinearity is employed in the constitutive laws of the shell. The governing equation is solved by utilizing Galerkin’s method in conjunction with the stress function concept. Finally, to find the nonlinear dynamic responses, the fourth order Runge-Kutta method is used. The effect of the four various types of the CNTs distributions, such as UD, FG-A, FG-X, and FG-O is considered on the cylindrical panel. The influence of material parameters, initial imperfection, and temperature on the nonlinear vibration response of functionally graded CNTRC cylindrical panel is presented.

ABSTRACT: The paper presents an application of the extended Refined Zigzag Theory (eRZT) in conjunction with the Ritz method to the analysis of bending, free vibration and buckling of functionally graded carbon nanotube-reinforced (FG-CNTR) sandwich plates. Two stacking sequences are taken into consideration: sandwich panels with a homogeneous core and functionally graded face-sheets and sandwich panels with homogeneous face-sheets and a functionally graded core.

After validating the convergence characteristics and the numerical accuracy of the developed approach using orthogonal and non-orthogonal admissible functions, a detailed parametric numerical investigation is carried

ABSTRACT: The aim of this study is to characterize and assess the effect of fabric structure on the damage resistance subjected to low velocity impact. Composite panels reinforced by layered unidirectional (LU), layered woven (LW) and 3D orthogonal woven (OW) fabric were prepared respectively and the impact tests were carried out on a low-velocity testbench. Finite element models at yarn-level were established to numerically investigate the material deformation and failure mechanism. The impact tests showed that the OW composite possessed better impact resistance with respect to impact-induced deformation and inelastic energy absorption. The roles of the z-binder have also been identified through comparison of impacted morphology and numerical results. The z-binder serves as cracking trigger due to the weak debonding with resin pocket around it and its zig-zag configuration impedes the growth of delamination by damage deflection. Therefore, the discontinuous resin damage in 3D composite allows the enhancement of impact resistance instead of delamination failure in the 2D panel. In addition, the in-plane interlacement of woven fabric causes that primary yarn breaks in the high stress region and forms a circle damage area, whereas the penetrating cracking along the fiber orientation of superficial layer is induced in the unidirectional composite.


ABSTRACT: This paper focuses on the nonlinear free and forced vibrations of porous sigmoid functionally graded material plates resting on nonlinear elastic foundations. Two types of porosity distributions, even and uneven, were considered. A nonlinear three-parameter foundation model was employed to estimate the plate-foundation interactions. The material properties of the plates, described by the sigmoid distribution law, were assumed to be graded in the thickness direction. All four edges of the plates were simply supported and had no in-plane displacements. Based on a higher-order shear deformation plate theory and general von Kármán-type equation, the equations of motion with the effects of nonlinear elastic foundations were developed. The equations of motion were solved by an improved perturbation technique to determine the nonlinear frequencies and dynamic responses of the plates. The numerical illustrations are presented in both tabular and graphical forms to show the effects of the nonlinear foundation parameters, pore volume fraction, and material volume fraction on the nonlinear vibration and dynamic responses of the plates.


ABSTRACT: An asymptotic shell theory is proposed for the analysis of hemispherical shells. Vibration characteristics of laminated specially orthotropic hemispherical shells are investigated using multiple scales asymptotic expansion method. The governing equations are formulated from the three dimensional elasticity equations without any initial assumptions. These equations are solved using differential quadrature method to obtain the numerical solution of the problem. Numerical results are presented for laminated hemispherical shells with an axial cut at the top for clamped-clamped boundary condition. A parametric study is conducted for different thickness ratios, angle of the axial cut, orthotropic ratios and laminate configurations.

ABSTRACT: An improved and efficient analytical solution is proposed to predict the behaviour and the ultimate strength of composite laminates containing delamination. For this purpose, a Layerwise Higher order Shear Deformation Theory based on polynomial shape functions using Rayleigh–Ritz approximation technique are utilized. The ultimate strength and initial stages of propagation of the delaminated zone are determined using fracture analysis. The results demonstrate continuous functions to calculate in-plane and out-of-plane displacements, rotations, strains, stresses, energy and load carrying capacity under in-plane compressive loading. Moreover, a significant experimental investigation has been carried out for specimens with cross-ply stacking sequence and various material properties, geometries, delamination type and boundary conditions. The experimental study includes fabrication process, tensile tests to determine material properties and buckling test of the defected specimens.


ABSTRACT: Composite sandwich panels with truss core have been widely studied for their outstanding characteristics and excellent designable properties, but very little of this work was focused on non-destructive testing (NDT) methods. Based on mode curvatures and a two-dimensional (2D) continuous wavelet transform (CWT), a baseline-free NDT method is proposed for damage identification in these types of sandwich panels. Initially, the 2D CWT is applied to process the mode curvatures from specific mode shapes. Then, considering the structural periodicity of the truss, which is a distinctive characteristic of these sandwich panels, a novel damage index is defined through a combination of the structural periodicity and the coefficients of the CWT. Numerical simulations and experimental tests were conducted to identify damage in the composite sandwich panels with core trusses forming a pyramidal lattice. Results show that the proposed method is efficient and reliable, and has a good resolution in identifying one or more truss bars missing detection without a baseline and thus has the potential in damage detection of composite sandwich panels.

Hossein Daemi and Hamidreza Eipakchi (Faculty of Mechanical and Mechatronics Engineering, Shahrood University of Technology, Shahrood, Iran), “Closed form solution for free vibrations analysis of FGPM thick cylinders employing FSDT under various boundary conditions”, Composite Structures, Vol. 229, Article 111403, 1 December 2019, https://doi.org/10.1016/j.compstruct.2019.111403

ABSTRACT: A porous material contains a structure in which its density reduces when the volume increases due to voids. The high strength, low weight and absorption of the sound or impact convert the porous materials desirable with vast applications to different fields of science and technology. In this paper, an analytical method is proposed for investigating the vibrations behavior of thick porous cylinders for various boundary conditions. The porosity variation is function of the thickness as symmetric, asymmetric or uniform. For mathematical modeling, the first-order shear deformation theory is used as displacement field, by considering the transverse normal strain effect. Hamilton’s principle in conjunction with the linear kinematic relations and Biot constitutive equations are employed to extract the motion equations. The governing equations contain four coupled partial differential equations. These equations are solved analytically and the natural frequencies and mode shapes are determined. A parametric study is performed and the effect of the materials and mechanical properties is studied for different boundary conditions. The results are compared with the finite element methods and the available results in the literature.

ABSTRACT: The aim of this research is to investigate the influence of residual stresses on the behaviour of thin-walled laminates during compression until failure. We investigate the compression of a squared cross-section, GFRP columns with dimensions: (width x height x thickness): 80x80x2 mm. The length of the tubes is equal to 250 mm. The material used to manufacture the specimens was eight-layered pre-preg and we analysed six combinations of angular arrangements. The autoclaving technique was employed to produce the samples. In this paper, a new FE model of tubes’ compression including residual stresses from the manufacturing process is presented. The FE model where residual stresses are not taken into account has been underestimated by the real structures’ behaviour. Therefore, the first part of the study is devoted to preparing a simplified model of the curing process, while in the second the manufacturing and curing stresses are transferred to the model of compression. Backed by experimental data, the study shows that residual stresses have a significant influence on buckling performance, which finds confirmation in the experiments.

Yilong Wang (1), Dengqing Cao (1), Jiaqi Peng (2), Hao Cheng (2), Huagang Lin (1) and Wenhu Huang (1)  
(1) School of Astronautics, Harbin Institute of Technology, Harbin 150001, PR China  
(2) Beijing Institute of Structure and Environment Engineering, Beijing 100076, PR China  
“Nonlinear random responses and fatigue prediction of elastically restrained laminated composite panels in thermo-acoustic environments”, Composite Structures, Vol. 229, Article 111391, 1 December 2019, 
https://doi.org/10.1016/j.compstruct.2019.111391

ABSTRACT: This paper presents a formulation for predicting the nonlinear random response of the elastically restrained laminated composite panel subjected to thermo-acoustic loads. Based on the laminated plate theory and Von Kármán large deflection and classical thin plate theories, the natural characteristics are obtained via Rayleigh-Ritz method and then the governing equations of the panel subjected to combined acoustic and thermal loads are formulated. The nonlinear partial differential equations of motion are transformed to a set of coupled nonlinear ordinary differential equations in truncated modal coordinates. A numerical example where the acoustic load is considered as the Gaussian band-limited white noise is given to perform the process of obtaining the mode and responses of the panel. Taking the natural frequency obtained from the finite element method as a reference value, the process of obtaining the natural frequencies is validated by comparing the frequency results. Numerical results show that the buckling, snap-through, and nonlinear random vibrations of the thermal-elastic restrained panel can be predicted accurately. Comparing stress PSD distributions with fatigue damage distributions, the first-order mode is proved to be valid for determining the most dangerous area for fatigue life prediction.

M. Shariyat, S. Jahanshahi and H. Rahimi (Faculty of Mechanical Engineering, K.N. Toosi University of Technology, Tehran 19991-43344, Iran), “Nonlinear Hermitian generalized hygrothermoelastic stress and wave propagation analyses of thick FGM spheres exhibiting temperature, moisture, and strain-rate material dependencies”, Composite Structures, Vol. 229, Article 111364, 1 December 2019, 
https://doi.org/10.1016/j.compstruct.2019.111364

ABSTRACT: The present article is dedicated to the dynamic stress and displacement distributions and hygrothermoelastic wave propagation and reflection responses of FG hollow spheres subjected to thermomechanical shocks. The strain-rate and temperature dependencies of the material properties are accounted for. Hence, the material properties of the sphere are dependent on coordinates, time, loading rate, temperature, and ambient humidity. Furthermore, material degradation due to moisture absorption is considered. It is the first time that such a complex and more realistic combination is taken into account in the wave propagation analysis. The nonlinear coupled Lord-Shulman-type generalized hygrothermoelasticity equations that are developed by the inclusion of the moisture absorption state variable into the free energy function, are solved by using a Galerkin-type finite element method, iterative solution algorithm, and a second-order Runge-Kutta time integration procedure. Results are extracted by using the C-continuous Hermitian rather than common C-continuous Lagrangian elements to guarantee exact continuity of the stresses at the mutual boundaries of the elements and preclude the numerical locking phenomenon. Comprehensive sensitivity analyses including the effects of various factors are performed. Results reveal the significant effects of the temperature, strain-rate, and moisture absorption on both the material properties and constitutive law and consequently, on the transient stress distribution and the hygrothermoelastic wave propagation/reflection phenomenon. Furthermore, the results confirm that in the FG structures, the thermal and stress wavefronts travel with variable and time-dependent speeds.
ABSTRACT: Both auxetic structures and hierarchical honeycombs are marked with lightweight and excellent mechanical properties. Here, we combine the characteristics of auxetic structures and hierarchical honeycombs, and propose two re-entrant hierarchical honeycombs constructed by replacing the cell walls of re-entrant honeycombs with regular hexagon substructure (RHH) and equilateral triangle substructure (RHT). The honeycombs are subjected to in-plane impact in order to investigate the crashworthiness by using the commercial software LS-DYNA. The plateau stress of RHH and RHT in x and y directions are derived by a two-scale method. The results from numerical simulation indicate that the specific energy absorption of RHT and RHH is improved up to 292% and 105%. RHT and RHH improve the mean crushing force value by 298%, 108% respectively compared with the classic re-entrant honeycomb (RH) under quasi-static loading at stress plateau region. The RHT and RHH still have the characteristic of negative Poisson’s ratio. Additionally, the parametric studies are further carried out to investigate the effects of impact velocities and relative densities on crashworthiness. All the findings of this study indicate that the proposed two hierarchical honeycombs exhibit an improved crushing performance, and RHT provides the highest energy absorption capacity among all specimens.


ABSTRACT: A clear understanding of failure mechanisms and coupling interaction of multiple failure modes greatly contributes to crashworthiness design of composite structure. Thus, the crashworthiness and failure of steeple-triggered hat-shaped composite structure (HSCS) is investigated based on finite element method. The stacked-shell model is adopted to capture both intra- and inter-laminar failure modes and validated with available experiments. The effect of oblique crushing on the crashworthiness of HSCS is predicted and analyzed. Further, to improve specific energy absorption (SEA), the HSCS as a sub-structure is used to design cellular structures including unit-cell, double-cell and four-cell structures. From the predicted results, failure process and complex coupling failure mechanisms of HSCS are revealed. It is found that the oblique crushing angle has a significant effect on the crashworthiness and there exists a critical angle. It is also revealed that the SEA increases with the increase of the cell number due to different splaying modes.


ABSTRACT: A unified semi-analytical method for dynamic homogenization and vibration analysis of lattice truss core sandwich beams is proposed. The method is developed based on prediction of both propagating and evanescent Bloch waves in the periodic truss core sandwich beam using a wave finite element method. This is accomplished very efficiently with the requirement of modeling only one unit cell of the periodic sandwich beam, which can be implemented simply by employing a conventional finite element package. A dynamic equivalent Timoshenko beam model is thereby built by matching its propagating and evanescent flexural wavenumbers to those predicted from the original sandwich beam. Dynamic equivalent beam parameters including equivalent flexural stiffness, equivalent shear stiffness, as well as equivalent Young’s modulus and shear modulus are identified and expressed as explicit formulations relating to the two matched flexural
wavenumbers. Free vibrations of finite-length lattice truss core sandwich beams with various common boundary conditions are further examined based on analytical natural frequency equations and normal mode functions. It is demonstrated that the proposed method shows excellent agreement with conventional finite element method and provides much better accuracy of natural frequency prediction than a representative existing method.

Chuanchuan Shen (1), Li Ma (2), Ping Xu (3) and Jinyang Zheng (1)
(1) Institute of Process Equipment, Zhejiang University, Hangzhou 310027, China
(2) Institute of Applied Mechanics, Zhejiang University of Technology, Hangzhou 310014, China
(3) Institute of Applied Mechanics, Zhejiang University, Hangzhou 310027, China


ABSTRACT: In this paper, a new method combined three-dimensional finite element method (FEM) with heterogeneity model of wrinkles was presented to predict the mechanical response of orthotropic plates under four different loading conditions: transverse compression, axial tension, bending and shearing. The effective elastic properties disturbed by wrinkles are determined based on a mesomechanics model and a homogenization technique. The computation combining heterogeneous wrinkles can be considered as a virtual test since it allows every computation to produce a different result according to different shapes, sizes and locations of wrinkles, which are believed to obey the normal and random distribution, respectively. It was found that the in-plane displacements of plates increase dramatically when the heterogeneity wrinkle model is considered. The fluctuant displacement fields of the plate under axial tensile load can be clearly observed, and the distortion of displacement contours becomes serious with the increment of standard deviation of normally distributed wrinkle defects. Also, the statistical characteristics of mechanical response corresponding to different standard deviations were obtained according to multiple computations.

Amit Yadav (1), Marco Amabili (2), Sarat Kumar Panda (1) and Tanish Dey (1)
(1) Department of Civil Engineering, Indian Institute of Technology (ISM), Dhanbad 826004, India
(2) Department of Mechanical Engineering, McGill University, Montreal, PQ H3A 2K6, Canada


ABSTRACT: The analysis of the non-linear vibration response is carried out for functionally graded (FG) circular cylindrical shells subjected to thermal environment along with mechanical in-plane non-uniformly distributed loading along the edges and harmonic radial force. The temperature dependent material properties of the simply supported shell are assumed to vary in the radial direction according to power-law distribution. Based on the first-order shear deformation theory and von-Kármán type geometric nonlinearity, the strain-displacement relationships are established for circular cylindrical shells. The coupled governing equations of motion for functionally graded cylindrical shells are then derived using Hamilton’s principle. Employing Galerkin’s method, the coupled partial differential equations of motions are reduced to a set of non-linear ordinary differential equations. In order to obtain the free and forced vibration response of the FG shell, the incremental harmonic balance method, in conjunction with the arc-length method, is used. The non-uniform in-plane loading is converted to Fourier series and the pre-buckling analysis is performed to determine the stress distribution within the shell. The non-linear frequency-amplitude response is studied to examine the effects of volume fractions of the constituents, static partial edge loadings, thermal loads, and radial periodic loadings.


ABSTRACT: This paper presents a new variable-kinematics continuum shell (VKCS) element that can be used to model laminated shell structures with arbitrary geometry in a finite element (FE) setting. The novelty is in the implementation of variable-kinematics capability in a continuum shell formulation, using Carrera’s Unified Formulation (CUF). The resultant model has completely general geometric and kinematic descriptions. In the formulation, the geometrical representation is based on a numerical isoparametric map with no simplifying assumptions on the shell geometry; whereas the element displacement fields are written in terms of the
Fundamental Nuclei according to CUF. In the variable-kinematics framework, the levels of $hp$– and $p$– refinements in the through-thickness and in-plane domains are free parameters that can be varied independently. By parametrically varying in-plane mesh densities and model kinematics, model settings with good trade-offs in computational cost and desired level of accuracy can be identified. In addition to the existing literature benchmarks, we include new 3D stress benchmarks for laminated shells with complex geometrical features, such as spatially varying curvatures, non-orthogonal coordinate lines and variable thicknesses. The higher-order models yield asymptotically correct three-dimensional stresses, even in regions near singularities, without requiring numerical artefacts nor stress recovery procedures. In terms of computational efficiency, the model variants utilising high $p$-level require fewer total degrees of freedom (dofs) compared with linear 3D finite element method (FEM) for convergence of the 3D stress field. In terms of wider applications, the compact formulation can allow for the same computer code and model mesh to be used across a wide range of analyses for complex shell structures that requires different model fidelity, with minimal inputs from the user.


ABSTRACT: The present work describes an optimization process based on the $\epsilon$-constraint method to find an optimum design to maximize the critical buckling load and minimize the structural weight of an angle grid plate. A comprehensive geometrical model is considered including all geometrical design variables of the grid. In order to achieve a precise and effective approximation of the buckling load, an artificial neural network (ANN) is employed. Training data for ANN is obtained by the Mindlin plate theory as well as the Ritz method. The ANN is combined with genetic algorithms (GA) to find the optimized design variables for an angle grid structure. The results provide a wide range of geometrical data for designers to choose the maximum buckling load at the minimum structural weight.

Özgür Kalbaran (1) and Hasan Kurtaran (2)
(1) Department of Mechanical Engineering, Gebze Technical University, Gebze, Kocaeli, Turkey
(2) Department of Mechanical Engineering, Adana Alparslan Türkêş Science and Technology University, Adana, Turkey


ABSTRACT: In this article, nonlinear transient behavior of laminated composite Parabolic Panels of Revolution Structure(s) (PPRS) with variable thickness resting on elastic foundation is investigated using Generalized Differential Quadrature (GDQ) method. Winkler-Pasternak model is used to represent elastic foundation. Linear, arch, sine and cosine thickness functions are used to express variable thickness. In transient analyses, First Order Shear Deformation Theory (FSDT) is used to consider the transverse shear effects. Nonlinearity is taken into account using Green-Lagrange nonlinear strain-displacement relations considering deepness effect. Virtual work principle is used to derive the equations of motion. Partial derivatives in the equation of motion are expressed with GDQ method and time integration is carried out using Newmark average acceleration method. Several problems are solved and compared with finite element results in order to validate the proposed method. After validation, effects of thickness functions, thickness variation parameter, geometric characteristic parameter of PPRS, boundary conditions, elastic foundation parameters as well as composite lamination scheme on nonlinear transient dynamic behaviour of PPRS are investigated.

Jiong-Feng Liang (1,3), Wan-Jie Zou (2), Zeng-Liang Wang (1) and Da-wei Liu (3)
(1) State Key Laboratory Breeding Base of Nuclear Resources and Environment, East China University of Technology, Nanchang, China
(2) College of Civil and Architecture Engineering, Guangxi University of Science and Technology, Liuzhou, China
(3) College of Architecture Engineering, East China University of Technology, Nanchang, China

ABSTRACT: This paper reports the compressive behavior of CFRP-confined partially encased concrete columns under axial loading. Nine CFRP-confined partially encased concrete columns and three partially encased concrete columns are axially tested. The failure modes, load versus displacement relationship, axial bearing capacity, ductility and initial stiffness are presented and analyzed. The results show that CFRP-confined partially encased concrete columns present a better mechanical performance than those without CFRP sheets confining (i.e. partially encased concrete columns). CFRP-confined partially encased concrete columns are eventually failed due to the local buckling of steel flange with rupture of CFRP sheet or without rupture of CFRP sheet. The ductility and axial bearing capacity of columns can be improved with increasing number of CFRP sheet layers. A simplified design formula of CFRP-confined partially encased concrete columns is proposed, which can satisfactorily agree with the test results.

Guo-dong Xu (1), Tao Zeng (2), Su Cheng (1), Xiao-hong Wang (1) and Kun Zhang (1)
(1) Department of Engineering Mechanics, Harbin University of Science and Technology, Harbin 150080, PR China
(2) Department of Civil and Environmental Engineering, College of Engineering, Shantou University, Shantou 515063, PR China


ABSTRACT: A continuous homogeneous theory is employed to formulate a governing equation for predicting the free vibration of the graded corrugated lattice core sandwich beam. The Rayleigh-Ritz method is adopted to solve the governing equation for various types of boundary conditions. The natural frequencies are obtained and the theoretical predictions are validated by the numerical simulations and experimental results. An auto-cutting process combined with mold-press method was used to fabricate the graded corrugated lattice core sandwich beams. Three kinds of graded corrugated lattice core sandwich beams were designed to investigate the vibration responses of the sandwich beams. The influences of the graded parameters on the natural frequencies were discussed. Numerical simulations were carried out to calculate the natural frequencies of the graded corrugated lattice core sandwich beams. The influences of face sheet thickness, core height, beam length and graded parameter on the natural frequencies of the graded corrugated lattice core sandwich beams were studied.

Sandra Kvaternik (1), Matteo Filippi (2), Domagoj Lanc (1), Goran Turkalj (1) and Erasmo Carrera (2)
(1) Department of Engineering Mechanics, Faculty of Engineering, University of Rijeka, Vukovarska 58, HR-51000 Rijeka, Croatia
(2) Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy


ABSTRACT: In this work, nonlinear buckling analysis of thin-walled beams by two different models is investigated: first one, developed by MUL2 group, based on Carrera Unified Formulation, and THINWALL v.16 beam model based on classical Euler-Bernoulli-Vlasov beam theory. In former, the refined beam theories are obtained on the basis of Taylor and Lagrange-type expansions. Latter is performed in framework of updated Lagrangian formulation adopting nonlinear displacement field of thin-walled cross-section. Isotropic and FG beams are referred to. It is observed that numerical results obtained by these methods match very well.

Dongying Liu (1), Zhi Li (1), Sritawat Kitipornchai (2) and Jie Yang (3)
(1) School of Civil Engineering, Guangzhou University, Guangzhou 510006, China
(2) School of Civil Engineering, University of Queensland, Brisbane, QLD 4072, Australia
(3) School of Engineering, RMIT University, Bundoora, VIC 3083, Australia

ABSTRACT: Based on the three-dimensional theory of elasticity, the free vibration and bending analyses of functionally graded graphene nanoplatelets-reinforced nanocomposite (FG-GPLRC) annular plates are performed in this paper. The state-space based differential quadrature method (SS-DQM) is employed to study the vibration and bending behaviors of multilayer FG-GPLRC annular plates with different boundary conditions. The modified Halpin-Tsai micromechanical model and rule of mixtures are used to evaluate the effective material properties of the graphene-based nanocomposites, and five different types of GPL distribution patterns are discussed. After convergence and validation studies to verify the present analyses, comprehensive parametric investigations are conducted to examine the effects of weight fraction, distribution pattern, and geometric parameters of GPLs on free vibration and bending characteristics of the FG-GPLRC annular plates. Numerical results reveal that pattern GPL-Y offers the best reinforcing effect for improved natural frequencies and deformation resistances of the nanocomposite annular plates.

M. Manoj Prabhakar (1), N. Rajini (1,2), Nadir Ayriilmis (2), K. Mayandi (1,2), Suchart Siengchin (3), K. Senthilkumar (1,3), S. Karthikeyan (1) and Sikiru O. Ismail (4)
(1) Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil 626126, Tamilnadu, India
(2) Department of Wood Mechanics and Technology, Faculty of Forestry, Istanbul University-Cerrahpasa, Bahcekoy, Sariyer, 34473 Istanbul, Turkey
(3) Department of Mechanical and Process Engineering, The Sirindhorn International Thai-German Graduate School of Engineering (TGGS), King Mongkut’s University of Technology North Bangkok, Bangkok 10800, Thailand
(4) Manufacturing, Materials, Biomedical and Civil Division, School of Engineering and Computer Science, University of Hertfordshire, Hatfield, Hertfordshire AL10 9AB, England, United Kingdom


ABSTRACT: The main aim of this review article was to address the performance of filament wound fibre reinforced polymer (FRP) composite pipes and their critical properties, such as burst, buckling, durability and corrosion. The importance of process parameters concerning merits and demerits of the manufacturing methods was discussed for the better-quality performance. Burst analysis revealed that the winding angle of ±55° was observed to be optimum with minimum failure mechanisms, such as matrix cracking, whitening, leakage and fracture. The reduction of buckling effect was reported in case of lower hoop stress value in the hoop to axial stress ratio against axial, compression and torsion. A significant improvement in energy absorption was observed in the hybrid composite pipes with the effect of thermal treatment. However, the varying winding angle in FRP pipe fabrication was reported as an influencing factor affecting all the aforementioned properties. Almost 90% of the reviewed studies was done using E-glass/epoxy materials for the composite pipe production. By overcoming associated limitations, such as replacing synthetic materials, designing new material combinations and cost-benefit analysis, the production cost of the lightweight FRP composite pipes can be decreased for the real-time applications.


ABSTRACT: Carbon/epoxy composites demonstrate significant promising improvements of weight to performance in the automotive industry. However, the design of carbon/epoxy composite components for crashworthiness remains challenging and normally requires laborious and repeated experimental work. This study adopts a predictive crush model of carbon/epoxy composites, which can partially replace the experimental work. The discontinuous Galerkin (DG) method with extrinsic cohesive laws is employed to simulate the failure patterns in the composite structures. The application of DG distinguishes the fracture model from the conventional approach where preset cohesive elements are used on the location where cracks are expected. The mixed mode cohesive laws are used to simulate the delamination between each layer. To capture different crack
propagations in different layups, the anisotropic cohesive law is used to simulate the intralaminar crack propagation in composites. To verify the adopted model, circular composite tube specimens with different layups have been simulated and compared with tests under quasi-static crush loadings. The comparisons of numerical results with experimental data show that the DG crush model can reproduce the experimental results with relatively high accuracy.


ABSTRACT: The nonlinear buckling and the post-buckling response of the Fiber Metal Laminate (FML) column of channel section including delamination phenomenon is analysed. Numerical model of FML thin-walled profile is created in a commercial finite element software with the application of solid-shell elements and Cohesive Zone Method for a delamination area modelled by contact elements. The location of delamination plane is predicted by Hashin failure criteria. During the nonlinear buckling analysis, geometric imperfections are included and the non-linear behaviour of the aluminium is taken into account. Outcomes of numerical analysis were compared with experimental results.


ABSTRACT: Thermally-cured fiber-reinforced polymeric laminates can exhibit bistable cylindrical shapes when their plies are configured orthogonally. Such “cross-ply” laminates have been studied extensively through modeling and experiments. However, bistable laminates with non-cylindrical shapes, especially through non-orthogonal ply orientations, have received little attention due to inherent design limitations. This paper presents an approach for developing non-cylindrical curved shapes based on bistability in mechanically-prestressed laminates; prestress is applied by laminating prestrained fiber-reinforced elastomeric laminae on either face of an initially stress-free isotropic layer. An analytical laminated-plate model is developed based on strain energy minimization and stable shapes are calculated for various orientations of the prestrained laminae. The modeled shapes are in agreement with the measured shapes of physical rectangular laminates within 11%. The minimum polynomial order for the calculation of non-cylindrical shapes is fourth; a simplified constitutive model for prestrained-elastomers is developed to reduce computation time. The domain of bistability is investigated taking into account the combined effect of prestrain orientation and the ratio of prestrains, laminate size, and aspect ratio. Modeling of snap-through actuation requirements shows that actuation effort is maximum when one of the prestressed laminae is on a diagonal and the angle between prestrains is 45°.


ABSTRACT: The objective of this work is to present a finite element formulation for dynamic analysis of sandwich shells with viscoelastic core under large deformation. The present study is based on an incremental updated Lagrangian approach together with the Newmark integration scheme. The viscoelastic constitutive model which is used to define the behavior of the core, comes from the Riesz theorem and the corresponding creep functions are estimated using Dirichlet-Prony series. Also, the viscoelastic deferred strain is derived in an appropriate incremental form using the state variables. The employed layerwise shell element which is based on zig-zag theory has eight nodes on its mid layer. What’s more, in addition to three translational and two rotational degrees of freedom per node, the upper and lower layers are allowed to rotate independently relative to their neighbor layers. Thus, the damping effect of the viscoelastic core could be well described within the shear deformable displacement field. The presented nonlinear formulation is then implemented to a nonlinear finite element program to be appraised by solving different kinds of problems. The obtained numerical results correlate well with those available in the literature.

ABSTRACT: The free vibrations of a circular cylindrical sandwich shell with a flexible core containing a flowing fluid are investigated. Within the framework of the higher-order sandwich panel theory which assumes a variable displacement through the thickness, the core flexibility is taken into account. Using Hamilton’s extended principle, for an inviscid, non-rotational, laminar and incompressible flow, via the potential flow theory, the governing equations of the coupled structure and fluid system are derived. The eigenvalue problem’s equations are found by implementing a modal expansion method which has been validated by the existing results and is found to be accurate. The effect of the axial flow velocity, circumferential wave number, core to total thickness ratio and total thickness to mean radius ratio on the natural frequencies are investigated. It is found that taking into account the core's flexibility results in lower frequency values. The study shows that, unlike in dry shells, increasing the ratio of core thickness to total thickness reduces the natural frequencies monotonically in wet shells. For a constant total shell thickness, the critical velocity of the fluid decreases with increases in core thickness.


ABSTRACT: This work deals with the free vibration analysis of laminated composite plates through a variable separation approach. The displacement field is approximated as a sum of separated functions of the in-plane coordinates $x,y$ and the transverse coordinate $z$. This choice yields to a non-linear problem that can be solved by an iterative process. That consists of solving a 2D and 1D eigenvalue problem successively. In the thickness direction, a fourth-order expansion in each layer is considered. For the in-plane description, classical Finite Element method is used. A wide range of numerical tests involving several representative laminated and sandwich plates is addressed to show the accuracy of the present LayerWise (LW) method. Different slenderness ratios and boundary conditions are also considered. By comparing with exact or 3D FEM solutions, it is shown that it can provide accurate results less costly than classical LW computations.

Stefano Francesco Pitton (1), Sergio Ricci (1) and Chiara Bisagni (2)
(1) Politecnico di Milano, Department of Aerospace Science and Technology, 20156 Milano, Italy
(2) Delft University of Technology, Faculty of Aerospace Engineering, 2629 HS Delft, The Netherlands

ABSTRACT: Thin-walled cylindrical shells are nowadays widely used for principal structures in the aerospace field. Despite the capacity to sustain high levels of axial compressive loads they are also easily prone to fall into buckling. One of the methods currently studied to increase the value of the critical load associated with this phenomenon consists in the use of curvilinear fibers, through which it is possible to continuously change the stiffness, and consequently the local behavior of the structure. The paper describes an optimization methodology developed for the buckling optimization of thin-walled variable stiffness cylindrical shells subjected to axial load, together with a general fibers path formulation. The framework proposed involves a synergic work between the finite element method and artificial intelligence techniques. The optimal configuration shows an increase of the buckling load of about 4% together with an increase of the pre-buckling stiffness of about 6%.


ABSTRACT: Sandwich panels manufactured from wood and wood-based materials promote optimal management of natural resources, as they are obtained from renewable materials. For this reason numerous
attempts are being made to use wood in the manufacture of light-weight layer composites exhibiting high rigidity and relatively low density. The aim of the study was to determine the energy absorption capacity in wooden sandwich panels with a prismatic core. This paper describes a method to manufacture a novel wood-based material with a prismatic core. Uniaxial compression tests and 3-point bending performed on the panels were discussed together with the method to determine the amounts of absorbed energy. Numerical models were presented for panels in compression and bending tests along with the method to calculate the results applying the Finite Element Method (FEM). These models were verified based on the results of experimental analyses to facilitate predictability for a new class of composite materials. It was shown that panels with a triple core are more resistant compared to panels with a single core. Moreover, these panels exhibit greater energy absorption capacity.

References listed at the end of the paper:
1 R.Mirsky, D.Dziurka, A.Banaszak, Properties of particleboards produced from various lignocellulosic particles, Biomass, 13 (2018), pp. 7758-7765, 10.15376/biores.13.4.7758-7765
2 R.Mirsky, P.Boruszewski, A.Trociński, D.Dziurka, The possibility to use long fibres from fast growing hemp (Cannabis sativa L.) for the production of boards for the building and furniture industry, Biomass, 12 (2017), pp. 3521-3529, 10.15376/biores.12.2.3521-3529
5 R.Mirsky, A.Derkowski, D.Dziurka, Possibility of using fine wood straws for the production of P5 type building boards, Biomass, 13 (2018), pp. 7188-7196, 10.15376/biores.13.4.7188-7196
6 D.Dziurka, R.Mirsky, D.Dukarska, A.Derkowski, Possibility of using the expanded polystyrene and rape straw to the manufacture of lightweight particleboards, Maderas Cienc y Tecnol, 17 (2015), 10.4067/S0718-221X2015005000057
24 C. Bekir, Y. Bektaş, Some mechanical properties of plywood produced from eucalyptus, beech, and poplar veneer, Maderas Cienc y Tecnol, 16 (2014), pp. 99-108, 10.4067/S0718-221X2014005000009
ABSTRACT: Corrugated panels have many potential applications in civil, mechanical and aerospace engineering. The research on morphing aircraft requires the derivation of deformation limits of corrugated panels, which can be used as the constraint conditions for the design and optimisation of morphing structures. The relationship between the local and global strains of the equivalent models for corrugated panels is derived, which makes the prediction of the maximum strain available. Thus, from the maximum strain criterion, the global strain limit is evaluated under different load conditions. The results from the proposed analytical method are compared to those from detailed finite element models, which indicates a good agreement for all of the analysed cases. The influence of the geometric parameters of the corrugation shape is also investigated.

C. Wang (1), Y. Xia (1), M.I. Friswell (1) and E.I. Saavedra Flores (2)
(1) College of Engineering, Swansea University, Swansea SA1 8EN, UK
(2) Departamento de Ingeniería en Obras Civiles, Universidad de Santiago de Chile, Av. Ecuador 3659, Santiago, Chile


ABSTRACT: Corrugated panels have many potential applications in civil, mechanical and aerospace engineering. The research on morphing aircraft requires the derivation of deformation limits of corrugated panels, which can be used as the constraint conditions for the design and optimisation of morphing structures. The relationship between the local and global strains of the equivalent models for corrugated panels is derived, which makes the prediction of the maximum strain available. Thus, from the maximum strain criterion, the global strain limit is evaluated under different load conditions. The results from the proposed analytical method are compared to those from detailed finite element models, which indicates a good agreement for all of the analysed cases. The influence of the geometric parameters of the corrugation shape is also investigated.

References listed at the end of the paper:
1 N. Buannic, P. Cartraud, T. Quesnel, Homogenization of corrugated core sandwich panels, Compos Struct, 59 (3) (2003), pp. 299-312


ABSTRACT: In this paper, aeroelastic characteristics of a sandwich plate subjected to a supersonic flow are studied. The material of face layers has piezoelectric effect and the core is a magnetorheological elastomer (MRE). The aerodynamic pressure due to supersonic flow is considered based on linear piston theory. The kinematic assumption of classical plate theory for face layers is considered and strain components of MRE core are written based on geometric relations of displacement field of face layers. The equations of motion are obtained in according to Hamilton’s principle. The generalized differential quadrature method (GDQM) is used as a solution technique of governing equations. In order to verify the validity of obtained results, a comparison of the first five natural frequencies is performed with those presented in the literature. The effects of magnetic field, type of piezoelectric material of face layers, boundary conditions, and geometric parameters on the supersonic aeroelastic stability of sandwich plate are investigated. The findings of this study indicate that the magnetic field has a beneficial effect on the maximization of stability boundary of sandwich plate. Also, by increasing the thickness of MRE core the critical aerodynamic pressure of the sandwich plate decreases.

Zeng Liu and Yong Xia (State Key Laboratory of Automotive Safety and Energy, School of Vehicle and Mobility, Tsinghua University, Beijing 100084, China), “Development of a numerical material model for axial crushing mechanical characterization of woven CFRP composites”, Composite Structures, Vol. 230, Article 111531, 15 December 2019, https://doi.org/10.1016/j.compstruct.2019.111531

ABSTRACT: Nowadays, the significant potential of carbon fiber reinforced polymer (CFRP) composites in terms of weight to performance has contributed to their wide application in industrial fields. However, it is widely accepted that design of CFRP components remains rather challenging as laborious experimental work is usually required. Therefore, to reduce the cost and improve the CFRP product development efficiency, the present work aims to develop a numerical material model for numerical prediction of mechanical responses of composite structures under external loading. Both intralaminar and interlaminar failure mechanisms are taken into account with the aid of user material subroutine VUMAT and cohesive surface capability in Abaqus/Explicit. Particularly, a plasticity formulation, post-failure definitions including both continuum damage mechanics and progressive damage mechanics models, and smeared formulation accounting for mesh independence are all incorporated into the intralaminar material model. Finally, the model has been assessed by using two off-angle tension cases and axial crushing tests of corrugated specimen, and good agreement between experiment and simulation demonstrates that the proposed methodology can be used for mechanical characterization of woven composites under these loading cases.

1 N. Buannic, P. Cartraud, T. Quesnel, Homogenization of corrugated core sandwich panels, Compos Struct, 59 (3) (2003), pp. 299-312

ABSTRACT: This paper aims to investigate the in-plane shear behavior of large-size composite plates with multi-bolt joints. A mechanical joint structure and an universal fixture were designed and in-plane shear tests were carried out. The distributed strain gauges were used to monitor the mechanical response and ultimate bearing capacity. The failure areas and failure modes of mechanical connections were studied by ultrasonic scanning. A non-linear finite element model (FEM) based on 2D shell element mesh was developed to predict the load distribution and failure modes of bolt joints between composite and titanium alloys. The results show that the shear failure load reaches 365.95 kN. The shear failure occurs on the outside edges of composites plate, and the delamination extends to the vicinity of the fixture bolts. The new FEM that requires very small computational cost can evaluate the structure strength and predict destruction area. The deviation between the predicted shear failure responses and the testing results is less than 10%. The failure mode and location are consistent with the testing results, which verifies the validity of the finite element model. It suggests that this model is applicable on large scale structures and suitable to use in conjunction with iterative schemes.


ABSTRACT: Thin-walled structures made of lightweight materials, e.g. aluminum, fiber reinforced composites, have been increasingly used as energy absorption structures in vehicles. This work aimed to characterize the lateral crushing behaviors of circular aluminum, glass fiber reinforced plastics (GFRP) and carbon fiber reinforced plastics (CFRP) tubes with different geometric configuration such as diameter-to-thickness (D/T) ratio or thickness. In the experimental investigation, four different D/T ratios varied from 10.78 to 48.02 were considered here for the aluminum, GFRP and CFRP tubes. Crushing behaviors such as force-displacement curves, deformation histories, and crushing force were quantified. The experimental results revealed that the load carrying capacities, energy absorption (EA) and specific energy absorption (SEA) of the circular tubes decline with increasing D/T ratio. It was found that better crashworthy characteristics of thicker composites, with a smaller D/T ratio, were due to the more favorable failure modes occurring throughout lateral compression. The lateral crashworthy performance of the GFRP tubes was marginally better than that of the CFRP counterparts. Due to ductile behavior of aluminum tubes and brittle behavior of composites, aluminum tubes showed much better lateral crashworthiness than that of the composite counterparts. Moreover, with the increase in the D/T ratio, aluminum tubes exhibited greater advantage on crashworthiness than the composite tubes. On the basis of the experimental data, explicit finite element analysis was further carried out for modeling the lateral crushing behavior of aluminum, GFRP and CFRP tubes. The numerical results were in good agreement with the experimental data, demonstrating the validity of these finite element (FE) models in...
predicting lateral crushing responses of aluminum, GFRP and CFRP tubes. The proposed FE models can be exploited to further study similar thin-walled metal and composite structures for design optimization.

Bin Qin (1,2,3), Rui Zhong (4), Tiantian Wang (1,2,3), Qingshan Wang (4), Yongge Xu (5) and Zehua Hu (4)
(1) Key Laboratory of Traffic Safety on Track, Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha 410075, PR China
(2) Joint International Research Laboratory of Key Technology for Rail Traffic Safety, Central South University, Changsha 410075, PR China
(3) National & Local Joint Engineering Research Center of Safety Technology for Rail Vehicle, Central South University, Changsha 410075, PR China
(4) State Key Laboratory of High Performance Complex Manufacturing, Central South University, Changsha 410083, PR China
(5) Overall R&D Department, CRRC Changchun Railway Vehicles Co. LTD, Changchun 130062, PR China


ABSTRACT: This research paper presents a unified Fourier series solution to solve the vibration problem of functionally graded carbon nanotube-reinforcement composite (FG-CNTRC) cylindrical shells, conical shells and annular plates subjected to general boundary conditions, so as to enrich the existing research results on FG-CNTRC structures. Utilizing a micro-mechanical model based on the developed rule of mixtures, the effective material properties of the FG-CNTRC structures which is strengthened by single-walled carbon nanotubes (SWCNTs) are scrutinized. The first-order shear deformation theory (FSDT) and the virtual boundary method are applied to achieve the energy expressions of FG-CNTRC structures. On the basis of that, the unified Fourier series solution in conjunction with the modified Fourier series and Ritz method, is utilized to receive the characteristic equation of the structural vibration. The correctness, convergence and several advantages of the present methodology are verified by numerous numerical examples. Furthermore, some novel numerical results, including the vibration results of FG-CNTRC cylindrical shells, conical shells and annular plates accompanied with classical boundary, elastic boundary, classical-elastic mixed boundary and parameterized results of structure and material parameters, will be presented for future researchers.

T.A.M. Guimarães (1), F.D. Marques (2) and A.J.M. Ferreira (3)
(1) Faculty of Mechanical Engineering, Federal University of Uberlândia, Uberlândia, Brazil
(2) São Carlos School of Engineering, University of São Paulo, São Carlos, Brazil
(3) Faculty of Engineering, University of Porto, Porto, Portugal


ABSTRACT: Panel flutter modeling and analysis had regained importance since the mid-90s. More recently, the idea of considering the mutual influence of adjacent panels in the flutter problem was revisited in studies of panels with multiple supports. These so-called multibay arrangements present flutter mechanism susceptible to jump phenomenon in the Hopf bifurcation diagram. Alternative methods to reduce the computational costs of multibay flutter analysis are desired. The authors propose in this work a comparative study on the supersonic multibay composite panel flutter between the finite element and Rayleigh-Ritz models. The aim is to show how good is the Rayleigh-Ritz approach to match the finite element model results, mainly when the jump phenomenon is present. By adopting the same hypotheses for thin-walled plates, relatively large geometric displacements through the von Kármán strain-displacement relations and first-order piston theory the finite element and Rayleigh-Ritz methods were used to attain the respective modeling. A specific symmetric laminate is used, and results from the literature are used to compare the results and to verify the ability of both methods. Furthermore, the computational gain in using the Rayleigh-Ritz compared with the finite element is discussed, thereby ensuring its potential to other analyses, e.g., in optimization schemes.

Tran Ngoc Doan (1), Do Van Thom (2), Nguyen Truong Thanh (3), Phan Van Chuong (3), Nguyen Chi Tho (4), Nguyen Tri Ta (4) and Hoang Nam Nguyen (5)
(1) Faculty of Aerospace Engineering, Le Quy Don Technical University, Hanoi City, Viet Nam
(2) Faculty of Mechanical Engineering, Le Quy Don Technical University, Hanoi City, Viet Nam
ABSTRACT: This paper presents the stress concentration phenomenon at the points with force jumping, structural jumping and sudden changes of boundary conditions of cylinder laminated shells. The threedimensional linear elastic equation is transformed into the two-dimensional linear elastic equation of the cylinder laminated shell by using the variational method and analyzing the displacement field into a polynomial function sequence according to the shell thickness. Equilibrium equations are achieved corresponding to the case of analyzing the displacement field into the cubic function. Based on established equations, we study the jumping zone phenomenon of the stress field in the structure. Effects of boundary conditions, the relative thickness and the relative length of the shell are investigated. Then, the application areas of each case based on the computed results are figured out when using these types of structures in engineering practice.


ABSTRACT: Bi-stable composite cylindrical shells have attracted many attentions due to their lightness, simple structure, high packaging efficiency, high specific strength and stiffness. However, the anti-symmetric cylindrical shell is susceptible to the effect of ambient temperature and humidity. In this paper, an analytical model of shell structure considering hydrothermal effect was built, and its strain energy expressions were derived. Based on the minimum energy principle, the effects of moist and heat on the bi-stability of cylindrical shell structure were analyzed. In addition, the finite element model of the anti-symmetric cylindrical shell was established to simulate its stable configurations. This study could provide reference for the practical application of bi-stable structure.

Mohamed Harhash (1), Rose Rogin Gilbert (2), Stefan Hartmann (2) and Heinz Palkowski (1)
(1) Institute of Metallurgy, Clausthal University of Technology, Robert-Koch-Str. 42, 38678 Clausthal-Zellerfeld, Germany
(2) Institute of Applied Mechanics, Clausthal University of Technology, Adolph-Roemer-Str. 2a, 38678 Clausthal-Zellerfeld, Germany


ABSTRACT: In this article, we continue the investigations on the forming behavior of the steel/polymer/steel (SPS) sandwich composites as introduced in Part 1 [1]. In this paper, the main focus lies on bending conditions, validated by analytical and numerical methods. A wide variety of SPS layer configurations and thicknesses were tested under three-point bending conditions considering different bending angles (60°, 90° and 150°) and different punch radii (1.5, 3, 6 and 12 mm). The results are validated in terms of the bending forces, springback degree, strain field distribution, and thickness reduction, where a good matching between the numerical and analytical results with the experimental ones was reached.

Wang Xianfeng (1), Wang Huaqiao (2), Ma Cheng (1), Xiao Jun (1) and Li Liang (1)
(1) College of Material Science & Technology, Nanjing University of Aeronautics and Astronautics, China
(2) School of Mechanical Science & Engineering, Huazhong University of Science and Technology, China

ABSTRACT: Firstly, based on modal experiment, this paper analyses composite fiber curve laminates, which includes [<0115>1],[<15130>1],[<3045>1],[<45160>1], [<60175>1], [<75190>1], and then gets damping ratio of each laminated plate. After analysis, the results showed that the curve of fiber layer for <3045> composite
laminated plate damping ratio is the maximum, however, the curve of fiber layer for $<60|75>$ composite laminated plate damping ratio is the maximum. Secondly, the simple harmonic test of laminated plates with curved layers was carried out. Those plates includes $[0/45<0|15>/-45]$, $[0/45<15|30>/-45]$, $[0/45<30|45>/-45]$, $[0/45<45|60>/-45]$, $[0/45<60|75>/-45]$, $[0/45<75|90>/-45]$. It is easy to get the acceleration response maps of each laminated plate. The above simple harmonic test results showed that larger the damping ratio, the better the damping effect and the smaller the amplitude of acceleration. The amplitude of acceleration changes inversely with the change of damping ratio. Finally, the conclusion is that the laminated plate with the best vibration damping effect is $[<30|45>]$, and the laminated plate with the worst vibration damping effect is $[<60|75>]$. 

F. Moleiro (1), E. Carrera (2), A.J.M. Ferreira (3) and J.N. Reddy (4)
(1) LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
(2) Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
(3) INEGI, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
(4) Texas A&M University, College Station, TX 77483-3123, USA

ABSTRACT: This work addresses the modelling and analysis of multilayered plates with embedded functionally graded material (FGM) layer(s) under hygro-thermo-mechanical loadings. The hygroscopic, thermal and mechanical problems are all solved simultaneously using a new layerwise mixed model based on least-squares formulation with multi-field independent variables, namely, displacements, temperature, moisture, transverse stresses, transverse heat flux, transverse moisture flux, in-plane strains and in-plane components of both thermal and moisture gradients. This mixed formulation ensures that interlaminar Co continuity requirements, where the material properties may actually change, are fully fulfilled a priori. An added feature is included to fully describe the FGM layer z-continuous effective properties through-thickness, using any homogenization method, by applying a high-order z-expansion to its effective properties, similarly to finite element approximations. The numerical results demonstrate the effects of hygrothermal environments in the analysis of distinct multilayered plates with embedded FGM layers, considering different side-to-thickness ratios, under a series of hygro-thermo-mechanical loadings. The rule of mixtures is used to estimate the FGM layer effective properties, including different material gradation profiles. Three-dimensional (3D) approximate solutions corroborate this model’s capability to predict accurately a quasi-3D hygro-thermo-mechanical description of the through-thickness distributions of displacements and stresses, temperature and heat flux, moisture and moisture flux.

L. Sinha (1), S.S. Mishra (1), A.N. Nayak (1) and S.K. Sahu (2)
(1) Department of Civil Engineering, Veer Surendra Sai University of Technology, Burla-768018, Sambalpur, Odisha, India
(2) Department of Civil Engineering, National Institute of Technology, Rourkela 769008, Odisha, India

ABSTRACT: This investigation deals with the numerical and experimental study on the free vibration of woven glass fibre laminated composite stiffened plates. Thirty-four stiffened plates fabricated from woven glass fibre and binder (epoxy and hardener) by varying the parameters, such as numbers, types and orientation of stiffeners; depth of stiffener to thickness of plate ratio; and aspect ratio and boundary conditions of plates; are tested in FFT analyser to obtain their natural frequencies. A finite element model is used for vibration of laminated composite stiffened plates for validation of the experimental results. The experimental and numerical results are compared, which shows a very good agreement between them. From this study, it is observed that the above-mentioned parameters significantly influence the fundamental frequency. Since, the experimental investigation on laminated composite stiffened plates is scanty; this study can be considered as a reference for the future work.
Chaofeng Li, Peiyong Li, Zixuan Zhang and Bangchun Wen (School of Mechanical Engineering and Automation, Northeastern University, 110819 Shenyang, China), “Optimal locations of discontinuous piezoelectric laminated cylindrical shell with point supported elastic boundary conditions for vibration control”, Composite Structures, Vol. 233, Article 111575, 1 February 2020, https://doi.org/10.1016/j.compstruct.2019.111575

ABSTRACT: In this paper, the vibration control of discontinuous piezoelectric laminated shell with point supported elastic boundary conditions are investigated, and the location of piezoelectric layer are optimized. The point supported boundary condition are simulated by using artificial springs. The position with the piezoelectric layer are considered to be a laminated shell, and the position without the piezoelectric layer are regarded as a thin-walled cylindrical shell. The strain and curvature expressions of the cylindrical shell are obtained by the first-order shear shell theory, and the Chebyshev polynomial is used as the admissible displacement functions. Then, the differential equation of coupling motion of piezoelectric laminated cylindrical shells is established by using Lagrange equation, and the negative velocity feedback control is used as the control strategy. The Newmark method is used to obtain the response curves. The accuracy of the model are verified by comparing with the ANSYS results. For better vibration control, the optimal locations of the piezoelectric layer are obtained by using the Multi-Objective Particle Swarm Optimization algorithm based on the crowding distance. Finally, the optimization results and the vibration control of the piezoelectric layer are verified by analyzing the radial displacement response of the cylindrical shell.


ABSTRACT: The asymptotic method for spherical shells at large deflections was developed in the case of composite shell subject to external pressure. Reissner’s equations describing axially symmetric deformation of deep shells with arbitrary deflections and rotation angles were considered as initial ones. They were significantly simplified and asymptotic formulae for deformation energy, external pressure and stresses depending on deformation amplitude were obtained. The energy barrier criterion was applied for the composite shell to estimate the shell metastability. Formula for design critical buckling pressure was derived for composite shells. It improves the significantly more conservative NASA SP-8032 recommendations. The full inversion of the shell was studied as well. Asymptotic formulae were obtained for evaluation of stresses and load deflection dependencies. They can be useful for design of diaphragms for positive expulsion propellant spherical tanks of launch vehicles and for other applications.


ABSTRACT: This paper investigates the nonlinear stability of the functionally graded porous (FGP) cylinder reinforced by graphene nanofillers (GNF). Both the pores and GNF are distributed symmetrically in the cross-section of the cylinder. The FGP-GNF cylinder deforms radially-inward only due to the restraint of the tightly-fitting encasement. This radially-inward deformation can be expressed by a cosine function. Associated with the thin-walled shell algorithm and calculus of variation, the nonlinear equilibrium equations are obtained and solved to calculate the critical buckling pressure of the heated FGP-GNF cylinder. Later, numerical verification is accomplished by comparing the numerical and analytical buckling pressure. Furthermore, the present analytical and numerical results are compared with other closed-form predictions when the FGP-GNF cylinder reduces to a homogeneous one. Finally, the main attention is paid to the parameters that may affect the buckling pressure, including the thermal effect, porosity coefficient, weight fraction and geometric shape of the GNF, interface friction, and Young’s modulus of the encasement.

thermomechanical buckling of orthotropic composite plates”, Composite Structures, Vol. 233, Article 111622, 1
ABSTRACT: A closed-form solution is derived for the buckling of orthotropic composite plates under the
effect of thermal and mechanical loads. The plates are subjected to constant temperature increment and length
variation while the width expansion is constrained. The problem is formulated in terms of displacement
components, studied using classical plate theory in combination with classical lamination theory. An analytical
formula that relates critical temperatures to applied plate displacements is obtained. The buckling of heated,
fully restrained plates is also derived as a particular case. Examples of plates made of different materials and
lay-ups are presented in graphical form, and are verified by finite element analysis. The obtained formula can be
used during initial design, for sensitivity analysis and also for obtaining desired buckling shapes.

Marco Gherlone (1), Daniele Versino (2) and Vincenzo Zarra (1)
(1) Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24,
10129 Torino, Italy
(2) Theoretical Division T-3, Los Alamos National Laboratory, Mail Stop B216, Los Alamos, NM 87545, USA
“Multilayered triangular and quadrilateral flat shell elements based on the Refined Zigzag Theory”, Composite
ABSTRACT: The paper presents a class of C-continuous, flat shell elements based on the Refined Zigzag
Theory (RZT) for the analysis of multilayered and curved composite and sandwich structures. The use of the
interdependent interpolation strategy allows eliminating the shear-locking phenomenon and introducing the
drilling rotation necessary to complete the set of classical nodal degrees of freedom (three displacements and
two rotations). Additional kinematic variables are present in RZT, the zigzag rotations around the in-plane
axes that measure the normal distortion typical of multilayered structures. An additional “drilling” zigzag
rotation is therefore included among the nodal degrees of freedom in order to properly model curved and built-
up structures. A stabilization procedure is adopted to suppress spurious zero-energy modes. A three-node
triangular and a four-node quadrilateral flat shell element are formulated with 9 degrees of freedom per node.
Example problems involving flat and curved multilayered structures are presented and discussed in order to
assess the accuracy and convergence properties of the presented elements. Both static response predictions and
free vibrations analyses are considered and the comparison is made with analytic RZT solutions, high-fidelity
3D finite element models and FSDT-based flat shell elements.

Guohua Zhu, Qiang Yu, Xuan Zhao, Lulu Wei and Hao Chen (School of Automobile, Chang’an University,
Xi’an 710064, China), “Energy-absorbing mechanisms and crashworthiness design of CFRP multi-cell
structures”, Composite Structures, Vol. 233, Article 111631, 1 February 2020,
https://doi.org/10.1016/j.compstruct.2019.111631
ABSTRACT: This study aims to investigate crashworthiness and energy-absorbing capacity of CFRP multi-cell
structures under the quasi-static axial loading. In the present study, CFRP single-cell and multi-cell tubes are
manufactured, and the same overall dimensions and mass for all specimens are guaranteed through allocating
different thickness of each side. The crushing process and energy-absorbing capacity of all specimens are
experimentally investigated under the quasi-static axial crushing load. According to the experimental results, it
is known that the single-cell tube develops unstable local buckling mode, and the multi-cell tubes with two
configurations crush progressively. Total energy absorption of the multi-cell tubes are almost 69% higher than
that of the single-cell tube. Subsequently, numerical simulations are further conducted to provide additional
insights into the underlying energy-absorbing mechanisms of the multi-cell tubes. The numerical results
indicate that intra-laminar energy is the primary energy-absorbing mechanism for all configurations, and the
energy absorbed by each part in the multi-cell tubes are much higher than the corresponding part in the single-
cell tube. Based on the validated numerical models, the influences of wall thickness and cells number (n) on
crashworthiness characteristics of multi-cell tubes are further investigated by performing a comparative
analysis. It is found that the energy-absorbing capacity is slightly increased with raising cells number, and
energy-absorbing capacity gradually increases with increasing layer number of inner cross beam. Finally, the
CFRP multi-cell tube with $n = 3$ is further optimized, and as a result SEA is improved by 4.68% from the initial
design. This study is expected to provide guideline for crashworthiness design of CFRP multi-cell structures.
ABSTRACT: In this paper, a concurrent multi-scale optimization framework is established for hybrid composite plates and shells, where fiber volume, fiber orientation and stacking sequence can be optimized simultaneously. Firstly, a finite element model of shell structure that contains patches is established. Then, the candidate material set of hybrid composites is calculated and assembled by different combinations of fiber volume, fiber orientation and stacking sequence at the material and laminate scales. Furthermore, the Discrete Material Optimization (DMO) method is employed to perform the concurrent multi-scale optimization. Two illustrative examples are used to verify the effectiveness of the proposed optimization framework, including a simple example of a hybrid composite plate and a complex engineering example of a double serpentine nozzle. In comparison to optimal results by the traditional constant-stiffness design method, the optimal results of the proposed framework achieve significant 19.8% and 14.0% improvements in the fundamental frequency under the constraint of material cost, respectively. It can be concluded that the proposed concurrent multi-scale optimization framework has huge potential in adaptive stiffness tailoring for hybrid composite plates and shells with complex multi-scale design variables, which can make full use of hybrid composite materials to improve the structural performance against vibration while maintaining the low material cost.


ABSTRACT: In the literature dealing with the stability of time-periodic structures, Bolotin’s method is widely used for generating the approximate stability charts. Further, increasing the order of approximation in Bolotin’s approach requires solving several eigenvalue problems and may not lead to the rapid convergence of stability charts. Floquet theory can be used to calculate accurate stability charts for time-periodic systems. In Floquet theory, a Floquet transition matrix (FTM) is computed, the dominant eigenvalue of the FTM determine the stability of the time-periodic system. For a large degree of freedom systems like finite element models of VAT panels, the calculation of FTM becomes computationally expensive. However, an implicit Floquet analysis can significantly reduce the computational load. In this technique, the dominant eigenvalue of the FTM is computed without calculating the full FTM matrix. In this work, the stability regions obtained from the implicit Floquet analysis are compared with the results from Bolotin’s approach and verified using the time response of the panel obtained from numerical integration. Also, unlike Bolotin’s method, Floquet analysis provides information about the damping present in different areas of stability charts and the nature of bifurcation through which the stability is lost.

Cong Gao (1), Fu zhen Pang (1), Hai chao Li (1) and Lei Li (2)
(1) College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, PR China
(2) Department of Naval Architecture, Ocean & Marine Engineering, University of Strathclyde, Glasgow, UK

ABSTRACT: Based on Ritz method, the vibration approximate solutions of uniform and stepped functionally graded (FG) spherical cap are carried out in this paper. The first-order shear deformation theory (FSDT) is used to derive energy expression. The selections of displacement functions are based on domain decomposition approach, in which the unified Jacobi polynomials are introduced to represent the displacement functions component along axial direction. In addition, the standard Fourier series still denote the displacement functions component along circumferential direction. The various boundary conditions are simulated by applying spring stiffness method. Then the Ritz method is employed to obtain the final results. The solutions of the same condition are compared with those obtained by finite element method (FEM) and published literatures to validate the present method. The results exhibit that the current approach has the advantages of high solution
accuracy and fast convergence. On this basis, the numerical results concerning the effects of geometric parameters and boundary conditions on the vibration responses of the structure are also considered.

Lucie Culliford (1), Rizwan Saeed Choudhry (2), Richard Butler (1) and Andrew Rhead (1)
(1) Materials and Structures Research Centre, Department of Mechanical Engineering, University of Bath, Bath, UK
(2) Department of Mechanical Engineering and Built Environment, College of Engineering, University of Derby, Derby, UK
ABSTRACT: Continuous variation of stiffness across flat plates has been shown, theoretically, to improve buckling performance by up to 60%. However, steered fibre manufacturing methods cannot achieve the minimum radius of curvature required for improvement whilst maintaining a high deposition rate. An alternative concept, Discrete Stiffness Tailoring (DST), which varies stiffness within a ply through discrete changes of angle, is compatible with high rate deposition methods such as Advanced Tape Laying. Through the simple example of redistribution of the material in a quasi-isotropic [±45/90/0]_2S laminate whilst maintaining ply percentages, DST is shown both experimentally and theoretically to improve buckling stress by at least 15% with no indication of failure in regions of discrete angle change (seams). However, the reduced tensile strength of seams obtained by virtual and experimental testing means that increased buckling performance in the principle load direction needs to be balanced against loss of transverse strength.

S.Q. Zhang (1,2), Y.S. Gao (1), G.Z. Zhao (2), Y.J. Yu (1), M. Chen (3) and X.F. Wang (1)
(1) School of Mechatronic Engineering and Automation, Shanghai University, Shanghai 200444, PR China
(2) State Key Laboratory of Structural Analysis for Industrial Equipment, Dalian University of Technology, PR China
(3) Department of Industrial Design, Xi’an Jiaotong – Liverpool University, Suzhou 215123, PR China
ABSTRACT: The paper develops a geometrically nonlinear finite element model with large rotation based on the first-order shear deformation (FOSD) hypothesis for static and dynamic analyses of piezoelectric integrated carbon nanotube reinforced functionally graded (P-CNT-FG) composite structures. A constant electric field distribution through the thickness of plate is considered. An eight-node quadrilateral plate element with five mechanical degrees of freedom (DOFs) and one electric degree of freedom is developed for finite element analysis. Four typical forms of CNT distributions are included in the model, namely uniform, V-shaped, O-shaped, and X-shaped distributions. The nonlinear model considers fully geometrically nonlinear strain-displacement relations and large rotations of the shell direction of plate. Using the Hamilton’s principle, a nonlinear dynamic model including dynamic and sensory equations is obtained. The proposed nonlinear model is validated by a frequency analysis of a simply supported P-CNT-FG composite plate. Furthermore, the effects of various parameters on the static and dynamic behavior are investigated, e.g. CNT-reinforcement orientation, CNT distribution, the number of laminate layers and volume fraction.

Chien H. Thai (1,2), A.J.M. Ferreira (3), T.D. Tran (4) and P. Phung-Van (5)
(1) Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(2) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(3) Departamento de Engenharia Mecanica, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
(4) Faculty of Construction, Ho Chi Minh City Open University, Ho Chi Minh City, Viet Nam
(5) Faculty of Civil Engineering, Ho Chi Minh City University of Technology (HUTECH), Ho Chi Minh City, Viet Nam
ABSTRACT: The paper presents a size-dependent model based on the NURBS basis functions integrated with quasi three-dimensional (quasi-3D) shear deformation theory and the modified couple stress theory (MCST) for free vibration and buckling analyses of multilayer functionally graded graphene platelet-reinforced composite (FG GPLRC) microplates. The quasi-3D shear deformation theory, which only includes four unknown variables, considers the bending, shear deformations and thickness stretching effect. To consider length scale effect, a material length scale parameter (MLSP) is added into the classical continuum theory. A rule of mixture is used to compute the effective density mass and Poisson's ratio, while the Young's modulus is determined according to the Halpin–Tsai model. The uniform and functionally graded distributions of graphene platelets (GPLs) are considered. The discretize governing equations are obtained by applying the principle of virtual work. Numerical validations are performed to evaluate effects of geometrical parameters, boundary conditions, material length scale parameter and weight fraction on natural frequencies and buckling load of the microplates. As shown in numerical results, it can be concluded that a rise of natural frequency and buckling load of multilayer FG GPLRC microplates is observed by using the MCST. Besides, the classical quasi-3D model is recovered when MLSP equals to zero.


ABSTRACT: This work presents the main aspects that should be taken into account to design biaxial experiments with cruciform specimens in the presence of compressive loading, applied on the arms of the sample by means of compression plates. The global buckling of the cruciform specimen and the local instability of the rectangular-shaped central region submitted to biaxial loading are described numerically and analytically. The analytical expressions are derived using the buckling effective lengths technique for calculating the bifurcation stress in simply supported and clamped rectangular thin–plates made of isotropic materials and ±45° angle-ply CFRP laminates. Furthermore, the influence of the arms-to-centre thickness-ratio on the compressive load that destabilises the cruciform geometry is reviewed numerically. Finally, the use of an anti-buckling device is numerically proved to reduce the risk of instabilities and to assure more reliable results. The device consists of a cross-shaped fixture that constrains the out-of-plane displacements and an optional L-shaped support in order to force the alignment of the fixture, the sample and the testing machine.


ABSTRACT: The in-plane elastic behavior of honeycombs under large deformations is analyzed based on the analytical and numerical approaches. The Reissner beam theory is used considering the axial, bending and shearing deformation of the inclined honeycomb wall. The influence of the tensile deformation of the node between the inclined and vertical walls on the effective elastic properties of the honeycombs is also considered. The effective in-plane elastic properties of the honeycombs change as the increase of the strain. The deformation of the node area has a significant effect on the effective elastic properties of the thick-walled honeycombs in the ribbon direction. The proposed method is suitable for predicting the in-plane elastic properties of thin/thick-walled honeycombs with different geometric parameters under small or large deformation.

Matej Vesenjak (1), Isabel Duarte (2), Joachim Baumeister (3), Hartmut Göhler (4), Lovre Krstulovic-Opara (5) and Žoran Ren (1)
(1) Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia
(2) Department of Mechanical Engineering, Centre for Mechanical Technology and Automation, TEMA, University of Aveiro, Aveiro, Portugal
(3) Fraunhofer Institute for Manufacturing Technology and Advanced Materials – IFAM, Bremen, Germany
(4) Fraunhofer Institute for Manufacturing Technology and Advanced Materials – IFAM, Dresden, Germany
ABSTRACT: A comprehensive bending performance and energy absorption capability of aluminium alloy tubes filled with different cost-effective cellular metal cores were experimentally evaluated for the first time. The following cellular metal cores were evaluated: i) Advanced Pore Morphology (APM) foam, ii) hybrid APM foam and iii) Metallic Hollow Sphere Structures (MHSS). The results have been compared also with the performance of aluminium alloy tubes filled with (ex-situ and in-situ) closed-cell aluminium alloy foam. The three-point bending tests have been performed at two loading rates (quasi-static and dynamic) and supported by infrared thermography to evaluate the deformation mechanism, damage progress and failure modes. A thorough heat treatment sensitivity (due to the fabrication procedures of composite structures) study on the aluminium tubes has been performed as well. The results show that a reliable and predictable mechanical behaviour and failure can be achieved with proper combination of tubes and cellular metal core. A low scatter of bending properties and energy absorption capability has been observed. The hybrid APM and the ex-situ foam filled tubes achieved the highest peak load. However, they also exhibit a rapid load drop and abrupt failure once the structure has reached the peak load. The APM, MHSS and in-situ foam filled tubes show more ductile behaviour with a predictable failure mode.

Yasin Heydarpour (1), Parviz Malekzadeh (1), Rossana Dimitri (2) and Francesco Tornabene (2)
(1) Department of Mechanical Engineering, School of Engineering, Persian Gulf University, Bushehr 7516913798, Iran
(2) Department of Innovation Engineering, University of Salento, Via per Monteroni, 73100 Lecce, Italy

ABSTRACT: This work investigates the effect of a thermal shock loading on the rotating multilayer functionally graded graphene platelets reinforced composite (FG-GPLRC) truncated conical shells. The problem is tackled numerically according to the Lord-Shulman (L-S) thermoelastic theory. The multilayer FG-GPLRC conical shells are decomposed into a set of co-axial nanocomposite shell layers, to capture accurately the variation of the thermoelastic field variables due to the layerwise variation of the material properties. The transformed differential quadrature method (TDQM) and a multi-step time integration scheme based on a non-uniform rational B-spline (NURBS) interpolation is applied to discretize the thermoelastic equations together with the related boundary conditions and compatibility conditions at the interface of two neighboring layers. After a preliminary validation of the approach, a parametric study aims at investigating the effect of different graphene platelets (GPLs) distribution patterns, GPLs weight fraction and dimension ratios, as well as the effect of the shell angular velocity and geometry parameters on the thermoelastic response of the system. It is verified that the addition of a small amount of GPLs in the polymer matrix increases significantly the heat wave speed, affects the thermoelastic field variables, and decreases the period of oscillatory portions of the mechanical field variables.

Krzysztof Magnucki (1), Jerzy Lewinski (1) and Ewa Magnucka-Blandzi (2)
(1) Łukasiewicz Research Network – Institute of Rail Vehicles “TABOR”, ul. Warszawska 181, 61-055 Poznan, Poland
(2) Institute Mathematics Poznan University of Technology, ul. Piotrowo 3A, 60-965 Poznan, Poland

ABSTRACT: The subject of the paper are two-layer beams with various mechanical properties, thicknesses and widths of the layers. The original noninear hypothesis-theory of planar cross section is developed. Based on the principle of stationary potential energy three differential equations of equilibrium are obtained. The system of the equations is analytically solved and the deflections and normal and shear stresses of example beams are...
calculated. The analytical calculation results are compared with numerical solutions obtained with FEM (SolidWorks). These results are presented in Tables and Figures.

ABSTRACT: In this study, we present continuum mechanics based beam elements for linear and nonlinear analyses of multi-layered composite beams with interlayer slips. Nonlinear kinematics of multi-layered beams allowing interlayer slips and the finite element formulation for nonlinear incremental analysis are derived. An important feature of the proposed beam element is an advanced modeling capability that originates from individual modeling of each beam layer using cross-sectional elements and layer degrees of freedom, which are embedded in the beam formulation. Complicated layered beam geometries including arbitrary numbers of layers and interlayers, varying and composite cross-sections, and eccentricities can be easily modeled without additional interface elements or constraints. Further, the proposed beam finite element is successfully applicable for predicting geometric and material nonlinear behaviors of the multi-layered beams including nonlinear load-slip relations at interlayers. The superb performance and predictive capability of the proposed beam element are demonstrated through several representative numerical examples.

Han-Gyu Kim (1) and Richard Wiebe (2)
(1) Department of Aeronautics and Astronautics, University of Washington, Seattle, WA 98195, USA
(2) Department of Civil and Environmental Engineering, University of Washington, Seattle, WA 98195, USA
ABSTRACT: The composite structures of super-/hyper-sonic vehicles can experience thermal or mechanical buckling due to aero-thermal-structural coupling. These buckled structures are susceptible to dynamic snap-through, which could possibly accelerate damage progression. This paper is part of a long-term project investigating structural dynamics and damage progression for composite structures under these extreme environments. The work herein focuses on analyzing the stress histories of thin laminated composite plates under various combinations of structural and forcing conditions including buckling and snap-through. A geometrically nonlinear model is developed in-house using MATLAB by incorporating the first-order shear deformation theory, von Kármán strains, and enhanced assumed strain elements. The global dynamic behaviors of this model in the post-buckled regime are first validated using experimental and numerical data. The impacts of buckling and snap-through on the internal stress states are then investigated. The results reveal that composite structures can experience significant stress amplification under such extreme environments. The potential impact of this phenomenon on fatigue is also discussed.

ABSTRACT: This paper aims to investigate the bending collapse and crashworthiness of the quadruple-cell Al/CFRP (aluminum/carbon fiber reinforced plastic) hybrid tubes under quasi-static and dynamic loading. Three-point bending tests were first conducted for pure Al tubes and Al/CFRP hybrid tubes with different wrapping angles. Experimental results showed that the enhancement effect of CFRP wrapping on energy absorption efficiency of hybrid structures was affected by several factors. Numerical analyses were then carried out by ABAQUS/Explicit, and good agreements were achieved between the simulation and experimental results. The validated numerical model was further employed to investigate the effects of the partial wrapping, wrapping angle and ply thickness on the crashworthiness of Al/CFRP hybrid tubes. Results showed that the increase of wrapping angle and ply thickness could enhance the bending resistance and delay or avoid the fracture of CFRP in the bottom flange. The Al/CFRP tube with appropriate partial wrapping could achieve 7.9% higher specific energy absorption (SEA) than the entirely wrapped counterpart. In addition, the sequential
response surface method (SRSM) was adopted to optimize the structural parameters and to further improve the crashworthiness of the hybrid tubes. The SEA of the Al/CFRP tube was increased by up to 30.3% by the RSM optimization.


ABSTRACT: In the context of variational differential quadrature finite element method (VDQFEM), the vibration and buckling of functionally graded graphene platelet reinforced composite (FG-GPLRC) plates with cutout are investigated in this study. The modified Halpin-Tsai model is used to compute the effective mechanical properties of nanocomposite plate. The mixed-type formulation of the higher-order shear deformation plate theory (HSDPT) is developed based on the Lagrange multiplier to model the mechanical behavior of FG-GPLRC plates. The variational-based differential quadrature element is developed to numerically solve the problem. Various comparative results are provided to check the validity of the proposed approach. Additionally, multiple numerical results are represented to examine the vibration and buckling behaviors of FG-GPLRC plates.

Tianyu Zhou (1,6), Yuansheng Cheng (1,2,3), Yanjie Zhao (4,5), Lunping Zhang (4), Haikun Wang (4,5), Ganchao Chen (1), Jun Liu (1,2,3) and Pan Zhang (1,2,3)
(1) School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
(2) Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai 200240, China
(3) Hubei Key Laboratory of Naval Architecture and Ocean Engineering Hydrodynamic, Wuhan 430074, China
(4) China Ship Scientific Research Center, Wuxi 214082, China
(5) Maritime Defense Technologies Innovation Center, Wuxi 214082, China
(6) Institute of Advanced Manufacturing Engineering, Chongqing University of Posts and Telecommunications, Chongqing 400065, China

ABSTRACT: This paper presents a blast experiment to investigate the performance of sandwich panels with metallic face sheets and ungraded/graded polyvinyl chloride (PVC) foam cores subjected to contact underwater explosion. The deformation and failure modes of the sandwich panels were identified and classified. The protective effect of sandwich panel was also evaluated by setting a witness plate. Particular attention was concentrated on the effects of the charge weight, face-sheet configuration, core height, and core gradation. Experimental results reveal that the panel front face suffered severe petalling failure and generated structural fragments; the PVC foam experienced spider-web-like crack failure and perforation failure; while the back face failed into petalling mode or plastic deformation without fracture. The increase of charge weight worsened the panel failure level as expected, yet did not affect the failure mechanisms. Adopting a thick core would benefit sandwich panel in terms of both the energy absorption enhancement and the damage level reduction. The panel system with a thick back face and a thin front face performed better in protecting the witness plate than the one with reverse configuration. Moreover, through designing the graded core with high/middle/low configuration, the panel performance could be further improved.

Liang Li (1,2), Wei-Hsin Liao (1), Dingguo Zhang (2) and Yongbin Guo (2)
(1) Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Shatin, NT, Hong Kong, China
(2) School of Science, Nanjing University of Science and Technology, Nanjing 210094, China

ABSTRACT: A comprehensive dynamic model for a free moving thin plate with fully covered active constrained layer damping (ACLD) treatment is developed. The discrete equations of motion of the moving
ACLD plate are derived by using Ritz method and Lagrange’s equations. Free vibration analysis of the composite plate undergoing large rotational or translational motions are performed by solving the complex modal eigenvalue problem of the system in open-loop and closed-loop cases. Interesting frequency curve veering, mode shape switching as well as damping ratio jumping phenomena are observed and discussed for the plate rotating around two different axes. It is demonstrated that the flexible plate undergoing rigid motions can not only generate dynamic stiffening effect but also dynamic softening effect. Effects of parameters such as angular velocity, acceleration, and control gain on the modal and damping characteristics of the ACLD plate are also investigated.


ABSTRACT: The current paper deals with the impact of geometrical and material parameters of the laminated conical shell on the load carrying capacity based on the finite element analysis. Various parameters were taken into account, that is, stiffness ratio, cone angle or shell height. Moreover, the mechanical behavior of conical shell having the concave and convex imperfections has been studied. Presented results confirmed the reduction of the buckling load with an increase of the cone angle connected with the rise in the base of the cone. The originality in this area is determining the approximately constant optimal initial fiber orientation even with the assumption of variable thickness and fiber orientation. Moreover, the results evidently showed that for a high value of cone angle the comparable value of the buckling load was obtained for a relatively wide range of the fiber orientations. The detailed analysis of the buckling modes for the particular structure is crucial from the optimization point of view.

References listed at the end of the paper:
3 P. Seide, Axisymmetrical buckling of circular cones under axial compression, J Appl Mech, 23 (1956), pp. 625-628
4 J. Arboez, Buckling of conical shells under axial compression, NASA, CR-1162 (1968.), pp. 1-52
9 J. Blachut, A. Muc, J. Ryś, Plastic buckling of cones subjected to axial compression and external pressure, J Pressure Vessel Technol, 135 (2013), Article 011205
10 J. Blachut, On plastic–plastic buckling of cones, Thin-Walled Struct, 49 (2011), pp. 45-52
16 Y. Goldfeld, J. Arboez, Buckling of laminated conical shells given the variations of the stiffness coefficients, AIAA J, 42 (2004), pp. 642-649
17 Y. Goldfeld, J. Arboez, A. Rothwell, Design and optimization of laminated conical shells for buckling, Thin-Walled Struct, 43 (2005), pp. 107-133
18 M.Z. Kabir, A.R. Shirazi, Optimum design of filament wound laminated conical shells for buckling using the penalty function, Iranian Aerospace Society, 5 (2008), pp. 113-121
19 F. Shadmeiri, S.V. Hoa, M. Hojjati, Buckling of conical composite shells, Compos Struct, 94 (2012), pp. 787-792
A parametric study: High performance double skin tubular column using rubberised concrete. After a comprehensive parametric investigation, this study summarized that RuCFDST columns can be considered as high performance concrete. The rubberised concrete specimens showed an improvement in the axial displacement at peak load and they indicated the effects of outer tube diameter to thickness ratio, outer tube yield strength, hollow section ratio, length to diameter ratio and outer tube to inner tube thickness ratio of columns with 0%, 15% and 30% rubber contents. The rubberised concrete specimens showed an improvement in the axial displacement at peak load and they were more ductile in the post-peak region compared to those with normal concrete. After a comprehensive parametric investigation, this study summarized that RuCFDST columns can be considered as high performance concrete.
structural columns for critical infrastructure applications in seismic prone areas and they can be specifically optimised for their ductile characteristics.

Chunlei Li, Qiang Han and Zhan Wang (School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, Guangdong Province 510640, PR China), “Semi-analytical isogeometric analysis for wrinkling instability of stiff films bonded to cylindrical modulus-graded compliant substrates”, Composite Structures, Vol. 235, Article 111787, 1 March 2020, https://doi.org/10.1016/j.compstruct.2019.111787
ABSTRACT: Surface wrinkles in film-substrate structures have received considerable attention in science and engineering. Understanding the wrinkling instability is the key to envisioned applications of these structures. In this paper, based on Floquet’s principle, an explicit semi-analytical isogeometric analysis method (SIGA) is proposed for predicting wrinkling instability of a stiff film on cylindrical graded substrate. In total Lagrangian framework, the wrinkle configuration is considered as the stressed state relative to the stress-free state. The linearized variational formulation with respect to stress (wrinkle) is derived from the principle of minimum potential energy and parameterized by non-uniform rational basis splines (NURBS). By using the SIGA method, only the radial direction of layered structure is parameterized and the dimension of model is reduced to the one-dimensional. Meanwhile, the analysis of wrinkling instability can be performed by a generalized eigenvalue problem, which explicitly determines critical wrinkling strain and wavelength. Compared to the finite element method, the proposed approach demonstrates distinct superior in computational efficiency and accuracy. Besides, two typical functions are employed to describe material distribution of inhomogeneous substrate. The critical conditions for wrinkling instability of the film-substrate system are computed and the influences of various geometric and material parameters are discussed in detail.

ABSTRACT: Through experiments and numerical simulation, the dynamic mechanical behaviors and mechanical properties of Nomex honeycomb sandwich panels under impact loads were investigated. On this basis, the effects of the density of honeycomb cores, face-sheet thickness, punch diameter, and impact energy on impact loads and failure modes were explored. The predicted contact time, impact load, and failure mode were consistent with the test results. Results showed that face-sheet thickness exhibited an extremely significant influence on the impact resistance of Nomex honeycomb sandwich panels; the density of honeycomb cores exerted a certain effect on the structural stiffness; the punch diameter and impact energy also influenced the mechanical properties and failure modes of sandwich panels.

J.J. Mao (1), H.M. Lu (1), W. Zhang (1) and S.K. Lai (2)
(1) Beijing Key Laboratory of Nonlinear Vibrations and Strength of Mechanical Structures, College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, PR China
(2) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, PR China
ABSTRACT: This paper investigates the small-scale effect on the linear and nonlinear vibrations of the graphene nanoplatelet (GNPL) reinforced functionally gradient piezoelectric composite microplate based on the nonlocal constitutive relation and von Karman geometric nonlinearity. The GNPL reinforced functionally gradient piezoelectric composite microplate is resting on the Winkler elastic foundation and is subjected to an external electric potential. The parallel model of Halpin Tsai is used to compute the effective Young’s modulus of the GNPL reinforced functionally gradient piezoelectric composite microplate. The Poisson’s ratio, mass density and piezoelectric properties of the GNPL reinforced functionally gradient piezoelectric composite microplate are calculated by using the rule of mixture. Hamilton’s principle is adopted to obtain the higher-order nonlinear partial differential governing equations of motion for the GNPL reinforced functionally gradient piezoelectric composite microplate. The partial differential governing equations of motion are reduced to a
proposed auxetic lattice reinforced polyethylene composite and studied the influence of lattice angle on homogenized effective properties of the core. Compared to non-auxetic sandwich structures, the properties obtained at the lower scales are used in a macroscale progressive damage analysis and impact simulations of semi-auxetic braided composite. The results obtained have been compared with experimental data from the literature for validation. The sandwich core holds further scope for tailoring its architecture that can enhance the sandwich performance. The high-velocity steel ball impact response of the sandwich structure with two types of auxetic 3D re-entrant lattice core have been simulated and compared with a non-auxetic core. Parametric studies have been performed at the mesoscale to study the influence of lattice angle on homogenized effective properties of the core. Compared to non-auxetic foam, proposed auxetic sandwich structures are lightweight, have better energy absorption and high stiffness values in the in-plane along with out-of-plane directions. A case study of trauma plate for the application of proposed auxetic lattice reinforced polyethylene composite in body armors is presented.

Rimen Jamatia (1,2) and Arghya Deb (3)
(1) Department of Civil Engineering, Indian Institute of Technology Jammu, J&K 181221, India
(2) Department of Civil Engineering, National Institute of Technology, Puducherry, Puducherry 609609, India
(3) Department of Civil Engineering, Indian Institute of Technology Kharagpur, West Bengal 721302, India

ABSTRACT: An analytical model is developed for fiber-reinforced polymer (FRP) confined hollow circular concrete columns subjected to axial compression to study the effect of cohesive stiffness on confining pressure. The results are corroborated using 3D finite element (FE) analysis. The FE model is used to study the effect of confining stiffness on the strength and mode of failure in hollow columns. For low confining pressures, quasi-brittle failure occurs due to shear banding in the concrete; whereas for confining pressures in excess of a threshold, the response is ductile. Strength and size effect in hollow columns are compared with solid columns with the same outer diameter, FRP thickness and material properties. It is seen that hollow columns have reduced strength and are more susceptible to a size effect than solid columns.

Pankaj S. Ghatage (1,2), Vishesh R. Kar (3) and P. Edwin Sudhagar (1)
(1) School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Vellore 632014, Tamilnadu, India
(2) Department of Automobile Engineering, Rajarambapu Institute of Technology, Rajaramnagar, Affiliated to Shivaji University, Kolhapur, Islampur 415414, Maharashtra, India
(3) Department of Mechanical Engineering, National Institute of Technology Jamshedpur, Jamshedpur 831014, Jharkhand, India


ABSTRACT: This study presents an exhaustive review on modelling and analysis of multi-directional graded (beam/plate/shell) structures. From the past few decades, a significant increase in publications and research activities are noticed in the field of functionally graded composite structures due to their high strength and stiffness, flexibility in design and greater features over conventional composites. However, most of the studies reported on functionally graded structures are confined to a unidirectional gradation of material constituents. Now, many applications are demanding functionally graded structures with multi-directional material properties in which material properties vary in two or more directions, to meet the multi-functional requirements. In this review article, various micromechanical material modelling for unidirectional and multi-directional graded materials are presented and an effort has been made to include research studies reported on multi-directional functionally graded beam, plate and shell structures with an emphasis on work published since 2000. In addition, on the basis of the reviewed literature, concluding remarks are presented to showcase the future directions in this research field.


ABSTRACT: In this study, the problem of vibration reduction in a cantilever beam under kinematic excitation is considered. Numerical studies and laboratory tests are performed on a composite beam with an embedded macro fibre composite actuator. Select methods of vibration reduction, that is, proportional (P), derivative (D), and PD controls, are presented. The properties of the control system are described using the first-order inertial term. The experimental results are used to identify the time constant and verify the proposed concept. Finally, the possibility of vibration control is demonstrated numerically using the finite element model.

Xiaoyu Zhang, Fei Xu, Yuyan Zang and Wei Feng (School of Aeronautics, Northwestern Polytechnical University, Xi’an, China), “Experimental and numerical investigation on damage behavior of honeycomb sandwich panel subjected to low-velocity impact”, Composite Structures, Vol. 236, Article 111882, 15 March 2020, https://doi.org/10.1016/j.compstruct.2020.111882

ABSTRACT: This paper presents the low-velocity impact behavior of sandwich panel with carbon fiber reinforced plastic (CFRP) composite facesheet and Nomex honeycomb core through experimental and numerical methods. Experiments were carried out on two thickness of honeycomb core at various impact energy levels. The dynamic response including contact force history and energy absorption as well as contact duration was recorded. The damage modes were obtained through non-destruction inspection (NDI) C-scan and microscopic observation. A refined three-dimensional finite element model combined with continuum damage mechanics (CDM) was developed with composite plies and detailed honeycomb core. Physically-based Puck’s
composite failure criteria and energy based progressive damage model were used to capture the intralaminar damage initiation and evolution, respectively. The interlaminar damage of facesheet and debonding of facesheet/core interface were predicted using cohesive element. The hexagonal honeycomb cells were characterized in FE model with an elasto-plastic constitutive model and damage criterion in detail during impact. The simulation results show good agreements with experiments and the model can be used to predict the low-velocity impact response and impact damage effectively. More detailed responses, such as internal damage details, damage modes and evolution, are observed and discussed with the numerical model proposed.

A. Moro (1), D. Filipovic (1), G. Kress (1) and M. Winkler (2)
(1) Laboratory of Composite Materials and Adaptive Structures, Department of Mechanical and Process Engineering, ETH Zürich, Tannenstr. 3, CH-8092 Zürich, Switzerland
(2) Faculty of Mechanical Engineering, Hochschule Ravensburg-Weingarten, University of Applied Sciences, Doggenriedstrasse, D-88250 Weingarten, Germany


ABSTRACT: The study considers a corrugated laminate with dimensions far larger than the length of one periodic unit cell and at regions where edge effects have decayed. Then, the linear elastic structural properties of the corrugated laminate are presented by a substitute plate matrix. Its entries are found by subjecting a unit cell model to the load cases which correspond to the entries of the plate deformation vector, and then calculating the reacting stress resultants. The enforced deformations are all states of generalized plane strain with respect to the span direction. A corrugation pattern consisting of circular segments and the assumption, that thin shell theory is valid for the modeling, facilitates finding of exact solutions even though the base laminate may exhibit all possible stiffness couplings. The exact interior solutions include displacements, plate deformations, stresses, and reaction forces from which the calculation of the substitute plate matrix follows naturally. The paper explains all derivations and gives results for a representative general laminate, studying the model limitations and illuminating on which mechanical effects are not naturally captured by thin shell theory. A parameter study on a non-symmetric cross-ply laminate is performed to identify the main effects caused by increasing corrugation amplitude. Rationales for the systematic deviations of thin-shell-theory from solid-volume-modeling predictions of some substitute-stiffness matrix entries are presented by using simplified analytical modeling.

Wei-Li Ma (1), Zi-Cheng Jiang (2), Kang-Yong Lee (3) and Xian-Fang Li (1)
(1) School of Civil Engineering, Central South University, Changsha 410075, PR China
(2) School of Resources and Safety Engineering, Central South University, Changsha 410075, PR China
(3) Department of Aerospace Engineering, San Diego State University, San Diego, CA 92182, United States


ABSTRACT: This paper presents a novel approach for analyzing transverse bending and vibration of functionally graded circular cylindrical tubes with radial nonhomogeneity. Different from the Euler-Bernoulli and Timoshenko theories of beams, a refined beam theory or third-order shear deformation beam theory for radially graded tubes is proposed, where warping, shear deformation and rotational moment of inertia of cross-section are all considered. The shear correction coefficient is not needed. Coupled governing equations for the deflection and rotation about the neutral axis of cross-section are derived from equilibrium equations, and then converted to a single fourth-order partial differential governing equation. The deflection and stress distribution for cantilever and simply-supported tubes are derived explicitly. The frequency equations for free flexural vibration of radially graded hollow cylinders with clamped-clamped, pinned-pinned, and clamped-free ends are obtained and the natural frequencies are calculated for different power-law gradients and various length/thicknesses ratios. The effects of radial gradient on the stress distribution and the natural frequencies are analyzed in detail.

ABSTRACT: Composite structures formed using thin-ply laminates are of interest to aerospace and other high-performance industries. This paper reviews recently published research into fibre reinforced polymer matrix composites formed using thin-ply (<100 μm thick) laminates. Due to their prominence in the literature, this review focuses on thin plies formed with carbon fibre tows. Research into the manufacture, microstructure, mechanical performance and implications for structural design are described. The benefits of thin plies compared with standard plies (~125 μm thick) are assessed, including flexibility in design, damage tolerance and potential for creating pseudo-ductile composite structures. Improvements to static and fatigue properties are discussed. The adverse effects of thin-ply polymer matrix composites are evaluated, including open-hole and notch sensitivity, as well as interlaminar fracture toughness. The underlying physical mechanisms responsible for the benefits and drawbacks of thin-ply composite laminates are described. One critical physical attribute of thin plies is found to be the relatively few number of fibres per ply, which allows for more variation in ply angle orientation compared with a laminate of the same thickness made with standard plies. Potential areas for further research are discussed, including processing techniques, joining, material hybrids, thermoplastics, durability, recyclability and applications to multifunctional composite structures.


ABSTRACT: Bendable metal-based composite sheets with a truncated dome core made of CFRTP (carbon fibre reinforced thermoplastics) were developed to expand the range of applications and improve the mechanical properties of sandwich structures. The newly proposed truncated dome core structure was composed of a periodic array of domes which were introduced into an initially flat CFRTP sheet through stamping. Theoretical analyses were conducted to determine the conditions required for successfully forming sandwich sheets into curved shapes. The flexural properties and formability of sandwich sheets were tested experimentally. The numerical simulation shows that the optimal relative density of the truncated dome core is 0.22. Experimental results of formability tests agree well with the theoretical predictions, which demonstrates the validity of the theoretical models. Sandwich sheets with both A2017P and SUS304 face sheets of a thickness of 0.5 mm can be bent without any failure at a bending radius of 60 mm.

Qian Zhang (1), Hui Xu (1), Xiaolong Jia, (2) Lei Zu (1), Shuo Cheng (1) and Huabi Wang (1)
(1) Anhui Province Key Lab of Aerospace Structural Parts Forming Technology and Equipment, Hefei University of Technology, Hefei 230009, China
(2) College of Materials Science and Engineering, Beijing University of Chemical Technology, Beijing 100029, China

ABSTRACT: The aim of this study is to propose methods for dome thickness distribution and the charge pressure of the liner for a 70 MPa type IV hydrogen storage vessel. The netting theory was employed to design the lay-up of the cylindrical section. For precise prediction of the dome thickness, a cubic spline function was utilized. Variable polar radii were used to reduce the fiber stacking and thickness accumulation near polar openings. To evaluate the designed lay-up, various failure criteria were applied so as to predict precisely the failure of composite layers in finite element analysis. In order to determine the most appropriate range of the internal pressure when filling hydrogen gas during filament winding process, the compressive pressure applied on the liner was calculated by taking into account the variety of winding tension, and the buckling and static analysis of the liner were carried out, respectively. The methods presented in this work provide a valuable reference for designing the type IV hydrogen storage vessels.

ABSTRACT: Functionally graded materials are well-known composite materials, characterized by a continuously varying mixture of materials’ phases, tailored to meet structures operating requirements while contributing to minimize abrupt stress transitions at dissimilar materials’ interfaces, as occur in composite laminates. Hence, designing a functionally graded material to comply with these objectives constitutes an important modelling tool to improve structures’ functionality. These graded composite materials present more commonly a mixture variation through the structures’ thickness direction. However, when dealing with thin structures this solution may present evident limitations, both from the manufacturing perspective as well as from the through-thickness distribution influence on the structure response. It is therefore important to explore other spatial mixture distributions’ possibilities.

To this purpose, the present work considers thin graded materials’ plates which constitution is defined by a set of different in-plane volume fraction distributions. The influence of these distributions on the free vibrations and dynamic instability of thin plates is assessed through a comprehensive set of parametric studies. The free vibration problem and the dynamic instability problem’s solutions are respectively obtained by Rayleigh-Ritz and Bolotin’s methods. As a complementary analysis contribution, image correlation studies are also developed for a set of fundamental mode shapes.

Michele Bacciocchi (1,2) and Angelo Marcello Tarantino (3)
(1) DICAM Department, University of Bologna, Bologna, Italy
(2) DESD Department, University of San Marino, San Marino
(3) DIEF Department, University of Modena and Reggio Emilia, Modena, Italy

ABSTRACT: The buckling analyses illustrated in this research aim to provide useful results for the design and application of sandwich plates with a honeycomb core and three-phase orthotropic skins, which are reinforced by both carbon nanotubes (CNTs) and straight oriented fibers. A multiscale approach is developed to this aim, which is based on the Eshelby-Mori-Tanaka scheme and the Hahn homogenization technique. The outcomes are presented in terms of critical buckling loads for different boundary conditions, lamination schemes, fiber orientation and mass fraction of CNTs, in order to prove that all these elements represent fundamental design parameters in the analysis, manufacturing and behavior of these sandwich plates. The theoretical framework is based on the Reissner-Mindlin theory for laminated plates and on the von Kármán hypothesis as far as the nonlinear terms are concerned. The kinematic model includes the Murakami’s function to deal with such peculiar mechanical configurations, which is required to capture the zig-zag effect due to the different mechanical properties of the core and the external skins. The numerical approach and the theoretical methodology are validated by means of the comparison with the experimental and the theoretical results available in the literature.

Zixiang Zhang (1), Airong Liu (1), Jie Yang (2), Yong-lin Pi (3), Yonghui Huang (1) Jiyang Fu (1)
(1) Guangzhou University-Tamkang University Joint Research Centre for Engineering Structure Disaster Prevention and Control, Guangzhou University, Guangzhou, China
(2) School of Engineering, RMIT University, PO Box 71, Bundoora, VIC 3083, Australia
(3) Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, The University of New South Wales, UNSW, Sydney, NSW, Australia

ABSTRACT: Nonlinear in-plane buckling behavior of fixed orthotropic composite arches under an arbitrary radial point load is investigated theoretically, numerically and experimentally in this paper. Analytical solutions that include the bending-stretching coupling effect are developed for both critical buckling load and nonlinear equilibrium path and are validated by the finite element model. A variable-speed displacement control loading system with automatic loading direction adjustment is designed and set up for the test to record the complete buckling evolution process. Comprehensive analytical and experimental results for the critical buckling load...
and nonlinear equilibrium path of the arches are presented in both tabular and graphical forms, followed by a parametric study with a particular focus on the influences of loading position, stacking sequence as well as the rise-span ratio on the buckling load. Research results indicate that the buckling mode of the composite arch is highly dependent on the modified slenderness ratio. Both buckling mode and the switching modified slenderness ratio are significantly influenced by the loading position. The buckling load is also highly sensitive to stacking sequence and decreases as the 90° lamina is placed far away from the mid-plane.


ABSTRACT: The applications of pultruded fiber reinforced polymer (PFRP) segmentation are increasing in construction due to features such as low weight, high fatigue resistance, corrosion resistance, thermal insulation and electrical insulation. In this paper, linear and nonlinear buckling behavior of the PFRP I-section beams are investigated. A total of 11 specimens are tested for studying their lateral-torsional buckling (LTB) behavior, with two types of I-shaped profiles in various heights and span lengths under pure bending with simply supported conditions. Numerical modeling is done in Abaqus finite element package by selecting the appropriate elements. An analytical response is obtained through the equation in the Eurocode 3 Regulation for each beam and this value is compared with experimental and numerical results. The experimental data are in a reasonable accordance with the numerical and analytical results. In addition, deviations of experimental results with the results from analytical and finite element analyses are less than 15%.


ABSTRACT: In this paper, an investigation on the postbuckling behavior of sandwich plates with functionally graded (FG) auxetic 3D lattice core is presented. Firstly, an auxetic 3D lattice metamaterial is designed and analyzed, of which all six effective Poisson’s ratios (EPRs) are negative, and the in-plane negative Poisson’s ratio (NPR) property can enhance the structural buckling capacity. For the first time, two symmetric FG configurations of the auxetic 3D lattice core through the plate thickness direction are proposed, and compared with the uniform distribution case. Two kinds of compressive postbuckling due to in-plane uni-axial or bi-axial compression, and thermal postbuckling under uniform temperature rise are taken into account. In the current study, full-scale FE modelling and nonlinear analysis are carried out, in which the constituent materials possess temperature-dependent properties. The results of comparison study show that the compressive buckling and thermal postbuckling loads of sandwich plates with NPR core are remarkably higher than those of their counterparts having the 3D lattice core with positive EPR. Parametric studies are further performed to demonstrate the effects of functionally graded configurations, temperature changes, load-proportional parameters and plate aspect ratios on the postbuckling load-deflection curves, along with the EPR-deflection curves in the large deflection region.


ABSTRACT: A geometrically nonlinear continuum shell element using a NURBS-based isogeometric analysis (IGA) approach is presented for the analysis of functionally graded material (FGM) structures. IGA offers a computationally efficient and geometrically exact representation of the original shell geometry and its underlying basis functions provide high-order continuity for the solution variables. The use of high-order smooth basis functions also alleviates shear and membrane locking phenomena that commonly occurred in shell structures. In addition, the developed continuum shell element features a precise description of the thickness-varying material properties in FGM in the sense that a set of desired high-order B-spline basis functions with sufficient number of quadrature points are employed for accurate through-thickness numerical integration. A simple power-law distribution function of the FGM is adopted in the current study. The performance of the proposed IGA solid shell element is demonstrated via a variety of nonlinear shell benchmark problems. The
effect of the FGM power-law exponent on the geometrically nonlinear response of the shell structures is investigated as well.

Armagan Karamanli (1) and Metin Aydogdu (2)
(1) Faculty of Engineering and Natural Sciences, Mechatronics Engineering, Bahcesehir University, 34353 Istanbul, Turkey
(2) Department of Mechanical Engineering, Trakya University, 22030 Edirne, Turkey
ABSTRACT: The size dependent natural frequencies of functionally graded (FG) shear and normal deformable porous square microplates are investigated within this paper for arbitrary boundary conditions. By utilizing the modified couple stress theory, the finite element model is developed based on a shear and normal deformation plate theory and the variational formulation. The material length scale parameter (MLSP) is taken as variable. The effects of the aspect ratio, gradient index, boundary condition, thickness to MLSP ratio, porosity volume fraction and variable MLSP on the dimensionless natural frequencies are investigated for the FG shear and normal deformable porous square microplates. It is found that the difference between the numerical computations employing the constant and variable material length scale parameters is significant. In addition, it is found that with an increment in the aspect ratio, the effect of the MLSP on the natural frequencies increases, especially for the thick microplates. It can be concluded that for the thick microplates (length/thickness less than or equal to 10), the effect of the variable MLSP on the natural frequencies with respect to the changing of the thickness to MLSP is more emphasized than the effect obtained by the constant MLSP for all studied boundary conditions.

Michele Iacopo Izzi (1), Marco Montemurro (1), Anita Catapano (2) and Jérôme Pailhès (1)
(1) Arts et Métiers Institute of Technology, Université de Bordeaux, CNRS, INRA, Bordeaux INP, HESAM Université, I2M UMR 5295, F-33405 Talence, France
(2) Bordeaux INP, Université de Bordeaux, Arts et Métiers Institute of Technology, CNRS, INRA, HESAM Université, I2M UMR 5295, F-33405 Talence, France
ABSTRACT: In this work, a multi-scale optimisation strategy for the preliminary design of composite structures involving design requirements at different scales, is presented. Such a strategy, denoted as GL-MS2LOS, has been formulated by integrating a dedicated global-local (GL) modelling approach into the multi-scale two-level optimisation strategy (MS2LOS). The GL-MS2LOS aims at proposing a very general formulation of the design problem, without introducing simplifying hypotheses and by considering, as design variables, the full set of geometric and mechanical parameters defining the behaviour of the composite structure at each pertinent scale. By employing a GL modelling approach, most of the limitations of well-established design strategies based on analytical or semi-empirical models are overcome. The effectiveness of the presented GL-MS2LOS is proven on a meaningful study case: the least-weight design of a composite fuselage barrel of a wide-body aircraft undergoing various loading conditions and subject to requirements of different nature. Fully parametric global and local FE models are interfaced with an in-house metaheuristic algorithm to perform the optimisation. Refined local FE models are created only for critical regions of the structure, automatically detected during the global analysis, and linked to the global one thanks to the implementation of a sub-modelling approach. The general nature of the GL-MS2LOS allows finding an optimised configuration characterised by a weight saving of 40% when compared to an optimised aluminium solution obtained through a similar GL optimisation strategy.

Vaishali (1), T. Mukhopadhyay (2), P.K. Karsh (3), B. Basu (4) and S. Dey (1)
(1) Department of Mechanical Engineering, National Institute of Technology Silchar, Silchar, India
(2) Department of Aerospace Engineering, Indian Institute of Technology Kanpur, Kanpur, India
(3) Department of Mechanical Engineering, Parul Institute of Engineering & Technology, Parul University, Vadodara, India
Canhui Zhang, Ruijie Chang and An Li (Department of Civil Engineering, Xiamen University, Xiamen 361005, China), “Novel two-level strategy to exactly solve multilayer composite cantilever tubes of cylindrically orthotropic materials”, Composite Structures, Vol. 237, Article 111866, 1 April 2020, https://doi.org/10.1016/j.compstruct.2020.111866
ABSTRACT: A novel two-level strategy is employed to solve the multilayer composite cantilever tubes in elasticity theory. On the first level of our strategy, a complete stress field is developed for the inclined winding cantilever tubes. Thus the tube can be considered as a bending-like tube including the proportional moments together with a shear-like tube including the constant shear forces. The pure bending formula is used to obtain the solution for the bending-like tube. However, the shear-like tube includes some additional terms from the bending-like tube. Therefore, on the second level of our strategy, the shear-like tube is broken into two independent systems according to whether the additional terms are included. Thus their different circumferential functions can be satisfactorily separated from the radial functions. In addition, an approach of undetermined coefficients is employed to find the particular solution for the second independent system. In the examples the method in this paper is used to exactly solve the composite cantilever tubes [90°], [45°] and [75°] as well as [(45°/75°), [75°/75°] and [(75°/75°)]. The good agreement of our exact results with the numerical simulation with fine finite elements shows the accuracy and effectiveness of the method in this paper.

ABSTRACT: In this study, the impact characteristics of non-sheared and sheared woven fabric composite structures were investigated by performing failure characterisations and estimating impact locations utilising several signal processing techniques based on a smart grid fabric (SGF) consisting of polyvinylidene difluoride ribbon sensors. To identify the effects of shear deformation on the impact characteristics of composite structures, SGF-embedded woven composite laminates with three different shear angles (0°, 30°, and 45°) were prepared. Additionally, impact characterisations of draped three-dimensional composite structures were performed by preparing an SGF-embedded composite hemisphere. Failure characterisations and impact localisations for these specimens were carried out by using a discrete wavelet transform and Bayesian regularised artificial neural network model, respectively. Finally, the feasibility of SGF in sheared composite structures was verified based on the results of various experiments and analyses.

Guoqi Zhao (1), Ben Wang (1), Wenfeng Hao (1,2), Ying Luo (1) and Haosen Chen (2)
ABSTRACT: This paper proposes a method to effectively locate and characterize mode I delamination in carbon fiber/epoxy (CF/EP) composite laminates using the local wavenumber method of propagating guided waves in a fine grid of spatial sampling points. Mode I interlaminar fracture tests were conducted using a double cantilever beam (DCB) specimen to evaluate the developed method. Wave propagation in composite laminates with delamination at different center frequencies were investigated by two-dimensional finite element (FE) simulation. The results revealed some unique mechanisms of interaction between guided wave and delamination in detail. They demonstrated that the wave propagation velocity is transformed at the delamination, and the wave attenuation and dispersion are larger with the increase of the center frequency. The guided waves were rapidly excited at each grid point using a non-contact scanning laser Doppler vibrometer (SLDV) system and actuated by a single fixed piezoelectric (PZT) sensor in the experimental study. The spatially dependent wavenumber value of the center frequency was determined by the local Fourier domain analysis method for processing guided wave filed data. The results showed that the local wavenumber method for guided waves is capable of locating and characterizing the delamination in composite laminates.

Pablo Vitale (1,2), Gaston Francucci (1), Helmut Rapp (2) and Ariel Stocchi (1)
(1) Research Institute for Materials Science and Technology (INTEMA), Universidad Nacional de Mar del Plata, CONICET, Av. Juan B. Justo 4302, B7608FDQ Mar del Plata, Argentina
(2) Institute of Lightweight Structures, Universität der Bundeswehr München, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany
ABSTRACT: In this work the shear performance of ultra-lightweight (ULW) carbon fiber reinforced polymer (CFRP) cores with 3-dimensional (3D) geometries is analyzed. The cores are made from a machined CFRP laminate. Using the interlocking method, CFRP sheets are assembled in order to obtain a square pattern. The density of all manufactured cores is achieved below than 48 kgm$^{-3}$. Through simple analytical mechanical models, it is possible to predict the failure behavior of the panels. Finite element analyses (FEA) are carried in order to contrast and validate the theoretical models. Good agreement among theoretical, finite element and experimental results is found. The experimental results show that the controlling failure mechanisms are shear failure of the base material or debonding, also predicted successfully by the numerical and analytical approaches. Finally, the cores are compared favorably as well with other competing known materials.
ABSTRACT: Composite sandwich constructions are now widely used in primary aircraft airframe structures and outstand by their high bending and stability performance. These structures are typically characterized by a continuous core which extends over the entire structural bay perimeter confined by adjacent framework structural members. This paper presents a novel design approach of asymmetric sandwich structures which is based upon a tailored discretization of the core area over the bay perimeter and enables an important increase of the weight efficiency of traditional sandwich shells. The discretization pattern of the core is a result of a topographic optimization of the bending stiffness with respect to an in-plane loading. The paper describes the basic rationale of the design approach and demonstrates its technological feasibility. The mechanical behavior is predicted by standard linear and non-linear numerical tools and verified by shear tests. Furthermore, the design approach is exemplarily applied within the context of real helicopter airframe structures hence proving its functional and practical suitability.


ABSTRACT: Out-of-plane loads induce unsymmetrical damage modes in the laminate thickness direction. Consequently, the authors have recently proposed overcoming the conventional laminate symmetry constraint by designing unsymmetrical laminates with zero coupling responses. While impact damage is able to be tailored with unsymmetrical laminates, comparing them to symmetric laminates and assessing their impact damage tolerances had yet to be addressed. In this paper, we study three unsymmetrical laminates with localized ply clusters positioned at different locations (at the impacted, at the middle and at the non-impacted sides), along with a standard symmetric laminate as a baseline. Using low-velocity impact, X-ray micro-computed tomography and compression after impact (CAI), we compared the impact and post-impact responses to understand the effect local ply clusters and the delamination location have on the CAI strength. Results revealed that the unsymmetrical laminate with the ply clusters in the middle, where the dominant delaminations also occurred, improved the CAI strength by a maximum of 10% when compared to the symmetric baseline. Laminates with delaminations at the outer surfaces offered lesser resistance to buckling. While our study demonstrates that symmetric laminates are not the optimal damage tolerant solution for impact load cases, it also evidences the feasibility of unsymmetrical laminates.


ABSTRACT: This paper presents a design for a sandwich-like plate containing mass-beam resonators to obtain a specific and low-frequency stopband. The resonators consist of a cantilever beam and mass block and are fixed between the two faceplates of the sandwich-like plate. The traditional sandwich structure can't be used to control or isolate the vibration precisely in a specific frequency range. The stopband of the present sandwich-like plate can be easily changed by adjusting the geometry of the cantilever beam and the mass of the block. Using the energy method, the dispersion equation relating the frequency to the wave numbers is derived and the two bounds of the stopband are obtained by solving the dispersion equation. The vibration transmission of the sandwich-like plate is investigated using numerical calculation, finite element simulation, and experiments; a good agreement between the results of the three methods is obtained. The results show that the stopband is determined by the natural frequency of the resonators and the mass ratio of the resonators and faceplates; the stopband width is significantly affected by the damping ratio of the resonators. The results of this study will be useful for the design of plate structures with good vibration attenuation and isolation.

Balakrishnan Devarajan (1) and Rakesh K. Kapania (2)
(1) Department of Biomedical Engineering and Mechanics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA

ABSTRACT: This research presents the Non-Uniform Rational B-Splines (NURBS) based isogeometric finite element analysis of stiffened laminated composite plates. A first-order shear deformation theory is used to derive the governing equations by employing a variational formulation. Isotropic, orthotropic and laminated composite plates stiffened with multiple curvilinear stiffeners of different profiles are investigated. A novel way to achieve displacement compatibility between the panel and stiffeners interfaces is introduced. An easy way of modeling plates with complicated cutouts by using edge curves and generating a ruled NURBS surface between them is described. Influence on the critical thermal buckling load due to the presence of circular and elliptical cutouts is also investigated. Results of parametric studies are presented which show the influence of ply orientation, size and orientation of the cutout, and the position and profile of the curvilinear stiffener. The numerical examples show high reliability and efficiency of the proposed formulation when compared to other published solutions and those obtained using ABAQUS, a commercial software.


ABSTRACT: In the presented investigation composites consisting of carbon and glass fiber reinforced plastics in combination with steel and elastomer layers are subjected to experimental drop-weight impact tests and compression after impact tests. The objective is to study the low-velocity impact behaviour, damage resistance and residual strength of composite laminates dependent on position and proportion of additional layers. In continuation of earlier studies two additional laminate configurations containing thin steel layers and two elastomer layers are tested. Impact damage and damage tolerance are determined respecting the aspect of differing bending stiffness and structure densities. It is found that concerning the elastomer addition the damage area, which mainly depends on the elastomer layer position, is an essential influencing factor on the residual strength. The steel addition leads to wide delaminations but high residual strengths.


ABSTRACT: This paper investigates the behaviour of thin-walled composite plates with a cut-out under compression. The effects of lamina ply orientation on the critical state and the behaviour of the plates in the post-critical range were examined. The scope of the research involved numerical modelling of linear and nonlinear stability problems by the finite element method, using the simulation software ABAQUS®. The created numerical models were then verified experimentally. The study was performed on a plate with an unsymmetric stacking sequence of plies. To force buckling into a higher mode, an unsymmetric laminate with extension-twisting and extension-bending coupling was used. This approach led to obtaining the natural, lowest mode of buckling (flexural-torsional), one that ensures stable performance of the structure in the post-critical range (no transition to flexural mode).


ABSTRACT: The study investigates short thin-walled channel section columns made of a carbon-epoxy laminate. The tested columns were subjected to compression, including an eccentric compressive load relative to the gravity center of the cross section of the column. The boundary conditions applied in the study reflected
simple support of the column. The scope of the study involved determining the effect of eccentric load on the structure’s stability and load-carrying capacity. At the same time, a numerical analysis by the finite element method was performed using the commercial simulation software Abaqus®. The non-linear numerical analysis of the compressed profiles was performed by the Newton-Raphson method. Failure of the composite material was described using a progressive damage model, wherein damage initiation in the composite material was described based on Hashin’s failure criteria while the evolution of damage was described by the energy-based progressive damage criterion. Results predicted by the numerical model were validated by experimental tests performed on real structures. The results enabled a comprehensive description of the composite material’s failure, starting from failure initiation until the total loss of load-carrying capacity of the column.

M. Cinefra (1), M. D’Ottavio (2), O. Polit (2) and E. Carrera (1)
(1) Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
(2) Laboratoire Energétique Mécanique Electromagnétique, Université Paris Nanterre, 50, rue de Sèvres, 92410 Ville d’Avray, France


ABSTRACT: This paper discusses the robustness of plate elements based on Mixed Interpolation of Tensorial Components (MITC) technique and the variable kinematics approach of Carrera Unified Formulation (CUF) with respect to the problem of distorted meshes. MITC was originally proposed for Reissner-Mindlin type plates to develop shear locking free plate elements. In the present framework, refined plate elements are obtained by referring to high-order Equivalent Single Layer as well as Layer-Wise models expressed in CUF for the analysis of multilayered anisotropic structures. Four-node and nine-node elements are considered and some applications are developed for both isotropic and multilayered composite plates. Results related to the MITC approach are compared to the isoparametric elements, including selectively reduced quadrature schemes, for both, the static and free-vibration analysis. They show that CUF-MITC elements maintain their effectiveness also in the case of distorted meshes, for all the materials studied and kinematic models considered: the obtained elements are robust as free from shear locking and spurious zero-energy modes.


ABSTRACT: Recent advances in artificial metamaterials have allowed unique structures to deform in distinct modes not previously found in traditional material form. Auxetic structures that induce twist through deformation have been a focus of recent research. In this paper a cell-based tubular structure with pre-deformed ligaments is proposed which exhibits efficient extension induced twist (EIT) without the limitations of buckling. An analytical model of the structure is proposed using cell parameters to characterize the non-linear twist-deformation relationship. Samples of the structure were fabricated using the Ultimaker 3 platform with elastomer based TPU 95a build material and PVA support material. The analytical model and FEM were validated by tensile experiments, where fabricated samples reached 60 degrees of non-linear axial twist over 40 mm of deformation. In order to further characterize the structure’s twist response, key design parameters of the lattice structure were varied and modelled. Actuation through tensile elastic deformation has key advantages in reliability and reduced complexity. Due to these advantages, this technology has potential applications in aerospace, biomedical and robotic fields.

Yao Zhu (1), Yu Chen (2), Kang He (2), Ran Feng (3), Xiaoyong Zhang (1), Qingxia Zhu (1) and Chao Tang (1)
(1) School of Urban Construction, Yangtze University, Jingzhou 434023, China
(2) College of Civil Engineering, Fuzhou University, Fuzhou 350116, China
(3) School of Civil and Environmental Engineering, Harbin Institute of Technology, Shenzhen 518055, China

ABSTRACT: Conventional concrete-filled aluminum alloy tube (CFAT) can effectively delay the inward local buckling of aluminum alloy tube (AA). This paper experimentally and numerically investigates the suitability of strengthening square and rectangular hollow section (SHS and RHS) CFAT beams with a layer of carbon-fiber reinforcement polymer (CFRP) under four-point bending. Among 40 beams, 30 square and rectangular CFAT beams were strengthened with CFRP comprising three arrangement schemes of CFRP and 10 conventional square and rectangular CFAT beams were treated as reference beams. Flexural stiffness of square and rectangular CFAT beams are remarkably enhanced by external bonded CFRP, while the ductility is decreased. The bottom flange-bonded CFRP scheme is less effective in enhancing ultimate strength of CFAT beams than that of four sides-bonded CFRP scheme. New design approaches for evaluating both initial and post-yield flexural stiffness of square and rectangular CFAT beams strengthened with CFRP are proposed. FE models are correctly simulated to analyze the flexural behavior of square and rectangular CFAT beams strengthened with CFRP. CFRP strengthening technique using in this study can remarkably enhance the ultimate strength of square and rectangular CFAT beams and effectively delay the outward local buckling of AA tubes.

Dimitri Goutaudier (1,2,3), Didier Gendre (2), Véronique Kehr-Candille (1) and Roger Ohayon (3)
(1) Onera, Department of Materials and Structures, Châtillon, France
(2) Airbus, Airport Operations, Blagnac, France
(3) Cnam, Structural Mechanics and Coupled Systems Lab., Paris, France

ABSTRACT: Classical triangulation techniques determine the impact point by capturing the Time of Arrival (TOA) delays of some elastic waves at different sensor locations. This paper presents an impact localization technique that exploits the low frequency content of the global vibration response. A modal signature of the impact location is described instead of a time signature based on the TOAs. The proposed approach uses the simple idea that the vibration modes of a structure are not excited in the same proportions depending on impact location. The proposed method is applied to a large aircraft composite panel equipped with a sparse distribution of accelerometers. An experimental modal analysis was performed prior to the impact tests to identify the first low frequency vibration modes of the structure within 10–50 Hz. The results of the study show that the technique successfully localizes impacts applied at any location on the panel.

Jin-Shui Yang (1,2,3,4), Wei-Ming Zhang (1), Fang Yang (1), Si-Yuan Chen (1), Ruediger Schmidt (5), Kai-Uwe Schroeder (5), Li Ma (4) and Lin-Zhi Wu (1,4)
(1) Key Laboratory of Advanced Ship Materials and Mechanics, College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin 150001, PR China
(2) State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha 410082, PR China
(3) State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi’an Jiaotong University, Xi’an 710049, PR China
(4) National Key Laboratory of Science and Technology on Advanced Composites in Special Environments, Harbin Institute of Technology, Harbin 150001, PR China
(5) Institute of Structural Mechanics and Lightweight Design, RWTH Aachen University, Wülchnerstraße 7, D-52062 Aachen, Germany

ABSTRACT: Composite thin-walled curved structures are widely used in aerospace, marine, automotive and building engineering application. In this paper we design and fabricate a series of carbon fibre composite axial and circular corrugated sandwich cylindrical panels (ACSCPs and CCSCPs) by an in-house hot press moulding method. Low velocity impact tests are carried out to evaluate the impact resistance and failure mechanisms of such structures. Furthermore, validated finite element analysis (FEA) models based on the Hashin failure criteria are adopted to study the effects of the relative density, impact energy and impact position on their impact responses. It is observed that generally the peak forces and absorbed energies of the specimens ascend with the increase of the relative density. The impact responses, especially the ultimate loads of the present structures are particularly dependent on the impact position, but insensitive to the increase of the impact energy.
By comparison, the ACSCPs generally have a more excellent impact resistance and energy absorption properties than that of CCSCPs. In addition, the corresponding energy contribution of the components for the ACSCPs and CCSCPs under different impact energy is also revealed, which could be useful for the multifunctional design of such kinds of composite curved sandwich structures.

Yiwen Ni (1,4), Shengbo Zhu (1), Jiabin Sun (2), Zhenzhen Tong (1,3), Zhenhuan Zhou (1) and Xinsheng Xu (1)
(1) Structural Analysis of Industrial Equipment and Department of Engineering Mechanics, Dalian University of Technology, National Center for Computational Mechanics, Dalian 116024, PR China
(2) Industrial Equipment and School of Ocean Science and Technology, Dalian University of Technology, Panjin 124221, PR China
(3) College of Locomotive and Rolling Stock Engineering, Dalian Jiaotong University, Dalian 116028, PR China
(4) Faculty of Mechanical Engineering & Mechanics, Ningbo University, Ningbo 315211, PR China


ABSTRACT: A new analytical buckling solution of a cylindrical shell made of two-phase magneto-electro-thermo-elastic (METE) composites under multi-physical fields is obtained by a Hamiltonian-based approach. Two types of technologically important distribution model are considered: continuous fibers and laminates. Based on the Reissner’s shell theory, the exact solution expanded into symplectic series is rigorously obtained from governing equations under the Hamiltonian description which has four possible forms of explicit expressions. Accurate critical buckling loads and analytical buckling mode shapes for various boundary conditions are obtained. A comprehensive comparison is presented to verify the proposed solution and very good agreement is reported. Effects of geometrical parameters, boundary conditions, cases of eigenfunctions, volume fractions and external magneto-electro-thermal loadings on buckling behaviors of the shell are investigated also.


ABSTRACT: The modes of vibration of a Variable Stiffness Composite Laminate were obtained by experimental modal analysis and compared with the ones resulting from theoretical/mathematical models. Three types of boundary condition were considered: CFFF, CFCC and FFFF, where C stands for clamped and F for free edges. Frequency response functions were experimentally obtained and employed to identify natural frequencies, modal damping ratios and mode shapes of vibration, using methods known as CMIF - Peak picking and circle-fit. The identified natural frequencies and mode shapes of vibration were compared with the ones resulting from models based on Classical Plate Theory and on First-order Shear Deformation Theory. Although two massive, stiff, steel blocks were bolted with the plate in-between in order to approach a clamped boundary, the modal properties are still significantly influenced by the flexibility of the resulting fixture. After introducing springs along the boundaries in the mathematical model, to better represent a “real clamped” boundary, quite good agreement between theoretical and experimental results was obtained. The experimental results here presented can be used to validate theoretical models of Variable Stiffness Composite Laminated plates.

Hongyang Zhou (1), Xuejian Zhang (1), Xiaojuan Wang (1), Yonghui Wang (2) and Tianfei Zhao (3)
(1) Urban Security and Disaster Engineering, Beijing University of Technology, Beijing 100124, China
(2) Structural Dynamic Behavior & Control, Harbin Institute of Technology, Harbin 150090, China
(3) School of Aeronautics, Northwestern Polytechnical University, Xian 710072, China


ABSTRACT: To prevent premature failure, aluminum honeycombs of the same areal density with and without foam concrete filling subjected to quasi-static and dynamic compression are experimentally tested. The influence of major governing factors including cell size of honeycomb, density of foam concrete, and loading rate on the performance in terms of compressive strength and energy absorption capacity are systematically investigated.
examined. It is found that without foam concrete filling, the out-of-plane strength and energy absorption capacity of honeycomb of the same areal density increase with decreasing cell size, under both quasi-static and dynamic crushing. With foam concrete filler, the load bearing and energy absorption capacity of the honeycombs increase by 33–207% compared to those of the corresponding foam concrete and honeycomb added up separately, and increase with increasing foam concrete density and decreasing honeycomb cell size, regardless of being compressed quasi-statically or dynamically.

Dongdong Chen (1), Guangyong Sun (1,2), Xihong Jin (3) and Qing Li (2)
(1) Advanced Design and Manufacture for Vehicle Body, Hunan University, Changsha 410082, China
(2) School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Sydney, NSW 2006, Australia
(3) CRRC Zhuzhou Locomotive Co., Ltd., Zhuzhou 412001, China


ABSTRACT: This study aims to characterize the crushing responses of hat-shaped composite tube under quasi-static three-point bending (TPB) and transverse compression (TC) conditions. The specimens were fabricated with different stacking configurations considering the effect of ply number, ply angle (containing [±45°] layers) and interply hybrid structure (sandwich-like) with carbon fiber reinforced plastic (CFRP) and glass fiber reinforced plastic (GFRP) through thermo-forming process. Mechanical parameters were also tested with non-hybrid laminates consisted of net carbon and net glass fibers. The crushing performance was evaluated by comparing load-displacement curves and the images taken in course of the testing processes. Cross-sections of the specimens were also inspected visually to identify the failure mechanisms after the tests. The comparative study on the energy absorption and cost efficiency was conducted for all the samples. It was found that failure modes varied with ply angle under the TPB tests but kept the same under the TC tests. Increasing wall thickness seemed to be an effective way to improve energy absorption under both TPB and TC loading. Addition of [±45°] layers exhibited considerable advantages on the TPB performance except the TC scenario. The hybrid structures comprised of both carbon and glass fiber layers exhibited limited improvement on crashworthiness but excellent cost efficiency. In addition, the initiation and propagation of cracks during tests were clearly visible when stacking glass fiber layers outside, which facilitate proper structural health monitoring.

Aghna Mukherjee (1), Michael Ian Friswell (2), Shaikh Faruque Ali (1) and A. Arockiarajan (1)
(1) Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai 600036, India
(2) College of Engineering, Bay Campus, Swansea University, Swansea SA1 8EN, UK


ABSTRACT: Multistable laminates have been widely analyzed in the recent past for their potential in morphing applications. However, all the analytical models developed up until now have taken into account only the free-free boundary condition. In this work two objectives are met: (a) an analytical model is developed, which extends the previously available models in literature to account for the cantilever boundary condition for a special class of hybrid bistable symmetric laminates (HBSL); (b) the previously proposed HBSL is modified by replacing the aluminum layers with bi-direction glass-epoxy prepregs in the layup. It is observed that the modified layup has a curvature similar to the previously proposed HBSL while maintaining bistability. The analytical model developed here successfully captures the equilibrium shapes and the snap-through behavior for this special class of laminates which is validated against the results obtained using ABAQUS® and experiments. The developed model is then subsequently used to study the design space and bistability characteristics of the HBSL and the proposed modified layup (m-HBSL) in the cantilever boundary condition.

Z. Ullah (1), Ł. Kaczmarczyk (2) and C.J. Pearce (2)
(1) Advanced Composites Research Group, School of Mechanical and Aerospace Engineering, Queen’s University Belfast, Ashby Building, Belfast BT9 5AH, UK
(2) Glasgow Computational Engineering Centre, The James Watt School of Engineering, University of Glasgow, Glasgow G12 8QQ, UK

ABSTRACT: A three-dimensional hierarchic finite element-based computational framework is developed for the investigation of inter-laminar stresses and displacements in composite laminates of finite width. As compared to the standard finite elements, hierarchic finite elements allow to change the order of approximation both locally and globally without modifying the underlying finite element mesh leading to very accurate results for relatively coarse meshes. In this paper, both symmetric cross-ply and angle-ply laminates subjected to uniaxial tension are considered as test cases. Tetrahedral elements are used for the discretisation of laminates and uniform or global p-refinement is used to increase the order of approximation. Each ply within laminates is modelled as a linear-elastic, homogenous and orthotropic material. With increasing the order of approximation, the developed computational framework is able to capture the complex profiles of inter-laminar stresses and displacements very accurately. Results are compared with reference results from the literature and found in a very good agreement. The computational model is implemented in our in-house finite element software library Mesh-Oriented Finite Element Method (MoFEM). The computational framework has additional flexibility of high-performance computing and makes use of the state-of-the-art computational libraries including Portable, Extensible Toolkit for Scientific Computation (PETSc) and the Mesh-Oriented datABase (MOAB).

Han Wang, Mingming Su and Hai Hao (Solidification Control and Digital Preparation Technology (Liaoning Province), School of Materials Science and Engineering, Dalian University of Technology, Dalian 116024, PR China). “The quasi-static axial compressive properties and energy absorption behavior of ex-situ ordered aluminum cellular structure filled tubes”, Composite Structures, Vol. 239 Article 112039, 1 May 2020, https://doi.org/10.1016/j.compstruct.2020.112039

ABSTRACT: In this study, the ex-situ ordered aluminum cellular structure filled tubes with different filler types, filling ratios and filling positions were fabricated by inserting the ordered aluminum cellular structure fillers into the aluminum tubes directly. The ordered aluminum cellular structure fillers were prepared by the selective laser sintering and the infiltration casting. The compressive properties and energy absorption behavior of ex-situ ordered aluminum cellular structure filled tubes were assessed by quasi-static axial compression tests. The effects of the ordered cellular structure types, filling ratios and filling positions on compressive properties and energy absorption behavior of ex-situ ordered aluminum cellular structure filled tubes were investigated. The results show that both the uniform and graded ordered aluminum cellular structures as filler materials can significantly improve the compressive properties and energy absorption behavior. Meanwhile, the compressive properties and energy absorption behavior of ex-situ ordered aluminum cellular structure filled tubes can be tailored by changing the filling ratios and positions. It is noticed that the ex-situ ordered aluminum cellular structure vertically filled the middle part of the thin-walled tubes exhibit superior compressive properties and energy absorption behavior compared with the ex-situ ordered aluminum cellular structure horizontally filled the bottom of the thin-walled tubes.


ABSTRACT: The paper presents large amplitude free vibration response of functionally graded porous (FGP) cylindrical panels considering different shell theories and boundary conditions. Nonlinear governing equations are obtained based on two shell theories, first order shear deformation theory (FSDT) and higher order shear deformation theory (HSDT). The von Karman geometrical nonlinearity along with the Hamilton principle is utilized. Mechanical properties of the open-cell foam are assumed to vary continuously through the thickness. This graded porosity offers a smooth stress distribution along the thickness of the panel. Generalized differential quadrature method (GDQM) is utilized to discretize the nonlinear dynamic governing equations along with three different boundary conditions. To solve the set of equations that include highly nonlinear parameters, the harmonic balance method along with the direct iterative approach is used. The results present the influence of geometrical parameters, vibration amplitude, porosity distribution, shell theories and boundary conditions on the nonlinear frequencies. It is found that both porosity distribution and porosity coefficient have a remarkable effect on the nonlinear natural frequencies of FGP cylindrical panel. To enhance the dynamic response of the cylindrical panel, porosity should be avoided near the panels’ surfaces.
The present study focuses on the mechanical and absorption properties of composites reinforced by *achatina fulica* snail (S-shell) and eggshell particles (E-shell). Epoxy composites of snail and eggshell particles were prepared separately with the filler content ranging from 5 to 20% by weight. Hybrid composites of both fillers were also prepared and assessed. Specimens of the composites and hybrid composites with different percentage weights of the reinforcing materials were fabricated using the resin casting method. Mechanical properties such as tensile strength, Young’s modulus, impact strength, hardness and water absorption properties of the specimens were evaluated experimentally. It was observed that the addition of shell...
particles improves the mechanical properties of neat epoxy irrespective of the percentage weight of the reinforcement. The mechanical and water absorption properties of composites and hybrid composites varied depending on the amount of the reinforcement. Significantly, hybrid reinforcement by S-shell and E-shell particles offered superior properties in most cases. High percentage weight of calcium carbonate in these naturally sourced fillers and the synergistic effect of the S-shell and E-shells particle fillers can be attributed to high strength, stiffness, and decrease in water uptake of the composites.

D. Feng (1) and F. Aymerich (2)
(1) College of Civil Engineering, Taiyuan University of Technology, Shanxi 030024, China
(2) Department of Mechanical, Chemical and Materials Engineering, University of Cagliari, 09123 Cagliari, Italy
ABSTRACT: The paper presents the results of an investigation into the effect of core density on the low-velocity impact response of foam-based sandwich composites. Drop-weight tests were conducted on sandwich panels with carbon/epoxy facesheets and a 10 mm thick PVC foam core. Three foam core densities (65, 100 and 160 kg/m³) and two facesheet layups ([0/90/0], [0/±45]) were examined in the study. The analyses show that the influence of core density on the damage resistance of the panels is strongly correlated to the layup of the skin. While the damage developing in [0/90/0] panels is not affected by core density, the damage area in [0/±45], panels reduces with increasing core density. The different influence of core properties on the damage response of [0/90/0] and [0/±45], sandwich panels may be attributed to the different bending stiffness of the facesheets, with a response to impact dominated by global bending in panels with thin [0/90/0] skins as opposed to one mainly governed by local shear rigidity in panels with thicker [0/±45], skins. FE analyses were finally carried out to assess the capability of a model developed by the authors to capture the role of foam density in the impact damage response of the panels.

A. Wagih (1,2), T.A. Sebaey (2,3), A. Yudhanto (1) and G. Lubineau (1)
(1) King Abdullah University of Science and Technology (KAUST), Physical Science and Engineering Division, COHMAS Laboratory, Thuwal 23955-6900, Saudi Arabia
(2) Mechanical Design and Production Department, Faculty of Engineering, Zagazig University, P.O. Box 44519, Zagazig, Sharkia, Egypt
(3) Engineering Management Department, College of Engineering, Prince Sultan University, Riyadh, Saudi Arabia
ABSTRACT: Hybrid polymeric composites are currently used in aerospace structures due to their specific strength and stiffness as well as larger design space. This paper presents an experimental study on residual flexural strength of impacted Carbon-aramid/Epoxy hybrid composite laminates. Specimens are designed in a sandwich form in which plies of aramid/epoxy represent the core and carbon/epoxy plies play the role of face sheets. This design is expected to take advantage of the high energy absorption capabilities of aramid/epoxy composites. We pre-damage such composites by performing low-velocity impact at different energy levels. Three-point bending tests then are used to measure the residual flexural strength for the impacted specimens. The damage sequence during three-point bending is monitored using a camera and, later on, with computed tomography. The results show that, unlike the all-carbon/epoxy laminates, the carbon fiber plies in the lower part of the laminate (non-impacted face) are not fractured after either the impact test or the three-point bending test. The damage is locally concentrated at the impacted face and the upper part of the aramid plies core. As a result, the strength losses are smaller, as compared to available results in the literature for carbon/epoxy composites, glass/epoxy and carbon fibers with aluminium core laminates.
end, a plate theory recently proposed by the authors is adapted by introducing a deformation ansatz for the transverse displacement and neglecting insignificant terms, yielding a theory with six degrees of freedom. From the governing equations of motion, dispersion relations for the propagation of bending wave are derived, which also allow to compute the natural frequencies and mode shapes of bounded plates. The weak formulation of the equations of motion is presented. The accuracy of the proposed theory is validated for a simply supported rectangular CLT panel for which an analytical solution is available. The results are compared with first order shear deformation theory, revealing the limitations of this simplified theory in the present context. Finally, finite element solutions for the rectangular plate with non-classical boundary conditions are presented, as well as incorporating a floating floor construction, underlining the importance of numerical solutions for the practical application of this plate theory.

Helong Wu (1), Jun Zhu (1), Sritawat Kitipornchai (2), Quan Wang (3), Liao-Liang Ke (4) and Jie Yang (5)
(1) College of Mechanical Engineering, Zhejiang University of Technology, Hangzhou 310014, China
(2) School of Civil Engineering, the University of Queensland, Brisbane, St Lucia 4072, Australia
(3) Department of Civil and Environmental Engineering, Shantou University, Shantou 515063, China
(4) School of Mechanical Engineering, Tianjin University, Tianjin 300350, China
(5) School of Engineering, RMIT University, PO Box 71, Bundoora, VIC 3083, Australia
ABSTRACT: This paper investigates the large amplitude vibration of functionally graded nanocomposite multilayer annular plates reinforced with graphene platelets (GPLs) in thermal environments. It is assumed that the GPL concentration varies from layer to layer across the plate thickness but remains constant in each individual GPL-reinforced composite (GPLRC) layer, whose elastic modulus is estimated by the modified Halpin-Tsai micromechanics model. Within the framework of first-order shear deformation theory and von Kármán geometric nonlinearity, the governing equations are derived by using the Hamilton’s principle and then solve by the differential quadrature method together with an iterative scheme. Numerical results are presented to show the influences of GPL geometry, distribution pattern and concentration, plate geometry, boundary conditions, as well as temperature rise on the nonlinear vibration behaviour of functionally graded GPLRC annular plates. It is found that dispersing more GPLs within the outer layers substantially decreases the nonlinear frequency ratio, while the effect of GPL geometry is insignificant.

ABSTRACT: The geometric details of variable thickness 3D woven composite plate, which features varying weft yarn cross section shapes and sizes at each layer and resulting diverse warp yarn path orientations, are quite different from the structure in constant thickness plate. A geometric model to handle these variances is presented in this paper which no doubt can also be used in constant thickness plate. Based on the idealized assumptions that the cross section shape of weft yarn is lenticular and warp yarn is rectangular, the inner structure details of variable thickness plate are illustrated in the efficient geometric model with weaving parameters and some measurements as input data. Two 3D woven sample materials are produced to confirm the accuracy of the proposed geometric model. Even though the idealizations in geometric model lead to some over predictions, the model still captures the majority of details in corresponding real sample architectures.

F. Schadt (1), M. Ruepapel (1), C. Brauner (1), Y. Courvoisier (2), K. Masania (1) and C. Dransfeld (1)
(1) Institute of Polymer Engineering, FHNW University of Applied Sciences and Arts Northwestern Switzerland, Klosterzelgstrasse 2, CH-5210 Windisch, Switzerland
(2) ENATA Industries FZE, Inner Harbour Plot HD-15, Hamriyah Free Zone, Sharjah, United Arab Emirates
ABSTRACT: Passive spanwise bending shape-adaption has the potential to increase the efficiency and manoeuvrability of vehicles with wing-like structures. By utilisation of compression flange buckling, the in-
plane stiffness can be tuned to design beams with contrasting pre-buckling and post-buckling bending stiffness. The investigated concept is experimentally validated using a thin-ply laminated composite four-point bending beam, which is designed to experience compression flange buckling in the span with constant moment. The bending stiffness was reduced by more than 41% after the onset of buckling which shows the effectiveness of compression flange buckling for non-linear bending compliance.

References listed at the end of the paper:

1 L. Campanile, Being lightweight: a crucial requirement, D. Wagg, I. Bond, P. Weaver, M. Friswell (Eds.), Adaptive Structures Engineering Applications, Ch. 4.4, John Wiley & Sons Ltd, Chichester, UK (2007), pp. 95-104
7 D. Filipovic, G. Kress, Manufacturing method for high-amplitude corrugated thin-walled laminates, Compos Struct, 222 (2019), Article 110955
10 M.R. Motley, Z. Liu, Y.L. Young, Utilizing fluid-structure interactions to improve energy efficiency of composite marine propellers in spatially varying wake, Compos Struct, 90 (3) (2009), pp. 304-313
17 A. Sofi, S. Meguid, K. Tan, W. Yeo, Shape morphing of aircraft wing: Status and challenges, Mater Des, 31 (3) (2010), pp. 1284-1292
18 A. Moosavian, F. Xi, S.M. Hashemi, Design and motion control of fully variable morphing wings, J Aircraft, 50 (4) (2013), pp. 1189-1201
21 J. Katz, A. Plotkin, Three-Dimensional Small-Disturbance Solutions, Low-Speed Aerodynamics (2nd ed.), Cambridge University Press, New York (2001), Ch. 8

ABSTRACT: Octet lattice structures were designed with carbon fiber reinforced polymer (CFRP) composite hollow cylindrical struts to improve the specific compressive strength and stiffness of these lightweight structures. A joint connector was designed and manufactured from balanced [0/90] CFRP laminates to assemble the designed octet lattice structures. The compressive modulus and strength of CFRP cylindrical tube-based octet lattice structures were measured under quasi-static compression. Two competing failure mechanisms were observed. The fiber fracture of CFRP hollow struts dominated the failure of lattice structures with a relative density (rho) of 2.17%. In contrast, lattice structures with lower relative densities (rho= 1.33% and 0.85%) failed by Euler buckling of the CFRP hollow struts. To gain further insight of the compressive behavior of the lattice structures, an analytical model and a series of finite element (FE) models were developed. The predictions showed good agreement with experimental observations of both the compressive properties and failure behaviors. The results demonstrate that CFRP tube-based octet lattice structures exhibited significantly higher relative strength and stiffness than CFRP laminated strut-based counterparts. These superior properties of CFRP tube-based octet lattice structure show a strong potential in high performance lightweight load-bearing application.

M. Beerhorst (1) and S. Thirusala Suresh Babu (2)
(1) German Aerospace Center (DLR), Lilienthalplatz 7, D-38108 Braunschweig, Germany
(2) Nanyang Technological University (Graduate Student), 50 Nanyang Avenue, Singapore 639798, Singapore


ABSTRACT: The present work deals with the buckling analysis of rectangular Mindlin plates consisting of laminated composites with symmetrical, balanced lay-up or isotropic materials. Along the longitudinal edges the plate is rotationally restrained by springs. The transversal edges are simply supported. In agreement with common notation, the boundary conditions are abbreviated as follows: simply supported (S), rotationally restrained (R), and fully clamped (C). As loading situation axial compression is considered. Aiming at high computational efficiency the problem is solved by the Rayleigh-Ritz-method. Since well suited shape functions for deflection and rotations with very few variables are used, closed-form approximate solutions for the buckling load can be obtained. For verification exact transcendental solutions and/or high fidelity finite element analyses are employed. Additionally, results are compared to those of existing closed-form approximate solutions. Apart from the special case of simply supported longitudinal edges where all methods yield exact or nearly exact results, the present method shows clear advantages: 1. Due to the type of shape functions it is able deal with unsymmetrical boundary conditions. 2. For the case of both longitudinal edges fully clamped where all closed-form approximate solutions show the greatest deviations the present method is significantly more accurate.


ABSTRACT: In this article, the vibrational behaviour of porous functionally graded magneto-electro-elastic (P-FGME) circular and annular plates is explored through finite element procedures. The influence of different electro-magnetic boundary conditions on the coupled natural frequencies of P-FGME plates are evaluated for the first time. The governing equations are arrived through Hamilton’s principle under the framework of higher order shear deformation theory (HSDT) in polar coordinates. The magneto-electro-elastic (MEE) material
properties are assumed to vary along the thickness based on power-law model. The proposed model is verified for its correctness with previously published literature and also with numerical software. In addition, the effects of various prominent parameters such as gradient index, porosity volume, functionally graded pattern, diameter ratio, coupling fields etc., on the frequency response of P-FGMEE circular and annular plates are also discussed. The results of this article can be effectively incorporated for the accurate design and development of functionally graded smart structures with porosities.

Kun Zhang (1), Tao Zeng (2,3), Guodong Xu (1), Su Cheng (1) and Siwen Yu (1)
(1) School of Materials Science and Engineering, Harbin University of Science and Technology, Harbin 150080, PR China
(2) Department of Civil and Environmental Engineering, College of Engineering, Shantou University, Shantou 515063, PR China
(3) Intelligent Manufacturing, Shantou University, Shantou 515063, PR China
ABSTRACT: Silicon carbide particle/silicon carbide (SiCp/SiC) composite lattice core sandwich panels were fabricated by selective laser sintering (SLS) combined with precursor impregnation and pyrolysis (PIP) process. The compression properties of the SiCp/SiC composite lattice core sandwich panels with three different configurations under room temperature and high temperature were investigated. The room temperature experiment results were compared with the analytical predictions. Experiment results indicated that the compression strength and modulus decreased 34.30% and 44.82% as the temperature increased from 1400 °C to 1800 °C. Moreover, the failure mechanisms of the SiCp/SiC composites were analyzed.

F. Alkhatib (1) , E. Mahdi (1) and A. Dean (2,3)
(1) Department of Mechanical and Industrial Engineering, College of Engineering, Qatar University, P.O. Box 2713, Doha, Qatar
(2) Institute of Structural Analysis, Leibniz Universität Hannover, Appelstr. 9A, 30167 Hannover, Germany
(3) Elasticity and Strength of Materials Group, School of Engineering, Universidad de Sevilla, Camino de los Descubrimientos s/n, 41092 Seville, Spain
ABSTRACT: This paper introduces a new carbon fiber reinforced plastic (CFRP) structural system in the field of crashworthiness. CFRP hat-shaped and angle-shaped stiffeners were used to develop a double-hat collapsible energy absorption system. Three different design alternatives were investigated. The first alternative is an open-cell design (OC) consisting of two flipped hat stiffeners with four right angles on the edges. The second alternative is a one-in-cell double-hat design (1C), consisting of OC design with additional one inside small hat stiffeners edged with angles. The third alternative is a two-in-cell double-hat design (2C), consisting of OC design with additional two inside small hat stiffeners edged with angles. Three modes of failure were observed, classified as local buckling (mode I), top wall bending (mode II), and brittle collapse that resulted from Euler buckling (mode III). The crashworthiness characteristics were evaluated for the three designs. The 2C double-hat design showed the highest peak load and specific energy absorption (SEA). Accordingly, the core of the 2C design was filled with foam to increase the energy absorption capability and enhance the structure’s stability. Results showed that the SEA of the 2C+ foam design was increased by more than 50% compared to the coreless 2C double-hat design.

ABSTRACT: Uni-axial compressive failure of silica-epoxy based heterogeneous honeycombs is investigated in detail for a range of volume fractions. Introduction of heterogeneity in compression of staggered-square honeycomb is seen to result in damage initiation at multiple locations and subsequent damage growth to be more stable compared to pure epoxy in which damage was observed to be localized until peak load when catastrophic failure of the honeycomb specimen occurs. The increase in stiffness and comparative stability of...
the response is accompanied with reduction in strength, however, between 0 and 5% the total work of compressive failure is comparable. From the elastic-plastic analysis it is evident that the non-linearity in the response of pure honeycombs, prior to peak load, is largely due to formation of plastic hinges near corners of cells, whereas in case of heterogeneous honeycomb the non-linearity is mostly due to debonding of hard filler particles and matrix cracking leading to damage growth in cell walls.


ABSTRACT: A three-dimensional (3D) theory of elasticity is presented for the solution of the generalized displacements and stresses in the composite laminated and sandwich cylindrical shell structures with covered or embedded piezoelectric layers based on the scaled boundary finite element method (SBFEM). The SBFEM is a weak-form differential technique, which can lead to accurate results performing discretization only on the middle plane of shell structures so that the considered model can be treated as a two-dimensional (2D) discretization problem. A new type 2D high order spectral element shape function is introduced both for approximations of geometry model and basis variables in the scaled boundary coordinate system. Employing the weighted residual principle in conjunction with Green’s theorem to the normalized static equilibrium equations of each layer leads to the SBFEM governing equation with respect to the radial generalized displacement fields. Then a system of a first-order ordinary differential equation is obtained by introducing a dual variable and analytically solved by using the precise integration technique (PIT). As a result, the major advantage of the proposed formulations for solving the bending problem of the composite laminated and sandwich cylindrical piezoelectric shell is no need to discretize the 3D model with a great deal of degrees of freedom while ensures the computational accuracy. Two test examples are carried out to demonstrate the adaptability and reliability of the present method and illustrate very good agreements and rapid convergence with the solutions based on the finite element approach only using a small number of elements. Numerical examples about the sandwich cylindrical piezoelectric shell are presented to investigate the parametric effects of the thickness ratio as well as the stacking sequence on the variation of generalized displacements and stresses. The results show that both the thickness ratio and stacking sequence have significant influence on the bending behaviors of the sandwich cylindrical piezoelectric shells.


ABSTRACT: This study concerns the buckling and post-buckling performance of composite stiffened panels with sub-stiffening structure subject to compression. The buckling response of the composite stiffened panel is first predicted and verified by experimental data available from the literature. Then sub-stiffeners are introduced into the composite stiffened panel. The distribution and stacking sequence of sub-stiffeners are optimized to improve the critical buckling load without adding weight. Further, to investigate the underlying mechanism of sub-stiffeners involved panels deformation and failure during compressive post-buckling process, different skin-stiffener interfacial parameters are considered. Results show that the introduction of sub-stiffeners to composite T-stiffened panel causes a significant improvement of buckling load (+122.66%) and induces reestablishment of the stress concentrated zone which leads to different local failure forms with different interfacial properties. In addition, the collapse load of sub-stiffened panel becomes more sensitive to interfacial parameters of skin-stiffener interface due to the presence of sub-stiffeners.

A. Arteiro (1), P.J. Gray (2) and P.P. Camanho (1)
(1) DEMeC, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, Portugal
(2) AIRBUS Operations GmbH, Kreetslag 10, 21129 Hamburg, Germany
ABSTRACT: This paper presents the application of a composite damage model to predict the edge impact and compression after edge impact (CAEI) response of CFRP laminates. First, a mesh sensitivity analysis is performed showing that the mesh needs to be sufficiently fine to accurately capture the permanent out-of-plane deformation at the impact location, which acts as the initiation site that induces laminate compressive failure at early stages in the deformation process. The simulations of edge impact are correlated with the impactor load-displacement data, impact area, and visible crack length data available in the literature. The experimentally measured stress-displacement curves are used to validate the residual strength predictions. The shape and size of the damage inflicted by the edge impact events on different laminates is well predicted, as well as the residual strength of the laminates subjected to CAEI. The model proposed can accurately capture stacking sequence effects, predicting significant changes in the shape of the damaged area when only the stacking sequence changes, in agreement with the experimental observations.

Kulmani Mehar (1), Subrata Kumar Panda (2), Yuvarajan Devarajan (1) and Gautam Choubey (1)
(1) Mechanical Engineering Department, Madanapalle Institute of Technology & Science, Madanapalle, Andhra Pradesh 517325, India
(2) Mechanical Engineering Department, National Institute of Technology Rourkela, Odisha 769008, India
ABSTRACT: The authors regret please replace affiliation of author 1st, 3rd and 4th such as “Mechanical Engineering Department, MITS, Madanapalle, Andra Pradesh 517325, India” to “Mechanical Engineering Department, Madanapalle Institute of Technology & Science, Madanapalle, Andhra Pradesh 517325, India”, that the change in affiliation of 1st, 3rd and 4th authors. The corrected affiliation has shown above.

Erfan Shafei (1), Shirko Faroughi (2) and Timon Rabczuk (3,4)
(1) Faculty of Civil Engineering, Urmia University of Technology, Urmia, Iran
(2) Faculty of Mechanical Engineering, Urmia University of Technology, Urmia, Iran
(3) Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(4) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
ABSTRACT: Conventional methods result in sharp variation of stiffness in analysis of variable angle tow (VAT) composite plates, which can be enhanced using high-order continuity of non-uniform rational B-spline (NURBS). To this end, a Bézier extraction-based isogeometric (IGA) model based on the higher-order shear deformation theory (HSDT) is developed for the parametric instability study of anisotropic VAT composite plates. Bézier extraction-based IGA approach expresses exactly the orientation function of VAT composites for multi-patch geometries, which provides accurate solution for general-shape plates. The accuracy and convergence of the developed framework is compared with recently formulated methods. Primary results shows that the developed concept solves VAT problems with much lower number of equations than variable kinematic models. Further, response characteristics of analyzed anisotropic VAT plates are presented and discussed considering various fiber orientation functions, boundary conditions and multi-patch geometry. Based on results, Bézier control mesh is more accurate than the NURBS-based IGA solution due to considering the continuity of strain field along coupled boundaries. Anisotropic VAT plates have severe deformation couplings and the current concept accurately captures this feature even with courser meshes. The interaction between boundary conditions and fiber orientations along edges affects mainly the dynamic instability regions (DIR) of modeled VAT plates, dislike to straight fiber ones. The dynamic instability opening (DIO) of VAT plates relies on the fiber orientation functions and boundaries. In anisotropic VAT plates, maximum frequency case and maximum buckling force case would not necessarily be the same. Modes shapes are variable of external force intensity and therefore the Rayleigh–Ritz based methods are not appropriate for dynamic stability analysis of VAT plates. It is essential to change the NURBS control mesh to the Bézier type to offer the required accuracy for the multi-patch domains.

Pruthwiraj Sahu (1), Nitin Sharma (1) and Subrata Kumar Panda (2)
(1) School of Mechanical Engineering, KIIT, Bhubaneswar 751024, Odisha, India
ABSTRACT: This research reveals the effect of hybridisation numerically for different advanced fibre (Glass/Carbon/Kevlar) reinforcement in polymer matrix composite on the eigen-characteristics. The higher-order displacement polynomial kinematics and curvature effect have been utilized for the modelling of the hybrid composite component including the necessary shear deformation. The adequate solution accuracy of the derived hybrid composite mathematical formulation has been examined by comparing with the first-five modal data considering the effect of aspect ratios, numbers of layers and the fibre types with the experimental data. The eigen-frequency solutions are obtained using an isoparametric linear finite element formulation in association with experimental properties for the hybrid composite. Also, the modal responses are obtained via a simulation model considering the individual layer effects of each fibre through the static-structural module of the commercial package (ANSYS). Finally, the influential structural design parameters (thickness ratio and constraint conditions) affecting the frequency characteristics including the geometrical shape are examined using the present numerical model. The computational results reveal that the numbers of layer and type of fibre affect the frequency parameter due to the variation in their stiffness.

H.S. Jason Lee (1) and Christopher B. York (2)
(1) University of Glasgow, School of Engineering, University Avenue, Glasgow G12 8QQ, Scotland
(2) Singapore Institute of Technology, 10 Dover Drive, Singapore 138683


ABSTRACT: This article investigates the compression and shear buckling performance of finite length Bending-Twisting coupled laminated plates with simply supported edges. New contour maps are developed, representing non-dimensional buckling factors, which are superimposed on the lamination parameter design spaces for laminates with standard ply orientations. Changes in buckling mode for finite length plates complicate the contour maps, which are shown to be continuous only within discrete regions of the lamination parameter design space and are strongly influenced by plate aspect ratio. The contour maps also serve to demonstrate the degrading effect of Bending-Twisting coupling on compression buckling performance as well as providing new insights into shear buckling performance improvements, including optima that are non-intuitive. The adoption of two recently developed laminate databases, to which common design rules are now applied, including ply percentages and ply contiguity constraints, ensure that the conclusions drawn are based on practical rather than hypothetical designs.


ABSTRACT: Three series of airframe composite panels with T-stiffener, I-stiffener and J-stiffener are designed and optimized to have the same local skin buckling load and weight. All the panels are designed to undergo local skin buckling between Design Limit Load (DLL) and Design Ultimate Load (DUL), approximately at 120% of DLL to utilize the reserve strength in structures. Additionally, identical panels are designed and fabricated from each series to study the effect of various extrinsic parameters such as disbond, delamination, impact damage and repeated loading to identify the best performing series for post-buckling design. All the panels are tested under compression to demonstrate no onset of damage before DUL. The influence of defects such as disbond, delamination and impact damage on the post-buckling behavior is also demonstrated. One pristine panel of each series is repeatedly loaded 1000 times beyond buckling to determine the onset of damage if any. The panels with I-stiffener and J-stiffener found to be the potential design choices for post-buckling design philosophy due to the high margin between skin buckling and collapse load even in the presence of damage. The results from this study would help in moving closer to the post-buckled composite design philosophy for airframe structure.
ABSTRACT: Chiral honeycombs of different types have been found to display auxetic behavior (a negative Poisson’s ratio). This paper investigates the constitutive relations and the auxetic properties of tetrachiral honeycombs. It is found that coupling between shearing and stretching exists in tetrachiral honeycombs and this causes some ambiguity when calculating the Poisson’s ratio. An “effective Poisson’s ratio” is proposed, as opposed to the traditional definition of Poisson’s ratio. This proposed parameter correctly describes the auxeticity of tetrachiral and other honeycombs. An analytical expression for this “effective Poisson’s ratio” is derived, which describes the relationship between the geometric dimensions and auxeticity of the tetrachiral honeycombs.

E. Zappino (1), N. Zobeiry (2), M. Petrolo (1), R. Vaziri (3), E. Carrera (1) and A. Poursartip (3)
(1) MUL2 Group, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
(2) Materials Science & Engineering Department, University of Washington, 302 Roberts Hall, Seattle, WA, USA
(3) Composites Research Network, Departments of Civil Engineering and Materials Engineering, The University of British Columbia, Vancouver, BC V6T 1Z4, Canada
“Analysis of process-induced deformations and residual stresses in curved composite parts considering transverse shear stress and thickness stretching”, Composite Structures, Vol. 241 Article 112057, 1 June 2020,
https://doi.org/10.1016/j.compstruct.2020.112057

ABSTRACT: A computationally efficient modeling approach for the accurate evaluation of process-induced deformations and residual stresses in composite parts is presented. A family of refined one-dimensional kinematic models, developed in the framework of the Carrera Unified Formulation, has been used to predict the accurate through-thickness deformation of layered structures during the manufacturing process. The composite material curing phase has been simulated exploiting the capabilities of the software RAVEN. A cure hardening instantaneously linear elastic model has been used. A benchmark based on an L-shaped component has been selected to compare the results obtained using different computational approaches. A closed-form solution, the present refined one-dimensional models and classical solid models, have been considered. The effects of the modeling approach on the prediction of the spring-in angle and on the residual stress field have been evaluated and discussed. The results demonstrate that the use of refined kinematic models can lead to a high-fidelity description of the problem and a quasi-3D accuracy while reducing the computational cost with respect to classical FEM approaches. The through-thickness effects have been predicted with a high level of accuracy and the use of layer-wise models has led to an accurate description of the stress field, including the transverse shear stresses.

Xiang Zhou and Guoshuang Shui (Department of Mechanics, Beijing Jiaotong University, Beijing 100044, China), “Propagation of transient elastic waves in multilayered composite structure subjected to dynamic anti-plane loading with thermal effects”, Composite Structures, Vol. 241 Article 112098, 1 June 2020,
https://doi.org/10.1016/j.compstruct.2020.112098

ABSTRACT: This paper investigates the transient responses of multilayered composite structure under the action of dynamical anti-plane concentrated forces with thermal effects. To obtain the transient solutions, the boundary value problem is presented by using Fourier-Laplace transform; the Cagniard’s method is adopted in inverting the solution to be expressed in time domain; and the theory of limit is employed to derive the corresponding static solution. Numerical results show that the closer the receiver’s vertical position is to the surface, the slower the transient response approaches the static value in the near field of the transient waves. A sharp fluctuation appears after a short time in the intermediate and far field; and the transient response finally approaches the static value in the end. Variation of the temperature does not affect the waveform and non-dimensional arriving time of the transient shear waves. However, the higher the variation of environmental temperature, the smaller the amplitude of the transient responses.

Pengchong Zhang (1,2), Chengzhi Qi (1,2), Hongyuan Fang (3) and Wei He (1)
Three dimensional mechanical behaviors of in-plane functionally graded plates

ABSTRACT: A semi-analytical solution procedure to investigate the distributions of displacement and stress components in the in-plane functionally graded plates based on the scaled boundary finite element method (SBFEM) in association with the precise integration algorithm (PIA) is developed in this paper. The proposed approach is applicable to conduct the flexural analysis on functionally graded plates with various geometric configurations, boundary conditions, aspect ratios and gradient functions. The elastic material parameters of functionally graded plates discussed here are mathematically formulated as power law, exponential and trigonometric functions varied along with the in-plane directions in a continuous pattern. Only a surface of the plate parallel to the middle plane is required to be discretized with two dimensional high order spectral elements, which contributes to reducing the computational expense. By virtue of the scaled boundary coordinates, the virtual work principle and the internal nodal force vector, the basic equations of elasticity are converted into a first order ordinary differential SBFEM matrix equation. The general solution of the governing equation is analytically expressed as a matrix exponential with respect to the transverse coordinate. According to the PIA, the stiffness matrix from the matrix exponential can be acquired. Considering that the PIA is a highly accurate method, any desired accuracy of the displacement and stress field can be obtained. The entire derivation process is built on the three dimensional elasticity equations without importing any assumptions on the plate kinematics. Comparisons with numerical solutions available from prevailing researchers are made to validate the high accuracy, efficiency and serviceability of the employed technique. Additionally, circular and perforated examples are provided to highlight the performance of the developed methodology and depict the influences of boundary conditions, thickness-to-length ratios and gradient indexes on the deformable behaviors of in-plane functionally graded plates.

Ge Qi (1), Yun-Long Chen (1), Philip Richert (2), Li Ma (1) and Kai-Uwe Schröder (2)
(1) Center for Composite Materials, Harbin Institute of Technology, Harbin 150001, PR China
(2) Institute of Structural Mechanics and Lightweight Design, RWTH Aachen University, Aachen 52062, Germany

A hybrid joining insert for sandwich panels with pyramidal lattice truss cores

ABSTRACT: Sophisticated and efficient technique of sandwich attachment for composite sandwich structure assembly is imperatively required by industries. Certain types of joining inserts are widely used to carry the localized loads, but little is known regarding to the joining method for composite lattice truss core sandwich structures. In this study, a novel hybrid insert fastener, which comprises a plurality of carbon-fiber-reinforced grid cells and a metallic part, is developed for pyramidal truss core sandwich structures. Finite element models are developed to predict the failure modes and the load capabilities of different insert locations. Static pull-out and shear experiments are carried out, and the failure behaviors for each load case are discussed. The results show that the shear performance is significantly improved, and the insert position greatly affects the static pull-out behavior. An optimization of the hybrid joining insert to enhance the pull-out characteristic is addressed and verified by the finite element analysis.

S. Aditya (1), M. Haboussi (2), S. Shubhendu (1), M. Ganapathi (1) and O. Polit (3)
(1) School of Mechanical Engineering, Vellore Institute of Technology, Vellore 632 014, India
(2) Université Paris 13-CNRS, LSPM, UPR 3407, Villetaneuse F-93430, France
(3) LEME, UPL, Univ. Paris Nanterre, 50 rue de Sevres, 92410 Ville d’Avray, France

Supersonic flutter study of porous 2D curved panels reinforced with graphene platelets using an accurate shear deformable finite element procedure

ABSTRACT: A novel hybrid insert fastener, which comprises a plurality of carbon-fiber-reinforced grid cells and a metallic part, is developed for pyramidal truss core sandwich structures. Finite element models are developed to predict the failure modes and the load capabilities of different insert locations. Static pull-out and shear experiments are carried out, and the failure behaviors for each load case are discussed. The results show that the shear performance is significantly improved, and the insert position greatly affects the static pull-out behavior. An optimization of the hybrid joining insert to enhance the pull-out characteristic is addressed and verified by the finite element analysis.

S. Aditya (1), M. Haboussi (2), S. Shubhendu (1), M. Ganapathi (1) and O. Polit (3)
(1) School of Mechanical Engineering, Vellore Institute of Technology, Vellore 632 014, India
(2) Université Paris 13-CNRS, LSPM, UPR 3407, Villetaneuse F-93430, France
(3) LEME, UPL, Univ. Paris Nanterre, 50 rue de Sevres, 92410 Ville d’Avray, France

ABSTRACT: The flutter behaviour of two-dimensional porous curved panels reinforced by graphene platelets exposed to supersonic flow on one side of the panels is investigated using the trigonometric shear deformation theory that satisfies stress free condition on the upper/lower surface of the panels. This structural model exhibits the thickness stretch effect thereby changing the transverse displacement. The effort to model the fluid-structure interaction is reduced by implementing the first-order approximation of piston theory aerodynamics to describe the flow. The solutions are found by introducing finite element methodology using a curved beam model. The critical flutter boundaries were predicted through the complex eigenvalue solution approach for the governing equations formulated adopting the Lagrangian formulation. Detailed numerical experimentation is made to show the effectiveness of the structural models, the influence of depth and length of curved panel, and panel edge conditions on the flutter boundaries of panels. Also, the material parameters such as porosity level, graphene platelet weight content, through-thickness distributions of nano-fillers and pores, size of nano-fillers are assessed on the flutter characteristics of 2D panels.


ABSTRACT: Fibre-reinforced polymer (FRP) tube-concrete-encased steel (FTCES) column, which consists of an FRP tube, encased steel section and concrete filled between them, attracts the attention of more and more researchers since it has excellent corrosion resistance, superior strength, stiffness and ductility. However, experimental studies on FTCES columns are relatively limited compared with other composite columns, such as concrete-filled-steel-tube columns. Moreover, existing analytical models predicting the load-strain relationships on the FTCES columns were all design-oriented models. A scientifically more rigorous analysis-oriented model is required to explain the complicated physical conditions at the interface among concrete, encased steel and FRP tube, which should consist of a concrete dilation model based on equilibrium and compatibility conditions. Herein, to understand more thoroughly and simulate the uni-axial performance of FTCES columns, an experimental study, consisting of 41 specimens has been conducted. The main parameters are FRP tube thickness, encased steel shape and ratio. Moreover, an analysis-based path dependent load-strain model, previously developed by the authors for the FRP tube-confined concrete columns, has been modified for the FTCES columns. The validity of the proposed model is confirmed by the good agreement obtained between the measured axial load-strain curves of FTCES columns and the theoretically proposed values.

Mostafa Mohammadabadi (1), Vikram Yadama (2) and Lloyd Smith (3)
(1) Material Science and Engineering Program and Composite Materials and Engineering Center, Washington State University, Pullman, WA 99164, USA
(2) Department of Civil and Environmental Engineering and Composite Materials and Engineering Center, Washington State University, Pullman, WA 99164, USA
(3) School of Mechanical and Materials Engineering, Washington State University, Pullman, WA 99164, USA

ABSTRACT: In this study, an analytical model was developed to evaluate the bending behavior of a wood composite sandwich panel with a biaxial corrugated core. To explore the effect of shear deformation, two plate theories were considered: classical plate theory (CPT) and a third-order shear deformation plate theory (TOSDPT). The effect of simply supported–simply supported, clamped–clamped, and simply supported–free boundary conditions on the bending behavior of the sandwich panel was investigated. A homogenization method was used to replace the corrugated geometry of the core with a continuous layer. Based on the deformation of the corrugated core, the effective properties of the homogenized layer were obtained. Classical lamination theory and the principle of minimum potential energy were applied to derive the governing equations and apply the boundary conditions. A generalized differential quadrature method was applied to solve the governing differential equations. The bending stiffness of a panel with simply supported–free boundary conditions agreed with the experiment within 3.67% and 0.28% for CPT and TOSDPT, respectively.
Łukasz Pyrzowski and Bartosz Sobczyk (Gdansk University of Technology, Faculty of Civil and Environmental Engineering, Department of Mechanics of Materials and Structures, 80-233 Gdansk, Narutowicza 11/12, Poland), “Local and global response of sandwich beams made of GFRP facings and PET foam core in three point bending test”, Composite Structures, Vol. 241 Article 112122, 1 June 2020, https://doi.org/10.1016/j.compstruct.2020.112122

ABSTRACT: In the paper behaviour of laminated sandwich beams (FRP face sheet – PET foam core – FRP face sheet) subjected to three point bending is studied. The paper aim is to find practical descriptions enabling effective and accurate estimation of the elastic response, damage and failure of the beams, basing on experiments and static calculations. Therefore a number of tests are described, that were done on laminated coupons and foam specimens in order to choose appropriate material models and find their constants. Experimental results of three-point bending tests of sandwich beams with three types of PET cores are analysed to evaluate the chosen material laws. The beam responses are predicted in numerical static simulations. The equations of problem are solved by means of finite element method (FEM). In the end the experimental and FEM results are compared. They are similar in terms of both their quantity and quality.

Paweł Szeptyński (Division of Structural Mechanics and Material Mechanics, Faculty of Civil Engineering, Cracow University of Technology, Poland), “Comparison and experimental verification of simplified one-dimensional linear elastic models of multilayer sandwich beams”, Composite Structures, Vol. 241 Article 112088, 1 June 2020, https://doi.org/10.1016/j.compstruct.2020.112088

ABSTRACT: Three analytical one-dimensional linear elastic models of composite laminated beams are considered – composite Bernoulli-Euler beam (BE), composite Timoshenko beam (T) and multilayer sandwich beam model (MS). They are compared with results obtained via finite element method for a two-dimensional model in plane stress state. Overall system stiffness is verified with experimental data obtained for two statical configurations – three-point bending and four-point bending. The first configuration concerned 8 types of three-panel cross-laminated timber (CLT) beams accounting for various materials and thickness of timber panels as well as various materials and thickness of adhesive layer, while the second one concerned 5 types of two-panel aluminium laminated beams accounting for different thickness of adhesive layer. Simplified multilayer sandwich model is found to be in good accordance with FEA results and with experimental data, while simple BE and T models are shown to provide erroneous estimates.

References listed at the end of the paper:

4 E. Carrera, M. Petrolo, Refined One-Dimensional Formulations for Laminated Structure Analysis, AIAA J, 50 (2012), pp. 176-189
6 F.J. Plantema, Sandwich construction: the bending and buckling of sandwich beams, plates, and shells, John Wiley and Sons, New York (1966)
12 T.P. Vo, H.T. Thai, Static behavior of composite beams using various refined shear deformation theories, Compos Struct, 94 (2012), pp. 2513-2522, 10.1016/j.comstruct.2012.02.010
13 D.I. Żuravskiy, Sur la résistance d’un corps prismatic et d’une pièce composée en bois ou en tôle de fer à une force perpendiculaire à leur longueur, Mémoires Ann Des Ponts Chaussées, 2 (1856), pp. 328-351
provides validation of some methods and indication of the degree of accuracy of some other methods. The
solution, finite element method and experimental measurement. The correlation between the different methods
stiffness, and strains. Methods for the determination of these behaviors inclu

ABSTRACT:

Composite Structur

Farjad Shadmehri, Daniel Rosca and

Saeid Khadem Moshir, Suong V. Hoa, Farjad Shadmehri, Daniel Rosca and Ashraf Ahmed (Concordia Center
for Composites, Department of Mechanical, Industrial and Aerospace Engineering, Concordia University,
Montreal, Quebec H3G 1M8, Canada), “Mechanical behavior of thick composite tubes under four-point
bending”, Composite Structures, Vol. 242 Article 112097, 15 June 2020,

https://doi.org/10.1016/j.compstruct.2020.112097

ABSTRACT: This paper presents the behavior of thick thermoplastic composite tubes made by an automated
fiber placement machine, and subjected to four-point bending load. The mechanical behavior includes flexural
stiffness, and strains. Methods for the determination of these behaviors include strength of material, analytical
solution, finite element method and experimental measurement. The correlation between the different methods
provides validation of some methods and indication of the degree of accuracy of some other methods. The

Vincenzo Gulizzi (1,2), Ivan Benedetti (2) and Alberto Milazzo (2)

(1) Center for Computational Sciences and Engineering (CCSE), Lawrence Berkeley National Laboratory MS,
50A-3111, Berkeley, CA 94720, USA

(2) Department of Engineering, University of Palermo, Viale delle Scienze, Edificio 8, 90128 Palermo, Italy

“A high-resolution layer-wise discontinuous Galerkin formulation for multilayered composite plates”,
Composite Structures, Vol. 242 Article 112137, 15 June 2020,

https://doi.org/10.1016/j.compstruct.2020.112137

ABSTRACT: In this work, a novel high-resolution formulation for multilayered composite plates is presented. The
formulations is referred to as high-resolution since it combines (i) Layer-Wise plate theories, which are
based on a per-layer, high-order expansion of the primary variables throughout the plate’s thickness, providing
a detailed layer-level description of the sought solution; (ii) The discontinuous Galerkin method, a numerical
formulation based on a discontinuous representation of the unknown fields over the mesh elements and on the
introduction of boundary integral operators enforcing inter-element continuity, which allow the natural
treatment of high-order mesh elements and provide high-resolution on the representation of the primary
variables and their derivatives; (iii) The implicitly-defined mesh technique, a meshing strategy based on an
implicit representation of the plate domain, which allows resolving the presence of curved boundaries with
high-order accuracy.

Numerical tests are provided to investigate the effect of the penalty parameter and to show the optimal
convergence of the proposed formulation, which is subsequently employed in combination with an implicitly-
defined hierarchical quad-tree mesh to resolve the stress distribution in a rectangular plate and in a plate with a
circular hole.
accuracy of some calculating methods provides the ability to predict the performance of other thick composite tubes subjected to similar loading and support conditions.


ABSTRACT: In this paper, for the first time, three-dimensional (3D) thermo-elastoplastic bending analysis of functionally graded (FG) sandwich plates with FG face sheets and FG/homogeneous core subjected to combined thermal and mechanical loads is performed. It is assumed that the functionally graded material (FGM) is composed of two different constituents (metal-ceramic) whose volume fractions vary continuously in the thickness direction according to a power law. The von-Mises yield criterion and isotropic strain hardening rule are employed, while temperature-dependent thermal and mechanical properties of the materials are taken into account. A complete 3D meshless numerical model based on the local radial point interpolation method (LRPIM) is developed and used in all analyses. Several numerical examples for temperature, deflection and stress analysis of FG sandwich plates are presented considering different material gradients, layer thickness ratios, thickness-to-length ratios, and boundary conditions. The numerical results are compared with the existing results of 3D, quasi-3D, and 2D shear deformation theories and an excellent agreement is observed.


ABSTRACT: In this research, a Jacobi-Ritz approach is introduced for dynamic analysis of laminated composite shallow shells subjected to arbitrary boundary conditions. The first-order shear deformation theory (FSDT) is utilized to construct the theoretical model. Under the present framework, the multi-segment partitioning strategy is employed. The displacement functions of each segment for the shallow shells are represented by a function of Jacobi polynomials along the length and width orientations. The artificial spring technique is brought into to deal with the issues with respect to continuity condition of the interface between adjacent segments and the arbitrary boundary condition. For the solution procedure, the Rayleigh-Ritz on the basis of the energy functions of the shallow shell is utilized. The proposed Jacobi-Ritz method is conveniently appropriate for various boundary conditions including both classical and elastic boundary conditions. Then, the accuracy and reliability of the methodology are confirmed by comparison with results from literature. At last, new results for free vibration of laminated composite shallow shells subjected to classic as well as elastic boundary conditions are exhibited, which may be served as reference data.


ABSTRACT: In this paper, a higher-order element based on the unified and integrated approach of Timoshenko beam theory is developed. A two-node beam element with Hermitian functions of a 5th-degree polynomial (4 DOFs per node) called UI element is proposed to solve the problems of static and free vibration. In this proposed element, the Timoshenko beam theory is modified in such a way to prevent shear locking while taking account of the transverse shear effect. The static and free vibration analyses are used to obtain the displacements and natural frequencies of rectangular Functionally Graded Material (FGM) beam for hinged-roll, clamped-free and clamped-clamped boundary conditions and to study the effects of the power-law exponent (coupling of the anisotropic material) on the displacements and natural frequencies. Results of the present work are compared with the published data to learn the effectiveness of the proposed element and to verify the validity of the model theory. The numerical analysis shows that the coupling of axial-bending should be taken into consideration in static and vibration analysis of FGM. The comparison study confirms the accuracy and the efficiency of the proposed element for static and vibration analysis of FGM beam.
Xiaodong Chen (1) and Guojun Nie (2)
(1) School of Civil and Transportation Engineering, Henan University of Urban Construction, Pingdingshan 467000, China
(2) School of Aerospace Engineering and Applied Mechanics, Tongji University, Shanghai 200092, China

“Prebuckling and buckling analysis of moderately thick variable angle tow composite plates considering the extension-shear coupling”, Composite Structures, Vol. 242 Article 112093, 15 June 2020,
https://doi.org/10.1016/j.compstruct.2020.112093

ABSTRACT: In this paper, an analytical model based on a generalized Rayleigh-Ritz method is developed to deal with both the prebuckling and buckling problems of moderately thick VAT composite plates under a more general in-plane boundary condition. The non-uniform in-plane stress fields of VAT composite plates under various in-plane boundary conditions is firstly determined based on the minimum complementary energy principle combined with the Airy’s stress function. Afterwards, the governing equation of buckling problem of VAT composite plates under non-uniform in-plane stress fields is derived based on third-order shear deformation theory of Reddy’s type. The innovation of this paper lies in that a linear fitting method combined with Chebyshev-Gauss-Labotto point distribution is introduced to retrieve the boundary stress coefficients from the stress constraint conditions generated by the Lagrangian multiplier method, and meanwhile an integral expression of work done by the unknown boundary force along the prescribed in-plane displacement is adopted to satisfy the displacement constraint condition along the boundary line. In so doing, three kinds of in-plane boundary conditions are taken into account, that is, pure stress boundary condition, pure displacement boundary condition and mixed stress and displacement boundary condition. In addition, no assumption is made on the extension-shear coupling terms and thus the proposed analytical model is suitable to the unbalanced layup. The accuracy and robustness of the proposed analytical model is validated by finite element analysis and with prior results. Effects of the in-plane boundary condition, extension-shear coupling and varying fibre orientation angles on both in-plane stress and buckling responses of VAT composite plates are studied by numerical examples. It is shown that for the balanced panels under uniform compression, the benign load redistribution mechanism offered by the VAT layups remain in effect even if there exists the non-uniform shear constraint along the loading edges. However, the buckling load of the panel can be reduced by the shear constraint along the loading edges to a certain degree. Furthermore, it is found that for some displacement-controlled shear loading cases, the extension-shear coupling plays a positive role in the load redistribution, which results in a sight improvement in the longitudinal load of the panel when critical buckling occurs.

Yu Feng (1), Binlin Ma (1), Ronghong Cui (1), Tao An, (1), Yutang He (2) and Shengbo Jiao (3)
(1) Aeronautics and Astronautics Engineering College, Air Force Engineering University, Xi’an 710038, China
(2) School of Aeronautics, Northwestern Polytechnical University, Xi’an 710072, China
(3) School of Aviation on Operations and Services, Aviation University of Air Force, Chang Chun 130000, China

“Effects of hygrothermal environment on the buckling and postbuckling performances of stiffened composite panels under axial compression”, Composite Structures, Vol. 242 Article 112132, 15 June 2020,
https://doi.org/10.1016/j.compstruct.2020.112132

ABSTRACT: Effects of hygrothermal environment on the buckling and postbuckling performances of stiffened composite panels under axial compression were investigated experimentally and numerically in this paper. Hygrothermal aging experiment on stiffened composite panels was conducted in 70 °C distilled water and the moisture uptake was analyzed every 24 h until to moisture saturation. Moisture uptake process and moisture content distribution along the thickness direction were analyzed by using finite element (FE) method. Thin region and thick region of stiffened composite panels were defined and classified respectively according to moisture uptake process. Then the axial compressive experiments were performed on the hygrothermal aged specimens, with comparison of compression on virgin specimens. Strains, loads, out-of-plane displacements, shortening and failure modes were analyzed comparatively. The results indicate the hygrothermal environment impose much negative effects on the stability and carrying ability of specimens. In the end, a new approach for simulating the dynamic properties of unsaturated specimens was proposed, which considered the gradient of moisture content. Effects of various moisture content on buckling and postbuckling performances were determined.

ABSTRACT: The deformation and failure of hybrid composite sandwich beams with an aluminum foam core under quasi-static load and low-velocity impact are investigated. The sandwich beams comprise of two carbon fiber-reinforced plastic (CFRP) face sheets which have identical/unidentical thicknesses. The experimental results show that hybrid composite sandwich beams exhibit four active failure modes: face-sheet fracture, indentation, core shear and core shear-tension. Core shear occurs in sandwich beams with two identical face sheets, while core shear-tension develops in sandwich beams with two unidentical face sheets. An asymmetrical sandwich beam with a thicker top face sheet has superior load-carrying capability than those with a thinner top face sheet for the same total thickness of the top and bottom face sheets. For the similar failure modes of hybrid composite sandwich beams under quasi-static load and low-velocity impact, the low-velocity impact collapse load is higher than that corresponding to quasi-static collapse. The collapse loads of hybrid composite sandwich beams predicted by simple theoretical solutions are in good agreement with the experimental values.


ABSTRACT: Previous studies suggested that the behaviors of confined concrete in concrete-filled steel tube (CFT) columns were dependent on their confining stress paths, which thus should be considered in order to well predict their behaviors. Several confining stress path dependent analytical models had been proposed, which, however, were all developed for fiber polymer (FRP) confined concretes. Although one of the existing models

Wei Zhang (1), Qinghua Qin (1,2), Jianfeng Li (1), Kaikai Li (1), L.H. Poh (3), Yan Li (4), Jianxun Zhang(1,2), Shejuan Xie (1), Hongen Chen (1) and Jianping Zhao (1)

1) Strength and Vibration of Mechanical Structures, Department of Engineering Mechanics, Xi’an Jiaotong University, Xi’an 710049, China
2) Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, China
3) Department of Civil and Environmental Engineering, National University of Singapore, Singapore
4) School of Aerospace Engineering and Applied Mechanics, Tongji University, Shanghai 200092, China


ABSTRACT: This paper describes an efficient framework for the design and optimization of the variable-stiffness composite plates. Equations of motion are solved using a Tchebychev polynomials-based spectral modeling approach that is extended for the classical laminated plate theory. This approach provides highly significant analysis speed-ups with respect to the conventional finite element method. The proposed framework builds on a variable-stiffness laminate design methodology that utilizes lamination parameters for representing the stiffness properties compactly and master node variables for modeling the stiffness variation through distance-based interpolation. The current study improves the existing method by optimizing the locations of the master nodes in addition to their lamination parameter values. The optimization process is promoted by the computationally efficient spectral-Tchebychev solution method. Case studies are performed for maximizing the fundamental frequencies of the plates with different boundary conditions and aspect ratios. The results show that significant improvements can be rapidly achieved compared to optimal constant-stiffness designs by utilizing the developed framework. In addition, the optimization of master node locations resulted in additional improvements in the optimal response values highlighting the importance of including the node positions within the design variables.
can also be applicable to CFT columns, it mainly focused on the specimens with normal strength concrete. Additionally, existing confining stress path dependent models may result in fluctuation issue of load-deflection curves for CFT specimens. This paper proposed a new confining stress path dependent analytical model that is applicable to normal, high and ultra-high strength concrete-filled steel tube columns. Experimental tests were collected to assess the performance of the proposed analytical model, and it was found that the proposed model performs quite well for normal, high and ultra-high strength concrete-filled steel tube columns and generally can avoid the fluctuation issue of load-deflection curves.

Anthony Nagle (1), Diane Wowk (1) and Catharine Marsden (2)
(1) Department of Mechanical and Aerospace Engineering, Royal Military College of Canada, PO Box 17000, Station Forces, Kingston, Ontario K7K 7B4, Canada
(2) Faculty of Engineering and Computer Science, Concordia University, Montreal, QC Canada

**ABSTRACT:** This paper presents the interlaminar normal stress distribution across the width of L-shaped composite components in bending, with special emphasis on the free edge effects and the induced loading due to boundary conditions. As L-shaped composite components are becoming more commonplace in engineering applications, it is of vital importance to understand their failure mechanisms and stress fields. An extensive literature review reveals that interlaminar delamination is the critical failure mode for curved composite components. Despite this, most literature only provides a two-dimensional analysis of the interlaminar stresses and the free edge effects and asymmetry due to induced torsion are not considered. This paper uses three-dimensional finite element modelling to address the following with respect to L-shaped laminate components in bending: (i) radial stress due to the presence of curvature, (ii) effect of lay-up on the free edge effect, (iii) determining how induced torsion affects the interlaminar normal stress distribution. The necessity of using a three-dimensional model to analyse the interlaminar normal stress across the width of a curved composite component is discussed. It was concluded that using a two-dimensional model could underpredict the interlaminar normal stresses by up to 37% for the lay-ups analysed in this research.

Mengchuan Xu (1), Yanzhi Yang (2), Hongshuai Lei (1), Panding Wang (1), Xinyu Li (1), Zhong Zhang (1) and Daining Fang (1)
(1) Lightweight Multi-functional Composite Materials and Structures, Beijing Institute of Technology, Beijing 100081, PR China
(2) Shanghai Aerospace System Engineering Institute, Shanghai 201109, PR China

**ABSTRACT:** This paper presents the interlaminar normal stress distribution across the width of L-shaped composite components in bending, with special emphasis on the free edge effects and the induced loading due to boundary conditions. As L-shaped composite components are becoming more commonplace in engineering applications, it is of vital importance to understand their failure mechanisms and stress fields. An extensive literature review reveals that interlaminar delamination is the critical failure mode for curved composite components. Despite this, most literature only provides a two-dimensional analysis of the interlaminar stresses and the free edge effects and asymmetry due to induced torsion are not considered. This paper uses three-dimensional finite element modelling to address the following with respect to L-shaped laminate components in bending: (i) radial stress due to the presence of curvature, (ii) effect of lay-up on the free edge effect, (iii) determining how induced torsion affects the interlaminar normal stress distribution. The necessity of using a three-dimensional model to analyse the interlaminar normal stress across the width of a curved composite component is discussed. It was concluded that using a two-dimensional model could underpredict the interlaminar normal stresses by up to 37% for the lay-ups analysed in this research.

ABSTRACT: The dynamic hygro-thermo-elastic response of cylindrical shells with a porous microcapsule coating under coupled transfer of heat and moisture is investigated in this article. This structure is treated as a double-layer cylindrical shell for simplifying the calculation. The one-dimensional Luikov’s equations are applied to build the coupling diffusion system of heat and moisture and the nonlinear dynamic governing equations are based on the classical shell theory. The differential quadrature method (DQM) and the Runge-Kutta method are used to achieve the numerical results of temperature and moisture fields. Moreover, the Runge-Kutta method is used to solve the nonlinear dynamic governing equations. Effect of different temperature and moisture boundary conditions, geometry size of microcapsules and porosity are considered in this paper. Investigations in this paper may offer theoretical references to researches of the microcapsule coating operating in complex environment conditions.

Tran Ich Thinh (1), Dao Huy Bich (2), Tran Minh Tu (3) and Nguyen Van Long (3)  
(1) Ha Noi University of Science and Technology, 1 Dai Co Viet Road, Hanoi, Viet Nam  
(2) Vietnam National University, No. 144 Xuan Thuy St., Cau Giay District, Hanoi, Viet Nam  
(3) National University of Civil Engineering, 55 Giai Phong Road, Hanoi, Viet Nam


ABSTRACT: This paper investigates analytically the non-linear buckling and post-buckling of functionally graded material (FGM) variable thickness toroidal shell segments subjected to axial compression, external pressure, including temperature effects. The improved Donnell shell theory with von Karman nonlinearity, Stein and McElman assumption are adopted to obtain the governing equations of non-linear buckling of toroidal shell segments. The static buckling loads and the post-buckling load-deflection curves for the variable thickness toroidal shell segments are determined by using the Galerkin’s method. The present results are validated by comparing with the solutions published in the available literature for the specific cases. Effects of geometrical and material parameters, the thickness distribution, and temperature change on the nonlinear buckling behavior of the toroidal shell segments are studied in detail.

Zhiwei Zhou (1), Meixia Chen (1), Wenchao Jia (1) and Kun Xie (2)  
(1) School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Wuhan 430074, China  
(2) College of Engineering, Huazhong Agricultural University, Wuhan 430070, China


ABSTRACT: This paper develops a theoretical approach to study free and forced vibrations of simply supported Z-reinforced sandwich structures with cavities in vacuum and water. A multi-level homogenization model is firstly proposed to transform the core layer of the sandwich structure to an orthotropic material. Then the first-order shear deformation theory (FSDT) is adopted to describe displacement fields and Hamilton’s principle is used to derive motion equations of the sandwich structure. In water domain, the acoustic pressure and the continuity on the fluid-structure coupling face are governed by Helmholtz equation and Euler’s equation respectively. By the aid of Green’s function, the transverse vibration formula is rebuilt through regarding the submerged sandwich structure as a thin plate. New motion equations are thus achieved. Under simply supported boundaries, natural frequencies and forced vibration responses are obtained via the Navier method. By comparing theoretical results with those from finite element (FE) and boundary element (BE) analyses, the high accuracy of the present approach is verified and a clear application frequency range is found. Besides, effects of diameters of reinforcements and cavities on free vibration are discussed. Influences of the external force location and fluid loading on forced vibration are also studied.

ABSTRACT: Up to date, a considerable experimental work has been performed to reveal the impact behavior of polymer foam core sandwich composites. Though, a few attempts have been made to integrate shear thickening fluids (STF) in closed cell rigid polyurethane foams (PU). STF possess a unique rheological property providing a rapid response to the structure against impact loads. The effects of STF on polymer foam cell morphology, thermal stability, and mechanical performance are investigated with advanced characterization techniques. The drop-weight impact test results of sandwich composites show that STF filled PU foam cores exhibit a higher energy absorption rate compared to its neat counterpart. Specific compressive strength and impact energy absorbing capability of STF filled PU foam cores increase with respect to the higher cell thickness-to-length ratios and higher cell densities achieved with STF inclusion. In addition, STF filled PU foam core sandwich composites are found to respond with lower damage width compared to neat PU foams.

Dong Han (1), Xiguang Gao (1), Huajun Zhang (2), Sheng Zhang (2), Guoqiang Yu (1) and Yingdong Song (1)
(1) Aerospace Power System, College of Energy and Power Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China
(2) Representative Office of No. 420 Factory, the Chinese People’s Liberation Army, Chengdu 610503, PR China


ABSTRACT: This study presents numerical simulations of a unidirectional ceramic matrix composite (CMC) plate under different loads considering the effect of fluid-structure interaction (FSI). The two-scale method was used in the dynamic simulation of CMC plate. The shear-lag model considering the damage modes of CMCs was used to simulate the constitutive behavior in the micro-scale. The explicit dynamic finite element method was used to simulate the dynamic response in the macro-scale. The dynamic responses of CMC plate under impulse and harmonic load were simulated. The incompressible Navier-Stokes equations were employed in the simulation of fluid. The dynamic response of CMC plate with FSI was solved based on the staggered method. The effect of fluid on the dynamic response of CMC plate was discussed.


ABSTRACT: In this paper, damped dynamic deflections of an advanced piezoelectric sandwich plate (APSP) subjected to thermo-electro-mechanical loads have been studied using a meshless method. In the considered APSP, two active piezoelectric layers are attached on to the faces of a passive advanced structure consisting of two thin graphene reinforced nanocomposite (GRNC) layers and a thick porous polymeric core. In GRNC layers, graphene content is assumed to be varied according to functional distribution profiles. Using modified Halpin-Tsai’ equations, temperature dependent material properties of nanocomposite layers have been determined. Reddy’s third order theory of plates (called TSDT) is utilized to obtain the coupled governing equations, and MLS shape functions are adopted in the meshless solution. The influences of graphene content, porosity, temperature, electro-mechanical loading and structural damping on dynamic deflection behavior have been investigated. The results reveal that adding graphene volume fraction from 3% to 7% significantly affects the damping ratio, settling time and dynamic response of APSPs. However, further addition of graphene content has little effect on those responses. Moreover, embedding more pores in the core layer remarkably changes the damped dynamic behavior of APSPs due to a significant reduction in structural weight and a slight decrease in structural stiffness.

Qingtao Gong (1), Haichao Li (2), Hailong Chen (2,3), Yao Teng (4) and Na Wang (3,5)
(1) Ulsan Ship and Ocean College, Ludong University, Yantai 264025, PR China
(2) College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, PR China
(3) Yantai Research Institute and Graduate School of Harbin Engineering University, Yantai 264000, PR China
(4) CIMC Raffles Offshore Ltd., Yantai 264000, PR China
(5) College of Power and Energy Engineering, Harbin Engineering University, Harbin 150001, PR China

ABSTRACT: This paper presents a generalized formulation to analyze the free vibration characteristics of stepped functionally graded spherical torus shell based on the Ritz method. Two kinds of the functionally graded model are considered in this study, and the first-order shear deformation theory (FSDT) is adopted to obtain the displacement fields of the model. The accurate results can be guaranteed by using domain decomposition method, in which the displacement functions component along axial direction and circumferential direction are respectively represented by unified Jacobi polynomials and Fourier series. In addition, the spring stiffness method is applied to simulate various complex boundary conditions, and the final solutions can be obtained by using Ritz method. The results of the same condition are compared with the numerical results which obtained by finite element method (FEM) and published literatures to verify the validation of the present method. On this basis, the vibration characteristics of stepped functionally graded spherical torus shell with general boundary conditions are further studied by a series of numerical examples.

Ran Wang (1), Hu Ding (1), Xuegang Yuan (2), Na Lv (2) and Li-Qun Chen (1)
(1) School of Mechanics and Engineering Science, Shanghai University, Shanghai 200072, China
(2) College of Science, Dalian Minzu University, Dalian 116600, China


ABSTRACT: Based on the hyperelastic material models, the propagation of nonlinear travelling waves in cylindrical rods has been studied. Here, different types of nonlinear travelling waves in a thermo-hyperelastic neo-Hookean cylindrical shell are determined. By using the variational principle, a complex differential dynamical system describing the axisymmetric motion of the shell is derived. The effect of the temperature fields is considered. Moreover, the structure is extended from a one-dimensional rod to a three-dimensional cylindrical shell. Then in terms of the bifurcation theory, a detailed qualitative analysis of the system is carried out, and for the bifurcation parameters, their corresponding critical bifurcation values are determined. Combining with the orbits in phase diagrams under different parameters, solitary waves and periodic waves are found in the shell. It is worth pointing out that the solitary waves with the valley form may appear in the radial direction of the shell. The implicit analytical solutions and profiles of these travelling waves are given. There is a promising prospect for the propagation of strongly nonlinear travelling waves to detect structural defects and determine material parameters.

Imam Jauhari Maknun (1), Irwan Katili (1), Adnan Ibrahimbegovic (2) and Andi Makarim Katili (1)
(1) Universitas Indonesia, Civil Engineering Department, Depok 16424, Indonesia
(2) Université de Technologie de Compiègne, Sorbonne Universities, CNRS FRE 2012 Roberval, 60203 Compiègne, France


ABSTRACT: In this paper, we propose an efficient 3-node shell element with 6 DOFs per node based on Naghd-Reissner-Mindlin theory. This new composite shell element, further denoted as DKMT18, takes into account shear deformation and coupled bending-membrane energy. DKMT18 element passes membrane, bending, and shear patch tests with no spurious mode. It also performs successfully in standard tests for thick and thin shells problems without membrane or shear locking. The proposed shell element is capable of dealing with composite laminated shell structures. The computed results by the DKMT18 element converge more rapidly towards the reference solution compared to any state-of-the-art shell element.

Zhengping Sun (1), Philippe Le Grognec (2) and Kahina Sad Saoud (3)
(1) Mines Douai, Polymers and Composites Technology & Mechanical Engineering Department, 941 rue Charles Bourseul, CS 10838 F-59508 Douai Cedex, France
(2) ENSTA Bretagne, UMR CNRS 6027, IRDL, F-29200 Brest, France
(3) Université de Sherbrooke, Department of Civil and Building Engineering, 2500 boulevard de l’Université, Sherbrooke, QC J1K 2R1, Canada

ABSTRACT: Sandwich structures are increasingly applied in many industrial fields of application, due to their lightweight combined with favorable mechanical properties. Despite this, such structures are subject to specific failure modes, such as buckling or vibratory resonance. In both cases, due to the presence of thin and stiff skins, global but also local modes may be of great interest when dimensioning such composite structures, which makes it impossible to use classical models. In this paper, the free vibration problem of classical sandwich columns (with homogeneous core materials) is investigated, using special kinematic models, so as to deal with both global and local eigenmodes in an effective and precise way. First, the problem is addressed analytically, where the two faces are represented by Euler-Bernoulli beams and the core material is considered as a 2D continuous solid, in small strain elasticity. Then, an enriched 1D finite element formulation is developed, so as to handle efficiently more general configurations encountered in practice. The homogeneous core layer is here described using hyperbolic functions, in accordance with the modal displacement fields obtained analytically. The present analytical and numerical solutions (natural frequencies and vibration modes) are contrasted against each other and compared to 2D reference numerical results.

Yu-Jia Hu (1), Hongtao Zhou (1), Weidong Zhu (2) and Jianmin Zhu (1)
(1) School of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai 200093, China
(2) Department of Mechanical Engineering, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA

ABSTRACT: A thermally-coupled elastic large-deformation model of a multilayered functionally graded material (FGM) curved beam with an arbitrary undeformed configuration is established based on two-variable geometrical relations that consider the effect of the curvature of an arbitrary undeformed configuration of a beam, thermally coupled constitutive relations, and balanced forces. By use of a reference strain and reference undeformed and deformed curvatures at the same reference layer of a multilayered FGM curved beam, the difficulty of determining the position of the neutral axis of a beam in its classical analysis is resolved. The differential quadrature method is used to solve the strongly nonlinear coupled model proposed in this work. As applications, thermally-coupled large-deformation analyses of a multilayered straight beam and FGM and multilayered FGM curved beams under thermal–mechanical loads are studied in detail. Numerical results show that there are significant differences between the current thermally coupled analysis and conventional thermoelastic analysis with a thermally-uncoupled constitutive relation. Various snap-through phenomena occur when the FGM curved beam is under thermal–mechanical loads.

D.A. Pereira (1,3), T.A.M. Guimarães (2), H.B. Resende (3) and D.A. Rade (1)
(1) ITA – Aeronautics Institute of Technology, Division of Mechanical Engineering, Brazil
(2) UFU – Federal University of Uberlândia, School of Mechanical Engineering, Brazil
(3) IPT – Lightweight Structures Laboratory, Institute for Technological Research, Brazil

ABSTRACT: This present paper is devoted to the numerical and experimental investigation of the modal characteristics of composite laminates, with emphasis on damping. Complementing previous studies dedicated to conventional laminates, one considers variable-angle tow laminates, in which the fibers are deposited following curvilinear trajectories. The main objective is to characterize the influence of fiber steering on the damping levels, and evaluate the possibility of achieving increased damping. A dynamic model is derived by combining the semi-analytical Rayleigh–Ritz approach, the Classical Lamination Theory, and the Strain Energy Method. This later enables to estimate the specific damping capacity of each vibration mode. Based on this model, analytical developments are performed aiming at putting in evidence the contribution of each strain component in each layer of the laminate to the specific damping capacities. The results of numerical simulations are presented, enabling to compare the values of specific damping capacities and vibration natural frequencies obtained for variable-angle tow and conventional laminates in a variety of simulation scenarios. Some of the
numerical results are validated by comparisons with experimental counterparts. The results confirm the effectiveness of design strategies intended to regulate and possibly increase the damping levels of composite laminates by exploring fiber steering.


ABSTRACT: It is widely acknowledged that laying up composite tapes and fabrics on doubly curved surfaces can introduce wrinkling and overlap defects. It is also not a straightforward task to define fibre angle directions. The latter problem amplifies when considering curvilinear fibre paths on doubly curved surfaces. Herein, we define a new fibre orientation datum curve and use this as a reference for optimisation purposes. A novel implementation of lamination parameters is introduced whereby we constrain the values of lamination parameters based on minimum turning radii of automated fibre placement machines and maximum ply angle change for stiffness optimisation. As an example, this approach is applied to a pre-twisted plate with 68 layers subjected to combined centrifugal and pressure loading. Lamination parameters are used to reduce the complexity and multiplicity of composite laminate design with many layers to a convex and continuous design space using a reduced number of variables. Lamination parameters are varied over the geometry using spline surface interpolation over a grid of control points and the optimal lamination parameter values are found using a gradient based optimiser. The fibre paths for each ply are then designed from the optimal lamination parameter variation using a two-stage optimisation process.


ABSTRACT: A generalization of physically-based fixed degrees of freedom 3-D zig-zag theories is developed, which allows for any arbitrary choice of layerwise and representation functions. Thereby users can choose arbitrarily the representation case-by-case. This paper aims to prove that the choice of global and layerwise functions is immaterial whenever coefficients are recalculated exactly (via symbolic calculus) by the enforcement of interfacial stress continuity, boundary conditions and equilibrium in point form, as prescribed by the elasticity theory. Vice versa, accuracy of theories partially fulfilling constraints will prove to largely depend on the assumptions made and to be inadequate when strong layerwise effects rise, under distributed/localized step loading and boundary conditions other than simply supported edges (tests carried out in closed-form). The present and previous authors’ theories are tested with the aim to understand in which cases an adequate level of accuracy is still achieved by lower-order theories that are derived as particularizations.

Yong-Chang Guo (1), Shu-Hua Xiao (1), Shu-Wei Shi (1), Jun-Jie Zeng (1), Wei-Qiang Wang (2) and Hong-Chao Zhao (3)
(1) School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, China
(2) School of Civil and Environmental Engineering, University of Technology Sydney, NSW 2007, Australia
(3) School of Geology and Mining Engineering, Xinjiang University, Xinjiang, Ürumqi 83000, China

ABSTRACT: This paper presents investigations on a new column form, namely, concrete-filled fiber-reinforced polymer-stem wire reinforced thermoplastics pipe (FRP-SRTP) columns (CFFSCs) which consist of a SRTP tube with an outer FRP confinement system and concrete filled in the core area. A series of axial compression tests were performed on CFFSCs, and parameters including the number of FRP layers, the FRP fiber type and the clear spacing of the FRP rings were investigated. The test results demonstrate that the concrete-filled SRTP tube columns have an excellent ductility and the outer FRP confinement system provides efficient confinement to CFFSCs. The dilation behavior of the concrete in CFFSCs with polyethylene terephthalate FRP is different to that of the concrete in CFFSCs with carbon FRP. Four existing design-oriented models are adopted to generate the ultimate axial stresses and their corresponding strains of concrete in CFFSCs. By comparing the test results and the theoretical predictions, it is found that the existing models provides inaccurate predictions for CFFSCs.
The new column form is particularly suitable as a form of standing support for underground mines, where a novel supporting system requires both a large deformation capacity and a good structural integrity.

Rogério Carrazedo, Rodrigo Ribeiro Paccola, Humberto Breves Coda and Rafael Correa Salomão (São Carlos School of Engineering, University of São Paulo, Av. Trabalhador São Carlense, 400, ZIP 13566-590 São Carlos, SP, Brazil), “Vibration and stress analysis of orthotropic laminated panels by active face prismatic finite element”, Composite Structures, Vol. 244 Article 112254, 15 July 2020,
https://doi.org/10.1016/j.compstruct.2020.112254
ABSTRACT: In this paper a strategy for the stress analysis of sandwich plates and shells employing the active face triangular-based prismatic finite element is provided, which combines three-dimensional membrane elements (called active face) with solid elements providing stiffening cells, usually called honeycomb. The connection of solid and active face elements is done by direct nodal correspondence, keeping the total number of degrees of freedom unaltered, which makes the technique highly economical from the numerical point of view. Orthotropic properties are specially addressed, which are important for material failure criteria studies. The accuracy of the active face prismatic finite element is also evaluated in the calculation of natural frequencies of honeycomb sandwich panels for acoustic vibration isolation purposes, for instance. Results for orthotropic sandwich plates and shells are presented and compared with established commercial software and literature results.

Jakub Marczak (Department of Structural Mechanics, Łódź University of Technology, Al. Politechniki 6, 90-924 Łódź, Poland), “On the correctness of results of averaged models of periodic sandwich plates depending on the set of fluctuation shape functions”, Composite Structures, Vol. 244 Article 112269, 15 July 2020,
https://doi.org/10.1016/j.compstruct.2020.112269
ABSTRACT: (None given)

Jincan Liu (1,2), Xiaowei Deng (3), Qingshan Wang (4), Rui Zhong (4), Rui Xiong (1) and Jing Zhao (2,3)
(1) School of Electromechanical Engineering, Guangdong University of Technology, Guangzhou, PR China
(2) Guangdong Provincial Key Laboratory of Technique and Equipment for Macromolecular Advanced Manufacturing, South China University of Technology, PR China
(3) Department of Civil Engineering, The University of Hong Kong, Hong Kong SAR, PR China
(4) State Key Laboratory of High Performance Complex Manufacturing, Central South University, Changsha, PR China
“A unified modeling method for dynamic analysis of GPL-reinforced FGP plate resting on Winkler-Pasternak foundation with elastic boundary conditions”, Composite Structures, Vol. 244 Article 112217, 15 July 2020,
https://doi.org/10.1016/j.compstruct.2020.112217
ABSTRACT: In this paper, dynamic analysis of functionally graded porous (FGP) plate with reinforcement of graphene platelets (GPLs) resting on elastic foundation and restrained by elastic boundary condition is investigated. Four types of porous materials reinforced with four types of graphene platelets varying along the thickness direction are considered. The analytical model of the GPLs-FGP plate is formulated by the first-order shear deformation theory and the multi-segment partition technique. For each plate segment, the displacement component of translation and revolution is implemented by Jacobi polynomials. Ultimately, the dynamics of the GPLs-FGP plate analysis model is solved by the Rayleigh-Ritz method. Aimed at validating the accuracy of the present method, the analytical results are compared with the results of finite element simulations after the convergence test is completed. Based on the above investigation, series of parametric studies with regard to the free, forced vibration and transient analysis are conducted, which provide reference data for future research.

Yang Wei (1), Yirui Zhang (1), Jile Chai (1), Gang Wu (2) and Zhiqiang Dong (2)
(1) College of Civil Engineering, Nanjing Forestry University, Nanjing, Nanjing 210037, China
(2) Concrete and Prestressed Concrete Structures, Southeast University, Nanjing 210096, China
“Experimental investigation of rectangular concrete-filled fiber reinforced polymer (FRP)-steel composite tube columns for various corner radii”, Composite Structures, Vol. 244 Article 112311, 15 July 2020,
https://doi.org/10.1016/j.compstruct.2020.112311
ABSTRACT: To study the compressive behavior of rectangular concrete-filled fiber reinforced polymer (FRP)-steel composite tube (CFCT) columns, twenty-nine specimens were tested under compression loading in five
series based on the corner radius. The variables are the corner radius of cross-section, the number of layers of FRP and the type of FRP wrapping. The experimental results revealed that the FRP wrapping may effectively suppress the local buckling for the steel tubes prior to FRP rupturing. The FRP fractures occurred at the corners in the middle of the specimens or at the longitudinal weld seams due to local stress concentrations. The stress–strain curves are influenced significantly by the corner radii for the rectangular CFCT columns. As the corner radius is increased, the linear ascending or descending slopes after the peak points of the stress–strain curve is generally enhanced, and a descending curve can be transformed into an ascending curve. For a given FRP confinement, the ultimate strength increased with increasing corner radius. Based on the experimental results and collected test data, a unified model with a simple and unified expression for predicting ultimate axial strength considering the shape and corner radius of the cross-section was proposed for the CFCT columns.


ABSTRACT: Free vibration and damping analysis of porous functionally graded (FG) sandwich plates are presented based on a modified Fourier-Ritz method. The sandwich plate is composed of a viscoelastic core and two porous FG face layers. A complex elasticity modulus is employed to describe the viscoelastic core. Material properties of the porous FG face layer are described continuously across each face thickness according to a volume fraction index and a porosity coefficient. The distribution of porosities within the face layers is formulated either evenly or unevenly. The displacements are constructed by the first-order shear deformation theory combined with the modified Fourier method. The free vibration and damping analysis of a porous single-
Cylindrical shells with the same weights including functionally graded viscoelastic, functionally graded, through the shell is ex

influence of various power

Next, the effects of geometrical and material characteristics on the transmission loss factor are investigated. The

with those of some researchers in the literature of elastic materials, and excellent concurrences are obs

to the lack of study on the vibro

varying continuously in the thickness direction as well as considering the

A study presents an analytical solution for calculating sound transmission through a cylindrical shell made of polymeric foam. The intended cylinder is excited by an acoustic plane wave.

ABSTRACT: This study presents an analytical solution for calculating sound transmission through a cylindrical shell made of polymeric foam. The intended cylinder is excited by an acoustic plane wave.


ABSTRACT: Carbon fibre-reinforced aluminium laminates are relatively new fibre-metal laminate materials. Their properties include low density, high resistance and rigidity, and high fatigue strength. This study aimed to evaluate the CARALL response to low-velocity impact, based on experimental tests and numerical analyses of damage initiation and propagation mechanisms. These experimental tests and numerical simulations involved the use of both quantitative and qualitative criteria for assessing the FML damage under dynamic load. It was shown that the mechanism of laminate damage is fairly complex and related to the internal degradation of the composite material with characteristic permanent deflection of the FML. Matrix fractures, carbon-fibre cracking, and delamination were found to be the main modes of damage. The delamination observed at the interfaces of specific multidirectional plies of the composite material and the delamination at the metal-composite interfaces were the critical damage modes of the FMLs. The proposed FEM, including its user-developed failure criteria and cohesive zone, can be used to further examine the influence of various parameters describing FMLs and other adhesive-bonded materials in an effective and reliable manner.

ABSTRACT: This study presents an analytical solution for calculating sound transmission through a cylindrical shell made of polymeric foam. The intended cylinder is excited by an acoustic plane wave.


ABSTRACT: In this work, the use of pultruded GFRP web stiffeners to enhance the flange local buckling behavior of pultruded GFRP open-section beams was proposed and demonstrated through a numerical study. The buckling strength of the GFRP I-beam was successfully increased by up to 207% via this approach. The influences of the stiffener geometry and spacing were investigated. The buckling strength of the GFRP I-beam increased as the stiffener width increased and the stiffener spacing decreased. Epoxy adhesive was found to provide a sufficient bonding effect between the web stiffeners and the beams. In addition, a design approach was proposed to predict the increased buckling strength of GFRP I-beams strengthened with web stiffeners. A comparison with finite element analysis and experimental results showed that the design equation was able to provide uniformly conservative predictions. Additionally, practical design suggestions were provided to ensure the best performance of the web stiffeners. The strengthening approach addressed in this work could potentially permit a longer span of GFRP profiles and a wider application of GFRP structures.

ABSTRACT: This study presents an analytical solution for calculating sound transmission through a cylindrical shell made of polymeric foam. The intended cylinder is excited by an acoustic plane wave.


ABSTRACT: This study presents an analytical solution for calculating sound transmission through a cylindrical shell made of polymeric foam. The intended cylinder is excited by an acoustic plane wave. The equations of motion for the cylindrical shell are derived by the first-order shear deformation. Besides, the polymeric foam is characterized using functionally graded Zener model in which the mechanical properties are varying continuously in the thickness direction as well as considering the frequency-dependent parameters. Due to the lack of study on the vibro-acoustic behavior of the viscoelastic graded materials, the results are compared with those of some researchers in the literature of elastic materials, and excellent concurrences are observed. Next, the effects of geometrical and material characteristics on the transmission loss factor are investigated. The influence of various power-law index illustrates that by reducing this parameter, the sound transmission loss through the shell is extensively increased. Finally, a comparison is performed along with four models of the cylindrical shells with the same weights including functionally graded viscoelastic, functionally graded,
viscoelastic and elastic materials. As a key result, it can be explored that the sound transmission loss in a functionally graded viscoelastic shell is more enhanced than the other cylinders.

Saeed Eyvazinejad Firouzsalari (1), Dmytro Dizhur (1), Krishnan Jayaraman (2), Nawawi Chouw (1) and Jason M. Ingham (1)
(1) Department of Civil and Environmental Engineering, The University of Auckland, New Zealand
(2) Department of Mechanical Engineering, The University of Auckland, New Zealand


ABSTRACT: Application of flax fibre as reinforcement in polymer composites used in the construction and manufacturing industries is a step towards achieving more sustainable construction practices. Flax fabric-reinforced epoxy (FFRE) was used to manufacture forty-two pipes with a variety of internal diameters and flax fabric layers, all with a length-to-internal diameter ratio of 1.5:1. Lateral compression loading was performed on the FFRE pipes to establish the effect of internal diameter and number of fabric layers on the strength, energy absorption capability, strains, and failure mechanism. When compared to previously reported test results for pipes manufactured from different natural fibre composites, the FFRE pipes manufactured in this study and subjected to lateral compression showed higher strength, flexibility, and specific energy absorbed while demonstrating comparable strength, specific strength, and specific energy absorbed with synthetic and hybrid fibre composite pipes.


ABSTRACT: This study presents closed-form solutions for the critical buckling pressures and characteristic frequencies of underwater composite cylinders. The analytical solutions were derived using the full stiffness definitions from composite laminate theory, making them suitable for symmetric, asymmetric, hybrid, and/or double-shell (sandwich) cylindrical composite structures. These closed-form solutions were developed for critical buckling pressures in a hydrostatic environment as well as for critical buckling energy in a dynamic environment with combined hydrostatic and transient loads. Also, the characteristic frequencies were derived for a submerged and pressurized environment to account for added fluid mass and hydrostatic pressures. Computational and experimental data were used to validate the derived analytical work. The resulting solutions for critical buckling pressures agreed with numerical and experimental results for single-shell cylindrical structures. Moreover, for double-shell cylindrical structures with foam cores (sandwich structures), the collapse pressure is shown to be proportional to the core’s transverse shear modulus. The solutions were suitable for predicting the collapse pressure for sandwich structures with relatively low-density cores. Lastly, solutions for estimating the energy emitted during an implosion event and the energy required for buckling in sub-critical pressure environments were also derived and validated with the experimental data.

Marco Amabili (1) and J.N. Reddy (2)
(1) Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street West, Montreal H3A 0C3, Canada
(2) J. Mike Walker ’66 Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843-3123, USA


ABSTRACT: The present study introduces a rigorous higher-order polynomial in the thickness coordinate to develop a theory with thickness and shear deformations for doubly curved, laminated composite shells. In this theory, the nonlinear terms in all the kinematic parameters are kept. By applying the conditions of zero transverse normal and shear stresses at the top and bottom surfaces of shells, a third-order thickness and shear deformation theory with six kinematic parameters is derived. This is a particularly interesting result since the developed theory presents a single additional parameter to describe the thickness deformation with respect to the popular Reddy’s third-order shear deformation theory, which has five parameters. The accuracy of the proposed six-parameter theory is tested for static and dynamic benchmark cases. Results are also very
satisfactorily compared to those obtained with a more sophisticated and computationally onerous nine-parameter theory. The considered cases are isotropic and cross-ply laminated circular cylindrical shells under radial forces and pressure, and nonlinear forced vibrations of a cross-ply laminated shell under harmonic radial excitation.

Mahdi Karimi (1), Korosh Khorshidi (1), Rossana Dimitri (2) and Francesco Tornabene (2) 
(1) Department of Mechanical Engineering, Faculty of Engineering, Arak University, Arak 38156-88349, Iran 
(2) Department of Innovation Engineering, Università del Salento, 73100 Lecce, Italy


ABSTRACT: This work focuses on the hydroelastic vibration of vertical functionally graded (FG) microplates partially in contact with a fluid. The nonlocal Lam strain gradient theory is here proposed to include small-scale effects, with the introduction of three higher-order material constants within the formulation. This non-classical model would revert to the modified couple stress theory (MCST) or the classical continuum model (CCM) for a vanishing value of two or three length scale parameters, respectively. A fifth-order shear deformation theory is employed to capture the transverse shear stresses and rotary inertia effects. An ideal fluid is also assumed to simplify the dynamic problem, where the continuity equation is enforced to determine the fluid velocity potential associated with bulging and sloshing modes. Once the kinetic and potential energy are calculated for the both of structure and interacting fluid, the Rayleigh-Ritz method is employed to determine the wet frequencies of the system. After a preliminary validation of the proposed model, a systematic investigation is performed to check effects of different mechanical and/or geometrical parameters on the vibrational characteristics of the microplate, namely, the small-scale parameters, the aspect ratio, the thickness ratio and the fluid dimensions contacting with the microstructure.


ABSTRACT: In this work, a third-order efficient layerwise theory (ELWT) has been developed for laminated composite and sandwich curved beams of deep curvatures. The circumferential displacement is assumed to have global third-order variation in thickness (radial) coordinate with a linear layerwise variation. The number of independent variables is reduced to 3 by imposing the continuity of displacement and transverse shear stress at interfaces and shear free conditions on the outer and inner surfaces. Equations of the motion are derived using Hamilton’s principle. Navier type analytical solution is obtained for simply supported ends. Results for static deflection, stresses, and natural frequencies are presented for laminated composites and sandwich curved beams of different radii of curvature and thicknesses. The importance of inclusion of the deepness terms (1 + z/R) in the formulation for the static and free vibration responses are discussed by comparing with the exact 2D elasticity solution. It is shown that the results predicted by the present ELWT are more accurate than equivalent single layer theories having same number of variables. For sandwich curved beams, the predictions of third-order theory (TOT) are extremely poor in comparison with ELWT. The results presented in the paper will be useful for assessing the accuracy of other simplified 1D theories.

E. Ansari (1), A.R. Setoodeh (1) and T. Rabczuk (2) 
(1) Department of Mechanical and Aerospace Engineering, Shiraz University of Technology, Shiraz 71555, Iran 
(2) Institute of Structural Mechanics, Bauhaus-Universität Weimar, Marienstrasse 15, 99423 Weimar, Germany


ABSTRACT: A systematically stepwise analysis (SSA) is presented for the free vibration analysis of rotating functionally graded (FG) turbo-machinery blades with linear and non-linear variable thickness operating in thermal environment. The governing equations are extracted by deployment of principle of the virtual work and Hamilton’s principle in the context of first-order shear deformation plate theory (FSDT) and the two-dimensional kinematics of the rotating blades. The nonlinear terms of the strain tensor are taking into account to insert the resulted stresses obtained from a pseudo-static analysis. Also, the inertia and Coriolis forces are
included in the second step of the vibrational analysis. Eventually, the isogeometric analysis (IGA) as a powerful numerical approach is employed to discretize the resulted governing equations. To exhibit the reliability and efficacy of the IGA, a comprehensive comparative study on the predicted natural frequencies and mode shapes of the FG blades is performed compared with the available solutions in published literatures as well as finite element analysis using ANSYS. In order to assist scientists and engineers during the design, the complicated frequency loci veering behavior and the associated mode shifting phenomena are investigated with precisely predicting the coupling between the in-plane, out of plane and torsional vibration.


ABSTRACT: The GFRP elastic gridshell is a type of spatial structure composed of long continuous hollow GFRP members and has been used in large-span roof structures. The elastic gridshell achieves its shape as the result of elastic deformations during the construction process of lifting or pushing. The shape-forming mechanism of such structures is very complicated due to significant geometric non-linearity. This research aims to propose analytic formulations to estimate the structural features of the GFRP elastic gridshell under lifting construction. An analytical theory, considering the large geometric deformations, is first presented for analyzing single lifted member. Based on the given theory and an iteration process, a form-finding method is further proposed for predicting the deformation, nodal forces and bending moment of biaxial symmetrical GFRP elastic gridshells during the lifting construction. The form-finding method is realized on the Matlab platform and a case study is carried out. Finite element analysis is further conducted to validate the accuracy and practicability of the proposed method. Results show that, the analytic theory is highly accurate for the analysis of lifted members, and the proposed form-finding method is applicable in predicting the structural behaviors of GFRP elastic gridshells for which the lifting construction is adopted.


ABSTRACT: In this study, the mechanical behaviour of a truss core glass-fibre reinforced polymer sandwich panel was analysed with an emphasis on the influence of the truss core geometry on the overall behaviour of the sandwich panel. First, the mechanical parameters of the sandwich components (skins and connectors) were experimentally determined, and compression, shear, and three-point bending tests were conducted to assess the main mechanical parameters of the specimens. Then, the analysed behaviours were modelled with finite elements using the Hashin model to predict the failure of the specimens. The model response was validated via comparisons with the experimental data. Finally, the influence of the geometrical and mechanical parameters of the truss core was studied by varying the elastic modulus, slope, diameter, and area density of the connectors. The modelling of connectors with truss elements and the effects of transversal connectors are also discussed.


ABSTRACT: This study is dedicated to understand the possibility of bending before the bifurcation buckling of the functionally graded (FG) plate which has the unsymmetrical material property distribution according to the its midplane. Based on the midplane formulation, the dimensionless critical buckling loads (DCBLS) of FG plates are computed by using a finite element method and shear and normal deformable plate theory for nine different boundary conditions (CCCC, CCSC, SCSC, SSSS, SSSF, SCSF, SSCS, SSSF and SFSF). And then, the FG plate is subjected to in-plane loads which are less than the associated DCBLS to observe the possibility of bending before buckling. It is found that the bifurcation buckling can only be obtained for CCCC, SCSC and SSSC BCs. The bifurcation buckling is impossible for other boundary conditions. For the FG plates having unsymmetrical design, the DCBLS are numerically calculated based on the neutral surface approach as well. It is noteworthy that the true bifurcation buckling can only be observed by using the neutral surface formulation.
The transverse deflection due to the bending is quite pronounced especially for the plates with free edge. Since in-plane load is applied to the free edge, the transverse deflection is inevitable for the FG plates.


ABSTRACT: The effect of circular cut-out and low velocity impact damage on shear buckling and post-buckling performances of composite plates was investigated experimentally and numerically. Numerical solution for the buckling problem was obtained using an approximate Ritz method. Experiments were carried out for shear loaded pristine and damaged specimens, with a comparison of out of plane displacements, strain field, failure modes and mechanisms. For the two different thicknesses tested namely thin and thick laminates, experimental results showed a decrease of 25% and 27% in the post-buckling load for impact damage and center circular cut-out, respectively for the thin laminate. Whereas no significant reduction was detected for the thick laminate. A good correlation between numerical and experimental results were shown in the results.


ABSTRACT: This paper presents an exact solution for doubly-curved shells subjected to thermal loads. The solution is based on equilibrium equations. The through-the-thickness shell temperature is calculated using the Fourier’s heat conduction equation. The governing equations for displacement and temperature are solved using Navier method, which is valid for shell panels with constant curvature and simply-supported edges. The governing equations for temperature and displacements are in term of the thickness variable and they are solved using the differential quadrature method (DQM). The structures are discretized by each layer applying the Chebyshev-Gauss-Lobatto grid distribution. Lagrange interpolation polynomials are used as basis functions. The inter-laminar continuity of transverse stresses and displacements is imposed. The out-of-plane zero-stresses condition are imposed at the top and bottom of the shell since no mechanical loadings are considered in the presented study. The results for spherical, cylindrical and rectangular plates are presented. The results demonstrate the capability of DQM to produce 3D elasticity when compared with other highly accurate available solutions. Consequently, the method can be used to solve multifield problems in continuum mechanics.


ABSTRACT: In this paper, two types of the foam-filled tubes (FFTs), including O-FFTs and T6-FFTs, were prepared by directly inserting Al foams (AFs) into 6061-O Al alloy empty tubes (O-ETs) and 6061-T6 Al alloy empty tubes (T6-ETs), respectively. Quasi-static compression tests of studied specimens were carried out using an environmental chamber under the temperatures ranging from 25 °C to 250 °C. The results show that the mechanical properties of FFTs decrease with temperature increasing. The T6-FFTs show better energy absorption capacities while the deformation modes are less stable than the O-FFTs. The T6-ETs and T6-FFTs change the deformation mode when the temperature is higher than 150 °C. Both of the number of defects and the lengths of cracks decrease for the T6-FFTs with the increment of temperature. A couple of criteria are proposed to effectively describe and predict the deformation mode of FFTs under quasi-static compression.


ABSTRACT: A novel mixed finite element formulation for the layerwise analysis of nonlocal multilayered composite plates is presented. The finite elements are formulated starting from the weak form of a set of governing equations for the laminate layers that were deduced via the Reissner Mixed Variational Theorem. The primary variables, namely displacements and out-of-plane stresses, are expressed at layer level as through-
the-thickness expansions of suitable selected functions with coefficients approximated by the finite element scheme. The through-the-thickness expansion order is considered as a free parameter. This way, finite elements for different refined higher order plate theories can be systematically developed by assembling the layers contributions associated with the variable expansion terms. These contributions are called fundamental nuclei and their definition is formally unique whatever the considered expansion order. The obtained finite elements inherently ensure stresses and displacements continuity at the layer interfaces and they allow to associate different values of the nonlocal parameter to the laminate layers. Standard 9-node and 16-node isoparametric, quadrilateral finite elements have been implemented to verify the viability of the proposed formulation. The obtained results compare favourably with literature solutions and highlight the characteristics of the approach. Original results are proposed also to serve as benchmarking data.


ABSTRACT: The low-velocity impact behaviour of novel composite structures, made of a polymer matrix composite with a superficial 3D printed metallic layer, was studied. The metallic layer was produced through cold spray deposition which is a relatively new additive coating technique allowing for the deposition of metallic coatings on thermal-sensitive substrates, such as the polymeric materials. Micron-sized aluminium particles were used to metallise the surface of basalt-nylon 6 (PA6) laminates manufactured by the compression moulding technique. Three different energy levels (10 J, 20 J, 30 J) were set for the impact tests. The results obtained pointed out the beneficial contributions of the metallic coating on the energy absorbing modes of the polymeric substrates; the positive effects on the damage mechanisms as well as the crack propagation were detected by plastic deformation analyses and ultrasonic damage controls.


ABSTRACT: Fluid seepage and viscoelasticity play important roles in the dissipation of the undesired vibration and impact energies of the poroelastic structures. In the present article, the impact behavior of viscoporoelastic functionally graded plates with bending-induced fluid-flow is analyzed, for the first time. Moreover, the effects of partial support are investigated. Biot’s poroelasticity and Zener’s viscoelasticity models are combined, for the first time and then, the governing equations of the impact of the plate are derived based on the non-linear Hertz law. The nonlinear finite element form of the governing integrodifferential equations of the solid skeleton and the fluid pressure is obtained based on Galerkin’s method and solved using a special accumulation-based time-marching procedure. Treating the adopted quadratic through-thickness distribution of the fluid pressure is another superiority of the present research. The second-order Runge-Kutta numerical time-integration, trapezoidal discretization, and Picard’s iterative updating techniques are employed to deal with the time-dependency of the resulting equations. The effects of the poroelastic, viscoelastic, and support parameters on the time variations of the contact force, indentation, lateral deflection, and pore pressure moment are investigated. Results reveal that the viscoporoelastic plates may exhibit some behaviors that are in contradiction to those of the traditional plates.


ABSTRACT: This paper presents results of study investigating the post-buckling and limit states of compressed thin-walled composite channel-section profiles. Both experimental and numerical methods were used. The primary objective of experiments was to determine the post-buckling characteristics of real structures subjected to compression over the full range of loading until final failure. The experiments involved axial and non-axial compression of the C-profiles with different stacking sequences of plies, fabricated by autoclaving. The effects of eccentric load and ply stacking sequence on the non-linear stability and load-carrying capacity of the
compressed structures were investigated. Numerical analysis was performed by the finite element method and it involved solving the problem of non-linear stability of the compressed thin-walled structures. The purpose of the analysis was to develop experimentally verified numerical models enabling the description of the structure's behaviour in the post-buckling range, including the moment of load-carrying capacity loss. A progressive damage model was used to assess the extent of damage in the composite material. The nonlinear calculations were made by the Newton-Raphson method using the commercial simulation software ABAQUS.


ABSTRACT: In this study, the sound radiation characteristics of the laminated structures reinforced by honeycomb and composed by viscoelastic material was investigated. Temperature- and frequency-dependent behaviors of the viscoelastic material were considered in this analysis, those parameters affected the dynamics effective properties of the composite structure. After the dynamic equivalent effective stiffness and the dynamic deformation of the structure are determined according to the homogenous asymptotic method, the sound radiation behaviors of the structures in fields of frequency and temperature are achieved. Consequently, the sound radiation characteristic, such as the sound pressure in far-field and the sound radiation efficiency that influenced by the geometry dimensions of the honeycomb structure was examined. Finally, the study is validated by the degeneration method with a degeneration mathematical model that performed in the published literature.


ABSTRACT: To improve the lightweight and crashworthiness in vehicular engineering, there has been growing interests in metal/composite hybrid configuration, which is relatively newer than traditional metallic or composite structures. It is of vital importance to understand lateral crushing behaviors of hybrid system to gain maximum benefits from the structural configuration. In this present study, quasi-static lateral compression tests were carried out experimentally to investigate the transverse failure modes and crashworthiness characteristics of four different circular hybrid tubes made of either aluminum/carbon fiber reinforced plastics (CFRP) or aluminum/glass fiber reinforced plastics (GFRP) materials. From the experiments, it is found that the load carrying capacity of the aluminum/composite hybrid tubes with an inner composite tube was substantially higher than that of hybrid tubes with an outer composite counterpart. This is due to the fact that more significant delamination was initiated and propagated around the inner composite tube under transverse loading, which improved its lateral crushing characteristics. The interactive effects between single aluminum tube and single composite (CFRP or GFRP) tube was also investigated; and it is found that the specific energy absorption (SEA) of hybrid tube AL-T2-CF-P8 (2.41 J/g) and AL-T2-GF-P8 (2.27 J/g) were 58% and 47% higher than the sum of single aluminum tube and single composite tube alone, respectively. Based upon the experimental results, the finite element (FE) models were developed and validated to further explore the effects of hybrid ratios (i.e. aluminum vs. CFRP/GFRP of 4:0, 3:1, 2:2, 1:3 and 0:4) and stacking sequence on lateral crashworthiness. It is found that the aluminum thickness of a higher-ratio configuration can largely improve the load carrying and energy absorption capacities under lateral compression. For the six different stacking sequences considered here, the hybrid tubes with a symmetrical configurations [CF-P4-AL-T1] and [GF-P4-AL-T1], are of the best crashworthiness performance with the highest SEA of 3.43 J/g and 3.29 J/g, respectively. This study provides thorough understanding of the aluminum/composite hybrid tube subject to transverse crushing load, and would be of considerable implication to vehicular applications.


ABSTRACT: The application of carbon fiber-reinforced laminated composites is restricted due to the dramatic decrease of compression strength after impact, which can reach 70% at most. So far, there is no method of
predicting the post-impact material performance that has been widely accepted by researchers, aircraft manufacturers and aviation safety administrations. Recently, an inverse method was proposed for post-impact strength prediction by modeling impact damage as a soft inclusion with apparent material properties from experiment. This study aims to explore the inverse method in compression-after-impact (CAI) strength prediction of aircraft structures. First, a model and computer program to implement the validation of the inverse method was developed to determine the damage area properties. Then, experiments were conducted with the help of digital image correlation technology and the optimization program to measure the displacement field around damage zones and calculate the apparent material properties. Finally, a strategy of predicting post-impact compression strength of laminated composites was proposed based on the investigation of the compression properties of T700/M21.

ABSTRACT: This work addresses the multiobjective design optimization of metal-ceramic functionally graded (FG) plates, which are composed of a main functionally graded material (FGM) layer and may include metal and/or ceramic faces, under thermo-mechanical loadings. The design variables are the thickness of the FGM layer, the index of its power-law distribution of metal-ceramic volume fractions, and if included, the thickness of the metal and/or ceramic faces. The three objectives focus on mass, maximum transverse displacement and maximum value of the Tsai-Hill failure criteria to measure the stress field, aiming to minimize all together. Both thermal and mechanical problems are solved simultaneously using a layerwise mixed model based on least-squares formulation with multi-field independent variables, namely, displacements, temperature, transverse stresses, transverse heat flux, in-plane strains and in-plane components of the thermal gradient. The FGM layer z-continuous effective properties are fully described via high-order z-expansions, similarly to finite element approximations. The multiobjective optimization problem is solved by Direct MultiSearch (DMS) derivative-free method, which uses the notion of Pareto dominance to retain a list of feasible non-dominated solutions. Numerical results provide optimal designs of FG plates under thermo-mechanical loadings, exploring different metal-ceramic constituent materials and different side-to-thickness ratios, including three-dimensional approximate solutions for validation.

ABSTRACT: This paper presents a three-variable high order shear deformation plate theory (THSDT) for free vibration, buckling and instability analysis of functionally graded porous (FGP) plates reinforced by graphene platelets (GPLs). The underlying approach only uses three primal variables in the same way as numerically solving three-dimensional (3D) solids. It fulfills the classical plate theory (CPT), the first-order shear deformation theory (FSDT) and the higher-order shear deformation theory (HSDT). THSDT has only three variables like CPT but unlike CPT, it takes into account the shear effect without requiring a shear correction factor. It gives a significant advantage in numerical computational aspects such as reducing the computational cost of plate problems using isogeometric analysis (IGA). This new form of the displacement field requires the high continuity with Ck where k \(\geq 3\) approximately. IGA can be prioritized as the best candidate for discrete approximations with the arbitrary smoothness of high-order derivatives in a differential weak form of asymmetric fourth order. Numerical validations are given for free vibration, buckling and instability of FGP-GPL plates in order to prove the reliability and accuracy of present method.

ABSTRACT: The experiments performed were oriented to produce and characterize a sandwich panel with an optimized composition of cork granules, obtained from industrial by-products, and a green epoxy resin. Static
bending tests were performed to characterize the mechanical strength and its viscoelastic response. Stress relaxation tests evidence a decrease of the stress over the time and the experimental data can be fitted by Kohlrausch-Williams-Watts (KWW) model successfully. In terms of creep, the displacement increases and while the KWW model is preferable to the Findley model for short-term predictions, the opposite trend occurs for long-term predictions. Fatigue life was also investigated, where the damage mechanisms that govern the fatigue strength, as well as the residual mechanical properties, were characterized. Small cracks were observed under the pin load contact region, between skin and core, which grow around the cork grains and follow the direction of middle plane toward the tips of the specimen.


ABSTRACT: This study illustrates the hybrid effect and damage evolution of carbon/aramid braided composites under low-velocity impact, using a finite element model (FEM) of a complete braided structure. The model was established based on a real three dimensional (3D), five directional (5d) braided structure by taking the interior, surface, corner braided and axial yarns into consideration. Constitutive material modeling and failure criteria were introduced into the model. The degree of damage was determined by comparing the volumes of units removed on failure. Three hybrid structure types were adopted to investigate the relationships between stress distribution and damage evolution. The results showed that the impact response and failure morphology were significantly dependent on hybrid effects under different low-velocity impacts. The impact response curves of hybrid structures showed obvious toughness characteristics. The addition of aramid fiber as an axial yarn could prolong the overall impact response time and reduce failures. Moreover, the hybrid effect strongly influenced the stress distribution and damage evolution in different circumstances. Hybrid structures led to a large stress distribution area and a low stress level, which could reduce the material failure caused by stress concentration. This work provides a sound method for designing hybrid structures and expanding the application potential of 3D braided composites.

Ahmed F. Radwan and Mohammed Sobhy, “Transient instability analysis of viscoelastic sandwich CNTs-reinforced microplates exposed to 2D magnetic field and hygrothermal conditions”, Composite Structures, Vol. 245 Article 112349, 1 August 2020, https://doi.org/10.1016/j.compstruct.2020.112349

ABSTRACT: Transient size-dependent mechanical and thermal buckling analyses of sandwich microplates with viscoelastic core and single-walled carbon nanotubes (CNTs)-reinforced face sheets are introduced in this paper. The CNTs are uniformly distributed or functionally graded (FG) through the thickness of the face layers. The viscoelastic sandwich microplate is resting on three-parameter viscoelastic foundations that modeled according to the viscoelastic Kelvin-Voigt model with a shear layer. Effects of a 2D magnetic field as well as hygrothermal conditions on the present analyses are studied. The modified couple stress model containing one material length scale parameter is employed to capture the small scale effect. A body force (Lorentz force) is deduced from Maxwell’s magnetic equations, that is applied to each particle of the structure. The higher-order shear deformation plate theory with four unknowns is utilized to describe the displacement field. The stability equations are obtained using the principle of virtual displacement. By applying Navier method, the stability equations are solved to obtain the mechanical and thermal buckling of viscoelastic sandwich microplates. Various numerical examples are presented including the effects of the length scale parameter, moisture concentration, magnetic field parameter and other parameters on the buckling of the viscoelastic FGCNTs-reinforced sandwich microplates.


ABSTRACT: The paper investigates the influence of eccentric compressive load on the buckling, post-buckling and load-carrying capacity of thin-walled top-hat section composite columns. The columns were made of a CFRP composite material with a symmetrical arrangement of the layers by the autoclave technique. The scope of the presented study involved performing experimental tests on actual profiles as well as numerical
calculations using the FEM analysis in ABAQUS® software. The experimental tests were carried out in the full range of loading, until the structure’s failure (post-buckling equilibrium paths and acoustic emission signals were measured). Regarding to FEM analysis, a nonlinear calculations using Newton-Raphson method were made. The damage initiation of the composite material was estimated based on Hashin’s theory, whereas damage evolution was described by the energy criterion (progressive failure analysis were used). The numerical results of eccentric compressive load on buckling and load-carrying capacity of composite columns were in good agreement with the experimental results.

ABSTRACT: The present paper aims at studying composite cambered structures, tracking the seminar work “Rotating Blade Vibration Analysis Using Shells” presented by Leissa in Journal of Engineering for Power, in 1982, devoted to homogeneous metallic blades. A refined unidimensional (1D) formulation is here implemented to overcome the limitations of classical beam theories. With an appropriate choice of cross-sectional expansions, it is possible to make the 1D model suitable for analyzing shallow blades. This approach enables one to generate both layerwise (LW) and equivalent single layer (ESL) descriptions of the problem unknowns. Furthermore, it is possible to implement classic theories as special cases. Natural frequencies are determined for isotropic and composite blades, showing the effects of changing the fiber lamination angle of symmetric and unsymmetric configurations. Besides, this study investigates the effects of thickness and rotational speed over the structure. Significant differences between classic and high-order theories are found, concerning the accuracy and the computational costs. The causes of these differences are discussed, and the results can be used as a benchmark for future studies.

ABSTRACT: With a goal of reducing the weight of fan blade containment system for jet engine, the high-velocity impact response of carbon fiber reinforced polymer (CFRP) panels reinforced with stiffeners were tested and analyzed. Ballistic impact tests on stiffened panels have been carried out with cylindrical Ti-6Al-4V projectiles at different velocities (210 m/s, 70 m/s and 90 m/s). Results showed there was a significant influence observed due to different impact velocities on the response of the panel skin and the stiffener, and the middle stiffener played an important role in impact energy absorption. Numerical simulations were conducted to provide further insight into the target response by employing a user subroutine VUMAT with revised Hou criteria in commercial finite element (FE) software ABAQUS. The stiffened CFRP panel was found to possess a 14% higher critical penetrating velocity than the CFRP laminated plates with same mass by using validated FE models. Combining with detailed discussion of high-velocity penetration process, the energy absorption mechanism of the stiffened panel under high-velocity impact was analyzed, indicating that the improvement on high-velocity impact response is due indirectly to structural alteration induced better energy absorption by less punch-shear laminate breakage and more fiber tensile failure.

ABSTRACT: In this paper, the effect of stacking sequences on the number of stable configurations for multipatch composite panel is studied. The model is designed by connecting a number of bi-stable composite patches in a grid. The total strain energy equation with a fourth order shape function including variations of the curvatures is applied in conjunction with a Rayleigh-Ritz technique for fast predication of stable shapes. A square panel model consisting of four connected patches of asymmetrical laminate is designed with 0° and 90° ply's angle, and then the model is extended by a mix of symmetric and asymmetric laminates. The stable shapes of model are validated using both FE predictions and experimental tests, and the results show quite good agreements in the stable configurations. Each case of panels exhibits two or more distinct stable configurations, which are mainly dependent on distribution of stacking sequences on surface. These stable configurations are
interesting shapes that may be used to create a large multi-stable surface as useful device in a morphing skin application. This work could be used as a guideline for design of a large multi-patch morphing skin for highly degree of stability.

ABSTRACT: The shear buckling performance of a flat laminated composite structure depends on various factors like the nature of the applied load, lamina orthotropy, stacking sequence and the support boundary conditions. The emphasis of the current work is to decipher the effect of the direction of applied shear on the post-buckling response and failure of a quasi-isotropic carbon CFRP panel. A comprehensive experimental test campaign involving 3D-digital image correlation (DIC), acoustic emission (AE) and strain gaging techniques are used to capture the post-buckling deformation and the associated failure mechanisms in the CFRP test panels under positive and negative shear load. Further, a generic finite element based progressive damage model involving 3D Hashin’s failure criteria in conjunction with the cohesive zone model is developed in Abaqus software for simulating the intra and inter-laminar damages in the quasi-isotropic laminate and later compared with the experimental results. The effect of positive and negative shear on the post-buckling response and the associated damage modes are investigated in detail. The outcome of the current investigations reveals that the direction of the shear load has a definite impact on the post-buckling response and failure behavior of the CFRP test panels.

ABSTRACT: A novel approach, based on energy balance method, to deal with the large-amplitude nonlinear free vibration problem of the rectangular porous functionally graded plates is presented in this paper. Both even and uneven porosity distributions are considered. The governing equations of the plates are established via von Kármán theory and Lagrange equation. A new deformation assumption for the vibration problem of plates is proposed. This deformation assumption allows a quadratic relationship between the in-plane and out-plane displacements, thus is more advantageous than the conventional one to describe the displacement field of the plate during the vibration period. The nonlinear frequency of the plate is obtained by adopting the energy balance method cooperating with the Newton-Raphson iterative method. Numerical examples are provided to inspect the influences of the porosity distribution type, porosity volume fraction, geometrical parameters and vibration amplitude on the nonlinear free vibration characteristic of the plates. The results indicate that the nonlinear-to-linear frequency ratio is less sensitive to the porosity volume fraction than the linear frequency for the porous functionally graded plates, and the nonlinear-to-linear frequency ratio of plate with uneven porosity distribution is more sensitive to the porosity volume fraction than that with even porosity distribution.

ABSTRACT: Mechanical metamaterials undergoing extreme deformations span an ever-increasing design space of mechanical performance. However, achieving selective deformability in load-carrying metamaterials remains unexplored. Anisotropic thin fiber-reinforced composite shells, which are soft in bending and stiff axially, present an attractive option for addressing this challenge but are difficult to realize in practice due to fabrication complexity. In this work, an integrated fabrication technique enabling single-step curing of complex composite mechanical metamaterials is proposed. By using 3D-printed tooling and silicone spacers, composite assemblies can be cured in an autoclave without the need for post-cure bonding of individual shells. The technique reduces manufacturing times and eliminates adhesive bonds, which add mass to the structure and can be points of failure. The proposed technique is demonstrated on a modified rotating square auxetic metamaterial geometry, with fabricated prototypes withstandng up to 60% global tensile strains elastically. The composite anisotropy is, moreover, used to control the deformation mechanism in the metamaterial, thereby delaying
failure of the structure and allowing tunability of elastic properties. This work sets the stage for the use of composites as a means of expanding the design space achieved by mechanical metamaterials for shape adaptation in lightweight, load-carrying applications.

References listed at the end of the paper:
2 R.M. Neville, F. Scarpa, A. Pirrera, Shape morphing Kirigami mechanical metamaterials, Sci Rep, 6 (2016), p. 31067, 10.1038/srep31067
14 P. Bettini, A. Airolidi, G. Sala, L.D. Landro, M. Ruzzene, A. Spadoni, Composite chiral structures for morphing airfoils: numerical analyses and development of a manufacturing process, Compos Part B Eng, 41 (2) (2010), pp. 133-147, 10.1016/j.compositesb.2009.10.005
19 T.W. Murphy, M.E. Peterson, M.M. Grigoriev, Large strain four-point bending of thin unidirectional composites, J Spacecr Rockets, 52 (3) (2015), pp. 882-895, 10.2514/1.A32841
22 S. Daynes, P.M. Weaver, K.D. Potter, Aeroelastic study of bistable composite airfoils, J Aircr, 46 (6) (2009), pp. 2169-2173, 10.2514/1.44287
34 R. Maurin, P. Davies, N. Baral, C. Baley, Transverse properties of carbon fibres by nano-indentation and micro-mechanics, Appl Compos Mater, 15 (2) (2008), pp. 61-73, 10.1017/CHO9781139524377.001

ABSTRACT: In this study, stresses distributions in the large deflection field of Functionally Graded (FG) structures are investigated. Numerical simulations are carried out using one-dimensional (1D) models combining the Finite Element Method (FEM) and Carrera Unified Formulation (CUF) to evaluate the three-dimensional (3D) displacement field over the cross-section, employing Lagrange and Taylor polynomials. Then, the geometrical nonlinear relations are solved with the Newton-Raphson linearization and constrained with an arc-length method. The nonlinear behavior of cantilever beams undergoing bending and compression loading conditions is calculated. The results show the influence of the adopted theory to approximate the displacement field over the cross-section on FG beams. According to the results of this study, it is emphasized that geometrical nonlinearities should be taken into consideration in the evaluation of stress distributions in FG structures.

ABSTRACT: In this article, the energy absorption capability and crushing behavior of composite corrugated tubes have been studied experimentally and numerically under quasi-static axial slipping crushing loading. Five corrugations with angles ranging between 35° and 55° with 5° increment have been studied. Two different unidirectional fibers have been used; CFRP and KFRP and the corrugated tubes were fabricated by the wet filament winding process. Firstly, the corrugated tubes were experimentally tested. The slipping-force-stroke curves were obtained and failure modes have been analyzed. Based on the obtained curves, the calculated crashworthiness parameters were evaluated and presented. Scanning electron microscopy (SEM) images were taken to gain further insight into the experimental results. Secondly, LS-DYNA finite element code was used to numerically analyze the crushing response of the composite corrugated tubes. Mesh optimization and parametric study for the failure modeling parameters of the material model MAT 054 were carried out. The simulation results showed very good agreement with the experimental observations.

ABSTRACT: In this paper, a nonuniform electric field model is proposed for the smart control of large amplitude vibration of porous piezoelectric conical sandwich panels resting on nonlinear elastic foundation within the framework of von Kármán type of geometrical nonlinearity and the first order shear deformation theory. The conical sandwich panel consists of a viscoelastic core and two porous piezoelectric material layers. By employing Hamilton’s principle, the nonlinear governing equations of porous piezoelectric conical sandwich panels are derived. Then, the semi-analytical solutions are given for the current system by utilizing the harmonic balance method to solve those coupled governing equations. Through numerical results, the influences of the control gain, uniform and nonuniform electric field models, type of porosity distribution, total porosity volume fraction, aspect ratio, linear and nonlinear foundation stiffnesses on the vibration control of porous piezoelectric conical sandwich panels are discussed in details. It is found that the uniform electric field model overrates the damping characteristic of the system with a great total porosity volume fraction when compared with the nonuniform electric field model.
ABSTRACT: This paper presents a thorough investigation of wrinkling within a path on a general surface for a composite tow constructed using the AFP process. Governing equations and assumptions for the presented model are derived based on geometrical considerations. A simple form of the wrinkled shape is assumed and applied to the inner edge of the tow path. For a given wavelength, the amplitude of the wrinkles can be approximated based on a worst-case scenario where all the difference in length between the edges of the path is absorbed through an out-of-plane wrinkle. The wrinkle wavelength can be obtained either from existing mechanics models in the literature or experimental measurements, otherwise an adequate wavelength can be assumed. A numerical solution is implemented to visualize wrinkles on the curved paths and to indicate potential regions for wrinkling on the surface. Several examples are presented to demonstrate the model, including constant angle paths on a double curved surface and curved paths on a flat surface. From a geometrical standpoint, increasing the tow width or the path curvature results in an increase in the wrinkles’ amplitude. Calculation of the wrinkles’ amplitude for a steered path on flat surface shows good agreement with experimental measurements.

ABSTRACT: Due to the extraordinary corrosion resistance of fiber-reinforced polymer (FRP), the use of seawater sea-sand concrete (SSC) combined with FRP materials becomes highly attractive in the constructions of coastal and marine infrastructures. To this end, a total of 40 CFRP confined seawater sea-sand concrete cylinders are constructed and tested under axial compressive load in this study. The main variables of the test include the concrete type, CFRP strengthening schemes and the number of CFRP layers. The failure modes, axial stress-strain curves, lateral strain-axial strain relationships and CFRP hoop strain distributions of the specimens are analyzed systematically. It can be detected from the test results that both unconfined and CFRP confined SSC exhibited similar mechanical properties compared with the corresponding specimens cast with normal concrete. Moreover, the clear spacing ratio and the confinement stiffness of CFRP were found to be the two most important factors in accounting for the axial compressive behaviors and the dilation properties.

ABSTRACT: or the comprehensive analysis of the mechanical performance of concrete structures wrapped with partial FRP strips, the development of an accurate and versatile axial stress-strain model is of significant importance. No research, however, has been conducted to present a satisfactory analysis-oriented stress-strain model for partially FRP confined concrete. To this end, this paper firstly investigates the performance of several existing analysis-oriented models in assessing the FRP partially wrapped columns. The results show that all selected models cannot provide reasonable predictions for the test specimens, especially for the specimens possessing strain-softening stress-strain relationships. Therefore, the dilation properties and the peak axial strength expressions of active-confined base models were both revised based on the test observations and a new analysis-oriented model was proposed for partially FRP confined concrete. Finally, a large database of CFRP partially wrapped columns was assembled through an extensive literature review to evaluate the accuracy of models. By comparing the test results with the predicted calculations, the proposed model can provide accurate and reasonable predictions both for the ultimate conditions and the complete axial stress-strain relationships, which were obviously superior to the other existing models.

ABSTRACT: Aiming at poor efficiency of the traditional materials in low-mid frequency sound absorption and its narrow bandwidth, we present an ultra-broadband acoustic metamaterial that can achieve near-perfect continuous absorption within 380 Hz–3600 Hz with a thickness of only 7.2 cm. Its basic cell is constructed by turning the original neck of a Helmholtz resonator into multiple smaller ones, and the neck panel becomes into a micro-perforated panel (MPP). By coupling the characteristics of the cavity’s multi-order resonance and the MPP’s broadband absorption, the cell’s high-order impedances can be tuned to more match that of the air medium. The cell can therefore obtain multiple excellent high-order absorption peaks besides the original one; meanwhile all the peaks can become broader resulting from the larger energy leakage rate. On this basis, a subwavelength 12-cell sample is obtained of which the absorption band is broadened almost 100% by the high-order peaks and has an average absorption coefficient above 90%. Characterized by the extraordinary absorption performance, thin thickness, and easy-fabricated structure, this proposed metamaterial has great potential in noise control engineering applications.


ABSTRACT: A guided wave simulation method for layered composites based on the wave and finite element scheme is presented. An approach for calculating complex displacement fields such as those generated from piezoelectric transducers is developed. The scattering of waves from different types of defects is computed. A rigorous energy based criteria is proposed for model order reduction. All calculations are carried out in the frequency domain and an inverse discrete fourier transform is performed to get the time domain result. Numerical examples of a multi-layered composite beam are performed to assess the performance and validate the methodology. Three types of damages are simulated namely a notch, a transverse crack and an internal delamination. The results are validated against finite element simulations and are found to be in excellent agreement. Moreover the approach is found to be orders of magnitude faster compared to finite element simulations.


ABSTRACT: A novel type of seawater and sea sand concrete (SSC)-filled FRP-carbon steel composite tube (SFSCT) column composed of FRP-carbon steel composite tubes and core-filled SSC is proposed. The FRP carbon steel composite tube is made by wrapping FRP sheets around the inner and outer walls of steel tubes to isolate the transport of chloride ions from the external corrosive environment and the internal SSC, respectively. A total of 36 SFSCT columns were tested under axial compression to investigate the axial compressive performance. The test parameters include the FRP thickness, FRP type and steel tube thickness. The test results show that internal FRPs and external FRPs can work together and effectively improve the bearing and deformation capacities of the structure under axial compression. Compared with concrete-filled steel tube (CFST) columns, with different numbers of FRP wrapping layers, the strength of the SFSCT columns can be increased by 11.7–66.5%. The confinement effect of CFRP is better than that of BFRP. Compared with the steel tube thickness, the FRP type and FRP thickness have a more significant influence on the stress-strain behaviour of SFSCT columns.


ABSTRACT: In the present paper the problems of optimal design of multilayered composite structures subjected to free vibration and supersonic flutter constraints are discussed. The analysis is carried out for
laminated flat plates and cylindrical panels with rectangular plan form. The solutions are derived with the aid of analytical and finite element formulations. A special attention is focused on the formulation of fundamental relations for panels with the use of the approximate Donnell-Mushtari-Vlasov shallow shell theory. The structures with different boundary conditions, geometrical parameters, angle-ply fibre orientations, discrete stacking sequences and air flow directions are considered. For discrete fibre orientations a new form of design variables (reduced to four only) is proposed and employed successfully in the optimal design. Both for flat plates and cylindrical panels the maximal values of aerodynamic pressures are obtained for angle-ply laminates, and not for discrete 0°, ±45°, 90°, (an even number of layers of the same thickness and mechanical properties) stacking sequences.

References listed at the end of the paper:
1 Nam-II Kim, Jae Hong Lee, Divergence and flutter behavior of Beck's type of laminated box beams, Int J Mech Sci, 84 (2014), pp. 91-101
2 M. Kameyama, H. Fukunaga, Optimum design of composite plate wings for aeroelastic characteristics using laminate parameters, Comput Struct, 85 (2007), pp. 213-224
3 S.J. Hollowell, J. Dugundji, Aeroelastic flutter and divergence of stiffness coupled, graphite/epoxy cantilevered plates, J Aircraft, 21 (1984), pp. 69-76
5 M.H. Shirk, T.J. Hertz, T.A. Weisshaar, Aeroelastic tailoring – theory, practice and promise, J Aircraft, 23 (1) (1986), pp. 6-18
7 Y. Hirano, A. Todoroki, Stacking-sequence optimization of composite delta wing to improve flutter limit using fractal branch and bound method, JSME International Journal, 48 (2) (2005), pp. 65-72
12 J. Li, Y. Narita, Analysis and optimal design for supersonic composite laminated plate, Compos Struct, 101 (2013), pp. 35-46
14 M.D. Olson, Finite elements applied to panel flutter, AIAA J, 5 (12) (1967), pp. 2267-2270
20 A. Muc, Natural Frequencies of Rectangular Laminated Plates—Introduction to Optimal Design in Aeroelastic Problems, Aerospace, 5 (2018), p. 95
21 M.K. Singha, Mandal Mukul, Supersonic flutter characteristics of composite cylindrical panels, Compos Struct, 82 (2008), pp. 295-301
22 A. Muc, Muc-Wierzgoń, An evolution strategy in structural shape optimization problems for plates and shells, Compos Struct, 94 (4) (2012), pp. 1461-1470
23 A. Muc, Choice of design variables in the stacking sequence optimization for laminated structures, Mech Comp Materials, 52 (2) (2016), pp. 211-224
26 A. Muc, Design of blended/tapered multilayered structures subjected to buckling constraints, Composite Str, 186 (2018), pp. 256-266

ABSTRACT: This paper studies the bending, buckling and free vibration analyses of functionally graded (FG) sandwich microbeams using the third-order beam theory. The modified strain gradient theory (MSGT) with three material length scale parameters (MLSPs) is used to capture the size effect. The Mori–Tanaka homogenization scheme is employed to model the material distributions through the thickness. Finite element model is formulated to solve the problems. Verification studies for epoxy and FG microbeams are carried out to validate of the present model. Comparisons of the results of three different models such as MSGT, the modified couple stress theory (MCST) and classical continuum theory (CCT) are presented. Effects of small size, gradient index, shear deformation and boundary conditions on the structural behaviours of microbeams are investigated. Some new results of FG sandwich microbeams for both models (MCST and MSGT) are presented for the first time and can be used as benchmark in future studies.


ABSTRACT: This study introduces the compressive behavior of FRP-confined steel-reinforced concrete (FCSR) columns using recycled aggregate concrete (RAC). The performance of RAC is generally inferior to the natural aggregate concrete (NAC). In terms of optimized use of different materials, FCSR column using RAC is a promising hybrid column because of the following merits: 1) using RAC in FCSR columns is deemed to overcome its weakness since RAC is double confined by the encased steel column and FRP; 2) local/global buckling of the encased steel section can be allayed or suppressed; 3) both concrete and steel section can be protected by FRP against harsh environmental attack. In this study, FCSR columns with RAC under concentric compression were tested to explore the effects of replacement ratio of recycled coarse aggregates (RCAs) and FRP confining stiffness. It has been revealed that the FCSR columns with RAC had similar compressive behavior as the FCSR columns with NAC although the use of RAC slightly decreased the load-carrying capacity. Favorable interactions existed among FRP, concrete and steel, but full composite effect was not achieved by combining the concrete-filled FRP tube (CFFT) and steel column due to the occurrence of local buckling in the encased steel column.


ABSTRACT: This paper presents a new, simple, containing only four unknown functions, individual-layer, static model for rectangular sandwich plate unsymmetrical with respect to its middle plane. The shear strains in the outer layers of the plate are neglected while the shear strains in the middle layer are variable and equivalent to zero on its outer surfaces. Local constitutive models of the layers consistent with the assumed kinematics are derived. A detailed analysis of all partial problems is presented. In order to determine the unknown functions, appearing in the kinematic model assumed, one needs to solve a set of three coupled partial differential equations and separately the fourth governing equation that contains only one unknown function. In the case of the plate symmetrical about its middle plane only two uncoupled partial differential equations for the bending problem must be solved. Deflections predicted by the present model for a symmetrical sandwich plate are compared with counterparts, existing in the literature, predicted by two theories that include flexibility of the middle layer of the plate. Good agreement of these results has been obtained.


ABSTRACT: Local buckling is often a main failure form of the FRP (Fiber Reinforced Plastic) foam sandwich cylinder under axial compression. In order to study its local buckling behavior under axial compression, axial compression test on the FRP foam sandwich cylinder was conducted in this paper, and two types of local buckling, i.e. local conjoint buckling and local layered buckling, were revealed. Then, based on Reissner’s first-order shear theory of laminated cylinder, the theoretical solution of local conjoint buckling force of this kind of member was derived; and by establishing the model of laminated cylinder on Pasternak foundation, the
Theoretical solution of local layered buckling force of this kind of member under axial compression was derived. The theoretical results were compared with the results obtained by FE buckling analysis and by the test, which verifies the applicability of the theoretical calculation method to ideal FRP foam sandwich cylinder. For actual FRP foam sandwich cylinder with initial defects, the defect factor for the theoretical solution was suggested.


ABSTRACT: Integrated and automated manufacturing processes of advanced composites have attracted extensive attention, aiming at the improvement of mechanical performance and cost efficiency of composites. This experimental study investigated the feasibility of a manufacturing process for co-cured integral hat-stiffened panels based on automated fiber placement. To achieve desirable manufacturing quality and simplify manufacturing process, a novel flexible inner mold was designed for the enclosed cavity between stringers and skin, which was suitable for curved and large hat-stiffened panels. Influences of flexible mold and processing parameters on dimensional accuracy were studied by both finite element analysis and experimental methods. Moreover, fiber distribution around the transition region between skin and stringer were obtained through microscopy observation. With the optimum inner mold and layup processing parameters, hat-stiffened composites can be manufactured integrally with improved surface quality and geometric accuracy, based on co-curing process and automated fiber placement.


ABSTRACT: The present paper studies size-dependent deflection analysis of FG graphene nanoplatelets (GNPs) reinforced composite micro-plates with porosity subjected to transverse load. Third-order shear deformation (TOSD) theory of Reddy’s and principle of virtual work are employed for derivation of governing equations of static bending via modified couple stress theory (CST). Various models of distribution of porosity and GNPs are employed in our analysis. Halpin-Tsai micromechanical model and rule of mixture is used for effective material. After derivation of governing equations and presentation of solution procedure, the numerical results are presented in terms of significant input parameters. The numerical outputs including displacements and stress components are presented in terms of porosity coefficient, distribution of porosity, distribution and amount of GNPs and various dimensionless geometric parameters of the composite micro-plate. A comprehensive comparison with previous works have been performed for validation of the present formulation and corresponding numerical results.


ABSTRACT: In this work, the passive damping in a sandwich beam is investigated for the inclusion of dispersed graphite particles within the viscoelastic core. The effective material properties of the viscoelastic particulate composite (VEPC) are estimated using a differential scheme and the elastic–viscoelastic correspondence principle. The corresponding results reveal increased effective storage moduli and decreased effective loss factor of a viscoelastic medium for the inclusion of graphite particles. As it implies both the possibilities of augmentation and deterioration of passive damping in the sandwich beam, the subsequent study is carried out on the variation of damping characteristics of the sandwich beam especially for different volume fractions of inclusion. It is found that the passive damping in the sandwich beam increases significantly for the inclusion of graphite particles within the viscoelastic core, and also an optimal volume fraction of inclusion corresponding to the maximum damping in the sandwich beam appears. Further study on the optimal utilization of VEPC patches within the core of the sandwich beam reveals a minimal change of weight of the overall beam for the replacement of patches of conventional viscoelastic material by VEPC patches while this replacement yields a remarkable improvement of passive damping in the sandwich beam.
ABSTRACT: In the present paper, a methodology for determination of a value of the bifurcation shortening and the corresponding bifurcation load of the real thin-walled laminated column under compression with initial imperfections, using an axial shortening versus squared deflection amplitude plot, is presented. A plate model of the column has been assumed. It has been shown that the post-buckling state is described with a linear relationship on this plot, whereas a value of the bifurcation shortening corresponds to a free term of the straight line approximating the post-buckling state on the plot and is proportional to the bifurcation load. Detailed calculations have been conducted for short composite angle columns under uniform compression. The eigenvalue problem and the non-linear post-buckling problem have been solved with the semi-analytical method (SAM) based on Byskov-Hutchinson’s method and the finite element method (FEM). The bifurcation shortening and the corresponding bifurcation load have been determined. An effect of the imperfection amplitude on the post-buckling behaviour of laminated thin-walled angle columns has been analysed. General configurations of laminate plies have been selected. All columns have been simply supported at both ends. A very good agreement between the results attained with both the methods for solving the non-linear problem has been obtained.

ABSTRACT: In this paper, optimal solutions for noise reduction in laminated viscoelastic soft core sandwich plates are obtained, using active control with surface bonded piezoelectric sensors and actuators. An in–house finite element implementation of the active laminated sandwich plate is used to obtain the frequency response of the panels. Since the structural/acoustic problem is lightly coupled, the sound transmission characteristics of the panels are evaluated by computing their radiated sound power, using the Rayleigh integral method. A negative velocity feedback control law has been used to implement the active damping. The optimal location of the surface co-located pairs of piezoelectric patches is then obtained, using the Direct MultiSearch (DMS) optimization algorithm to minimize simultaneously the added weight, the number of controllers and noise radiation. The minimization of noise radiation is accomplished by minimizing the total length of the radiated sound power frequency response curve. Trade-off Pareto fronts and the respective optimal active patch configurations are obtained and discussed.

ABSTRACT: With the development of additive manufacturing (AM), lattice structures are gaining ever-increasing popularity in lightweight and multi-functional design. Due to the big difference in the size scales of unit cell and lattice structure, existing numerical methodologies adopting solid elements may lead to large models that are both costly and time-consuming. Taking into account both the material concentration in the vicinity of the intersecting nodes and general defects in the member struts issued from AM, we propose in this present work a novel approach for the modelling of lattice structures based on beam elements with variable cross-section. The geometric parameters that characterize the non-uniform beams are calibrated with experimental data by an inverse approach. The calibrated model has been fully validated on both numerical and experimental data, and it is shown to achieve an analysis accuracy that is comparable to the one obtained from the corresponding model based on solid elements. The resulting efficiency improvement is expected to accelerate the optimization phase of the lattice core for more advanced or tailored performances of sandwich panels.

ABSTRACT: With an exquisite design that allows the elastic modulus to decrease in the surface layer and vary periodically inside, the stomatopod dactyl club can easily penetrate a hard and tough conch shell. Inspired by this idea, in this paper, a surface gradient target and a periodic layered target were designed. The failure processes of the two bionic targets and a uniform target under impact were studied with the finite element method (FEM), and the mechanism that allows the bionic designs of elastic modulus to optimize stress distribution and improve compatibility of deformation to greatly strengthen impact resistance of the targets was revealed.


ABSTRACT: Vibration analysis is conducted for functionally grade porous (FGP) beams with arbitrary boundary conditions based on a general formulation. On the basis of higher-order shear deformation theory, the multi-segment strategy is employed for the modeling, where the FGP beam is separated into several segments. The artificial spring technique is introduced to simulate the boundary and continuity conditions. The Jacobi orthogonal polynomials are used to express the admissible displacement functions. Both free and forced (steady-state and transient) vibration analyses are conducted for the FGP beams, where three types of porous distributions are considered. The convergence characteristics and correctness of the present method are presented through convergence and comparison studies. Parametric studies are conducted for the dynamic analysis of FGP beams, where the effects of porous distribution type, porous coefficient, boundary conditions (including both classic and elastic boundary conditions) and load pulses are investigated.


ABSTRACT: Two-dimensional plate/beam composite element is an effective method for deformation modeling of large thin-walled structure with stiffeners. However, the interface discontinuity is caused by the different stiffness of plate and beam structures, especially in the case of warping and torsional deformation, which reduces the calculation accuracy. In this paper, a composite plate/plate element model is proposed to describe the deformation of the stiffened plate structures. The plate element is developed via the absolute nodal coordinate formulation (ANCF) method and the slope of position is used to describe the rotation deformation, which releases the assumption of infinitesimal rotation in traditional shell element and may describe the large deformation problem. The consistent deformation conditions at contact interface between the plate and stiffener structures are deduced. Then, the mass, stiffness and generalized external force matrices of new plate/plate element are deduced. The static and dynamic analyses of the stiffened plate are conducted to verify the applicability of the new composite element, in which the cross-section size and the number of stiffeners are considered. The results show that the new plate/plate element may describe the mechanical behavior of stiffened plate structures and has a higher calculation accuracy than the common plate/beam elements.


ABSTRACT: To determine the damping properties of co-cured composite structures with different numbers of viscoelastic damping membranes, a dynamic analytical model of the structure was established according to a structural geometric equation and a constitutive relationship. Considering the damping performance of the fiber-reinforced layer itself, the natural frequency and loss factor of the structure were calculated using the Rayleigh–Ritz method based on the first-order ZIG-ZAG model. The calculation results were compared with those from
the finite element method, and the correctness of the theory verified. The relationship of the natural frequency and loss factor variation with the change of structural parameters was determined.


ABSTRACT: Composite structures are susceptible for low velocity impact, which leads to the reduction of the residual strength. In present paper, an explicit–implicit combined model based on stress-based failure and damage evolution laws is introduced for predicting residual strengths of composite cylinders subjected to low-velocity impact. The whole-process of damage evolution in composites can be explored by using direct damage state at the end of impact for residual strength analysis instead of traditional equivalent method. Then the proposed model is implemented by user-defined subroutines and Python scripting language in ABAQUS. VUAMT and UMAT subroutines are used for explicit impact analysis and implicit residual strength analysis, and Python scripting language is applied for damage data linking between the explicit–implicit modules. Relatively consistent experimental data and numerical results for the low velocity impact behaviors and residual tensile strength in T300/YH69 laminates validate the current model. Finally, residual strengths of composite cylinders after impact consisting of five impact energies are numerically explored. The residual burst pressure after impact and damage mechanism withstanding internal pressure of cylinders are predicted. The fiber damage caused by impact loading at hoop layers is determined as the dominant influencing mechanism affecting the residual strength of composite cylinders.


ABSTRACT: We introduce a consistent displacement-based finite element formulation for the analysis of laminated composites with nonlinear interlaminar constitutive law. The computational model includes the nonlinear Reissner beam for modelling the bulk material and continuously distributed system of nonlinear springs to describe the connection between layers. We can introduce general functions for describing the stiffness of springs. Therefore, our model is able to describe a variety of physical phenomena, such as friction between layers, contact, cohesive forces, etc. The displacement field on which the stiffness function depends upon is expressed in a local, deformed basis. Distributed force which results from the interaction between layers, is introduced into the governing equations in order to avoid the need for additional interface elements and to simplify the numerical solution method. Precise experiments on thick partially delaminated beam, solid beam, shear lap joint beams and film-substrate composite as well as comparison with the results from the literature, demonstrate the efficiency and versatility of the proposed numerical procedure.


ABSTRACT: Literature on the mechanical performance of additively manufactured (AM) negative Poisson’s ratio (ω) structures has been primarily focused on beam-based re-entrant structures with chevron crosslinks. The walled variants of this architecture have been shown to exhibit lateral instability. This is where a layered framework can be advantageous as they provide increased lateral stability. Much less is known regarding the behaviour of such architecture, let alone their thin/thick-walled variants. This study explores the influence of design parameters namely wall thickness (t) and angle (θ) on the mechanical performance of thin and thick-walled inherently stable lattices. The design is achieved through conceiving linearly arranged AlSi10Mg re-entrant unit-cells while discarding the traditional chevron crosslinks. The printed prototypes were experimentally tested and response surface (RS) models were generated to study the parametric influence on the elastic modulus (E), compressive strength (σ), failure strain (εf), and relative density (DR). The results demonstrate that both thin- and thick-walled structures exhibit of −0.108 to −0.257 despite the interaction effects between and . The elastic modulus can be increased by either increasing or without considering the interaction effects at mm and
45° ≤ θ ≤ 85°. This study presents a new understanding regarding the fabrication and performance of re-entrant structures by AM. (Math expressions not printed in this abstract. Please do not put math in your abstracts.)


ABSTRACT: The longitudinal compressive properties of carbon fiber/nanoparticles reinforced polymer unidirectional composites are investigated by experiments and a series of numerical simulations based on fast Fourier transforms (FFT) method taking into consideration matrix plastic behavior and initial fiber waviness. The efficient and accurate FFT-based method is convenient and has the low computation cost to discuss the effects of material and geometric parameters on the longitudinal compressive strength in details. The proper filling nanoparticles can significantly increase the longitudinal compressive strength. The computational results for failure mechanisms and strength show a good consistency with our experimental results. The present study provides reliable guidance for designing the fiber reinforced polymer composites with better damage tolerance.


ABSTRACT: The main goal of the present work was to investigate the effect of infill density on dynamic behavior of 3D printed parts. The short carbon-fibre-reinforced PolyEtherKetoneKetone composites (CF-PEKK) was selected as material which has an excellent mechanical, physical, thermal and energy absorbing performance. It’s employed widely in a vast range of industries due to their ultra-low density, multi-functionality and ability to undergo large deformations at low loads. For this purpose, a procedure for characterizing the dynamic behavior of this material fabricated with Fused Filament Fabrication (FFF) is presented in this research. Three infill densities (20%, 50% and 100%) were experimentally compressed for different impact pressures (1,4 bar; 1,7 bar; 2 bar and 2,4 bar) using Split Hopkinson Pressure Bar (SHPB). A FASTCAM high-speed camera was positioned in front of the SHPB test set-up to capture the dynamic deformation processes. The special attention is also given to examine the dynamic response of 3D printed CF-PEKK (100% infill density) subjected to repeated impacts. The obtained results proved that the low density and high-density infills were more cost-effective when compared to solid samples. The repeated impact drastically changed the dynamic behavior of the material compared to standard impact. With increasing the number of impact loading to the final failure, the dynamic parameters (i.e dynamic modulus, maximum stress…etc.) decreased remarkably and the material suffered catastrophic cumulated damage.


ABSTRACT: Auxetic metamaterials have demonstrated promising applications in crushing energy absorption. This paper proposes cell-wall angle graded auxetic metamaterials and investigates the potential benefits to in-plane impact resistance by using dynamic finite element analysis. It is the first study on enhancing impact resistant ability of auxetic metamaterials by using the cell-wall angle graded design. Firstly, the effectiveness of this graded design for enhanced energy absorption is uncovered and the underlying mechanism is discussed. Then, various influencing factors, including impact velocity, magnitude of cell-wall angle gradient, cell-wall thickness, are explored in details, and the results for the graded structures and uniform structures are compared. The experiment testing is also conducted to validate the initial simulation model by using a 3D printed specimen of the graded design. It is discovered that for the impact with a quasi-static or low velocity, the angle graded design could always deliver an enhanced energy absorption. Also, with the increase of the impact speed, the enhanced energy absorption could only happen when the crushing direction is along the structural weak-to-strong direction. The results shed light on a new approach to realize the application potential of mechanical metamaterials.
ABSTRACT: This paper focus on the experimental study of the buckling of composite laminates with multiple delaminations, as a succession to the theoretical and numerical studies in Part I. Test specimens containing delaminations of different length and different depth were fabricated by embedding Teflon plastic film using hot pressing machine. Compressive tests were carried out to investigate the influence of the delamination conditions on the buckling and post-buckling performances of the composite laminates. It was found that a surface delamination deteriorates the stiffness of the laminate less than a deep-buried delamination does, while iso-thickness-spaced multiple delaminations damage the stiffness severely compared with non-equal-thickness-spaced delamination for the same number of delamination. In general the larger the length and the number of delamination, the smaller the buckling load. Nevertheless, when the total length and the number of the delamination are fixed, the laminates containing multiple delaminations of equal length have a higher buckling load. Furthermore, it was observed that regardless of the number of delamination, all laminates are suffered to a global buckling. Local buckling does not occur until global buckling occurs. The experimental results justify the theoretical prediction; thereby confirm the correctness and validity of the theoretical approach proposed in Part I.

ABSTRACT: Considering the modified couple stress theory, nonlinear vibration and snap-buckling analyses of porous FG curved micro-tubes are performed in this research. Curved micro-tubes with shallow curvature resting on nonlinear elastic foundation are analysed. Properties of the micro-tube with uniform distributed porosity are graded across the radius of cross-section by means of a power law function. The equations of motion are derived based on the high-order shear deformation theory by applying the Hamilton principle. Governing equations are obtained using the von Kármán assumptions as a system of nonlinear differential equations. For curved micro-tubes which are simply supported in flexure and axially immovable, governing equations are solved using an analytical approach. A two-step perturbation technique is used to obtain the closed-form solutions for nonlinear free vibration and snap-buckling problems. Since the porous FG curved micro-tube is not analysed in literature, the results are compared with the case of FG tubes. Parametric studies are provided to explore the effect of geometrical characteristics of the curved micro-tube on the static and dynamic responses of these structures. The influences of material length scale parameter, functionally graded patterns, porosity parameter and nonlinear elastic foundation are also investigated.

ABSTRACT: In the present work, a quasi three-dimensional trigonometric shear deformation plate theory (quasi-3D TSDPT) is proposed for the wave propagation analysis of porous functionally graded material (FGM) sandwich plates resting on a viscoelastic foundation. The present plate theory accounts for the transverse shear and normal deformations by dividing the transverse displacement into bending, shear, and stretching components. Different types of FGM sandwich plates are taken into account. The porosities in the FGM layers of the sandwich structures are described by introducing the porosity volume fraction and the step function. The equations of motion governing the wave propagation behavior of porous FGM sandwich plates are derived by employing Hamilton’s principle. The analytical solutions to the wave dispersion relations are presented. Additionally, the parametric research is conducted to highlight the effects of the wave number, the porosity volume fraction, the viscoelastic foundation, the power-law exponent and the core-to-thickness ratio on the wave propagation. Results manifest that the influences of these parameters are significant on the wave propagation characteristics of porous FGM sandwich plates.

ABSTRACT: Nonlinear vibrations of a fluid-conveying functionally graded (FG) cylindrical shell with piezoelectric actuator layer and subjected to external excitation and piezoelectric parametric excitation are analyzed theoretically. Considering the electric-thermo-fluid-structure interaction effect, a nonlinear dynamic model of fluid-conveying FG cylindrical shell with piezoelectric actuator layer is developed based on Hamilton’s principle and von-Karman geometrical nonlinearity. The inviscid, incompressible, isentropic and irrotational fluid is coupled into governing equations using the linearized potential theory. The nonlinear coupled differential governing equations of system are obtained by using Galerkin’s method with two modes. The developed coupled model is validated by comparing with the prior data and good agreements are observed. Multiple scales method is used to obtain nonlinear dynamic behaviors of the coupled system in case of 1:2 internal resonance, primary parametric resonance and 1/2 subharmonic resonance. The effects of three coupling cases between two modes on the dynamic behaviors of system are explored. Considering strongly coupled effect between two modes, the effect of external excitation, damping coefficient, piezoelectric harmonic voltage, fluid flow velocity, temperature and volume fraction exponent of FG cylindrical shell on the frequency-response curves are investigated. The influence of detuning parameters on force-amplitude response and voltage-amplitude response of system are also discussed.


ABSTRACT: Crashworthiness is the ability of a structure to withstand a crash event ensuring the safety of its passengers. The aim of this work is to investigate the damage onset and evolution in a composite fuselage barrel undergoing a vertical drop test on a rigid surface. The mechanical behaviour of the barrel has been assessed by means of a Numerical-Experimental study. Indeed, the experimental data from a full scale barrel test, performed at the CIRA facilities, have been used in conjunction with numerical results, obtained by means of an advanced 3D FEM model, to investigate, in detail, the deformations and the damage development during the crash event. The adopted three-dimensional numerical model, based on an explicit FE formulation, uses Continuum Shell elements and CDM to take into account the onset and the evolution of the intra-laminar damages in each subcomponent of the investigated composite fuselage barrel. The obtained numerical results have been compared with experimental data in terms of accelerations, displacements and deformations to provide a preliminary validation of the adopted FEM model. A special attention has been given to sub-components which demonstrated to mainly influence the global mechanical behaviour of the investigated composite fuselage barrel during the experimental test.


ABSTRACT: Experimental investigations of channel-section profiles subjected to compression after impacts (20 J and 30 J) leading to global failure are presented. The columns under discussion were made of an eight-layer GFRP laminate with quasi-isotropic, quasi-orthotropic and angle ply arrangements of layers. The profiles were impacted in the corner in three variants: perpendicularly to the flange, at an angle of 45 to the web and perpendicularly to the web. All impact cases were characterized by a high level of absorbed energy (over 75%), which led to a barely visible impact damage, extensive fiber rupture, visible cracks in the laminate or material continuity loss. The load carrying capacity of the profiles degraded by the corner impact always decreases in relation to the not-impacted structures but every case was characterized by stable, postbuckling equilibrium paths. The most dangerous scenario was the corner impact introduced perpendicular to the web.

References listed at the end of the paper:
1 R. Degenhardt, R. Rolles, R. Zimmermann, K. Rohwer, COCOMAT - improved material exploitation of composite airframe structures by accurate simulation of postbuckling and collapse, Compos Struct, 73 (2006), pp. 175-178

ABSTRACT: The effects of vibrations in vehicles range from simple noise and reduced comfort, to decreased performance, from wear and material fatigue to irreversible failures and danger. A study of the dynamic behaviour of reinforced composite panels is here presented, applied to the construction of an ultralight photovoltaic roof in the case of a solar sport car. This is an extreme race prototype where design and materials solutions, as high strength carbon fiber reinforced polymers and sandwich-structured composites, were addressed to optimize the stiffness-to-weight ratio. A modal analysis was performed considering materials anisotropies by a layered-shell finite element model and through-the-thickness integration points with the scope to discretize the multi-layered sandwich structure. Additional aspects, as gravity force and external constrains, were also included. Experimental evidences were used for validating the numerical model and underscored an outstanding accuracy. The same design procedure was finally applied to change the preexisting structural solution achieving an optimized roof that was manufactured, installed and tested.

ABSTRACT: This study presents the findings of a combined experimental and numerical investigation to study process-induced deformation in sandwich structures manufactured using autoclave molding techniques. U-shaped sandwich structure based on woven carbon prepregs and an over-expanded Nomex honeycomb core were manufactured. For purposes of comparison, a U-shaped composite laminate, i.e. without the inclusion of a core, was also manufactured and modeled. Process-induced spring-in at different locations within the U-shaped parts were measured, both optically and using a feeler gauge. Thermo-chemical and stress-deformation finite element models were employed to predict the degree of spring-in for both the sandwich structures and the plain laminates using the ABAQUS/COMPRO. The predicted spring-in values were shown to be in good agreement with those measured experimentally. Parametric studies to investigate the effect of changing both the tooling material and the sandwich core have shown that employing an aluminum tool and an aluminum core reduced the degree of spring-in and warpage in the structures. However, spring-in phenomena is dominated by the core structure and geometry of the part. Finally, it has been shown that the process-induced deformation is less in the curved sandwich structures than in their laminated counterparts, with both structures deforming due to the combined effects of spring-in and warpage of the flat regions.


ABSTRACT: The aim of this work is to provide a virtual testing for the three-layered shells made of the optimized corrugated core sandwich panels. Starting from the unit cells level, we define their geometry found from the preliminary optimization and ensured the requirements of strength, stability and effective thermal conductivity. Effective stiffness properties of the core are evaluated then by using asymptotic homogenization method. The mechanical performance of the non-axisymmetric stiffened shell made of the considered sandwiches is studied numerically for the low-velocity impact. Solid-shell model with homogenized properties of the core is used for the skin material of the shell. Multi-scale approach is involved in the evaluation of the global and local stress state of the panels using stress concentration tensor estimated during asymptotic homogenization. As result, we check the robustness of the design approaches for the unit cells and its validity in the case of the complex loading conditions in the three-dimensional structure.


ABSTRACT: Damage can significantly modify the behaviour of composites laminates subjected to high-velocity impacts. Due to the high energy-absorption capability and low density of agglomerated cork, a possibility to reduce the impact damage, and improve the impact resistance of composites structures, is to incorporate a layer of this material as core of a sandwich structure. In this work, an experimental analysis of ballistic impact behaviour of damaged monolithic laminates and composite sandwich plates, with agglomerated cork core, was carried out. First, both types of specimens were damaged by a low-velocity impact at two impact energies. In order to ensure that the resulting damage was different, typical low-velocity impact variables were analysed. Later, reference (intact) and damaged specimens were subjected to ballistic impacts. For intact specimens, no significant differences between the impact behaviour of sandwich plates and laminates were observed. Nevertheless, the ballistic limit per areal density of damaged laminates was reduced when compared to the value given for reference laminates, whereas in sandwich structures it was almost constant.


ABSTRACT: The manufacturing of composites typically produces residual stresses that can significantly affect the final shape of the structure. The process of automated fiber placement (AFP) has become a prominent manufacturing technique in developing layups with tailored, variable stiffness morphology. The steered patterns of fiber tows with and without overlaps produce residual deformations that are distinctive from traditional layups. Digital image correlation was used to measure the AFP lamina coefficients of thermal expansion, which
were incorporated into finite element analyses (FEA) to model the cooling phase of the cure cycle. The effects of nonlinear analysis and temperature-dependent lamina properties calculated using self-consistent field micromechanics, on the resulting residual deformation of shells, were also modeled. The predicted residual deformation was analyzed by considering out-of-roundness in cylindrical shells and compared to the experimental results. The shell FEA results were well-correlated with the overall deformed shape of the AFP cylinder with overlaps, while the shell FEA model of the AFP cylinder without overlaps did not show as good of qualitative match of the deformation pattern. Analytical correlation with measured results were insensitive to material softening at elevated temperatures, geometric nonlinearities, and variations in measured lamina thermal properties. To improve the accuracy of the residual deformation analysis, these results suggest that the thermo-chemical shrinkages preceding the cooldown should be considered, as well as possible variations in ply level microstructure due to the presence of the embedded fiber tow gaps and overlaps.


ABSTRACT: Material viscoelasticity may play a significant role in the bistable composite shells, especially after long-term storage. This article investigates the influence of viscoelastic effects on the mechanical behaviors of bistable composite cylindrical shells in coiled state, for which a novel modeling approach for viscoelastic analysis in integral form of laminated composite shells is proposed based on the nonlinear continuum mechanics and the absolute nodal coordinate formulation. The model presented herein is also very appropriate for the dynamics analysis of deployment of bistable tape springs. Furthermore, an efficient calculation scheme of the highly nonlinear viscoelastic forces with hereditary integral is presented. By comparing the predictions of viscoelastic and elastic analyses for the radii, stresses distributions, and configurations of coiled shells, the effect of viscoelasticity on the second stable equilibrium is illustrated. The results show that relaxation behaviors of bistable composite shells at high strains are evident.


ABSTRACT: The aerospace industry is on a perpetual drive to optimize structures with developments in modeling and analysis capabilities. The traditionally used laminates with orientations are called Legacy QUAD Laminates (LQL). The recent discovery of Trace of an orthotropic stress tensor allows reduction of design variables by the replacement of LQL with equivalent stiffness DD- (double-double) laminate having self-repeating orientations in a set of. The optimized LQL structures are with mid-plane symmetry, excessive ply-migrations, and variability in ply-orientations, which make the manufacturing process cumbersome. On the other hand, DD-laminates are simplified, thinner and free from mid-plane symmetry, thus enable ten-fold reduction in production resources. The present study, an artificial intelligent (AI) genetic-algorithm based stochastic optimizer replaces LQL with DD-laminates, which follows DD-drop design for mass optimization. The optimization algorithm works with unit-circle failure, buckling mode, and wing-tip deflection design criteria and derives optimal-wing with lowest mass, well suited for design requirements in multiple design load-case. The application of algorithm shows 68–70% mass reduction to an initial full-length ply wing-box model of LQL. The minimization of ply-migrations by D/DD-drop optimization yields structures with better resistance for delamination and well suited for automated production. (Math not printed. Please do not put math in your abstracts.)


ABSTRACT: The free-vibration analysis of functionally graded materials (FGM) axisymmetric plate-shell type structures are presented in this work. A numerical solution is obtained by expanding the variables in Fourier series in the circumferential direction and using conical frustum finite elements in the meridional direction. The finite element model, having two nodal circles and ten degrees of freedom per node, is based in the Kirchhoff-Love theory that include the transverse shear deformations by introducing a penalty function, and using one
Gauss point integration scheme which gave excellent results for both thin and thick axisymmetric plate/shells structures. The reduced number of finite elements, which are required to model even complex structures, combined with the use of a small number of discrete layers to model the continuous variation of the mechanical properties through the thickness of the structure, result in an extremely low computational time required for FGM applications. An in-house program has been developed, and applications in a variety of axisymmetric shells are solved, including circular plates. The solutions obtained are discussed and compared with solutions obtained by alternative models.


ABSTRACT: Sandwich panels with cellular cores are increasingly used in engineering due to their superb dynamic performance. In this type of structure, core design significantly affects its mechanical property. This article is to study optimal design of a multi-cellular core to minimize dynamic response of the sandwich panel under harmonic excitation by use of topology optimization. In this study, structural dynamic responses to harmonic excitation are discussed and formulations of the dynamic response in terms of strain and kinetic energy densities are derived. Topology optimization with multi-fractional volume constraint is conducted for multi-cellular core design to minimize the dynamic response of the sandwich panel under harmonic excitation. The optimization to minimize or maximize the dynamic responses are discussed in optimal core designs of sandwich panels. A multi-objective optimisation problem is also considered to optimally suppress harmonic vibrations with a range of several frequencies. Numerical examples are presented to validate the derived formulations and to optimally design multi-cellular cores for sandwich panels to achieve better dynamic performance.


ABSTRACT: Carbon fiber reinforced polymers (CFRP) has been increasingly applied in automobile industry for vehicle body lightweight and safety performance improvement. However, design of CFRP components especially for crushing structures is still highly ambiguous. The present study aims to study the deformation behaviour and energy absorption of the hat shaped CFRP structures and optimize the section shape. Two types of hat shaped CFRP structures with various thicknesses and ply orientation were tested under axial quasi-static crushing. The results show that the Type II hat shaped structure presents a stable progressive crushing mode and better energy absorbing ability as compared with the Type I hat shaped structure. Then, a finite element model was developed using the multi-layer shell element method, and was validated by the axial crushing test results. Finally, the section shape of the Type II CFRP structure was optimized through the surrogate model of radial basis function and global response surface method, and the influences of the section shape on crushing behaviours and energy absorbing abilities were analysed.


ABSTRACT: In this article, a method allowing for prediction of the effective structural damping given the mesoscale architecture of a composite is presented. The method enables a fast and accurate calculation of the loss factor as a function of the direction of the wave propagation and the frequency in any periodic textile composite. The scheme combines two reduction methods, the first being the wave and finite element method that employs periodic structure theory to reduce the size of the problem by allowing for modelling only a unit cell of a periodic structure, while the second reduction approach is a mode-based component mode synthesis that reduces the size of the dynamic stiffness matrix of a unit cell. The exhibited methodology allows for structural damping prediction and optimisation through judicious design of the textile architecture. Numerical examples several complex architectures are exhibited.

**ABSTRACT:** Nonlinear forced vibrations of laminated composite conical shells are investigated by using a higher-order shear deformation theory that includes rotary inertia and geometric nonlinearity in all the kinematic parameters. The system was discretized by using trigonometric expansions. The convergence of the solutions was studied versus the number of degrees of freedom retained in the model. The nonlinear vibration response of laminated composite conical shells to harmonic excitation was studied for different cone angles: hardening and softening response were found according to the geometry. Due to the axial symmetry, a one-to-one internal resonance appeared, as well as quasi-period vibrations. The effect of different lamination sequences on the nonlinear forced vibration response was investigated.


**ABSTRACT:** Based on the first-order shear deformation theory, free vibration and sound insulation of functionally graded material (FGM) sandwich plates with four simply supported edges are studied and analyzed. The sandwich plate with FGM face sheets and homogeneous core and the sandwich plate with FGM core and homogeneous face sheets are considered. Using Navier method and fluid–solid coupling conditions, the vibration and coupled vibro-acoustic dynamic equations for FGM sandwich plates with simply supported edges are established and solved numerically. The natural frequencies and the sound insulation of FGM sandwich plates obtained theoretically are compared with the numerical simulation results. It is shown that the theoretical model of the vibration and the coupling vibro-acoustic theoretical model for the FGM sandwich plate are accurate and feasible. On this basis, the sound insulation characteristics of two types of FGM sandwich plates are analyzed, and the effects of parameter changes (incident angles, gradient index, core thickness, Poisson's ratio) on the fundamental frequency and sound insulation are discussed.

Daniel Pietras (1), Emanoil Linul (2), Tomasz Sadowski (1) and Alexis Rusinek (3)
(1) Department of Solid Mechanics, Lublin University of Technology, Nadbystrzycka 40 Str., 20-618 Lublin, Poland
(2) Department of Mechanics and Strength of Materials, Politehnica University of Timisoara, 1 Mihai Viteazu Avenue, 300 222 Timisoara, Romania
(3) Laboratory of Microstructure Studies and Mechanics of Materials, UMR-CNRS 7239, Lorraine University, 7 rue Félix Savart, BP 15082, CEDEX 03, 57073 Metz, France


**ABSTRACT:** This work reports the out-of-plane crushing response of aluminum honeycomb (HC) filled with polyurethane (PU) foams. For the filling of the HC, two types of PU foams were manufactured: unreinforced PU (UR/PU) foam and PU foam reinforced (GR/PU) with reduced graphene oxide (rGO) flakes. In this investigation, the static and low velocity impact compressive tests were performed on the separate constituents (UR/PU foam, GR/PU foam and empty HC) and their combinations (UR/PU foam-filled HC and GR/PU foam-filled HC). By the addition of 0.02% rGO flakes, to UR/PU, an increase (over 41%) of the strength and energy absorption properties was obtained. Moreover, due to the interaction effect, the foam-filled HC composite highlights better properties (up to 61%) than the empty HC structure. Further, it has been observed that exposure of the specimens to ultraviolet (UV) radiation do not change the foam density, but their properties increase by up to 30%. Finally, it was noticed that the in-situ foam-filled HC manufacturing technique is clearly superior to the ex-situ method, while the foam material dictates the filled HC collapse mechanisms considerably.

References listed at the end of the paper:
1 Z. Wang, Recent advances in novel metallic honeycomb structure, Compos B Eng, 166 (2019), pp. 731-741
37 D. Pietras, T. Sadowski, Parametric study of geometry effect on response to applied loadings of metallic honeycomb structures by virtual testing of mesoscale models, Arch Metall Mater, 63 (2) (2018), pp. 953-961
38 S. Liu, J. Tian, L. Wang, X. Sun, A method for the production of reduced graphene oxide using benzylamine as a reducing and stabilizing agent and its subsequent decoration with Ag nanoparticles for enzymeless hydrogen peroxide detection, Carbon, 49 (2011), pp. 3158-3164
41 J. Lee, J. Kim, Y. Shin, I. Jung, Ultra-robust wide-range pressure sensor with fast response based on polyurethane foam doubly coated with conformal silicone rubber and CNT/TPU nanocomposites islands, Compos B Eng, 177 (2019), Article 107364
42 ISO13314, Mechanical testing of metals. — Ductility testing — Compression test for porous and cellular metals, 2011.
44 T. Fiedler, K. Al-Sahlan, P.A. Linul, E. Linul, Mechanical properties of A356 and ZA27 metallic syntactic foams at cryogenic temperature, J Alloy Compd, 813 (2020), Article 152181
50 E. Linul, L. Marsavina, P.A. Linul, J. Kovacik, Cryogenic and high temperature compressive properties of Metal Foam Matrix Composites, Compos Struct, 209 (2019), pp. 490-498
52 E. Linul, D. Lell, N. Movahedi, C. Codrean, T. Fiedler, Compressive properties of Zinc Syntactic Foams at elevated temperatures, Compos B Eng, 167 (2019), pp. 122-134
59 P. Lucki, A. Derlatka, J. Winowiecka, Analysis of the composite I-beam reinforced with PU foam with the addition of chopped glass fiber, Compos Struct, 218 (2019), pp. 60-70

ABSTRACT: The aluminum/carbon fiber reinforced plastics (CFRP)/aluminum hybrid tube (H-III) with a good interface bonding was prepared by spinning forming to explore its crushing behaviors and energy absorption mechanism. The quasi-static crushing test was conducted to analyze the crashworthiness. Wrapped hybrid tube (H-I) and assembling aluminum/CFRP/aluminum hybrid tube (H-II) were involved for comparative purpose. The results showed that H-III tube outperformed all hybrid structures in crashworthiness and possessed 20.5% higher energy absorption than the summation of the individual components. Good bonding interaction between CFRP/metal interface obtained by spinning forming promoted the extra restriction from outer aluminum tube on the CFRP layer, which significantly improved the crashworthiness. Delamination failure behavior in CFRP/metal interface was numerically investigated. Moreover, the deformation modes of each layer in H-III hybrid structure comparing with corresponding single structure were explored. It was found that the development of delamination failure during crushing was bound to contribute to the improvement of energy absorption. The aluminum tubes in the single structure exhibited concertina mode while diamond mode dominated those in the hybrid structure under the bonding interaction. The more adequate damaged CFRP layer was identified in the hybrid structure than the single structure, making more contribution to energy absorption.


ABSTRACT: Buckling of composite laminates containing multiple delaminations are analyzed theoretically based on the proposed equivalent model. From the exact analysis in which the nonlinear contact effect between the two portions above and beneath the delamination is included, it is found that (1) the two portions above and below the delamination undergoes exactly identical global deflection; (1) the composite laminate is subjected to Mode II delamination propagation due to in-plane slipping. According to such observations, an equivalent model which is perfect, delamination free is proposed to replace the delaminated portion of the laminate. The substitute model has the same geometric size and is stacked in the same sequence as that of the delaminated portion. The exact solution of the global deflection mode also suggests that the stiffness of the substitute model is taken as the sum of the stiffness of the two portions above and beneath the delamination. Buckling of composite laminates simply supported at the four sides with a single delamination is examined for different delamination length and depth using equivalent model, exact model and the finite element model. A good agreement between them demonstrates the efficiency and accuracy of the presented equivalent model. Using the established equivalent model, buckling of composite laminates with multiple delaminations along thickness and horizontal directions are investigated. Parametric studies are executed analytically and numerically to inspect the influence of delamination conditions, such as the number of delamination as well as the depth, the position and the length of each delamination, on the buckling performance of the composite laminates.


70 L. Marsavina, T. Sadowski, Fracture parameters at bi-material ceramic interfaces under bi-axial state of stress, Computational Materials Science, 45 (3) (2009), pp. 603-697
ABSTRACT: The objective of this research is to investigate the influence of the laminate code and autoclaving process parameters on the buckling and post-buckling behaviour of thin-walled, composite profiles with square cross-section. A compression of profiles with the following dimensions was investigated: (width × height × thickness) 80 mm × 80 mm × 1.2 mm and length equal to 240 mm. The laminates were cured in two autoclaving processes: the nominal process on an empty aluminium mandrel and slow curing process on a full aluminium mandrel. Five different laminate codes were inspected – two symmetric and three anti-symmetric ones with respect to the midplane of the laminate. In total, 40 samples were inspected. The results were compared with two FE models. The first did not include the residual stresses in the material while the second did. A comparison of experimental data with the results of FE modelling proves that residual stresses significantly contribute in the buckling and post-buckling behaviour of thin-walled laminated structures with closed cross-section. Their occurrence has a positive effect on the stability of the columns. The study also covers the discussion about the failure loads of the considered columns.

References listed at the end of the paper:
22 P. Czapski, T. Kubiak, Influence of residual stresses on the buckling behaviour of thin-walled, composite tubes with closed cross-section – Numerical and experimental investigations, Compos Struct, 229 (2019), Article 111407
27 S. Daynes, K.D. Potter, P.M. Weaver, Bistable prestressed buckled laminates, Compos Sci Technol, 68 (2008), pp. 3431-3437
28 S.F. Müller de Almeida, J.S. Hansen, Enhanced elastic buckling loads of composite plates with tailored residual stresses, J Appl Mech, 64 (1997), pp. 772-780
32 H. Lahtinen, Calculation of residual stresses of cross-ply laminates, J Compos Mater, 37 (2003), pp. 945-966
35 A. Ding, S. Li, J. Sun, J. Wang, L. Zu, A thermo-viscoelastic model of process-induced residual stresses in composite structures with considering thermal dependence, Compos Struct, 136 (2016), pp. 34-43
40 L. Liu, B.M. Zhang, D.F. Wang, Effects of cure cycles on void content and mechanical properties of composite laminates, Comp Struct, 73 (3) (2006), pp. 303-309
43 User’s Guide ANSYS 19.1, Houston, USA: Ansys Inc.
45 M. Paszkiewicz, T. Kubiak, Selected problems concerning determination of the buckling load of channel section beams and columns, Thin Walled Struct, 93 (2015), pp. 112-121
47 H. Debksi, A. Teter, T. Kubiak, Numerical and experimental studies of compressed composite columns with complex open cross-sections, Compos Struct, 118 (2014), pp. 28-36
48 H. Debksi, T. Kubiak, A. Teter, Experimental investigation of channel-section composite profiles’ behavior with various sequences of plies subjected to static compression, Thin Walled Struct, 71 (2013), pp. 147-154
50 H.T. Nguyen, S.E. Kim, Buckling of composite columns of lipped-channel and hat sections with web stiffener, Thin Walled Struct, 47 (2009), pp. 1149-1160
51 D. Visy, M. Szedlák, B.B. Geleji, S. Ádány, Flexural buckling of thin-walled lipped channel columns with slotted webs: numerical and analytical studies, Eng Struct, 197 (2019), Article 109399
52 D. Banat, R.J. Mania, Stability and strength analysis of thin-walled GLARE composite profiles subjected to axial loading, Compos Struct, 212 (2019), pp. 338-345

ABSTRACT: Buckling strength and ductility of a metallic cylindrical shell can be enhanced significantly by externally wrapping fiber-reinforced polymer (FRP) composite sheet(s). This paper presents an in-depth numerical study on inelastic buckling of glass FRP (GFRP) strengthened steel tube. The influence of boundary conditions, geometric imperfections, transverse moduli of GFRP, metal-FRP interfacial bond, FRP damage, and other challenges in numerical modeling and computation on buckling behavior are investigated. The predictions demonstrate good agreement with published experiments Teng and Hu [1]. It is shown that accurate prediction of i) post-yield behavior is possible only by the inclusion of metal-FRP interfacial damage, and ii) point of buckling and buckling failure modes require the inclusion of FRP damage as well. Further, this study reveals that i) the metal-FRP interfacial damage happens just before or immediately after the initiation of tube yielding, ii) the axisymmetric buckle initiates at same loading irrespective of amount of FRP strengthening, iii) FRP matrix compression damage and buckle growth aid each other, and iv) an increase in FRP strengthening retards the buckling growth to the point of strain localization.


ABSTRACT: In this study, mechanical behavior of multilayer corrugated core laminated composite sandwich panel subjected to quasi-static three-point bending is investigated experimentally as well as numerically. Parameters such as contact force, energy absorption and specific absorbed energy (unit mass energy) for different geometries of corrugated core (rectangular, trapezoidal and triangular) are studied during loading process and failure. Composite plates and corrugated cores have been manually made using ML506 epoxy resin with 15% hardener and 45% volumetric woven glass fibers. Experimental results show that multilayer sandwich composite panels not only strengthen the structure in the quasi-static three-point bending process, but also make the absorbed energy grow significantly by increasing the contact force and displacement up to the complete failure. The main mechanisms of damage and failure of sandwich panel specimens during load bearing process are matrix cracking, fiber breakage, delamination, local indentation, global bending, crushing and buckling of cell walls and face sheet and core de-bonding. Rectangular geometry of corrugated core, in terms of energy absorption and specific energy exhibits better results in comparison to other shapes. Numerical simulation using ABAQUS FEA package led to results, which are in good agreement with experimental ones and make it possible to use simulation instead of costly tests for analysis and design.


ABSTRACT: Stability of thin-walled, composite, aerospace structures is a key issue in an analysis of its safety. This research aims to investigate the influence of the curing parameters on the stability (buckling behaviour) of thin-walled, GFRP laminates. Under inspection was taken the compression of eight-layered (layup [45/-45/45/-45]), composite columns with a square cross-section with the dimensions: (width × height × thickness) 80 mm × 80 mm × 1.2 mm and length equal to 240 mm. The composite was cured in two autoclaving curing cycles. The first is a nominal curing cycle on an empty aluminium mandrel, while the second is a modified curing cycle on a full aluminium mandrel. To verify the quality of the manufactured composite, an assessment of the microstructure has been performed. Then, compression tests were performed and two FE models were prepared, with and without the inclusion of residual stresses in the material. Additionally, for the purpose of the second FE model, coefficients of thermal expansion of the laminate were determined experimentally. A comparison of FE models with experimental data leads to the conclusion that residual stresses are not negligible and must be taken into account FE modelling of columns with closed cross-section.

References listed at the end of the paper:
38 M. Paszkiewicz, T. Kubiak, Selected problems concerning determination of the buckling load of channel section beams and columns, Thin-Walled Struct, 93 (2015), pp. 112-121
40 H. Debski, A. Teter, T. Kubiak, Numerical and experimental studies of compressed composite columns with complex open cross-sections, Compos Struct, 118 (2014), pp. 28-36
41 H. Debski, T. Kubiak, A. Teter, Experimental investigation of channel-section composite profiles’ behavior with various sequences of plies subjected to static compression, Thin Walled Struct, 71 (2013), pp. 147-154

ABSTRACT: This paper presents the results of axial compression tests of concrete-filled GFRP tubular (CFGT) stub columns after being subjected to acid corrosion. Fifty-four specimens subjected to acid corrosion and nine specimens untreated with acid solutions are axially tested. The main parameters considered in this study include the wall thickness of GFRP tube, concrete strength, PH value of acid solution, and immersion duration. CFGT stub columns after being subjected to acid corrosion are all failed with the fracturing of GFRP tube and crushing of core concrete. The ultimate strength of the CFGT stub columns corroded by acid solution decreases remarkably compared with those without acid corrosion. The longer the immersion duration, the lower the ultimate strength of the acid corroded CFGT stub columns. Immersion duration has the greatest influence on the percentage decrease of ultimate strength of the acid corroded CFGT stub columns, followed by the PH value of acid solution. However, the effects of the wall thickness of GFRP tube and concrete strength on the percentage decrease of ultimate strength can be neglected. Additionally, the finite element models are also developed for the acid corroded CFGT stub columns by the ABAQUS software and are verified with the experimental results.

ABSTRACT: This work studies large amplitude free vibration of piezoelectric laminated doubly curved panels reinforced with zigzag/armchair graphene sheets under uniform temperature rise. Thermomechanical and kinematic relations are derived using refined Halpin-Tsai approach and Amabili-Reddy (fourth-order shear deformation) theory which remains all nonlinear terms in the in-plane displacements. The explicit form of the quadratic variation of electric potential with Green-Lagrange strains and pyroelectric effects under open and closed circuits are presented. As a first endeavor, the explicit forms of six-coupled PDEs of motions are extracted using Gibbs energy, Hamilton principle and Maxwell equation. For the first time, the eigenvalue problem is solved via the Gálérkin and extended He variational method. To verify, linear frequencies of piezoelectric, graphene-reinforced composite and nonlinear frequencies of laminated composite plates are compared with available results and it is shown that Amabili-Reddy theory has less sensitivity to electric surface condition than first-order shear deformation theory. Parametric studies reveal that panels with low thickness of piezoelectric layer, closed circuit and high temperature show higher frequency ratios than other panels. Moreover, panels with BaTiO3 layers display more sensitivity to the amplitude and less sensitivity to electric surface condition than panels integrated with PZT-4 and PZT-5A layers in ambient temperature.

ABSTRACT: This paper investigates the free vibration and crack identification of functionally graded material (FGM) plates with a through-width edge crack. The material properties of the FGM plates change continuously with the power law distribution along the plate thickness direction. The crack in an FGM plate is simulated as a massless rotational spring and the plate is separated into two sub-plates at the crack location connected by the line spring. The stress intensity factor (SIF) in the FGM strip is calculated to determine the stiffness of the spring. The governing equations of cracked FGM plates are derived from the Mindlin plate theory and solved by the differential quadrature (DQ) method to obtain modal parameters. The vibrational mode of a cracked FGM plate is analyzed by utilizing continuous wavelet transform (CWT). A novel damage index (DI) is developed based on calculated wavelet coefficients to localize the crack in FGM plates. This method can localize the crack accurately and reduce the edge effect even with the measurement noise.


ABSTRACT: A new generalized 5-variable shear deformation theory is proposed to calculate the static response of functionally graded plates. A small exponential function with a shape parameter $m$ is multiplied to a classical trigonometric shear strain shape function to make more accurate distribution of the transverse shear strain in the thickness direction of the functionally graded plates. The novelty of this work is that the shear strain function with the shape parameter $m$ is assumed to vary with power-law indexes. Golden section search is used to determine the values of the optimal shape parameter $m$. The present shear strain shape function satisfies the stress-free condition at top and bottom surfaces without using any transverse shear correction factors. The governing equations and boundary conditions are derived from the Hamilton principle, and the closed form solutions of Navier-type under simply supported boundary conditions are obtained. The accuracy of the proposed theory is verified by comparing the results of numerical examples with the other existing 2D and quasi-3D solutions. The effect of gradient index, side-to-thickness ratio and aspect ratio on the static response is also studied.


ABSTRACT: Existing of cracks within blade structures can cause stiffness degradation and hence changes their vibration characteristics. This study investigates the vibration behaviors of rotating pre-twisted hybrid composite blades containing functionally graded carbon nanotube-reinforced composite (FG-CNTRC) laminae and damaged fiber-reinforced composite (FRC) laminae. The degraded stiffness of the cracked lamina is modeled through the self-consistent model (SCM). The blade is modeled as a shell structure that is formed by twisting a plate around its mean line. With the help of the differential geometry theory, a novel shell model has been derived to describe the kinetics of the blade. The effect of the Coriolis and centrifugal force are both presented in the formulation, which results in a damped-like free vibration system governed by a system of second-order ordinary differential equations (ODEs). Utilizing the state space technique, the system is reformulated to a system of first-order ODEs. The IMLS-Ritz method is then used for discretizing the ODEs. After carefully validating the effectiveness of the presented model through a series of comparison studies, parametric studies including CNT distribution configuration, rotating speed, geometrical parameters on the vibration responses of cross-plied composite blades are systematically examined. The vibration characteristics of angle-plied composite blades are also investigated.

Saifeng Zhong, Guoyong Jin, Tiangui Ye, Jianhua Zhang, Yaqiang Xue and Mingfei Chen, “Isogeometric vibration analysis of multi-directional functionally gradient circular, elliptical and sector plates with variable
9 R. Mindlin, Micro-structure in linear elasticity, Arch Rat Mech Anal, 16 (1964), pp. 52-78
7 W. Nowacki, Theory of micropolar elasticity, Springer (1972)
6 Cosserat E, Cosserat F., Theorie des corps deformables. Hermann Archives (reprint 2009); 1909.
5 W. Voigt, Theoretische Studien uber die Elasticitatsverhaltnisse der Krystalle. III., Untersuchung des elastischen Verhaltens eines Cylinders aus krystallinscher Substanz, auf dessen Mantelflache keine aussern Drucke wirken, wenn die in seinem Innern wirkenden Spannungen lineare Functionen der Axenrichtung sind, Abhandlungen der Mathematischen Classe der Koniglichen Gesellschaft der Wissenschaften zu Gottingen, 34 (1887), pp. 53-79
4 W. Voigt, Theoretische Studien uber die Elasticitatsverhaltnisse der Krystalle. II. Untersuchung des elastischen Verhaltens eines Cylinders aus krystallinscher Substanz, auf dessen Mantelflache keine Kraften wirken, wenn die in seinem Innern wirkenden Spannungen langs der Cylinderaxe constant sind, Abhandlungen der Mathematischen Classe der Koniglichen Gesellschaft der Wissenschaften zu Gottingen, 34 (1887), pp. 3-52
2 A. Muc, M. Chwa, Vibration control of defects in carbon nanotubes, IUTAM Bookseries, 30 (2011), pp. 239-246
1 A. Muc, Design and identification methods of effective mechanical parameters, boundary conditions (BCs), thickness variation index are investigated and discussed specifically.

References listed at the end of the paper:
1 A. Muc, Design and identification methods of effective mechanical properties for carbon nanotubes, Mater Des, 31 (4) (2010), pp. 1671-1675
2 A. Muc, M. Chwa, Vibration control of defects in carbon nanotubes, IUTAM Bookseries, 30 (2011), pp. 239-246
4 W. Voigt, Theoretische Studien uber die Elasticitatsverhaltnisse der Krystalle. II. Untersuchung des elastischen Verhaltens eines Cylinders aus krystallinscher Substanz, auf dessen Mantelflache keine Kraften wirken, wenn die in seinem Innern wirkenden Spannungen langs der Cylinderaxe constant sind, Abhandlungen der Mathematischen Classe der Koniglichen Gesellschaft der Wissenschaften zu Gottingen, 34 (1887), pp. 53-79
5 W. Voigt, Theoretische Studien uber die Elasticitatsverhaltnisse der Krystalle. III., Untersuchung des elastischen Verhaltens eines Cylinders aus krystallinscher Substanz, auf dessen Mantelflache keine aussern Drucke wirken, wenn die in seinem Innern wirkenden Spannungen lineare Functionen der Axenrichtung sind, Abhandlungen der Mathematischen Classe der Koniglichen Gesellschaft der Wissenschaften zu Gottingen, 34 (1887), pp. 80-100
6 Cosserat E, Cosserat F., Theorie des corps deformables. Hermann Archives (reprint 2009); 1909.
7 W. Nowacki, Theory of micropolar elasticity, Springer (1972)
9 R. Mindlin, Micro-structure in linear elasticity, Arch Rat Mech Anal, 16 (1964), pp. 52-78
15 N. Fantuzzi, P. Trovalusci, S. Dharasura, Mechanical behavior of anisotropic composite materials as micropolar continua, Front Mater, 6 (2019) [Article 59]

ABSTRACT: This study aims to investigate the free vibration of multi-directional functionally gradient (multi-directional FG) circular, elliptical and sector plates with variable thickness. A numerical analysis procedure based on the isogeometric analysis (IGA) and high-order shear deformation theory (HSDT) is applied. For the HSDT, the effect of shear deformation can be considered, and no shear correction coefficient is needed. By using isogeometric analysis with the non-uniform rational B-spline (NURBS) as the basis function, the precise geometric models and high-order approximation are obtained so that the C continuity of HSDT can be directly achieved without any additional variables. The plates in this paper are considered inhomogeneous in multiple directions, and the thickness of plates also changes along both x- and y-axes. To verify the correctness and validity of the current numerical analysis procedure, several numerical examples for the above plates are obtained and results are compared with those from the literature. Then the effects of material variation parameters, boundary conditions (BCs), thickness variation index are investigated and discussed specifically.
27 R. Barretta, R. Luciano, Marotti de Sciarra F., A fully gradient model for euler-bernoulli nanobeams. Math Prob Eng vol. 2015, 8 p., Article ID 495095
30 Chwaf M., Nonlocal beam model and FEM of free vibration for pristine and defective CNTs. J Phys Conf Ser; 2020 [accepted for publication].
32 M. Arefi, T. Rabczuk, A nonlocal higher order shear deformation theory for electro-elastic analysis of a piezoelectric doubly curved nano shell, Compos Part B, 168 (2019), pp. 496-510
34 I. Kholmanov, E. Cavaliere, M. Fanetti, C. Cepek, L. Gavioli, Growth of curved graphene sheets on graphite by chemical vapor deposition, Phys Rev B, 79 (2009), Article 234603
ABSTRACT: This work presents refined shell finite element (FE) models based on Reissner’s Mixed Variational Theorem (RMVT) with layer-wise (LW) Node-Dependent Kinematics (NDK) for the analysis of multi-layered composite structures. LW descriptions of displacements and transverse stresses employing hierarchical Legendre polynomials (HLP) are adopted. Developed in the framework of Carrera Unified Formulation (CUF), adaptable refinement through hierarchical shell elements with NDK is extended to the RMVT formulations. The numerical accuracy and efficiency are assessed by comparing the FE solutions for bending shells against references available in the literature or from modeling with commercial software.

ABSTRACT: In the present paper, effects of porous material on bifurcation buckling and natural vibrations of nanobeams are investigated based on the higher-order nonlocal strain gradient theory. The displacement field of the nanobeam satisfies assumptions of Reddy higher-order shear deformation beam theory. The displacements gradients are assumed to be small so that the components of the Green-Lagrange strain tensor are linear and infinitesimal. The constitutive relations for functionally graded porous material are expressed by nonlocal and length scale parameters and power-law variation of material parameters in conjunction with cosine functions to create a possibility to investigate the effect of diverse distributions of porosity on mechanics of nanostructures. Effect of Winkler-Pasternak foundation on mechanics of nanobeam is also considered. The Hamilton’s variational principle is utilized to derive governing equations of motion of the composite nanobeam. For the first time, the critical porosity is defined and examined for bifurcation buckling analysis of elastically supported nanobeams with symmetric distribution of porosity. Influence of axial forces and types of porosity distributions on eigenfrequencies of functionally graded nanobeams is studied. Classical theory without nonlocal effects is obtained as a special case and valid for all considered distributions of functionally graded material and volume fractions of voids.

ABSTRACT: This article defines the effective stiffness of a laminated composite rectangular plate with holes by the homogenization method. Based on the continuous model, a theory is presented for conducting a free vibration analysis of the laminated composite rectangular plate with holes. The theory is derived by the Ritz method. The validity of the theory is verified by comparing the results of the finite element analysis (static/modal analyses). Finally, we investigate the effects of the design parameters on the vibration characteristics of the laminated composite rectangular plates with holes by a parametric analysis based on the present method. The results allow a database to be obtained on the structural characteristics of laminated composite rectangular plates for applying aerospace applications. Consequently, it is concluded that the theory is well suited to free vibration analysis of a laminated composite rectangular plate with holes for aerospace applications due to their relative simplicity and computational efficiency.

ABSTRACT: A complex mode superposition method based on equivalent viscous damping model (CEV) is proposed for time-domain dynamic responses of non-classically damped composite structures. The damping matrix of hysteretic non-classically damped composite structures can be easily obtained and complex mode superposition method based on hysteretic damping model is directly realized in the physical space. However, hysteretic damping model is not causal, and is only applied in frequency-domain analysis. By the aid of constitutive model of Kelvin-Voigt model, viscous damping model which is equivalent to the hysteretic
damping model is obtained based on single degree of freedom system. Combined with complex mode superposition method of hysteretic damping model and mathematical simplicity of equivalent viscous damping model, CEV can be realized. Structural vibration responses of shaking table test under random excitations are measured, which are compared with the corresponding calculation results using CEV and traditional complex mode superposition method based on viscous damping model (CR), respectively. The calculation results obtained by the two complex mode superposition methods are consistent with the test results. Compared with CR, the calculation results of CEV are unique, computational efficiency of CEV is higher and the problem of choosing reasonable modes has been avoided.


ABSTRACT: Nonlinear stability behavior of rotationally-restrained stiffened laminated composite doubly-curved shallow shells with imperfection subjected to in-plane shear and compression loading is evaluated using a new and unique semi-analytical method. The new equivalent model with variable stiffness for both centrically- and eccentrically-stiffened shells is developed, and Heaviside function is uniquely applied to construct the variable stiffness of stiffened shells along two orthogonal directions. The Galerkin method is implemented to solve the nonlinear governing equation, and the snapping phenomenon of stiffened shell structures is then captured by the arc-length method (Riks method). The nonlinear load-deflection equilibrium paths of centrically- and eccentrically-stiffened plates and four typical shallow shell structures are studied, and both the real geometry and equivalent models by the numerical finite element method are used to validate the present semi-analytical approach. Finally, the influence of amplitude of imperfection, edge rotational restraint spring stiffness, load ratios, curvature radii, and distribution of stiffeners on nonlinear stability behavior of stiffened shells are discussed to demonstrate effective application of present semi-analytical method.

Fabrizio Greco, Lorenzo Leonetti, Paolo Lonetti, Raimondo Luciano and Andrea Pranno, “A multiscale analysis of instability-induced failure mechanisms in fiber-reinforced composite structures via alternative modeling approaches”, Composite Structures, Vol. 251 Article 112529, 1 November 2020,

https://doi.org/10.1016/j.compstruct.2020.112529

ABSTRACT: Multiscale techniques have been widely shown to potentially overcome the limitation of homogenization schemes in representing the microscopic failure mechanisms in heterogeneous media as well as their influence on their structural response at the macroscopic level. Such techniques allow the use of fully detailed models to be avoided, thus resulting in a notable decrease in the overall computational cost at fixed numerical accuracy compared to the so-called direct numerical simulations. In the present work, two different multiscale modeling approaches are presented for the analysis of microstructural instability-induced failure in locally periodic fiber-reinforced composite materials subjected to general loading conditions involving large deformations. The first approach, which is of a semi-concurrent kind, consists in the “on-the-fly” derivation of the macroscopic constitutive response of the composite structure together with its microscopic stability properties through a two-way computational homogenization scheme. The latter one is a novel hybrid hierarchical/concurrent multiscale approach relying on a two-level domain decomposition scheme used in conjunction with a nonlinear homogenization scheme performed at the preprocessing stage. Both multiscale approaches have been suitably validated through comparisons with reference direct numerical simulations, by which the ability of the latter approach in capturing boundary layer effects has been demonstrated.


ABSTRACT: All-metallic sandwich panels with lattice truss cores are typically ultralight, stiff and strong, yet poor in passive vibration damping. Novel laser-welded corrugated-core (LASCOR) sandwich panels with polyurea-metal laminates (PML) as face sheets were proposed and fabricated, and their vibration and damping characteristics were systematically investigated, both experimentally and numerically. Frequency/time response curves, natural frequencies, vibration mode shapes and damping loss factors were measured and compared with
LASCOR sandwich panels without embedded polyurea layers. A combined finite element-modal strain energy (FE-MSE) method was proposed to predict the vibration damping performance and explore the underlying enhancement mechanisms, with the frequency-dependent damping behaviors of polyurea considered. Good agreement was achieved between numerical simulations and experimental measurements. The PML face sheets enabled remarkable damping enhancement, due mainly to viscoelastic energy dissipation of the polyurea layers. The capacity of the sandwich panel in passive vibration suppression could be further improved by tailoring the polyurea layer thickness and the distribution of polyurea layers.


ABSTRACT: In this article, by means of nonlocal elasticity theory with using a higher order shear deformation theory (HSDT), the size-dependent wave propagation in functionally graded (FG) doubly-curved shells is investigated. In this HSDT, an exponential function along with a trigonometric formula represents the displacements and the implementation of Hamilton’s principle resulted in obtaining the governing equations. Shells are considered to be made of three different types of material properties: 1. FG carbon nanotubes-reinforced composite (FG-CNTRC), 2. FG graphene nanoplatelets-reinforced composite (FG-GNPRC), 3. FG porous ceramic–metal (FG-PCM). The properties for FG-CNTRC are estimated by the rule of mixture, for FG-GNPRC are evaluated by Halpin-Tsai model and for FG-PCM are modeled by a power law function combined with a cosine formula. The accuracy of proposed models are verified with open literatures’ results. The effects of CNTs’ percentage, GNP’s’ weight fraction, intensity of porosity, distribution patterns of CNTs as well as GNP’s and porosities, wave numbers, nonlocal parameter and thickness of shells on the results of FG doubly-curved shells are also presented.


ABSTRACT: In this paper, a novel nonlocal strain gradient isogeometric model using the nonlocal strain gradient theory (NSGT) and isogeometric analysis (IGA) is developed to analyze free vibration and bending behaviors of functionally graded (FG) plates. Based on the higher-order shear deformation theory (HSDT) and NSGT, the weak form of the governing equation motion of the plates is presented. To homogenize material properties, the Mori-Tanaka scheme is used. The proposed model is capable of capturing both nonlocal effects and strain gradient effects in nanoplate structures due to adding two parameters, i.e. nonlocal and strain gradient parameters, into the elastic constants of FG materials. Thanks to those two parameters, both stiffness reduction and stiffness enhancement mechanism of FG plates are observed. The principle of virtual work is used to derive governing equations, subsequently, the natural frequencies and deflections of the FG plates are determined. Numerical results are presented to evaluate effects of the geometry, boundary condition, length-to-thickness ratio, exponential factor, nonlocal parameter and strain gradient parameter on the natural frequency and deflection of FG plates. In addition, the pure nonlocal and strain gradient models can be restored from the proposed model when taking the zero of the strain gradient and nonlocal parameters, respectively.


ABSTRACT: In this paper, the low velocity impact (LVI) on a quasi-isotropic laminate [45/0/−45/90]. (QIL) is studied to predict the deformation response and damage state of the laminate. This stacking of a QIL is a benchmark case that results in a “rotating-fan” pattern of delamination damage due to the impact. Drop-tower tests were performed with an impact energy of 25 J and an impactor mass of 7.5 kg. 3D digital image correlation (3D DIC) was carried out to measure the in situ deformation of the laminate. Non-destructive inspection (NDI) including ultrasound C-scanning and X-ray micro computed tomography (micro-CT) were done to characterize the overall damage footprint and the internal detailed damage morphology. The computational model is an extension and refinement of the model developed in Refs. [74], [76]. Enhanced
Schapery Theory (EST) is used as the constitutive model and implemented with a user material subroutine in the commercial code Abaqus. The EST uses Schapery theory for pre-peak damage and the crack band model for post peak failure. The major contributions reported in this paper are as follows; in the experimental study, the damage mechanisms have been illustrated with high-resolution micro-CT scanning, while in the numerical study, the “rotating-fan” pattern, damage-free cone and damage modes interaction have been accurately and efficiently captured with a uniform, non-fiber-aligned mesh.


ABSTRACT: The influence of the hygrothermal effect is considered in the constitutive relation of carbon fiber reinforced composite (CFRP) based Reddy’s high-order shear deformation theory. The geometric nonlinear governing equations are derived by using virtual displacement method; and the boundary conditions are elastic restraint against rotation. Then, the physical parameters of CFRP are considered as constant in the hygrothermal effect, and the governing equations are solved by using Galerkin method, where clamped rectangular CFRP laminate is used. Finally, the effects of the different hygrothermal effect, length height ratio, length width ratio and total number of plies are discussed on the load-central deflection and bending moment.


ABSTRACT: The mechanical behavior of sandwich panels with a buckling-dominated lattice core (SPBLC) are studied in this work. Based on an analysis of the structural force, deformation, yield point, plastic limit, and bifurcation buckling, the formulas for predicting the structural stiffness and strength are established and then validated by experimental tests and numerical simulations. The negative effects of the initial rod curvatures on the structural stiffness and strength are investigated for SPBLCs with different relative densities, different initial rod curvatures, and different cross-section shapes. Moreover, a comparative study on the energy absorption ability of SPBLCs and traditional sandwich panels with stretching-dominated lattice cores (SPSLCs) is conducted, which shows that a better energy absorption performance can be achieved by rationally designing the initial rod curvature. This work provides a theoretical model and design criteria for sandwich panels with buckling-dominated lattice cores, and it is instructive for the design of other buckling-dominated structures.


ABSTRACT: This study intends to model the effect of porosity type defect and analyze the consequences of porosity on the buckling characteristic of various types of FGM sandwich combinations. Here, we consider four types of FGM sandwich combinations considering the multiple arrangements of the constituent layers (i.e., two face sheets and a core). Further, the combinations of all kinds of sandwiches are considered in such a way that there is no material discontinuity or jump. The porosity defects are modeled in this work as the criteria of stiffness reduction and incorporated in the rule of mixture. Finally, results are calculated by considering two types of porosity distribution, evenly and unevenly, while modeling the FGM plate. The buckling response of FGM sandwich plates has been analyzed under a nonuniform in-plane edge load. The application of nonuniform in-plane loads causes in-plane stresses to be nonlinear. Hence, in-plane stresses need to be calculated apriori for the buckling study of the FGM plate under nonuniform load. Further, the effects of various parameters like porosity contents, sandwich combinations, aspect ratio, thickness ratio, boundary conditions on buckling load of FGM plate have been studied in this paper.

ABSTRACT: Herein, the damage problem of quasi-isotropic composite laminates subjected to a quasi-static transverse load has been studied analytically. The damage was modeled as multiple equal-sized annular delaminations of equal-interval in the thickness direction without any opening during transverse loading. This simplified damage shape was adopted according to the typical damage morphology of impact-tested laminates. Closed-form expressions of the responses, such as a deflection and an energy release rate, were developed in terms of the applied force, dimensions of the plates, and damage under arbitrary boundary conditions based on the Mindlin plate theory. Though their applicability is limited owing to an assumption of linearity, the closed-form expressions provide fundamental information, particularly at the initiation and early growth of the damage, on the effects of the boundary conditions, dimensions, fundamental material properties, and ply thickness of the composite laminates.


ABSTRACT: The composite sandwich structures, as a representative of lightweight and high-strength structures, exhibit extraordinary engineering application potential. However, the weak connection between panel and core limits their application. This paper focuses on investigating the panel-core connection and impact properties of the carbon fiber reinforced polyether ether ketone (CF/PEEK) sandwich structure with truss core. An in-suit hot-pressing connection technology distinguishing from traditional brazing (for metal materials) and bonding (for thermosetting composites) methods is proposed for connecting panels and truss cores. The low velocity impact test were carried out to investigate the impact response and failure modes of the CF/PEEK sandwich structures. The finite element (FE) model is established to predict the structural response under low velocity impact loading. The impact response of the structure is analyzed using experimental and simulation results, which are affected by relative density of core, impact energy and impact site. Besides, parametric analyses on impactor diameter and unit cell number was carried out. This work provides guidance for studying the impact performance of composite sandwich structures.


ABSTRACT: Crashworthiness plays a key role in energy absorption and hence in vehicle accidents. The energy absorption capacity of laminated composite materials is heavily investigated in the industry due to their low cost, corrosion resistance, and high strength to weight ratio. Thus, this paper experimentally investigates the effect of the addition of woven fiber laminates and fiber steel sandwich laminates on the strength and energy absorption capacity of PVC polymer tubes. The sandwich-structured composite is formed from two glass-fiber composite layers with a steel layer in between. Four normal and hybrid reinforcement configurations are proposed, evaluated, and compared to the benchmark unreinforced tube. The crashworthiness characteristics of the reinforced composite tubes were identified using quasi-static axial compression tests. The crushing parameters, in terms of load–displacement response, load-carrying capacity, Specific Energy (SE) absorption capability, and Crush Force Efficiency (CFE) were determined for each sample. Moreover, Scanning Electron Microscope (SEM) analysis was carried out to investigate the microstructures, which clearly indicate the fractured surfaces. The results show that the tube reinforced with a 1 mm steel layer sandwiched between 2 layers and 4 layers of woven glass-fiber has the highest SE and CFE of 14 J/g and 0.91, respectively, while the tube reinforced with 7 layers of glass fiber layers only has the highest Initial Peak Load (IPF) of 139.36 kN.


ABSTRACT: The studies on the higher-order beam theory and its application to functionally graded (FG), laminated composite and sandwich beams have received much research attention over recent years. While significant progress has been made, there is an issue with the selection of the appropriate distribution function
for describing section warping due to transverse loading. In the present study, a rational approach is proposed for the determination of correct warping functions for symmetric cross sections. Two new conditions on warping function are suggested: first, the warping function should vanish on the neutral plane; and second, the first derivative of warping function should take unity value on the neutral plane. A rigorous procedure is then developed by using the equilibrium condition and three conditions. An exact higher-order theory is then developed for creating accurate analysis models to consider both material and geometry variations over the beam cross section. A finite element analysis model is presented and a two-node beam element with bubble displacement modes is implemented. Results for sandwich and FG beam problems are shown and numerical results are compared with those of plane stress continuum models to demonstrate the correctness and application of the new theory and finite element model.


ABSTRACT: For an unsymmetric plate, a pure bending (plate curvature) inevitably causes a certain amount of stretching to the geometric mid-plane due to the stretching-bending coupling. According to classical thin plate theory, the geometric mid-plane is assumed to remain unstrained under pure bending. In this study, we demonstrate that the classical thin plate theory based on Kirchhoff-Love hypothesis is not accurate enough to model the structural behavior of unsymmetric plates. To overcome this limitation, we propose an improved theoretical model for unsymmetric plates through taking advantages of neutral plane strains in defining the geometric functions instead of mid-plane strains. Subsequently, the new governing equations and energy expression for the cylindrical bending of unsymmetric plates are derived using a modified constitutive equation. An alternative derivation approach based on the general stress equations is also presented for further validation. A direct consideration of stretching-bending coupling in the constitutive equation can significantly reduce the number of unknown parameters in establishing an accurate analytical model for unsymmetric plates. The pure bending problem of unsymmetric plates with small deformation is first studied, for which the improved model proposed in this paper is shown to capture the out-of-plane deformation of unsymmetric plates, accurately. However, many previous works have to take into account the nonlinear von Kármán strains even in the model of this small deformation problem. For the pure plate bending problem with large deformation, few unknown terms are needed for the improved model to give accurate results compared with the conventional mid-plane strain based method. Later, this improved model is applied to predict the stable configurations, the bifurcation/loss-of-bifurcation and the static snap-through phenomena of bistable cross-ply composite laminates. Furthermore, the application of this improved model for the accurate simulation of the nonlinear dynamics of unsymmetric plates is also demonstrated. Applying this proposed improved model, the model is reduced into an analogous one for isotropic or symmetric plates, therefore, the problem of unsymmetric plates can be solved readily and accurately.


ABSTRACT: A design framework is here presented for the development of an architected solid with targeted mechanical properties thanks to an optimized porosity distribution. A 2D lattice of regular hexagons is considered as core element of a sandwich panel and a Bloch-Floquet-based approach is adopted to derive homogenized equivalent properties. The density distribution of the equivalent continuum is taken as objective function to be minimized in the optimization process. To this end, suitable constraints are designed to avoid empty regions and ensure a minimized density where required by the mechanical actions. A de-homogenization process is carried out on the optimized equivalent continuum to derive the configuration of regular hexagons with optimally varying wall thickness. Static and buckling responses of the optimized architected solid are compared with that of a 2D continuum whose material density distribution is determined through a classical topology optimization. It is shown that the architected 2D solid can absorb higher strain energy, with respect to classically optimized structures, which suffer a buckling-driven collapse below the elasticity threshold. The architected solid is also shown to have an improved energy absorption capability, that may increase considerably its performance, depending on the ductility of the adopted material.

ABSTRACT: This study presents a numerical mesoscale approach to simulate the damage and failure mechanisms of woven laminated composites under low velocity impact loading conditions. First, some measurements were made on samples to obtain a realistic reproduction of the microstructure. This allows relating failure mechanisms in composite laminates with their geometry and topology. A three-dimensional Hashin criterion was developed to investigate the impact behaviour, by accounting for both intralaminar and interlaminar damages. Four failure modes were considered relatively to fibre damage initiation in tension and compression and Puck criteria was employed to capture the initiation of the yarn’s matrix damage. The matrix surrounding undulated yarns were taken into account by an elastoplastic behaviour with maximum-stress failure criteria. Good correlation between numerical and experimental results demonstrated the robustness and the accuracy of the proposed multiscale approach.


ABSTRACT: In this paper, the nonlinear bending analysis of Functionally Graded Porous (FGP) beams is investigated using an efficient numerical algorithm associating a meshless collocation technique uses the Multiquadric Radial Basis Function (MQRBF) approximation method and a higher-order Taylor series-based continuation procedure. Material properties of the FGP beams are described by adopting a modified power-law function taking into account the effect of porosities. Based on the First Order Shear Deformation Theory (FSDT) of beams with the von-Kármán kinematic hypothesis, the strong form of nonlinear equations is established. For an efficient application of the proposed numerical approach, a quadratic matrix strong form of the problem is presented. The resulting nonlinear equations are solved numerically with the proposed algorithm which leaned on the following three steps: a higher-order Taylor series expansion to transform the quadratic nonlinear equations into a sequence of linear ones, a meshless collocation technique based on MQRBF approximation method to solve numerically the resulting linear equations and a continuation procedure to get the whole solution branch. To demonstrate the robustness of the developed algorithm, convergence and validation studies have been carried out. Furthermore, the effects of power-law index, porosity volume fraction, Young’s modulus ratio, loads and boundary conditions are investigated.


ABSTRACT: The function of the metamaterials is determined by the configuration and spatial arrangement of the lattice microstructure. Once manufactured, the geometry and function of the metamaterials are irreversible and cannot be adapted to the environment to be variable and adjustable. This paper studies a shape-reconfigurable, functionally deployable, mechanically adjustable and reusable intelligent multi-stable metamaterial. Based on a 4D printing method that combines digital additive manufacturing technique and thermally induced shape memory polymer exhibiting significant change in modulus of elasticity, this metamaterial is created with reconfigurable, self-expandable and mechanical properties adjustable features. The macroscopic deformation and the morphology change of the lattice microstructure on the metamaterial during the compression test are analyzed using experiment and finite element method. The adjustable, selectable, and controllable for micro-lattice in the metamaterial during deformation and recovery can be achieved by microstructure gradients and composite design methods. The new micro-lattice programmable mechanical metamaterial has excellent versatility and the ability to adapt to environmental changes. This 4D printed multi-stable metamaterial has broad application prospects, such as in soft robots, smart damping interfaces, aerospace adjustable and expandable structures, and tunable function devices.
ABSTRACT: This research is geared towards the improvement of the dynamic response of the corrugated sandwiched composite structures under low-velocity impact. A novel glass fibre reinforced double-corrugated sandwiched composite (DCSC) structure was designed and was manufactured by using a vacuum assisted resin infusion (VARI) technique. The lattice core of the DCSC was formed by crosslinked composites as reinforced layers and PVC foam blocks as energy absorption components. The dynamic response of the proposed sandwiched composite structures on different locations was evaluated through low-velocity drop-weight impact tests and was compared to that of traditional single-corrugated sandwiched composite (SCSC) structures. Finally, the optical microscopy and µ-CT technique were utilized to explore failure mechanisms and damage affected zone within the specimens. The results indicated that the maximum impact load and the energy absorption capability before the structural failure of the DSCS structure were significantly improved combined with a lower indentation comparing to the traditional SCSC configuration only with a slight weight increase. No severe damage was observed given low impact energy. Fibre fracture, foam rupture and face-to-foam debonding became dominant while the energy was increased.

ABSTRACT: In the present work, an innovative two-phases local/nonlocal constitutive mixture model based on the stress-driven model for free vibrations problems is presented. The above two-phases model has been formulated by defining a convex combination of local/nonlocal phases through a mixture parameter and the closed form solution for free vibrations problems is given. The proposed local/nonlocal model has been applied to compute the natural frequencies of four nanobeams study cases. The results are presented in terms of normalised natural frequency as function of both nonlocal and mixture parameters. First, the influence of the two parameters is studied. The effectiveness of the present model is discussed by comparing the results with those obtained by applying the Gradient Elasticity theory. Finally, the normalised natural frequencies for the second, third and fourth modes of vibrations are presented and discussed for each study case.

ABSTRACT: The ballistic performance of ultra-high molecular weight polyethylene (UHMWPE) laminated plates and UHMWPE encapsulated aluminum structures were numerically characterized. Full three-dimensional continuum model for each type of target was built, and the UHMWPE was simulated using a sub-laminate approach with a composite material model. Simulation results were compared with existing experimental measurements, with good agreement achieved both on final deformation morphology and ballistic data. Underlying penetration mechanisms of laminated plate were then explored, and the effect of interface strength was quantified. The ballistic improvement of UHMWPE encapsulated aluminum structures was mainly attributed to the stretching of lateral swathing laminates. However, the benefit of encapsulation decreased as the initial impact velocity or lateral dimensions of encapsulated structure were increased. These findings are helpful for designing lightweight UHMWPE composite structures with superior ballistic resistance.

ABSTRACT: Braided composite laminates allow a reinforcement architecture design method of varying ply-to-ply braided structure instead of rotating fiber orientation in traditional unidirectional laminates. The stacking
sequence sensitivities of braided laminates subjected to low-velocity impact were experimentally studied. Uniform ([±45°]) and non-uniform ([±30°/±45°/±60°]) architectures were designed to evaluate the effect of braided structure on impact performance. In addition, non-uniform laminate was impacted on both sides to identify the role of impact side on the failure mode. Quasi-static indentation was conducted to understand the damage initiation and propagation of braided laminates. The experimental results show that braided ply with high crimp level in impact side induced the main cracks along the load-carrying yarn, causing that the laminate failed in a kink-band dominated mode. For braided ply with low crimp level, a micro-buckling damage was found in the impact side, leading to the delamination dominated failure mode. It was also found that uniform braided laminate presents inferior impact resistance with respect to lower peak load and more concentrated damage because the kink-band can propagate into the specimen along braiding yarn easily.


ABSTRACT: Design optimization of moderately thick hexagonal honeycomb sandwich plate has been investigated via employing an improved multi-objective particle swarm optimization with genetic algorithm (MOPSOGA). Based on the first-order shear deformation theory (FSDT), governing equations of the plate are obtained. The equations are solved analytically. Total weight and maximum deflection of the plate under static gravity loads are considered to be objective functions of the problem. Core height, faces thickness, cell walls thickness, vertical and inclined cell wall length and the angle between inclined cell wall and horizontal line are set to be design variables of the problem. The geometrical and failure constrains are chosen to have desirable performance and stability of the sandwich plate. In the used multi-objective optimization technique, the optimum velocity parameter, inertia weight and acceleration coefficients for next iteration of the MOPSO are obtained by employing the genetic algorithm via minimizing generational distance between the sets of dominated and non-dominated particles in the previous iteration. Efficiency and accuracy of the proposed solution procedure are demonstrated and effects of different parameters on design optimization of the plate are studied. Also, TOPSIS multi-criteria decision-making method has been selected to report appreciate results from the Pareto-front curve of the MOPSOGA.


ABSTRACT: In this paper, the buckling of cross-ply and angle-ply composite beams under hygro-thermo-mechanical loading is presented by the analytical approach. This approach is based on theory of hyperbolic refined shear deformation. This approach which has strong resemblance with beam theory of Euler Bernoulli in various aspects, accounts for a second-degree variation of the transverse shear strains through the thickness and verified the zero traction of boundary conditions on the bottom and top beam surfaces sans employing shear correction factors. The effects of temperature and moisture concentration, thus the effect of the ratios of modulus, length to thickness and coefficient of thermal expansion respectively on hygro-thermo-mechanical buckling of cross-ply and angle-ply laminated beams are studied.


ABSTRACT: Due to broad usage of anisotropic composite beams in modern engineering structures, the main goal of the present work is to examine their geometrically nonlinear vibration. To this end, a third-order shear deformation theory with a nonlinear von-Kármán strain field is used for anisotropic beams and combined with the advantages of the isogeometric framework. The layup properties are assumed to be anisotropic in the depth direction and a transient tip follower force is considered. The governing nonlinear equations of vibration are integrated by means of the Newmark approach and solved with the Newton–Raphson method. Flutter loads as well as natural frequencies are obtained by eigenvalue analysis. The effects of various important factors such as non-prismatic shape, orientation of the composite fibers, critical follower force and bifurcation point are
studied, using both $h$- and $p$-refinements. The results show that the nonlinear vibration and flutter characteristics of the anisotropic composite beams are completely different from those for orthotropic and isotropic ones. Thick beams with anisotropic layups are more sensitive to the shear parameter than conventional ones and deform primarily in shear mode rather than in bending. Anisotropic beams reveal a higher flutter instability force than other cases for a given shear parameter value. Another important phenomenon is that the stress distribution in anisotropic layups shows irregular patterns both in depth and time. Anisotropic layups with ply angles between 15 deg. and 45 deg. seem to present enhanced nonlinear performance with respect to other layup choices. A coarse mesh of quartic C3 B-splines is observed to provide high accuracy for nonlinear deflections in anisotropic cases even for rather low shear parameters.

Bo Zhu, Qi Xu, Ming Li and Yinghui Li, “Nonlinear free and forced vibrations of porous functionally graded pipes conveying fluid and resting on nonlinear elastic foundation”, Composite Structures, Vol. 252 Article 112672, 15 November 2020, https://doi.org/10.1016/j.compstruct.2020.112672
ABSTRACT: This paper studies the nonlinear free and forced vibrations of fluid-conveying pipes that are made of porous functionally graded materials and supported on nonlinear elastic foundation. A modified power-law function is adopted to model the porous functionally graded materials, with both even and uneven porosity distributions to represent different material imperfections. Equations of motion of the pipe system are then derived through Hamilton’s principle based on Euler–Bernoulli beam theory, with foundation and von Kármán nonlinearities and damping effect being considered. The nonlinear free vibration and the primary resonance of the pipe system are investigated analytically, by employing the variational iteration method and the direct method of multiple scales, respectively. Detailed parametric studies for the free and forced vibrations are then carried out numerically, considering different parameters including power-law index, porosity characteristics, fluid velocity, pipe geometries, foundation parameters and so on.

ABSTRACT: Out-of-plane failure is common in composite layered materials. Its detection in numerical simulations usually involves a high-level of spatial refinement which may lead to an excessive computational time for large structures. This paper presents a formulation for the recovery of the transverse stresses in conventional linear shell elements based on First-Order Shear Deformation Theory. Starting from the equilibrium equations, the proposed formulation allows the calculations to be made for arbitrary curvatures including variable ones. Compared to the Extended-2D method, it has the advantage of including all the contributions from the force and moment derivatives making it reliable in complex load cases. Several examples with different laminates, curvatures and loads are presented. The numerical results confirm the potential of the proposed method to be used both as post-processing tool for conventional models and as an enrichment criterion for adaptive modelling.

ABSTRACT: Additive manufacturing offers new design opportunities for composite sandwich structures. The work presented herein builds on the concepts of the coating approach for topology optimization of shell-infill structures by using density gradients to determine local material orientations. A generalized material property interpolation scheme is presented and the sensitivity analysis for the minimum compliance optimization problem is developed. The approach is demonstrated for an orthotropic shell using the Messerschmitt-Bölkow-Blohm benchmark problem and results approach the isotropic solution when an equivalent in-plane modulus is considered. To adapt the approach to composite sandwich structures, a methodology based on the addition of a contour finding step is presented to define separate properties in the exterior shell from interior shells. The work introduces a new approach in topology optimization to tackle composite fibre reinforced sandwich structures that would benefit from a complex core structure obtained by additive manufacturing.

ABSTRACT: A separation-of-variable method was proposed in 2009 by the present authors and co-workers (Xing YF, Liu B. New exact solutions for free vibrations of thin orthotropic rectangular plates. Compos Struct 2009;89;567–74), but this traditional separation-of-variable method is incapable for free boundary conditions. Hence, this work is to improve the traditional separation-of-variable method to make it capable of dealing with free boundary conditions. This new method is called the improved separation-of-variable method, in which the characteristic differential governing equation is solved directly, and the free boundary conditions also have separable forms, which are achieved with the Rayleigh’s variational principle. In addition, the relationships between spatial eigenvalues and temporal eigenvalue are quite concise. For plates without free edges, the proposed method reduces to the traditional separation-of-variable method. Numerical experiments validate the improved method. The present technique of handling free boundary conditions is a general methodology for eigenvalue problems such as free vibration and eigenbuckling.


ABSTRACT: This paper presents an accurate two-noded laminated piezoelectric beam element for the dynamic analysis and active vibration control of laminated composite beams with piezoelectric layers. A refined third-order shear deformation plate theory is used to model the kinematics, and a piecewise linear interpolation is used to characterize the electrical potential. The equations of motion are derived from Hamilton’s principle. The quasi-conforming element technique is adopted to evaluate the explicit element stiffness matrix. The resulting two-noded piezolaminated beam element is free from shear locking and the numerical integration. Linear Quadratic Regulator (LQR) control scheme is used for the active vibration control and Genetic Algorism (QA) is employed to determine the optimal weighting matrix used in the control performance index. The laminated piezoelectric beam element is validated by numerical examples. The numerical results show that present laminated piezoelectric beam element is very accurate in dynamic analysis of laminated piezoelectric beams and it is an effective strategy to use QA to merely evaluate the optimal weighting matrix for the vibration control performance by fixing the weighting matrix for the control input cost as an identity matrix in the LQR-based active vibration control.


ABSTRACT: In this study, the dynamic buckling of bi-directional functionally graded porous (BD-FG) truncated conical shell resting on an elastic foundation is investigated for different boundary conditions. The structure is under an axial compression loading at the two ends. First order shear deformation theory (FSDT) and Hamilton's principle are used to derive the governing equations. The material characteristics change according to modified power-law model across thickness and along length directions for even and uneven distributions of porosity pattern. The governing equations are solved numerically by means of the Generalized Differential Quadrature method. Afterwards, the Bolotin’s method is employed for attaining the dynamic instability region of structure. The results are compared and validated with those cases from published papers. Subsequently, the effect of circumferential half wave number, geometrical parameters, power-law indexes, porosity volume fraction, boundary conditions, static load factor and elastic foundation parameters on the dynamic instability region are investigated.

ABSTRACT: In this paper, a protect system consists of a re-entrant hexagon honeycomb cored sandwich panel and a homogenous steel plate was firstly proposed. The parametric study including boundary conditions, geometric and thickness parameters of the protect system was conducted. It was found that, under the presented set-up, the boundary conditions did not affect the energy absorption of the protect system, they only altered the internal energy distribution among the protect system. Finally, a novel multi-scale optimization was conducted to further improve the performance of the protect system. Another conventional multi-objective optimization was also conducted for comparison. The results showed that, by affording less computational effort, the multi-scale optimization improved the ASEA (areal specific energy absorption) by 4.9% and reduced MaxD (maximum displacement) by 1.8%, comparing to the conventional multi-objective optimization.


ABSTRACT: This paper presents the results of a study investigating the eccentric compression loading of thin-walled composite profiles with Z, channel and top-hat sections. The buckling, post-buckling and limit state of the profiles are investigated. The primary objective of the study was to determine the effect of load eccentricity and profile section type on the stability and load-carrying capacity of the profiles. The thin-walled profiles made of CFRP by the autoclave technique were subjected to static compression over the full range of loading until final failure. At the same time, the compressed profiles were examined by nonlinear numerical analysis with the finite element method using the commercial simulation software ABAQUS®. Damage initiation in the composite material was analysed using the Hashin criteria and a progressive damage model. Numerical models were validated by experimental tests. Obtained numerical and experimental results show a high agreement.


ABSTRACT: Dynamic response of sandwich plates with a metal honeycomb core under low-velocity impact has been investigated. Experiments of the fully clamped sandwich plates subjected to low-velocity impact of the drop-hammer with a hemispherical nose have been conducted and plastic failure modes have been measured. Structural damage mechanism of sandwich plates has been identified and explored. It is found that finite element simulations of these experiments are in good agreement with the experimental measurements. Analytical solutions for permanent deflections and peak impact forces are derived and capture the experimental results with reasonable accuracy. It is shown that the impact positions have important influence on the dynamic response of sandwich plates subjected to low-velocity impact. The impact resistance of sandwich plate decreases from the central position to the non-central positions.


ABSTRACT: Thin-walled carbon/epoxy composite plate elements with a central cut-out under compressive loading are investigated. The work focused on the original concept of this element, for use as elastic or load-bearing element and whether possibility to shape their structural rigidity by changing the cut-out geometry or the laminate’s lay-up. The lowest buckling mode exhibits a small postcritical rigidity and is reached at low loads. The calculations carried out earlier show that plates with forced higher form of buckling are characterized by stable, progressive paths of post-critical equilibrium, enabling their use as elastic elements. The aim of the study, partially revealed in this abstract, requires a thorough analysis of the effect of the B matrix form on the coupled composite behaviour. Coupling stiffness matrices of unsymmetrical laminates have been thoroughly described by, among others, York, Altenbach. The commercial ABAQUS program using the finite element method was used to develop the discrete model and perform numerical calculations. Experiment was performed on a universal testing machine. The obtained results are of significant practical importance in the design of structures with elastic elements, allowing to achieve the required maintenance characteristics of the device.

ABSTRACT: This work presents an efficient methodology for optimum design of functionally graded plates. Isogeometric analysis is used to evaluate the structural responses and the material gradation is described using B-Splines to enhance design flexibility. A constraint is included in the optimization model to ensure a smooth material gradation. In order to improve the computational efficiency of the optimization process, a surrogate model based on Radial Basis Functions is used to accurately approximate the structural responses. Different methods to define the width of basis functions based on analytical and cross-validation techniques are adopted and compared. Two infill criteria based on the expected improvement technique are used to continuously improve the surrogate model accuracy by balancing both the local and global searches. The accuracy and efficiency of the proposed approaches are assessed through a set of problems involving the maximization of the buckling load and the fundamental frequency of functionally graded plates, showing excellent results.


ABSTRACT: The nonlinear dynamic response of a laminated glass plate under the pressure generated by a blast wave, described via the Friedlander’s model, is investigated. In order to account for the heterogeneity of the laminated package, composed by two glass plies sandwiching a thin and soft polymeric interlayer, a geometrically nonlinear, third-order shear deformation theory with rotary inertia is used. Within the quasi-elastic approximation, the constitutive response of the polymer is described by its secant elastic moduli for short-term loading at room temperature, while the dissipation associated with its viscosity is taken into account through an equivalent effective damping. The problem is discretized by a reduced-order model retaining 40 degrees of freedom and the first four vibration modes, which are the ones receiving most of the energy from the blast. A geometrically nonlinear damping model is introduced to simulate the increase in damping associated with large-amplitude oscillations of the plate, which results from the interaction between the large deflections of the glass plies and the viscosity of the interlayer. Forced nonlinear vibrations around the frequency of the fundamental mode are also investigated, to complete the study of the nonlinear dynamics. The results highlight the importance of the nonlinear effects of damping, which can almost halve the deformations and stresses in laminated glass with respect the linear case at high levels of excitation, while still remaining within the limits of material strengths.


ABSTRACT: Sixty-three circular concrete filled winding glass fibre reinforced plastic (GFRP) tubular columns after lateral impact damage were tested, which were used to investigate the behaviour of circular concrete filled winding GFRP tubular (CFWGT) columns under compressive loading in this paper. The influence of the thickness of the GFRP tube, the height of the lateral impact and the location of the lateral impact on the mechanical properties of the specimens were analyzed. Test results show that the lateral impact had a negative impact on the vertical bearing capacity of the circular CFWGT column. As the height of the lateral impact increased, the vertical bearing capacity and initial stiffness of the specimens decreased. When the position of the lateral impact is closer to the end of the specimen, the lower the vertical bearing capacity and initial stiffness of the specimen are. The negative effects of lateral impact on the vertical bearing capacity and initial stiffness of CFWGT columns can be reduced by increasing the GFRP tube thickness. According to the test results, the calculation formula, which was based on a mechanics calculation model, was presented to calculate the vertical capacity of circular CFWGT columns after lateral impact.

ABSTRACT: This paper presents the results of an experimental investigation on the mechanical behavior of three-layer toughened sandwich glass with trilateral simple support under uniform lateral loads. A total of sixty-four specimens with different test parameters are designed and tested to consider the effects of the thickness of single layer, supporting width and loading length. It was observed that the specimens failed with all pieces of cracks combined together as an entire unit rather than to separate into a large number of glass fragments. The cracks occurred only at the lower layer of toughened sandwich glass and extended in a way similar to the spider web. The ultimate bending strength and bending rigidity of the toughened sandwich glass are enhanced as the thickness of single layer, the supporting width, and the loading length increase. Among the above parameters, the thickness of single layer plays a leading role in improving the ultimate bending strength and bending rigidity of toughened sandwich glass. However, the enhancement effect of supporting width on the ultimate bending strength and bending rigidity of toughened sandwich glass is quite limited. Based on elastic thin plate theory, the derived mechanical formulae were presented to evaluate the ultimate bending strength of three-layer toughened sandwich glass with trilateral simple support under uniform lateral load, which was verified to be reasonable and accurate.


ABSTRACT: The structure of latticed/cellular materials is often designed with the lack of information about macro-material. Material information of each macro-element is realized by reducing the scale, homogenizing the microstructure, and calculating the properties of an equivalent material for the macro-element. The lattice structure is simultaneously optimized at both the macro- and microstructural levels with additional connectivity constraints, while finite element analysis (FEA) and design variable updates are required twice (at the macro- and micro-levels) for each optimization loop. This approach requires significant storage and has a substantial computational cost. In addition, when the size of the unit cell is quite large compared to the macrostructure, the homogenization method could fail to provide sufficient accuracy. To deal with these issues, in this work, we propose a new multiscale topology optimization approach for the direct and simultaneous design of lattice materials, without material homogenization at the microscale, using adaptive geometric components. The adaptive geometric components are projected onto macro- and micro-element density fields to calculate the effective densities of grid elements. Macro- and microstructures are simultaneously optimized, considering the load and boundary conditions of the overall structure without any additional constraints. FEA and design variable updates are required only once for each optimization loop. Furthermore, the minimum length scales of the macrostructure and the length scales of microstructures can be simultaneously controlled explicitly by simply adjusting the bounds of the size parameters. Some benchmark structures are topologically optimized with different types of lattice materials (such as square, diamond, and triangle) to verify the effectiveness of the proposed method.


ABSTRACT: In the presented computational approach, a mathematical derivation is made to develop a nonlinear dynamic model for the nonlinear frequency and chaotic responses of the multi-scale hybrid Nano-composites reinforced disk (MHCD) embedded in a viscoelastic media and subject to a harmonic load. Using Hamilton's principle and Von Karman nonlinear theory, the nonlinear governing equation is derived. For developing an accurate solution approach, generalized differential quadrature method (GDQM) and perturbation approach (PA) are finally employed. Various geometrically parameters are taken into account to investigate the chaotic motion of the viscoelastic disk subject to harmonic excitation. The golden results of this paper is that the
chaotic motion and nonlinear frequency of the disk is hardly dependent on the value of the outer to inner radius ratio \((\text{Ro}/\text{Ri})\) and viscoelastic parameters and it means that by increasing the value of \(\text{Ro}/\text{Ri}\) parameter and taking into account the viscoelastic foundation, the motion of the system tend to show the chaotic motion. Moreover, at the lower value of the \(\text{Ro}/\text{Ri}\) parameter, quasi-harmonic and chaotic responses can be seen for the conditions with and without considering the effect of viscoelastic foundation and at the higher value of the parameter, the chaosity of the system decreases.


ABSTRACT: This paper is concerned with the nonlinear in-plane buckling of shear deformable laminated composite shallow arches under a uniform radial loading. The virtual work method is used to establish both governing differential equations and buckling equilibrium equations based on the first order shear deformation theory to include the effect of shear deformation for which analytical solutions for both limit point buckling and bifurcation point buckling are derived. A specific parameter that defines the switch between buckling and pre-buckling, limit point buckling and bifurcation buckling is proposed and defined. The effect of shear deformation on the buckling load is discussed in detail. It is observed from typical equilibrium paths of the arch that the shear deformation decreases the critical buckling load of laminated arches and this effect becomes more important and cannot be neglected for fixed arches with slenderness ratio \(S/\rho_x < 150\) and pinned arches with \(S/\rho_x < 100\). Direct comparisons with finite element results demonstrate that the proposed analytical solutions can provide a good prediction for the nonlinear buckling of shallow laminated arches under a uniform radial loading.


ABSTRACT: Vibration correlation technique (VCT) is an effective non-destructive buckling experimental technique for shell structures. In this study, VCT is studied from the point-of-view of being a buckling load numerical prediction method by numerically simulating the experimental procedure of VCT. Firstly, the formulas of VCT are introduced for axially loaded cylindrical shells and conical shells under the clamped–clamped boundary condition. According to the VCT formulas, the numerical procedure of VCT is provided. In order to accelerate the repeated eigenvalue analysis of VCT, the proper orthogonal decomposition (POD) method is integrated into VCT, and the POD-VCT is developed. Extensive examples are presented to verify the effectiveness of the proposed method, including unstiffened cylindrical shell with real measured imperfection, unstiffened conical shell with single perturbation load imperfection, composite cylindrical shell with eigenmode imperfection, and hierarchical stiffened cylindrical shell with combined imperfection. In comparison to buckling test results, high-fidelity explicit dynamic method and VCT method, the high prediction accuracy and efficiency of the proposed POD-VCT are fully demonstrated. Additionally, example results indicate the strong applicability of the proposed POD-VCT for various types of structural configurations, materials and imperfections. Above all, the POD-VCT is verified to be a fast buckling load numerical prediction method for imperfect shells.


ABSTRACT: In this paper, a new exact analytical solution of buckling of sandwich panels/beams is presented. The transverse shear deformation of the face-sheet (caused by the interlayer shear effect), which has been usually neglected in previous works, is considered for the first time in our theoretical framework. In the constituent phases of the sandwich plates, the core is assumed to be isotropic, and the faces are assumed to be orthotropic, so the model can be applied to sandwich plates with composite faces. Next, the solution is
compared with different results in the literatures, and the finite element computations is then carried out as a standard for measuring the accuracy. It is shown that the present solution leads to better accuracy after considering the transverse shear effect. Despite the global buckling mode is also involved in this unified solution, the emphasis of this study is on the wrinkling (short-wave) mode; the authors have shown that the transverse shear effect is particularly apparent in those short-wave modes. In the end, we determine a boundary where the shear effect will produce a non-negligible influence to the critical buckling of sandwich plates.


ABSTRACT: Structural theories based on 1D component-wise models are proposed to investigate the progressive disbonding in sandwich structures. The structural framework adopts the Carrera Unified Formulation to generate higher-order theories of structures via a variable kinematic approach. The component-wise approach, formulated within the Lagrange polynomial based CUF models, permits modelling of various components of a complex structure through 1D CUF models at reduced computational costs and 3D accuracy. The disbonding constitutive models are retrieved from well-established works in the literature and based on cohesive elements. The results verify the accuracy of 1D models with some 10–20% computational time as compared to 3D finite elements.


ABSTRACT: This paper carries out three-dimensional (3D) free vibration analyses of laminated shells made of functionally graded materials (FGMs) in both thermal and non-thermal environments by a hierarchical quadrature element method (HQEM). Two configurations of FGM laminated shells were considered, the first with FGM face sheets and homogeneous core, while the second with homogeneous face sheets and FGM core. Effective material properties of the FGMs were estimated in terms of two micromechanical models called Voigt’s rule of mixture (ROM) and Mori-Tanaka (MT) scheme. For shells in thermal environment, a nonlinear temperature distribution along thickness direction was considered while the elasticity properties were assumed to be temperature-dependent. Natural frequencies obtained by the presented formulation for FGM laminated shells under non-thermal conditions but varied geometric and boundary conditions were compared with those obtained by two-dimensional (2D) finite element method (FEM) and semi-analytical approaches in literatures first to assess the correctness and accuracy. Then the influence of volume fraction index, core thickness, and temperature gradient on natural frequencies of FGM laminated shells under thermal environment were investigated. The three-dimensional formulations of this work were shown to need similar computational cost as 2D ones but with the accuracy of 3D theory.


ABSTRACT: This paper presents a robust and analytically solution based on the refined higher-order shear deformation theory for establishing the buckling capacity of a series of simply-supported sandwich plates. Each sandwich plate consists of an open-cell metal foam core with various pore distributions and two metal face sheets. Cores with and without GNP-reinforcements are considered. Three different distributions of porosity are considered for the core (i.e., uniform and two different non-uniform distributions along the thickness of the core). The effective properties of the porous cores are estimated by employing the modified Halpin-Tsai micromechanical model and the rule of mixture. The governing differential equations are solved analytically using the Navier method. Subsequently, the Box-Behnken design (BBD) statistical method, which is a subset of the response surface methodology (RSM), is employed to investigate the simultaneous effect of the input variables (i.e., porosity coefficient, the core to total thickness ratio and the weight fraction of graphene nanoplatelets (GNPs)) on the buckling capacity of the sandwich plates. This is followed by the development of a set of simple and practical equations for evaluating the critical buckling capacity of the sandwich plates as a function of the input variables.

ABSTRACT: This paper presents experimental investigations on the flexural behavior of double-layer toughened sandwich glass with trilateral simple support. A total of sixty-four pieces of toughened sandwich glass with different thickness of single layer, supporting width, and loading length were subjected to out-of-plane flexural loading tests. It was demonstrated that the specimens failed with all pieces of cracks combined together as an entire unit rather than to separate into a large number of glass fragments. The cracks appeared only at the lower layer of toughened sandwich glass and the upper layer of the toughened sandwich glass was integral and undamaged. The ultimate capacity and flexural rigidity of the toughened sandwich glass are enhanced with increasing the thickness of single layer, supporting width, and loading length. Among all studied parameters, the thickness of single layer exerts the largest influence on the ultimate capacity and flexural rigidity of toughened sandwich glass, while the effect of supporting width is quite limited. A simplified design formula was put forward to predict the ultimate capacity of double-layer toughened sandwich glass with trilateral simple support under out-of-plane flexural loading, which was verified to be reasonable and accurate.


ABSTRACT: In this article, the study on the geometrically nonlinear free vibration behaviour of higher order shear deformable Carbon nanotube reinforced magneto-electro-elastic (CNTMEE) doubly curved shells has been performed. The displacement fields and geometric nonlinearity are assumed to follow Donnell Shell theory and von-Karman’s relation, respectively. Using Hamilton’s principle the governing equations of motion are derived. A special attention has been paid to investigate the effect of electro-magnetic circuits on the nonlinear frequency response of CNTMEE shells for the first time. Numerical examples are illustrated to assess the influence of different parameters including shell geometry, CNT distribution, volume fraction, shallowness ratio, thickness ratio, aspect ratio in detail. Also, the contribution of combined/individual coupling fields on nonlinear free vibrations has been examined. The results suggest that the geometric and material parameters alter the nonlinear characteristics of CNTMEE shells significantly.


ABSTRACT: Stability of Kirchhoff-Love-type circular cylindrical shells having geometrical, elastic and inertial properties densely and periodically varying in circumferential direction (uniperiodic shells) is considered. In order to take into account the effect of a cell size on the global stability behaviour of such shells (the length-scale effect), a new mathematical averaged model is formulated. This so-called the general non-asymptotic tolerance model is derived by applying a certain extended version of the well known tolerance modelling technique. This version is based on a new notion of weakly slowly-varying functions being an extension of the known more restrictive concept of slowly-varying functions occurring in the classical tolerance approach. Governing equations of the proposed model have constant coefficients depending also on a microstructure size, contrary to starting shell equations with periodic, non-continuous and oscillating coefficients. As examples, two special length-scale stationary stability problems will be analysed in the framework of the proposed model. It will be shown that within this model not only fundamental cell-independent but also the new additional cell-dependent critical forces can be derived and analysed.

ABSTRACT: This study presents a novel approach for the vibration and damping analysis of arbitrarily curved n-layered sandwich beams. The governing equations are derived using Hamilton’s principle and solved by the generalized differential quadrature method (GDQM). Results are compared with the ones that exist in the literature for various types of curved beams either laminated composite or sandwich with a viscoelastic core. In addition, the results of an in-house finite element (FE) solver are added to the comparisons and a very good agreement between the results is observed. Finally, a spiral curved sandwich beam with a parametric mid-section curve and a frequency-dependent viscoelastic core is studied. The effects subtended angle and the core thickness on the vibration and damping behavior are analyzed in detail.


ABSTRACT: This study investigates the vibration and buckling behavior of functionally graded porous composite plates reinforced with graphene platelets (GPLs) using spectral-Chebyshev approach. Buckling strength and vibration behavior depend highly on the dispersion of porosity and nanofiller material along the thickness of the composite plates. The effective material properties are determined based on the volume fractions of the constituent materials. To accurately capture the material gradation, the plate is divided into multiple layers. The governing boundary value problem is derived using first order shear deformation theory (FSDT) and following an energy based approach. To accurately and efficiently solve the boundary value problem, a meshless/spectral method based on Chebyshev polynomials is used. The developed solution approach enables the solution of functionally graded (porous) composite plates under various loading and boundary conditions. To demonstrate the accuracy and the computational performance of the solution approach, two case studies are investigated including composite plates having different porosity distributions and reinforcement amounts. Furthermore, comprehensive parametric studies are carried out to understand how porosity distribution and GPL reinforcements affect the vibration and buckling behavior of composite plates.


ABSTRACT: An analytical shell model is here proposed for the sound transmission analysis of composite multilayered structures embedding viscoelastic sheets. The present analytical solution, based on the Navier approach, is developed starting from the Principle of Virtual Displacements, through the use of advanced layer-wise higher-order models and by considering real viscoelastic frequency-dependent materials with fractional derivative constitutive models. Several simply-supported shell structures with isotropic and cross-ply composite layers embedding viscoelastic frequency-dependent sheets are considered and the results of the passive noise reduction analysis are given in terms of acoustic parameters based on Rayleigh integral method. Moreover a comprehensive study on different types of time loads is taken into account, considering impulse time load, time-window load histories, space–time dependent loads.


ABSTRACT: Four reinforced concrete (RC) beam models undamaged, damaged by notches and strengthened by external bonded (EB) glass fiber reinforced polymer (GFRP) strips have been experimentally studied. The paper aims to assess the availability of strengthening with EB GFRP strips in RC beams having a deep localized damage. The behavior of RC beams has been analysed under bending loading until failure. Furthermore, the assessment of RC beam models foresaw nondestructive control of damaged and strengthened models by free vibration tests to obtain frequency values at different damage degree. Damage, artificially obtained by notches with different width, on the midspan section and on the lateral location of beams, has been analysed. The envelope of frequency response functions (FRFs) obtained by dynamic tests was elaborated and changes of natural frequency values are then correlated to damage both to non-strengthened beam with notches and to strengthened beam models. Results of static tests on RC beams strengthened with filled mortar in the notched
sections and EB GFRP strips have allowed to validate the strengthening of RC elements with composite material characterized by relatively low elastic modulus; further, it has been assessed maintenance of bond between concrete surface and GFRP strips until failure under bending loading.

ABSTRACT: In this paper we will investigate the impact of in-plane negative Poisson’s ratio (NPR) on the post-buckling responses of graphene-reinforced metal matrix composite (GRMMC) laminated plates under uni- and bi-axial in-plane compressive loads. The effects of temperature variation and foundation support on the post-buckling responses of GRMMC laminated plates are also taken into consideration. The graphene volume fractions in each layer of a GRMMC plate may vary along the plate thickness direction to achieve a functionally graded (FG) arrangement. The GRMMC layers have temperature-dependent material properties that can be modeled by the extended Halpin–Tsai model. Employing the Reddy’s third order shear deformation plate theory, the governing equations containing both thermal and foundation effects for the post-buckling problem of FG-GRMMC plates are formulated. The von Kármán geometrical nonlinearity is also considered. The post-buckling responses of the FG-GRMMC laminated plates are obtained by solving the governing equations using a two-step perturbation approach. The results have revealed that in-plane NPR has a substantial impact on the post-buckling responses of GRMMC laminated plates.

ABSTRACT: This study presents a new state-based PeriDynamic (PD) model of a composite laminate with arbitrary laminate layup; it captures all types of material couplings in the presence of transverse shear deformation. It consists of normal and shear bonds instead of fiber and matrix bonds to allow arbitrary fiber orientations. Also, rotational degrees of freedom are included in the equilibrium equations in order to evaluate the transverse shear angle and curvature. Mindlin-Reissner plate theory, employed in this model, permits the use of existing composite constitutive law which leads to the coupling between different deformation modes. In addition, a quasi-local boundary condition applied only to the first row of material points avoids the approximation of nonlocal boundary values. The accuracy of this model is verified against benchmark solutions, and validated by comparison with experimental results.

ABSTRACT: A fully open-source available framework for the parametric cross-sectional analysis and design optimization of slender composite structures, such as helicopter or wind turbine blades, is presented. The framework—Structural Optimization and Aeroelastic Analysis (SONATA)—incorporates two structural solvers, the commercial tool VABS, and the novel open-source code ANBA4. SONATA also parameterizes the design inputs, postprocesses and visualizes the results, and generates the structural inputs to a variety of aeroelastic analysis tools. It is linked to the optimization library OpenMDAO. This work presents the methodology and explains the fundamental approaches of SONATA. Structural characteristics were successfully verified for both VABS and ANBA4 using box beam examples from literature, thereby verifying the parametric approach to generating the topology and mesh in a cross section as well as the solver integration. The framework was furthermore exercised by analyzing and evaluating a fully resolved highly flexible wind turbine blade. Computed structural characteristics correlated between VABS and ANBA4, including off-diagonal terms. Stresses, strains, and deformations were recovered from loads derived through coupling with aeroelastic analysis. The framework, therefore, proves effective in accurately analyzing and optimizing slender composite structures on a high-fidelity level that is close to a three-dimensional finite element model. References listed at the end of the paper:


041001


16 J.P. Blasques, M. Stolpe, Multi-material topology optimization of laminated composite beam cross sections, J Compos Struct, 94 (2012), pp. 3278–3289, 10.1016/j.compstruct.2012.05.002


26 S. Han, O.A. Bauchau, On saint-venant’s problem for helicoidal beams, J Appl Mech, 83 (2) (2015), 10.1115/1.4031935


correlations of SCS sandwich structural connections is of major importance in SCS structures. The present study evaluated the existing shear strength reliability assessments of sandwich structures by kriging method, Ala Ameryan, Mansour Ghalehnoi and Mohsen Rashki, “Investigation of shear strength correlations and reliability assessments of sandwich structures by kriging method”, Composite Structures, Vol. 253 Article 112782, 1 December 2020, https://doi.org/10.1016/j.compstruc.2020.112782
ABSTRACT: Steel-concrete–steel (SCS) sandwich composite structure with corrugated-strip connectors (CSC) is the promising structure which is applied in offshore and building structures. The behavior prediction of shear connections is of major importance in SCS structures. The present study evaluated the existing shear strength correlations of SCS sandwich structures exploiting experimental data and Finite Element Analysis (FEA).
considered system is a double steel skin sandwich structure with CSC (DSCS). Due to the limitation of the literature regarding CSC development, some new correlations were proposed and studied relying on several FEA results through the Genetic Programming method. The accuracy of the estimated shear strength predicted by the existing and proposed equations was evaluated using the FEA data and push-out test results. The FE models were verified through experimental data. Moreover, the correlations were investigated based on reliability assessment due to the high importance of the reliability analysis of such structures. Given that high accuracy in estimating the shear strength fails to necessarily lead to acceptable results in structural reliability analysis, the reliability of the existing and proposed equations was evaluated using the Kriging model by considering experimental data. This meta-model could predict accurate values with a limited number of initial training samples.


ABSTRACT: This paper investigates the effect of high temperature (600 °C, 800 °C, 1000 °C and 1100 °C) and the layers of carbon fibre reinforced plastics (CFRP) sheets (one, two, three, four) on the behaviour of fire-exposed steel tubular stub columns. Forty specimens were tested to investigate the failure modes, ultimate bearing capacity under axial compression, load-strain relationship, load-displacement relationship and initial stiffness of the specimens. Ultimate bearing capacity and initial stiffness decrease with the increase of temperature. The ultimate bearing capacity and ductility of fire-exposed specimens wrapped with CFRP sheets increase with the increase of CFRP sheets layers. After being strengthened by CFRP sheets with the same number of winding layers, circular steel tubular (CST) stub columns obtained a greater load-bearing capacity increase than square steel tubular (SST) stub columns. The largest enhancement of the ultimate bearing capacity of fire-exposed specimens is 59.47%. A recommended formula for the calculation of ultimate bearing capacity of fire-exposed specimens wrapped with CFRP sheets is proposed.


ABSTRACT: Pultruded glass fiber reinforced polymer (GFRP) sections have gained increasing acceptance in building and construction industries considering their promising physical and mechanical properties. However, they are prone to premature web crippling failure due to their orthotropic nature and relatively low interlaminar shear strength and modulus when subjected to transverse bearing load. This paper presents a study on the effect of bearing length on web crippling behavior of pultruded GFRP channel sections. Four channel sections with different sectional dimensions were selected for web crippling testing. Two loading conditions including end-two-flange (ETF) and interior-two-flange (ITF) were adopted. Transverse loading was applied through bearing plates with five different lengths of 20 mm, 50 mm, 100 mm, 150 mm and 200 mm. Failure modes, load–displacement curves and web crippling capacities were reported and discussed associated with the effect of bearing length. Mechanism based design equations which were able to consider effect of bearing length were proposed, and the predicted web crippling capacities agreed well with experimental results.


ABSTRACT: This paper focuses on effects of non-uniform elastic foundation, that impact on non-linear thermal dynamics of the simply supported plate reinforced by functionally graded (FG) graphene nanoplatelets (GNPs). The Halpin-Tsai micromechanical model and the rule of mixtures are employed to calculate the material properties. By adjusting the volume fraction of matrix/GNPs in the thickness direction, the various distribution patterns of the plates are considered as the uniform distribution (UD) and functionally graded (FG) reinforcements. The governing equations is expressed by using the classical theory, Von Karman-Donnell geometrical nonlinearity assumption, and combining the temperature change. Then the dynamical behaviors of
the FG-GNPs reinforced plates are obtained by applying the Airy's stress function and the Galerkin's method. The obtained results are described by the column charts, the 2D and 3D graphs and written by codes of Wolfram-Mathematica. In addition, the present study scrutinizes the effects of the thermal environment, GNPs weight fraction, GNPs distribution patterns, damping coefficient and geometric parameters. More importantly, the influences of the longitudinal variable thickness of Pasternak’s subgrade model on the dynamical characteristics are analyzed to optimize structures. Altogether these findings have significant applications in industries engineering and lead to breakthroughs in the microstructures design.


ABSTRACT: In this paper, dynamic analysis of a stiffened doubly curved sandwich composite plate with a functionally graded material (FGM) core and two isotropic layers in thermal environment is presented. Based on von Kármán non-linear strain-displacement relationships and classical plate theory, a list of non-linear dynamic equilibrium equations for stiffened FGM sandwich doubly curved plates under impact in thermal field are established by using the Hamilton’s variation principle, then combining with boundary and initial conditions, the whole problem is solved by adopting the finite difference method, Newmark method and iterative method synthetically. To verify the accuracy of the present work, comparisons are made with previously published results. The detailed studies about the influence of prime parameters like initial impact velocity, material property, temperature boundary condition, geometry parameters of doubly curved plate and non-uniform stiffeners on nonlinear dynamic response of the structure subject to impact with thermal effect are carried out.


ABSTRACT: In present work, the flutter analysis of laminated composite structures has been performed using the p-k method in Carrera Unified Formulation (CUF). In the framework of CUF, a hierarchical kinematic finite element model is used to compute the flutter condition of laminated composite plate and box-beam structures as it is very accurate and computationally efficient. The CUF refined theories are based on the Lagrange and Taylor-like cross-sectional displacement fields. In CUF, the order of the expansion can be chosen arbitrary, which is an independent parameter in the formulation. The governing equation is based on the principle of virtual displacement and defined in the form of “fundamental nuclei” using CUF. Theodorsen theory was used to define the aerodynamics loading conditions and the p-k method was used to compute the flutter conditions. Flutter conditions of different types of laminated composite structures with Lagrange and Taylor expansion were performed. A similar model was developed in MSC-Nastran and computed results were compared with literature and CUF model. The results indicate that the analyzed model has good agreement with reference and MSC-Nastran. The study suggests that the CUF models can produce accurate results with a low computational cost.


ABSTRACT: Carbon Fiber Reinforced Polymer (CFRP) has been widely utilized to wrap concrete column in order to improve the axial compressive bearing capacity. In this study, the size effect of CFRP-wrapped square concrete columns was investigated using both experimental and numerical approaches. A total of 30 geometri­cally-similar CFRP-wrapped concrete columns with a maximum cross-sectional width of 600 mm were designed and tested with repeated axial compression. The influences of loading type, structural size and reinforcement configuration on the failure of the columns were explored and measured. Moreover, a 3D meso-scale simulation approach considering the influence of concrete heterogeneity and CFRP-concrete interactions was utilized to furtherly investigate the size effect of CFRP-wrapped columns. In the 3D meso-scale simulations, the failure of columns with larger structural sizes and larger CFRP fiber ratios was analyzed. The
size effect on the nominal compressive strength of CFRP-wrapped columns was examined and discussed in detail. Finally, an updated size effect law (SEL) was established to describe the size effect in CFRP-wrapped concrete columns. The updated SEL is proved to be reasonable, which shows good consistence with the present experimental data and simulation results.


ABSTRACT: Despite major advances in morphing wing technology, morphing skins as a structural part of an adaptive aerospace system are still in their early development phase due to heavily contradicting requirements, such as highly anisotropic mechanical behaviour, air-tightness and lightness. Usually, airtightness in structural morphing skins is achieved with elastomeric covers which show poor mechanical performance and high weight. A novel design for an elastomer-free morphing skin unit cell is introduced and analysed in this work. A foldable unit cell is manufactured fully from lightweight engineering materials, based on hinge-like carbon fibre reinforced polymer ligaments. The latter reversibly fold a supported mid-section in order to generate large in-plane displacements with low actuation forces, while preserving a smooth surface in both states. The geometric parameters of the unit and the ligament design itself determine the mechanical response of the system. Within the design space of the unit cell, extreme global strains up to 100% and highly anisotropic mechanical behaviour is achieved, where resistance against aerodynamic loads exceeds the in-plane actuation force by a factor of 3.64. When used periodically, the novel unit cell is a promising base for a functional morphing skin system involving large displacements.


ABSTRACT: A unified theory to formulate a family of quasi-2D composite finite elements that capture through-the-thickness effects is proposed. The formulation is based on the superposition of global and local displacement fields and includes thermal effects, as a response to the claim of the scientific community. First are presented the fundamentals of the unified formulation: the kinematic assumptions; the imposition of continuity of displacements and transverse stresses, and of non-homogeneous boundary conditions; and the mathematical manipulations that render its numerical efficiency. Then, the new family of elements is assessed in problems involving different boundary conditions. Results are compared to analytical and highly refined 2D finite elements solutions, providing a benchmark of the elements capabilities. Mesh convergence is assessed, together with the influence of the global and local displacement fields. The numerical efficiency of the formulation is attested and an expansion for a 3D formulation is outlined.


ABSTRACT: Two of the most important of the loads exposed to the structures whose construction material is pultruded GFRP are buckling and vibration loads. Therefore, it is crucial to determine the behavior of this material against buckling and vibration loads considering the fiber and layer configurations. Pursuant to this goal, comprehensive experimental, numerical and analytical studies have been undertaken. An exact analytical solution based on first order shear deformation plate theory was used for the solution of stability and vibration problems. The virtual displacement principle was utilized herein to derive governing differential equations. Effective material properties of pultruded GFRP composites were obtained by using the mixture rule model. The laminated plate was assumed to be a plate strip in cylindrical bending. The solutions were obtained with an infinite series. On the other hand, a numerical study was conducted by a finite element software, ABAQUS. Burn-out and mechanical tests were performed to determine the mechanical properties of the obtained pultruded GFRP composite specimens. The buckling and modal analysis for natural frequencies tests were utilized to investigate the performance of pultruded GFRP specimens. The experimental findings were compared with the calculated analytical and numerical results, and good conformance was obtained. Macro and micro mechanical damage analyses were performed to better understand the behavior of the pultruded GFRP composite specimens.

ABSTRACT: A new equivalent shell finite element (FE) for modelling damped multi-layered structures is presented in this study. The method used for developing the new FE for such structures is based on the idea that the strain energy of the equivalent single-layer FE must be equal to the sum of the strain energies of individual layers. The so-called energy coefficients are defined for this purpose for the extensional, bending and shear deformations of the composite structure. These coefficients are then determined and used as correction multipliers during stacking the elemental matrices of individual layers. Two approaches, based on second-order strain or stress distribution assumption through the composite thickness, are investigated for deriving the shear energy coefficients. The damping capability of the FE developed here originates from using complex Young’s modulus to define the material properties of individual layers. The resulting equivalent single-layer shell element with four nodes has six degrees-of-freedom per node. The accuracy, advantages and limitations of the composite FE developed in this work are investigated using experimental as well as theoretical results. In the light of the finding of these investigations, further enhancement in the formulation is made by also utilising a new shear correction factor for the individual layers in the equivalent shell element. Final results for free- and constrained-layered structures confirm that the equivalent shell FE developed here can be used effectively for the prediction of the modal properties of damped multi-layered structures.


ABSTRACT: The characteristics of vibration frequency band-gaps for the composite laminate metamaterial plates are improved by equidistantly placing macro-fiber composite (MFC) piezoelectric patches along one direction of the plates. An acceleration feedback control strategy is proposed to actively regulate the band-gap characteristics of the metamaterial plates. The spectral element method (SEM) and transfer matrix method are used to calculate frequency response curves and attenuation constants of the metamaterial plates, and the calculated results by the SEM are compared with that of the finite element method (FEM) to validate the correctness and accuracy of the present numerical method. The obtained results demonstrate that when lattice constant of the structure is properly designed, superior band-gap properties in the low and medium frequency ranges can be achieved by adjusting the dimensions of the MFC piezoelectric patches. Improved characteristics of the Bragg scattering band-gaps in the medium and high frequency regions can also be obtained using the acceleration feedback control strategy. Moreover, band-gap widths can be significantly enlarged by actively tuning the acceleration feedback gain. In addition, the starting frequencies and band-gap widths of the composite laminate metamaterial plates can be adjusted using different cross-ply angles of the MFC piezoelectric patches and composite laminate metamaterial plates.


ABSTRACT: A mathematical procedure has been presented to study the vibrational behavior of a composite cylindrical shell under moving internal pressure. The shell contains three layers in which the internal and external layers have elastic and isotropic properties and the middle layer consists of an auxetic honeycomb structure which has negative Poisson’s ratio. The equations of motion have been extracted based on the classical shell theory and Hamilton’s principle. The governing equations which are a system of coupled partial differential equations, are solved using an analytical solution, and the natural frequencies, the critical velocities and dynamic response have been determined. To investigate the sensitivity of the geometrical parameters and material properties on the natural frequency, critical velocity, and dynamic response, a parametric study has been conducted. To verify the analytical method, the results have been compared with the finite element results and some available literature results.
ABSTRACT: Auxetic materials exhibit interesting mechanical properties. In this work, a novel auxetic unit cell was proposed with an aim to improve the strength and energy absorption of the auxetic structure constituting these unit cells. In the developed unit cell, the vertical member of a conventional re-entrant unit cell was replaced by a diamond. The corresponding structure was named re-entrant diamond structure. Specimens were fabricated using Multi-Jet Fusion (MJF) technique and experimentally tested to investigate their mechanical performance under uniaxial quasi-static and dynamic compression. Finite element model was also developed in ABAQUS/Explicit and validated using experimental results. Moreover, in order to improve stiffness of the diamonds, a cross-link member was introduced in each diamond. Subsequently, a parametric study was conducted to study the influence of diamond angle ($\theta$) and length ratio ($L_2/L_1$) on the deformation mode, stress–strain curve, Poisson’s ratio, and energy absorption of the re-entrant diamond structures with and without cross-links. This study revealed that larger diamond angle ($\theta$) and smaller length ratio ($L_2/L_1$) are desirable for high strength. Furthermore, the re-entrant diamond structures with and without cross-links were compared with the conventional re-entrant and hexagonal honeycombs in terms of strength and energy absorption.

ABSTRACT: This paper proposes an improved first-order beam theory by separation of variables for bending and buckling analysis of thin-walled functionally graded (FG) sandwich I-beams resting on a two-parameter elastic foundation. By dividing the displacements into bending and shear parts, this model can produce the deflections for both two cases with and without shear effect. The mechanical properties of beams based on the power law distribution of volume fraction of ceramic or metal. Governing equations are established from Lagrange’s equations. The new Ritz’s approximation functions, which are combined between orthogonal polynomial and exponential functions, are proposed to solve problem. The deflections and critical buckling loads of thin-walled FG sandwich I-beams are presented and compared with those available literature to verify the present theory. The effects of material distribution, boundary conditions, length-to-height ratio, shear deformation and foundation parameters on the results are investigated in detail.

Zhihua Wang (1,2), José Humberto S. Almeida Jr. (3), Luc St-Pierre (3), Zhonglai Wang (2) and Saullo G.P. Castro (1)
(1) Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands
(2) School of Mechanical and Electrical Engineering, University of Electronic Science and Technology of China, Chengdu, China
(3) Department of Mechanical Engineering, Aalto University, Espoo, Finland
ABSTRACT: A reliability-based optimization framework is introduced and used to design filament-wound cylindrical shells with variable angle tow. Seven design cases are investigated to enable a comparison between constant-stiffness and variable angle tow designs, also considering effects of thickness variation created due to overlapping tow paths, determined using the kinematics of the filament winding manufacturing process. The uncertainty in the winding angle is considered in the optimization by means of metamodels constructed using the Kriging method. Moving search windows are incorporated into the Kriging metamodel to accelerate its convergence by reducing the number of training iterations. The results prove the efficacy of the proposed framework and clearly demonstrate the advantage of variable-stiffness designs over conventional ones for achieving a maximum load carrying capacity, while keeping the robustness of the design towards manufacturing uncertainties.
References listed at the end of the paper:
and numerical results are compared to experimental data in terms of specific absorbed energy absorption capacity and influence of structural gradient distributions. Experimental observation showed that failure of HTCHGS was induced and constrained as expected, stable rising load plateau achieved by presented staggered conical HTCHGS. The staggered conical HTCHGS obtained mean value of 0.64 and 1.56 J/g on crushing force efficiency and specific energy absorption at the densification displacement. FEM simulations were carried out among presented configurations by parameterized modeling, validated the induced deformation processes by structural gradient which matched well with the tests. Stress distributions were compared among six configurations at typical deformation stage, found core components of staggered configurations contribute more to energy absorption than that of regular configurations. Staggered dumbbell HTCHGS provide long and stable deformation plateau till densification, and staggered conical HTCHGS are considered as optimal energy absorbing components among the configurations which give possible guidance for engineering structural designs.


ABSTRACT: The crushing response of fiber-reinforced composite structures under compressive loading is investigated experimentally and then simulated using two damage models implemented in ESI Virtual Performance Solution explicit solver. The conventional Ladevèze continuum damage is compared to the recently implemented Waas-Pineda model, which uses non-local damage approach: virtual cracks are embedded with prescribed traction-separation laws and direct input of modal fracture energies. Initially, characterization tests of a unidirectional carbon fiber/epoxy tape are carried out to implement material card data and elementary simulations are performed for calibration. In a second stage, quasistatic crush compression of reference coupons are used for validation and numerical results are compared to experimental data in terms of specific absorbed energy.
energy. Results show that the Waas-Pineda model is easier to set up than the Ladevèze one and it also better reproduces the experimental results. The Ladevèze model underestimates the sustained crush stress since some damage modes could not be well identified from coupon testing of brittle material.


ABSTRACT: In this paper, Reddy’s higher-order and Mindlin’s first-order plate theories are used for buckling analysis of porous rectangular plates subjected to various types of mechanical loading. The condition of the internal pores is considered to be either free of or saturated by fluid. Biot’s theory of poroelasticity is thereby employed to model the behaviour of fluid. Distribution of pores is assumed to vary through the thickness according to an asymmetric distribution. For each displacement field considered, five highly coupled partial differential equations are derived by means of variational principle. These systems of equations are first decoupled through an efficient method, and then solved analytically for Levy-type boundary conditions. Accuracy of the approach is examined by comparing the obtained results with those available in literature. Eventually, comprehensive parametric studies are provided to investigate the effects of geometrical parameters, boundary conditions, loading conditions, porosity coefficient and pore fluid compressibility on the buckling response of the system. The results suggest that a structure with higher equivalent rigidity is met, when its corresponding internal pores are saturated by fluid. The results of the current work can be considered as a benchmark for future studies.


ABSTRACT: In this paper, a new C<sub>20</sub> layerwise wavelet finite element is proposed for the static and free vibration analysis of composite plates. The refined zigzag theory is adopted to introduce the zigzag effects in multilayered plate structures by using piecewise linear C<sub>0</sub> continuous functions. Then the layerwise wavelet-based BSWI element is derived based on the higher-order plate theory by means of two-dimensional BSWI scaling functions. The proposed model satisfies the conditions of transverse shear stress continuity at the layer interfaces as well as yields to the stress-free boundary conditions on the surface of plate without a shear correction factor. What’s more, the layerwise wavelet-based BSWI element also possesses the advantages of high convergence, high accuracy and reliability with fewer degrees of freedom on account of the excellent approximation property of BSWI. The accuracy and effectiveness of proposed layerwise wavelet-based BSWI element is assessed for static and free vibration analysis of laminated composite and sandwich plates with available 3D elasticity solutions, finite element solutions and other referential solutions in published literatures.


ABSTRACT: Studies on functionally graded (FG) curved microbeam structures are rather rare in the literature, and we thus present an effective computational approach on the basic combination of isogeometric analysis (IGA) and modified couple stress theory (MCST) for mechanical behavior analysis of such FG curved microbeams. The proposed method can cope with simultaneous complexities in material properties and geometries of the FG curved microbeams. The material properties of microbeams vary continuously along the thickness direction. The non-uniform rational B-spline (NURBS) basis functions are used to describe exactly geometries of the curved beams and displacement approximation. The MCST is adopted to capture the small-scale effects. Several examples of static bending and free vibration behaviors are presented to demonstrate the effectiveness and accuracy of the developed method. The effects of some factors (e.g., material gradient, size effect, boundary conditions, curvature, and aspect ratio of the beams) on mechanical behaviors of FG curved microbeams are investigated. The numerical results reveal that the small-scale effects decrease the deflection and increase the natural frequency because of increasing the stiffness.

Miroslav Marjanović, Günther Meschke and Emilija Damnjanović, “Object-oriented framework for 3D bending and free vibration analysis of multilayer plates: Application to cross-laminated timber and soft-core sandwich
ABSTRACT: In the paper, the main steps involved in the development of an object-oriented computational framework for the 3D bending and free vibration analysis of multilayer plates are presented. The mathematical formulation for layered finite elements is based on Reddy’s plate theory for laminated composites. The analysis model has been implemented into Matlab, and the pre- and post-processing phases are performed using GiD. The proposed solver is characterized by a fast assembly procedure of sparse matrices using matrix vectorization, and a novel algorithm for the evaluation of interlaminar stresses satisfying continuity at layer interfaces. The performance, efficiency and accuracy of the computational framework are demonstrated through a number of validation examples by comparing the obtained results against the exact solution. Results from both static and dynamic analyses of multilayer panels are shown.

References listed at the end of the paper:
16 E. Carrera, Theories and finite elements for multilayered, anisotropic, composite plates and shells, Arch Comput Methods Eng, 9 (2) (2002), pp. 87-140
29 L. Cheni, FEM: an innovative finite element methods package in Matlab, University of Maryland (2008)
plates using a layerwise displacement model with contact conditions. 


56 M. Marjanović, Nonlinear analysis of laminated composite plates and shells with delaminations using finite element method, Faculty of civil engineering, University of Belgrade (2016)


58 https://github.com/miregrf/FLWTFEM


60 M. Marjanović, Dj Vuksanović, Layerwise solution of free vibrations and buckling of laminated composite and sandwich plates with embedded delaminations, Compos Struct, 108 (2014), pp. 9-20

61 DIAB guide to core and sandwich. DIAB group AB, Sweden, 2012. – www.diabgroup.com


63 N. Pagano, Exact solutions for rectangular bidirectional composites and sandwich plates, J Compos Mater, 4 (1970), pp. 20-34


65 M. Marjanović, G. Meschke, Dj Vuksanović, A finite element model for propagating delamination in laminated composite plates based on the Virtual Crack Closure method, Compos Struct, 150 (2016), pp. 8-19

66 M. Marjanović, Dj Vuksanović, G. Meschke, Geometrically nonlinear transient analysis of delaminated composite and sandwich plates using a layerwise displacement model with contact conditions, Compos Struct, 122 (2015), pp. 67-81

ABSTRACT: In this study, damage behaviors and residual crashworthiness characteristics of braided composite tube with transverse pre-impact damages subjected to axial compression were investigated by experimental and numerical methods. The compression tests were conducted on intact, single impact and repeated impact tubes at identical, adjacent and opposite positions to analyze the effects of impact damages. A multi-step finite element model considering the progressive damage characteristics was developed in ABAQUS/Explicit to predict the failure behaviors of braided tube. It was found that the damage behavior and residual performance of braided tube subjected to axial compression were dominated by impact induced delamination distribution with respect to area and position. A relatively small delamination area induced by single impact resulted in similar progressive folding damage mode and energy absorption capacity as in intact tube. For repeated impact, delamination with increased area at identical position led to local buckling damage mode, while small delamination areas distributed at adjacent and opposite positions caused U-shape and W-shape fracturing damage modes, respectively. Consequently, the transformation of damage mode resulted in significantly reduced residual crashworthiness characteristics in repeated impact tubes compared to intact and single impact tubes.


ABSTRACT: The synergy of additive manufacturing (AM) with topology optimization has become a useful method for developing ultralight, ultrastiff structures with high energy absorption capability. To improve the weight-specific stiffness and energy absorption capability of the conventional dome commonly used as the core of sandwich sheets, a new concept of filling the solid part of the dome with stretch-optimized topology optimization method with the lattice structure. The compressive and bending stiffnesses of the optimized variable-density microlattice domes are demonstrated to be 41.8% and 33.7% higher than those of the conventional solid domes, while the energy absorption of the microlattice dome during compression and three-point bending is increased by 297.5% and 85%, respectively. Investigation of the cell size effect on the mechanical properties of the microlattice dome reveals that a larger cell size contributes more to the weight-specific stiffness and energy absorption capability at a given overall volume fraction constraint. The topology optimization and construction methods described in this paper are universal and can be used for the further development of ultralight, ultrastiff structures with arbitrary macro shapes with microlattices as constituent units.

References listed at the end of the paper:
8 V.V. Vasiliev, V.A. Barynin, A.F. Razin, Anisogrid composite lattice structures - Development and aerospace applications, Compos Struct, 94 (2012), pp. 1117-1127, 10.1016/j.compstruct.2011.10.023
that the H3DP structure had relatively higher energy absorption capacity than the primitive sheet structure as crashworthiness comparison of the H3DP structure and the traditional energy absorbed structures, it is found that the ALPORAS® aluminium foams are used to be the load-reducing material for the buffer, respectively. The constitutive model for the material has been validated by comparing the numerical results with the compressive tests data. Six deformation and failure modes: Local Failure (LF), Warping Deformation/Failure (WD/WF), Wedging-In Failure (WIF), Euler Failure (EF), Inversion and Curling (IC), Complete Disintegration (CD) are found in the nose cap during water entry at constant vertical velocity. Among these modes, the wedging force in WIF mode is the dominant cause of the severe damage of the nose cap. The results show that the material performance of the damper has a more significant influence on the CD mode time than the length of nose cap, the beginning time of WIF mode and the duration of WIF mode. Moreover, the ALPORAS® aluminium foam has the best load-reducing performance (highest load-reducing ratio up to 75.3%) among the three foam materials. This paper provides an engineering reference for the design of buffer applied in high-speed water entry.

Hanfeng Yin (1.2), Xianjun Zheng (1.2), Guilin Wen (1.2), Chao Zhang (3,4) and Zhantao Wu (1)
(1) State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, Hunan 410082, PR China
(2) Key Laboratory of Advanced Design and Simulation Techniques for Special Equipment, Ministry of Education, Hunan University, Changsha, Hunan 410082, PR China
(3) Department of Aeronautical Structure Engineering, School of Aeronautics, Northwestern Polytechnical University, Xi’an, Shaanxi 710072, PR China
(4) Shaanxi Key Laboratory of Impact Dynamics and Engineering Applications, Northwestern Polytechnical University, Xi’an, Shaanxi 710072, PR China


ABSTRACT: Porous structure is widely used in automobile, aerospace and other industrial fields due to its lightweight and high energy absorption capacity. In this study, a novel porous structure, i.e. hierarchical three-dimensional porous (H3DP) structure inspired by the bone in nature is created based on the primitive triply periodic minimal surface sheet structure, which is a basic three-dimensional periodic porous structure consist of triply periodic minimal surfaces. The numerical simulation for the axial crushing of the H3DP structures is carried out using the nonlinear finite element code through LS-DYNA. For accuracy of the numerical results, the finite element model is validated by the experiment performed for H3DP structures which are manufactured by selective laser melting technology using a EOS M290 machine. The numerical results showed that this novel bio-inspired H3DP structure had excellent energy absorption capacity. However, the crashworthiness of the H3DP structure is affected by design parameters such as wall thickness, ribs thickness, number of inner ribs and distance between the inner and outer walls. In order to obtain the optimal design of the H3DP structure with the best crashworthiness, a multi-objective optimization is implemented employing the Kriging (KRG) surrogate modeling method and Non-Dominated Sorting Genetic Algorithm II (NSGA-II). According to the crashworthiness comparison of the H3DP structure and the traditional energy absorbed structures, it is found that the H3DP structure had relatively higher energy absorption capacity than the primitive sheet structure as...
well as lots of previous traditional materials or structures in nature and engineering. Thus, the H3DP structure can be used as a good energy absorbing structure and had good application prospect in the field of impact engineering.

References listed at the end of the paper:
3. X. Huo, G. Sun, H. Zhang, X. Lv, Q. Li, Experimental study on low-velocity impact responses and residual properties of composite sandwiches with metallic foam core, Compos Struct, 223 (2019), Article 110835
12. V. Karageorgiou, D. Kaplan, Porosity of 3D biomaterial scaffolds and osteogenesis, Biomaterials, 26 (27) (2005), pp. 5474-5491
15. Z. Wang, Recent advances in novel metallic honeycomb structure, Compos B Eng, 166 (2019), pp. 731-741
20. X. Suchao, W. Hao, Y. Chengxing, Z. Hui, F. Zhejun, Mechanical properties of combined structures of stacked multilayer Nomex honeycombs, Thin-Walled Struct, 151 (2020), Article 106729
35 D.J. Yoo, Heterogeneous porous scaffold design using the continuous transformations of triply periodic minimal surface models, Int J Precis Eng Manuf, 14 (10) (2013), pp. 1743-1753
46 H. Qing, L. Mishnaevsky Jr., 3D hierarchical computational model of wood as a cellular material with fibril reinforced, heterogeneous multiple layers, Mech Mater, 41 (9) (2009), pp. 1034-1049
51 H.L. Tan, Z.C. He, K.X. Li, E. Li, A.G. Cheng, B. Xu, In-plane crashworthiness of re-entrant hierarchical honeycombs with negative Poisson’s ratio, Compos Struct, 229 (2019), Article 111415
56 X. Suchao, W. Ning, Y. Weiling, L.i. Haihong, Energy absorption performance of thin-walled metal plate due to upheaval deformation based on experiments and numerical simulation, Thin-Walled Struct, 131 (2018), pp. 258-273


ABSTRACT: This study focuses on epoxy fiberglass (E-glass) laminates used as printed circuit boards, more particularly as flexible substrates in fracture assemblies for the test of attachments of electronic components
such as solder and adhesive joints. Breaking these joints often requires large bending of E-glass substrates. Such circumstances have not been investigated before. In fact, most research focused on the linear elastic behaviour of E-glass. Therefore, static large bending tests were conducted on instrumented cantilever and square plates. Test data consisting of pull force and strain versus deflection curves revealed that the behaviour of E-glass laminates is overall non-linear-elastic. Next, the correlation between simulated and measured structural responses of test prototypes led to determining E-glass lamina properties applicable upon large bending.


ABSTRACT: The present study deals with the nonlinear vibration of functionally graded porous (FGP) variable thickness toroidal shell segments surrounded by elastic medium subjected to axial compression and external pressure, including the thermal effects. Three types of uniform, symmetric, and non-symmetric porosity distributions are considered. The improved Donnell shell theory with von-Karman nonlinearity, and Stein and McElman’s assumptions are used to obtain the equations of motion of toroidal shell segments. The dynamic characteristics of shells such as natural frequencies and nonlinear frequency-amplitude relation are determined by using the solution in terms of displacements in conjunction with Galerkin's method. The present approach is validated by comparing with the available results for particular cases. Effects of geometrical characteristics, the porosity distribution types, the porosity coefficient, the thickness distribution parameter, temperature and pre-loaded static axial compression on the nonlinear vibration response of the FGP variable thickness convex and concave toroidal shell segments are studied in detail.

References listed at the end of the paper:

3 P. Malekzadeh, Y. Heydarpour, Free vibration analysis of rotating functionally graded cylindrical shells in thermal environment, Compos Struct, 94 (9) (2012), pp. 2971-2981
5 S.S. Vel, Exact elasticity solution for the vibration of functionally graded anisotropic cylindrical shells, Compos Struct, 92 (11) (2010), pp. 2712-2727
6 S. Pradhan, et al., Vibration characteristics of functionally graded cylindrical shells under various boundary conditions, Appl Acoust, 61 (1) (2000), pp. 111-129
7 D. Punera, T. Kant, Free vibration of functionally graded open cylindrical shells based on several refined higher order displacement models, Thin-Walled Struct, 119 (2017), pp. 707-726
8 A. Sofiyev, N. Kuruoglu, Buckling and vibration of shear deformable functionally graded orthotropic cylindrical shells under external pressures, Thin-Walled Struct, 78 (2014), pp. 121-130
9 A. Sofiyev, N. Kuruoglu, On a problem of the vibration of functionally graded conical shells with mixed boundary conditions, Compos B Eng, 70 (2015), pp. 122-130
10 Z. Su, G. Jin, T. Ye, Three-dimensional vibration analysis of thick functionally graded conical, cylindrical shell and annular plate structures with arbitrary elastic restraints, Compos Struct, 118 (2014), pp. 432-447
11 H.-S. Shen, Nonlinear vibration of shear deformable FGM cylindrical shells surrounded by an elastic medium, Compos Struct, 94 (3) (2012), pp. 1144-1154
12 H.-S. Shen, H. Wang, Nonlinear vibration of shear deformable FGM cylindrical panels resting on elastic foundations in thermal environments, Compos B Eng, 60 (2014), pp. 167-177
13 A. Sofiyev, The non-linear vibration of FGM truncated conical shells, Compos Struct, 94 (7) (2012), pp. 2237-2245
16 A. Sofiyev, N. Kuruoglu, Large-amplitude vibration of the geometrically imperfect FGM truncated conical shell, J Vib Control, 21 (1) (2015), pp. 142-156
17 G. Sheng, et al., The nonlinear vibrations of functionally graded cylindrical shells surrounded by an elastic foundation, Nonlinear Dyn, 78 (2) (2014), pp. 1421-1434
18 A. Sofiyev, et al., The nonlinear vibration of orthotropic functionally graded cylindrical shells surrounded by an elastic foundation within first order shear deformation theory, Compos B Eng, 116 (2017), pp. 170-185
27 H. Li, et al., Vibration analysis of functionally graded porous cylindrical shell with arbitrary boundary restraints by using a semi analytical method, Compos B Eng, 164 (2019), pp. 249-264
28 J. Zhao, et al., A unified solution for the vibration analysis of functionally graded porous (FGP) shallow shells with general boundary conditions, Compos B Eng, 156 (2019), pp. 406-424
30 M.-C. Trinh, S.-E. KimA three variable refined shear deformation theory for porous functionally graded doubly curved shell analysis, Aerosp Sci Technol, 94 (2019), Article 105356
31 M. Keleshteri, J. Jelovica, Nonlinear vibration behavior of functionally graded porous cylindrical panels, Compos Struct, 239 (2020), Article 112028
32 M. Stein, J.A. McElman, Buckling of segments of toroidal shells, AIAA J, 3 (9) (1965), pp. 1704-1709
34 B.H. Dao, N.G. Dinh, T.I. Tran, Buckling analysis of eccentrically stiffened functionally graded toroidal shell segments under mechanical load, J Eng Mech, 142 (1) (2016), p. 04015054
36 D. Dung, P. Vuong, Nonlinear analysis on dynamic buckling of eccentrically stiffened functionally graded material toroidal shell segment surrounded by elastic foundations in thermal environment and under time-dependent torsional loads, Appl Math Mech, 37 (7) (2016), pp. 835-860
37 D.H. Bich, D.G. Ninh, T.I. Thinh, Non-linear buckling analysis of FGM toroidal shell segments filled inside by an elastic medium under external pressure loads including temperature effects, Compos B Eng, 87 (2016), pp. 75-91
40 Brush DO, Almroth BO, Buckling of bars, plates, and shells. 1975.
41 S. Volmir, Nonlinear dynamics of plates and shells, Science, Moscow (1972)
45 D.H. Bich, et al., Nonlinear dynamical analyses of eccentrically stiffened functionally graded toroidal shell segments surrounded by elastic foundation in thermal environment, Compos B Eng, 95 (2016), pp. 355-373
47 K.K. Raju, G.V. Rao, Large amplitude asymmetric vibrations of some thin shells of revolution, J Sound Vib, 44 (3) (1976), pp. 327-333
48 T.I. Thinh, et al., Nonlinear analysis of buckling and postbuckling of functionally graded variable thickness toroidal shell segments based on improved Donnell shell theory, Compos Struct, 243 (2020), Article 112173

ABSTRACT: Composite laminated plates have found several applications in engineering field. For instance, aerospace and automotive industry use these structures in several components of their products due to their exceptional specific properties along the direction of the fibres. There are several two-dimensional plate models that aim to more accurately and more efficiently predict the kinematics of those structures. Unlike the Classical Plate Theory (CLPT), which can only be applied to thin laminates, the First-Order Shear Deformation Theory (FSDT), developed by Reissner and Mindlin, already accounts shear effects and, due to that, it can describe in a satisfactory way the kinematic of a generic thick laminated plate. Nevertheless, the FSDT considers linear shape functions to describe the in-plane displacements through the plate thickness, which results in constant shear strains. Thus, the traction boundary conditions on the top and bottom surface of plate are violated. Additionally, the FSDT needs shear correction factors, which are not easily obtained for a generic problem. Equivalent single layer (ESL) theories following high-order shear deformation theories (HSDTs) have been proposed and more efficiently applied to composite laminated plates. These theories allow to represent the nonlinear variation of transverse shear stresses through thickness of plate because they possess nonlinear shape functions interpolating the in-plane displacements. Thus, the kinematics of these structural elements can be better described and more accurate stress fields can be obtained for problems that cannot be handled with the FSDT. These structures have been analysed for several years using the Finite Element Method (FEM), which is the most popular numerical tool in structural analysis. However, several other advanced numerical techniques, such as meshless methods, can also handle this kind of problems and, in some cases, in a more efficient way. This work makes use of a recently developed meshless method – the Natural Neighbour Radial Point Interpolation Method (NNRPIM) (Belinha, 2014) – to study the bending of antisymmetric angle-ply composite laminates using distinct HSDTs.


ABSTRACT: The free linear vibration of an adaptive sandwich beam consisting of a frequency- and field-dependent magnetorheological fluid core and an axially functionally graded constraining layer is investigated. The Euler-Bernoulli and Timoshenko beam theories are utilized for defining the longitudinal and lateral deformation of the sandwich beam. The Rayleigh–Ritz method is used to derive the frequency-dependent eigenvalue problem through the kinetic and strain energy expressions of the sandwich beam. In order to deal with the frequency dependency of the core, the approached complex eigenmodes method is implemented. The validity of the formulation and solution method is confirmed through comparison with the results available in the literature. Finally, the effects of the magnetic field, axially functionally graded material power-law index, constraining, and core layers thickness on the free vibration behavior of the sandwich beam are studied thoroughly for clamped-clamped, simply supported, and clamped-free boundary conditions. It is shown that any change in each of these parameters would have significant effects on the beam's free vibration properties.

References listed at the end of the paper:
2 E.M. Kerwin Jr, Damping of flexural waves by a constrained viscoelastic layer, J Acoust Soc Am, 31 (7) (1959), pp. 952-962
6 M. Asgari, M.A. Kouchakzadeh, Aeroelastic characteristics of magneto-rheological fluid sandwich beams in supersonic airflow, Compos Struct, 143 (2016), pp. 93-102
under the variational principle. To account for the properties of composite materials, the Halpin–Pasternak energy functional of the beam model is represented by a Winkler foundation.

ABSTRACT: This work presents a novel computational approach, the DSC regularized Dirac–delta method for dynamic analysis of FG graphene platelet-reinforced porous beams on elastic foundation under a moving load. Based on the Timoshenko beam theory, the energy functional of the beam model is represented by a newly constructed basis function and is minimized under the variational principle. To account for the properties of composite materials, the Halpin–Tsai model is...
used to predict the elastic modulus of graphene-reinforced composites. A coupling of the DSC regularized Dirac-delta method and the Newmark-β integration scheme is then adopted for solving the dynamic problem. The DSC-based approach exhibits controllable accuracy for approximations and shows excellent flexibility in handling time-dependent moving load problems, because the equally spaced grid system used in the DSC numerical approach can achieve a preferable representation of moving load sources. An intensive parametric study is provided with a particular focus on the influence of moving loads, foundation supports and material properties (e.g., weight fraction, porosity distribution, dispersion pattern and geometry size of graphene reinforcements). First-known solutions reported in tabular and graphical forms should be useful for researchers and engineers in designing such beam problems.


ABSTRACT: Fiber reinforced plastics can absorb energy, in the unlikely event of a crash, on the other hand, foam improves the structural integrity of the device being filled with. Therefore, foam-filled carbon fiber reinforced plastic (CFRP) composites are extensively used as an energy absorber for safety enhancement. Current study aims to characterize the impact response of CFRP composite tubes filled with polyurethane foam with five different combinations. The CFRP tubes were internally stiffened with sheets, tubes and hats made of CFRP composite. In addition, the internally stiffened tubes were filled with polyurethane (PU) foam for structural integrity. Specimens were then tested under dynamic crushing using a drop weight impactor with an impact energy of 75 J. During the tests, the behaviors of specimens were recorded by high speed camera. Visual inspections and micrographs of the specimens were also investigated. The results revealed that the peak force, threshold force, and energy absorbed were increased by using the PU foam inside the CFRP composite tubes. The energy absorption did not show significant improvement by adding the internal CFRP reinforcements, whereas, the peak load improvement was considerable. The specimen filled with only PU foam yielded the best specific energy absorption among all the specimens.

References listed at the end of the paper:
4 A. Tastan, E. Acar, M.A. Guler, U. Kilincayaa, Optimum crashworthiness design of tapered thin-walled tubes with lateral circular cutouts, Thin-Walled Struct, 107 (2016), pp. 543-553
5 A. Baroutaji, M.D. Gilchrist, A.G. Olabi, Quasi-static, impact and energy absorption of internally nested tubes subjected to lateral loading, Thin-Walled Struct, 98 (2016), pp. 337-350
7 F. Ahmad, J.-W. Hong, Choi HS, Park MK, Park S-J (2015), p. 16
10 E. Acar, M.A. Guler, B. Gerceker, M.E. Cerit, B. Bayram, Multi-objective crashworthiness optimization of tapered thin-walled tubes with axisymmetric indentations, Thin-Walled Struct, 49 (2011), pp. 94-105
16 D.S. Sön, H. Mehboob, S.H. Chang, Simulation of the bone healing process of fractured long bones applied with a composite bone plate with consideration of the blood vessel growth, Compos Part B-Eng, 58 (2014), pp. 443-450
17 A. Mehboob, H. Mehboob, J. Kim, S.H. Chang, F. Tarlochan, Influence of initial biomechanical environment provided by fibrous composite intramedullary nails on bone fracture healing, Compos Struct, 175 (2017), pp. 123-134
23 T.A. Sebaey, E. Mandi, Crushing behavior of a unit cell of CFRP lattice core for sandwich structures' application, Thin-Walled Struct, 116 (2017), pp. 91-95
30 A. Othman, S. Abdullah, A.K. Ariffin, N.A.N. Mohamed, Investigating the crushing behavior of quasi-static oblique loading on polymeric foam filled pultruded composite square tubes, Compos Part B-Eng, 95 (2016), pp. 493-514
42 T.A. Sebaey, E. Mahdi, Using thin-ply to improve the damage resistance and tolerance of aeronautical CFRP composites, Compos A Appl Sci Manuf, 86 (2016), pp. 31-38

ABSTRACT: Analysis of graphene nanoplatelets (GPLs) reinforced cylindrical shell subjected to thermo-mechanical loads is studied in this paper based on shear deformation theory. Halpin-Tsai micromechanical model and rule of mixtures are used for calculation of effective material properties of composite materials with different distributions of reinforcements including uniform symmetric and asymmetric distributions for nanoplatelet material. The various distributions are included UD (uniform distribution of GPLs along the thickness direction), FG-O(linear variation of GPLs, where highest amount is locates at middle layer) and FG-X(linear variation of GPLs, where highest amount is locates at top and bottom layers). The shear strains especially at both ends of cylindrical shell are included in our formulation using the two-dimensional first-order shear deformation theory (FSDT). Minimum total potential energy principle is used to derive the governing
equations using Hooke’s law and application of Euler equations using the functional of the system. Eigenvalue and eigenvector method is used for solution of the governing equations. The radial and axial displacements and various components of stress are calculated in terms of number of layers, GPLs weight fraction, thermal loading, various distributions of reinforcement and coefficient of the elastic foundation. The numerical results indicate that maximum and minimum stresses are obtained for FG-O and FG-X distributions. Also, the biggest and lowest radial displacements are obtained for UD and FG-X distributions, respectively.

References listed at the end of the paper:

18. Z. Zhao, C. Feng, Y. Wang, J. Yang, Bending and vibration analysis of functionally graded trapezoidal nanocomposite plates reinforced with graphene nanoplatelets (GPLs), Compos Struct, 180 (2017), pp. 799-808
20. M. Song, J. Yang, S. Kitipornchai, Bending and buckling analyses of functionally graded polymer composite plates reinforced with graphene nanoplatelets, Compos Part B: Eng, 134 (2018), pp. 106-113
22. Z. Shi, T. Zhang, Bending analysis of a piezoelectric curved actuator with a generally graded property for the piezoelectric parameter, Smart Mater Struct, 17 (4) (2008), Article 045018

ABSTRACT: In this paper, a novel higher order cubic-quintic nonlinear model is proposed for the nonlinear free vibration of damped and undamped bi-directional functionally graded (2D FG) beams. To the best of the researchers’ knowledge, no study has focused on damping characteristics of 2D FG beams. Thus, the present paper extends the previous studies in this field. It is assumed that the material properties of the beam change in the axial and lateral directions simultaneously according to exponential and power-law functions, respectively. A new neutral surface is defined to remove the stretching and bending couplings effect. The variational iteration method (VIM) and the Hamiltonian approach (HA) are applied to obtain closed-form analytical solutions for the nonlinear vibration of damped and undamped 2D FG beams, respectively. Based on the results, an increase in the material grading indices can similarly decrease the damping coefficient for an underdamped 2D FG beam, and more time is required for dying out the oscillations. Further, compared to the homogeneous beams, a significant difference is observed between the cubic and cubic-quintic models indicating the importance of applying higher order nonlinear models for the nonlinear analysis of 2D FG beams.

References listed at the end of the paper:
3 M. Hong, I. Park, U. Lee, Dynamics and waves characteristics of the FGM axial bars by using spectral element method, Compos Struct, 107 (2014), pp. 585-593
4 M. Şimşek, T. Kocatürk, Free and forced vibration of a functionally graded beam subjected to a concentrated moving harmonic load, Compos Struct, 90 (2009), pp. 465-473

ABSTRACT: The present study develops a novel size optimization method to control the buckling mode shape and associated buckling temperatures of plates. From a structural stability point of view, predicting the buckling temperature and mode shape of structures is one of the most important research topics in engineering. However, coming up with optimized engineering structures through engineering intuition for controlling these aspects is challenging. To address this limitation, the present study proposes the combination of finite element simulation and a size optimization scheme. Based on the idea that the structural buckling temperature and mode shape of a plate are mainly influenced by the thickness of the plate, in the optimization process, the thickness values of the divided sections of the target plate are set as the design variables. The buckling mode shape and buckling temperature are set as the objective functions, subjected to the total volume of the target plate. By applying the size optimization scheme, it is possible to determine the optimal thickness distributions for inducing the desired buckling mode shapes and buckling temperature values. The validity of the proposed size optimization method has been verified using several numerical examples.

References listed at the end of the paper:
1 J.M. Jenkins, W.J. Sefic, Experimental investigation of thermal-buckling characteristics of flanged, thin-shell leading edges, Natl Aeronaut Space Admin Edwards (1966)
2 J. Bai, J. Xiong, Temperature effect on buckling properties of ultra-thin-walled lenticular collapsible composite tube subjected to axial compression, Chin J Aeronaut, 27 (2014), pp. 1312-1317
7 J.F. Rakow, A.M. Waas, Thermal buckling of metal foam sandwich panels for convective thermal protection systems, J Spacecraft Rockets, 42 (2005), pp. 832-844
11 J. Cui, J. Adams, Y. Zhu, Pop-up assembly of 3D structures actuated by heat shrinkable polymers, Smart Mater Struct, 26 (2017), Article 125011
12 S. Saha, A. Ali, Thermal buckling and postbuckling characteristics of extensional slender elastic rods, J Mech Eng, 40 (2009), pp. 1-8

ABSTRACT: This paper aims to investigate the mechanical properties of concrete-filled glass fiber reinforced plastic (GFRP) tubular stub columns after being subjected to freeze-thaw cycles (FTCs). A total of 72 concrete-filled GFRP tubular (CFGF) stub columns treated with different FTCs were tested under axial load. The ultimate capacity, initial stiffness, load-displacement curves, load-strain curves, and failure modes were obtained and analyzed. Test results indicated that the failure phenomena of the specimens under axial compression were similar, mainly including the fracturing of GFRP tube and crushing of core concrete. The FTCs, concrete strength and column height all had a significant influence on the failure modes of the specimens. The ultimate capacity and initial stiffness decreased evidently with the increase of the number of FTCs. By increasing the height of the column, the ultimate capacity and deformation capacity of square column after FTCs could be effectively improved. The change of ultimate capacity of the CFGT column after FTCs was the result of the combined effect of FTCs, concrete compressive strength and column height. Finally, the simplified formulas for calculating the ultimate capacity of CFGT stub columns after FTCs were proposed.


ABSTRACT: An efficient computational approach to simulate the damage during an impact event and subsequently predict the remaining compression strength is presented in this paper. The two-step explicit finite element modeling scheme to simulate the damage as interlaminar delaminations during an impact event and the ensuing failure during a compression test is developed to eliminate the typical issues associated with manual transfer of damage details between an impact simulation and a quasi-static compression failure simulation. The residual strength after impact simulation is predicted based on the damage state predicted by the impact model. Experiments were performed to validate the numerical study for 24 and 32 ply quasi-isotropic laminates, generally used in aircraft structure, with two different boundary conditions to ensure that the model is capable enough to predict the behavior of an impact even under different boundary conditions. A strong correlation is found between the delamination damage observed experimentally and the model predictions. Furthermore, the finite element approach presented in this paper was able to accurately simulate the compression strength after impact.


ABSTRACT: Sandwich plates with two thin stiff face-sheets and a soft center core have been used in many constructions for which the dominating load is transverse bending. Many theoretical/numerical analyses have been devoted to studying the deformation mechanism of such a structure. But relatively limited experimental investigations are present in this field and they are often self-content with little connection to the existing theoretical pursuits. In this paper, a composite sandwich structure made with carbon fiber woven face sheets and a relatively compliant foam core was loaded in 3-point bending. Images were captured of the specimen before and after deformation, which were then analyzed with a Digital Image Correlation (DIC) program. The full field displacements and strain fields were obtained for the specimen. The experimental deflection of the beam was compared with five theoretical models and one numerical solution. The result shows that only one model predicts the reality well.

References listed at the end of the paper:

ABSTRACT: To investigate the reinforcement effect of external CFRP strengthening on pultruded concrete-filled GFRP tubular (CFGT) short columns under axial compression, a total of 60 specimens were axially tested, including 48 specimens strengthened with different layers of CFRP and 12 specimens without CFRP strengthening. The main parameters considered in this study consist of the height of the column, concrete strength, and strengthening layers of CFRP. The failure modes, ultimate strength, load–displacement curves, load–strain curves, initial stiffness, and ductility of all specimens were obtained and discussed. Test results indicate that the specimens unstrengthened with CFRP are failed with the brittle failure under axial compression. The failure modes of specimens gradually change from the brittle failure to ductile failure with the increase of strengthening layers of CFRP. Compared with the unstrengthened CFGT short columns, the ultimate strength, deformability, and ductility of columns strengthened with CFRP are significantly enhanced. The more strengthening layers of the CFRP has, the larger the ultimate strength of specimens is. However, the strengthening layers of CFRP have little effects on the initial stiffness of CFGT short columns. Among the above three parameters, the strengthening layers of CFRP exert the most significant and positive influence on the ultimate strength of specimens, while the influence of the column height is completely adverse. Based on the experimental achievements, a formula for the calculation of ultimate strength of pultruded CFGT short columns externally strengthened with CFRP is proposed, which shows great accuracy and rationality in comparison with the experimental results.

References listed at the end of the paper:

1 L. Van Den Einde, L. Zhao, F. Seible, Use of FRP composites in civil structural application, Constr Build Mater, 17 (2003), pp. 389-403
6 Y. Bai, T. Vallée, T. Keller, Delamination of pultruded fiber-reinforced polymer composites subjected to axial compression, Compos Struct, 91 (2009), pp. 66-73
7 Z.A. Hashem, R.L. Yuan, Experimental and analytical investigations on short GFRP composite compression members, Compos B Eng, 31 (2000), pp. 611-618
8 Y. Kusumawardaningsih, M.N.S. Hadi, Comparative behavior of hollow columns confined with FRP composites, Compos Struct, 93 (2010), pp. 198-205
11 Y. Shao, Z. Zhu, A. Mirmiran, Cyclic modeling of FRP-confined concrete with improved ductility, Cem Concr Compos, 28 (2006), pp. 959-968
17 H. Toutanji, L. Zhao, Y. Zhang, Flexural behavior of reinforced concrete beams externally wrapped with CFRP sheets bonded with an inorganic matrix, Eng Struct. 28 (2006), pp. 557-566
20 C. Li, L. Ke, J. He, Z. Chen, Y. Jiao, Effects of mechanical properties of adhesive and CFRP on the bond behavior in CFRP-strengthened steel structures, Compos Struct, 211 (2019), pp. 163-174
31 K. He, Y. Chen, Experimental evaluation of built-in channel steel concrete-filled GFRP tubular short columns under axial compression, Compos Struct, 219 (2019), pp. 51-68
32 Z. Tao, L.H. Han, Behavior of fire-exposed concrete-filled steel tubular beam columns repaired with CFRP wraps, Thin-Walled Struct, 45 (2007), pp. 63-76
33 Y.F. Yang, L.H. Han, Behavior of concrete filled steel tubular (CFST) short columns under eccentric partial compression, Thin-Walled Struct, 49 (2011), pp. 379-395
34 Y.F. Yang, L.H. Han, Concrete filled steel tube (CFST) columns subjected to concentrically partial compression, Thin-Walled Struct, 50 (2012), pp. 147-156


ABSTRACT: This paper focuses on nonlinear parametric resonance behaviors of rotating composite laminated cylindrical shells subjected to periodic axial loads and hygrothermal environment. With effects of the time-varying axial loads, hygrothermal expansion deformation, Coriolis and centrifugal forces as well as the rotation-induced initial hoop tension taken into account, the nonlinear dynamic equations of the shell are obtained on the base of Love’s nonlinear shell theory and Hamilton’s principle. Then, an analytical formulation on the steady state response of the shell is derived by the method of multiple scales, and the stability conditions of trivial and nontrivial solutions are determined by the Routh–Hurwitz criterion. Some numerical results are utilized to conduct detailed parametric studies on vibration characteristics, amplitude–frequency response curves and instability regions of forward and backward travelling waves of the shell. Of particular interest in the process is the combined effect of dynamic axial loads and hygrothermal effects on the resonance behaviors of the rotating nonlinear cylindrical shell.

References listed at the end of the paper:
1 R.F. Gibson, A review of recent research on mechanics of multifunctional composite materials and structures, Composite Structures, 92 (12) (2010), pp. 2793-2810
2 T. Liu, W. Zhang, J.F. Wang, Nonlinear dynamics of composite laminated circular cylindrical shell clamped along a generatrix and with membranes at both ends, Nonlinear Dyn, 90 (2) (2017), pp. 1393-1417
6 P. Malekzadeh, Y. Heydarpour, Free vibration analysis of rotating functionally graded cylindrical shells in thermal environment, Composite Structures, 94 (9) (2012), pp. 2971-2981
20 X. Song, J. Zhai, Y. Chen, Q. Han, Traveling wave analysis of rotating cross-ply laminated cylindrical shells with arbitrary boundary conditions via Rayleigh–Ritz method, Composite Structures, 133 (2015), pp. 1101-1115
21 Ö. Civalek, Discrete singular convolution method for the free vibration analysis of rotating shells with different material properties, Composite Structures, 160 (2017), pp. 267-279
29 T. Ye, G. Jin, S. Gao, Three-dimensional hygrothermal vibration of multilayered cylindrical shells, Composite Structures, 201 (2018), pp. 867-881
36 W. Zhang, S.W. Yang, J.J. Mao, Nonlinear radial breathing vibrations of CFRP laminated cylindrical shell with non-normal boundary conditions subjected to axial pressure and radial line load at two ends, Composite Structures, 190 (2018), pp. 52-78
ABSTRACT: The paper is devoted to generalization of the analytical model of sandwich structures. The individual nonlinear theory of deformation of the straight line normal to the neutral surface is developed. This analytical model of sandwich structures is presented in detail for the example rectangular plate. Based on the principle of stationary potential energy two differential equations of equilibrium of the plate are obtained. The maximum deflection and critical loads of the example plates are analytically solved. The results of the studies of bending and buckling problems of rectangular plates”, Composite Structures, Vol. 255 Article 112944, 1 January 2021, https://doi.org/10.1016/j.compstruct.2020.112944

REFERENCES listed at the end of the paper:


ABSTRACT: The paper is devoted to generalization of the analytical model of sandwich structures. The individual nonlinear theory of deformation of the straight line normal to the neutral surface is developed. This analytical model of sandwich structures is presented in detail for the example rectangular plate. Based on the principle of stationary potential energy two differential equations of equilibrium of the plate are obtained. The system of equations is analytically solved. The maximum deflection and critical loads of the example plates are derived. Results of these analytical studies are presented in Figures and Tables.

References listed at the end of the paper:
A. Boussoula, B. Boucham, M. Bourada, A. Tounsi, A. Bousahla, A. Tounsi, A simple nth-order shear deformation theory for thermomechanical bending analysis of different configurations of FG sandwich plates, Smart Struct Syst, 25 (2) (2020), pp. 197-218

Magnucki K, Lewinski J, Magnucka-Blandz E., An improved shear deformation theory for bending beams with symmetrically varying mechanical properties in the depth direction. Acta Mech 2020 (Published online: 03 August).

ABSTRACT: Cellular solids, as a class of materials, are known for a high strength to weight ratio. Their design into non-stochastic configurations is known to be beneficial for the tailor and control of their mechanical properties. The current developments on additive manufacturing allow a successful route to manufacture these scaffolds and gives a novel freedom in their design process. This study explores the deformation behavior of axisymmetric non-stochastic cellular solids, allowing the understanding of the mechanisms that enhance their mechanical properties relatively to regular extruded lattices. It is shown that axisymmetric samples display a circumferential deformation effect that distributed loads along the volume of the material. This effect, however, is more prominent in axisymmetric samples with auxetic behavior. The coupling of circumferential deformation and the dynamic density changes in auxetic samples generate an overall increase in modulus, collapse stress and energy absorption.

ABSTRACT: Variable stiffness composite (VSC) is a viable design extension of carbon fiber reinforced plastic (CFRP) laminates to obtain unique mechanical properties by changing the fiber orientation in a curvilinear manner. We optimized a VSC for open-hole tension laminates considering the automatic processing by the tow prepreg curve placement and evaluated the strength improvement with experiments. Multi-objective optimization using fracture criterion and mean curvature as objective functions resulted in higher strength gains for solutions with higher mean curvature and lower processability. Besides, by giving the molding conditions as constraints for optimization, the strength was improved while satisfying the molding conditions. The fabrication of optimum VSCs involved using a tabletop automated fiber placement. Strength tests showed a 34.3% improvement in the curvilinear prepreg path.

ABSTRACT: This paper focuses on strengthening carbon fiber composite honeycombs which provide the higher strength than other competitive lightweight materials by the design of curved wall topology. And the carbon fiber composite curved honeycombs (CCCHs) are manufactured via a molding and bonding process. The out-of-plane compressive properties of the woven and unidirectional laminated CCCHs are measured and analyzed. In addition, the effects of curvature radius and wall thickness on the compressive strength of the laminated CCCHs are investigated. The experimental results show that the out-of-plane compressive strengths increase when only the curvature radius decreases or the wall thickness increases. By comparison, the out-of-plane compressive strengths of the laminated CCCHs show superior to those of almost existing competitive lightweight honeycombs, and it can be considered as a selective lightweight sandwich structure. It provides a possibility for the honeycomb structure to be used as load-bearing components.

ABSTRACT: Advanced composite laminated cylindrical shells are increasingly being desired in modern aerospace structures, for improving their structural efficiency and performance. In this paper, compared with the previous failure analysis, which considered buckling-failure only, a competitive failure analysis framework for
composite laminated cylindrical shells is presented, in which linear buckling interacting curve method was considered for buckling-failure analysis and strength ratio based on Tsai-Wu failure criterion was used for stress-failure analysis. The proposed framework agreed well with the published data, which verified it’s feasibility. The competitive failure analysis of composite laminated cylindrical shells and parametric studies were conducted to reveal the failure mode. It is found that the higher ratios of longitudinal compressive strength to longitudinal modulus and shear strength to longitudinal modulus of composite materials, the more likely buckling-failure occurs; otherwise, stress-failure occurs. As the ratio of radius to thickness reduces, the possibility of occurrence of stress-failure increases. Moreover, the stress-failure for [90°/0°/90°] stacking sequence is more likely to occur than [0°/θ/0°], and 0°<θ<90°. Finally, the presented study offers a strategy to increase the load carrying capacity of the composite laminated shell under combined axial compression and torsional loads.

References listed at the end of the paper:
4 Y. Gong, L. Zhao, J. Zhang, N. Hu, An improved power law criterion for the delamination propagation with the effect of large-scale fiber bridging in composite multidirectional laminates, Compos Struct, 184 (2018), pp. 961-967
5 O. Civalek, Buckling analysis of composite panels and shells with different material properties by discrete singular convolution (DSC) method, Compos Struct, 161 (2017), pp. 93-110
7 H. Wagner, E. Petersen, R. Khakimova, C. Hühne, Buckling analysis of an imperfection-insensitive hybrid composite cylinder under axial compression—numerical simulation, destructive and non-destructive experimental testing, Compos Struct, 225 (2019), Article 111152
8 L. Friedrich, S. Loosen, K. Liang, M. Ruess, C. Bisagni, K.-U. Schröder, Stacking sequence influence on imperfection sensitivity of cylindrical composite shells under axial compression, Compos Struct, 134 (2015), pp. 750-761
9 D. Shahgholian-Ghaftarokhi, G. Rahimi, Buckling load prediction of grid-stiffened composite cylindrical shells using the vibration correlation technique, Compos Sci Technol, 167 (2018), pp. 470-481
14 H.-S. Shen, Y. Xiang, Buckling and postbuckling of anisotropic laminated cylindrical shells under combined axial compression and torsion, Compos Struct, 84 (2008), pp. 375-386
15 D.J. Wilkins, T.S. Love, Combined compression-torsion buckling tests of laminated composite cylindrical shells, J Aircraft, 12 (1975), pp. 885-889
18 C.G. Diacou, M. Sato, H. Sekine, Buckling characteristics and layup optimization of long laminated composite cylindrical shells subjected to combined loads using lattice parameters, Compos Struct, 58 (2002), pp. 423-433
20 C. Bisagni, R. Zimmermann, Buckling of axially compressed fiber composite cylindrical shells due to impulsive loading, Proceedings of European conference on spacecraft structures, materials and mechanical testing. Braunschweig, Germany (1999), pp. 557-562
21 V. Chitra, R. Priyadarsini, Dynamic buckling of composite cylindrical shells subjected to axial impulse, IJSER (2013), p. 159
24 E. Eglitis, K. Kaliņiš, O. Ozoliņš, Experimental and numerical study on buckling of axially compressed composite cylinders, Sci J Rtu, 10 (2009), pp. 33-49
25 C. Bisagni, Experimental buckling of thin composite cylinders in compression, AIAA J, 37 (1999), pp. 276-278

**ABSTRACT:** In this paper, the stress response characteristics of the hydraulic composite pipe subjected to random vibrations were studied. Based on 3D-anisotropy elasticity, the motion equation of the hydraulic composite pipe was established by utilizing the Hamilton principle subjected to random vibration, and takes into account the fluid-structure interaction (FSI). The discrete analysis method of random vibration is employed to solve the random vibration under the excitation of white noise. Also, the effects of different parameters including external excitation, fluid velocity, fluid pressure and structural parameters on the stress response of composite pipe are investigated. Experimental results agreed with the simulation results, demonstrating that the analytical method could provide theoretical reference for the design, improved efficiency, and fatigue reduction of the composite pipe subjected to random vibration.


**ABSTRACT:** This work proposes a novel quasi three-dimensional (3D) approach for the bending analysis of moderately thick plates with a functionally graded material (FGM), in presence of porosities due to some incorrect manufacturing processes. Such porosities can appear within the plate in two forms, namely, even and uneven distributions. The modeled system has a polymer matrix where both shear and transverse factors coexist. The bending equations of the problem are obtained from the Hamiltonian principle. In order to apply the quantum effects for the nanosystem, the well-known nonlocal theory of Eringen is here assumed, while checking for its numerical accuracy. A physically-consistent analysis of the nanostructures would investigate possible surrounding effects. Thus, the thermal and humidity influence is accounted for the 3D problem, whose governing equations are solved through a semi-analytical polynomial method (SAPM), as recently proposed in literature for different applications. The proposed method is based on a simple procedure with very accurate numerical outcomes, whose performance is checked against the available literature. After computing the deflection relations, a systematic study is performed for the bending response of nanoporous FGMs in a hygro-thermal surrounding environment, with promising results for practical applications.

References listed at the end of the paper:

5 M. Malikan, F. Tornabene, R. Dimitri, Nonlocal three-dimensional theory of elasticity for buckling behavior of functionally graded porous nanoplates using volume integrals, Mater Res Express, 5 (2018), Article 095006
6 R. Ansari, A. Shahabodini, M. Faghih Shojaii, Nonlocal three-dimensional theory of elasticity with application to free vibration of functionally graded nanoplates on elastic foundations, Phys E: Low-dim Syst Nanostruct, 76 (2016), pp. 70-81
Compos Part B: Eng, 152 (2018), pp. 71

Astronaut, 143 (2018), pp. 263

30 M. Malikan, M. Ghasemi-Ghalebahan, A. Soltanimaleki, R. Dimitri, F. Tornabene, Thermal vibration analysis of SMA hybrid composite double curved sandwich panels, Compos Struct, 224 (2019), Article 111035


36 M. Malikan, V.B. Nguyen, F. Tornabene, Electromagnetic forced vibrations of composite nanoplates using nonlocal strain gradient theory, Mater Res Express, 5 (2018), Article 075031

ABSTRACT: This paper presents an experimental investigation on the mechanical properties of sandwich tempered glass unidirectional composite laminate under uniformly distributed load. A total of sixty-four specimens are tested to investigate the influence of individual layer thickness of tempered glass panel ($T$), bearing length ($BL$), and length of loading end ($LLE$). According to this experiment, the failure modes of tested specimens were observed in detail during load procedure. The effects of the three variables on the ultimate bearing capacity, stiffness and stress distribution of sandwich tempered glass unidirectional composite laminate are discussed. The results indicate that the three variables have positive effect on bearing capacity and secant stiffness of the sandwich tempered glass unidirectional composite laminate. And the individual layer thickness of tempered glass panel has the greatest influence on the ultimate bearing capacity and secant stiffness of specimens. With increasing of thickness, bearing length and length of loading end, the bearing capacity and the stiffness are increased. Based on the results of parametric studies, the designed formulas are proposed to estimate the ultimate bearing capacity of sandwich tempered glass unidirectional composite laminate under local uniformly distributed load.

M.S.H. Al-Furjan (1,2), Mohammad Amin Oyarhossein (3), Mostafa Habibi (4,5), Hamed Safarpour (6), Dong Won Jung (7) and Abdelouahed Tounsi (8)
(1) School of Mechanical Engineering, Hangzhou Dianzi University, Hangzhou 310018, China
(2) School of Materials Science and Engineering, State Key Laboratory of Silicon Materials, Zhejiang University, Hangzhou 310027, China
(3) Department of Civil Engineering, University of Aveiro, Aveiro, Portugal
(4) Institute of Research and Development, Duy Tan University, Da Nang 550000, Viet Nam
(5) Faculty of Electrical–Electronic Engineering, Duy Tan University, Da Nang 550000, Viet Nam
(6) Faculty of Engineering, Department of Mechanics, Imam Khomeini International University, Qazvin, Iran
(7) School of Mechanical Engineering, Jeju National University, Jeju, Jeju-do 690-756, South Korea
(8) Material and Hydrology Laboratory, University of Sidi Bel Abbes, Faculty of Technology, Civil Engineering Department, Algeria


ABSTRACT: In this paper, wave propagation analysis of multi-hybrid nanocomposite (MHC) reinforced doubly curved panel embedded in the viscoelastic foundation is carried out. Higher-order shear deformable theory (HSDT) is utilized to express the displacement kinematics. The rule of mixture and modified Halpin–Tsai model are engaged to provide the effective material constant of the MHC reinforced doubly curved panel. By employing Hamilton’s principle, the governing equations of the structure are derived and solved with the aid of an analytical method. Afterward, a parametric study is carried out to investigate the effects of the viscoelastic foundation, carbon nanotubes’ (CNTs’) weight fraction, various MHC patterns, radius to total thickness ratio, and carbon fibers angel on the phase velocity of the MHC reinforced doubly curved panel in the viscoelastic medium. The results show that, by considering the viscous parameter, the relation between wavenumber and phase velocity changes from exponential increase to logarithmic boost. A useful suggestion of this research is that the effects of fiber angel and damping parameter on the phase velocity of a doubly curved panel are hardly dependent on the wavenumber. The presented study outputs can be used in ultrasonic inspection techniques and structural health monitoring.

References listed at the end of the paper:
1 V. Farhangi, M. Karakouzian, Effect of fiber reinforced polymer tubes filled with recycled materials and concrete on structural capacity of pile foundations, Appl Sci, 10 (2020), p. 1554
2 M.H. Ghayesh, Nonlinear vibration analysis of axially functionally graded shear-deformable tapered beams, Appl Math Model, 59 (2018), pp. 583-596
3 M.H. Ghayesh, Viscoelastic mechanics of Timoshenko functionally graded imperfect microbeams, Compos Struct, 225 (2019), Article 110974
4 M.H. Ghayesh, Subharmonic dynamics of an axially accelerating beam, Arch Appl Mech, 82 (2012), pp. 1169-1181


79 H. Moayedi, R. Darabi, A. Ghabussi, M. Habibi, L.K. Foong, Weld orientation effects on the formability of tailor welded thin steel sheets, Thin-Walled Struct, 149 (2020), Article 106669

80 A. Shariati, A. Ghabussi, M. Habibi, H. Safarpour, M. Safarpour, A. Tounsí, et al., Extremely large oscillation and nonlinear frequency of a multi-scale hybrid disk resting on nonlinear elastic foundation, Thin-Walled Struct, 154 (2020), Article 106840


85 F. Ebrahimi, A. Dabbagh, Vibration analysis of multi-scale hybrid nanocomposite plates based on a Halpin-Tsai homogenization model, Compos B Eng, 173 (2019), Article 106955


Rosa Penna, Luciano Feo, Antonio Fortunato and Raimondo Luciano, “Nonlinear free vibrations analysis of geometrically imperfect FG nano-beams based on stress-driven nonlocal elasticity with initial pretension force”, Composite Structures, Vol. 255 Article 112856, 1 January 2021,
https://doi.org/10.1016/j.compstruct.2020.112856

ABSTRACT: Size-dependent flexural nonlinear free vibrations of geometrically imperfect straight Bernoulli-Euler functionally graded nano-beams are investigated by the stress-driven nonlocal integral model (SDM). By using the Galerkin method, the governing equations is reduced to a nonlinear ordinary differential equation. The closed form analytical solution of the nonlinear natural flexural frequency for Simply-Supported, Clamped-Simply Supported and Clamped-Clamped nano-beams is then established using the Hamiltonian approach to nonlinear oscillators. Effects of nonlocal scale parameter and an initial axial tension force on fundamental frequencies are examined and compared with those obtained by Eringen’s nonlocal model. It is shown that the nonlinear approach based on nonlocal stress model, with the appropriate constitutive boundary conditions, is capable of capturing the dynamical responses of the nano-beams and provides an advantageous method for the

T. Liu (1), W. Zhang (1), M.Q. Wu (1), Y. Zheng (1) and Y.F. Zhang (2)
(1) Beijing Key Laboratory of Nonlinear Vibrations and Strength of Mechanical Structures, College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, PR China
(2) School of Aerospace Engineering, Shenyang Aerospace University, Liaoning 110136, PR China

“Metastable nonlinear vibrations: Third chaos of bistable asymmetric composite laminated square shallow shell under foundation excitation”, Composite Structures, Vol. 255 Article 112966, 1 January 2021,
https://doi.org/10.1016/j.compstruct.2020.112966

ABSTRACT: The occurrence conditions of the metastable chaotic vibrations are firstly studied in the bistable asymmetric composite laminated square shallow shell under the foundation excitation. The metastable chaos is observed in the vibration experiments of the bistable asymmetric composite laminated square shallow shell. Based on the dynamic model of the bistable asymmetric composite laminated square shallow shell, the critical instability condition of the zero equilibrium point is analyzed in the bistable asymmetric composite laminated square shallow shell by using Jacobian matrix and Routh-Hurwitz criterion. We perform numerical simulations based on Runge-Kutta algorithm and the vibration experiments. A sufficient condition is found for the existence of the metastable chaos in the bistable asymmetric composite laminated square shallow shell. It is found that the zero equilibrium point of the bistable asymmetric composite laminated square shallow shell is unstable when the parametric excitation exceeds a specific critical value. The numerical results verify the theoretical analyses of the metastable chaos. It is demonstrated that the increase of the parametric excitation leads to the easier occurrence of the metastable chaos through observing the characteristics of the nonlinear dynamic behaviors of the system. Moreover, the existence of the metastable chaotic vibrations is confirmed in the bistable asymmetric composite laminated square shallow shell under the foundation excitation by using the vibration experiments. The large parametric excitation subjecting to the bistable asymmetric composite laminated square shallow shell is a key factor for the existence of the metastable chaos in the bistable asymmetric composite laminated square shallow shell under the foundation excitation.

References listed at the end of the paper:
1 S.A. Emam, D.J. Inman, A review on bistable asymmetric composite laminates for morphing and energy harvesting, Appl Mech Rev, 67 (2015), Article 060803
2 S.A. Emam, J. Hobeck, D.J. Inman, Experimental investigation into the nonlinear dynamics of a bistable laminate, Nonlinear Dyn, 95 (2019), pp. 3019-3039
4 A.N. Souza, M. Tao, Metastable transitions in inertial Langevin systems: what can be different from the overdamped case, Eur J Appl Math (2018), pp. 1-23
7 W. Zhang, Y.Z. Liu, M.Q. Wu, Theory and experiment of nonlinear vibrations and dynamic snap-through phenomena for bi-stable asymmetric laminated composite square panels under foundation excitation, Compos Struct, 225 (2019), Article 111140
8 M.W. Hyer, Some observations on the cured shape of thin unsymmetric laminates, J Compos Mater, 15 (1981), pp. 175-194
12 K.A. Seffen, ‘Morphing’ bistable orthotropic elliptical shallow shells

ABSTRACT: A unified modeling method is proposed in this work to obtain the exact solution for dynamic analysis of carbon fiber reinforced composite (CFRC) circular arch with porous graphene platelet coating (PGPC) and general boundary conditions in hygrothermal environment. The modeling method adopts first-order shear beam theory to express the displacement field of the in-plane vibration first, and then the stress is given by using Hooke’s Law. According to the definition of classical mechanics, the energy of dynamic model is expressed in terms of stress and strain. Also, the stored energy of general boundary is introduced by the virtual boundary springs technology. Furthermore, the hygrothermal environment is also considered in this work, and the effects of the hygrothermal environment are given in details. Finally, the stability and effectiveness of the proposed method are validated, and the dynamic response of the CFRC-PGPC circular arche with different parameters, such as geometry, material and environment variables are calculated.


ABSTRACT: This study presents a semi-analytical solution of nonlinear vibrations of circular cylindrical shells made of carbon nanotube (CNT) fiber-reinforced composite (CNT-FRC). Vibrations are produced by a radial harmonic force and viscous structural damping is considered. The effective properties of a lamina of the CNT-FRC shell are evaluated in two steps. The elastic properties of randomly distributed CNTs in a polymeric matrix (i.e., hybrid matrix) are computed by the Eshelby-Mori-Tanaka/Voigt scheme to consider the CNTs agglomeration effect in the hybrid matrix. Then, the resulting hybrid matrix is reinforced with aligned fibers in order to prepare the lamina of the CNT-FRC shell; its effective properties are estimated by the Halpin Tsai homogenization approach. The CNT-FRC shell is modelled incorporating the von Kármán geometric nonlinearity and first-order shear deformation theory (FSDT). The nonlinear governing partial differential equations (PDEs) of the CNT-FRC shells are derived by the Hamilton’s principle. These PDEs are discretized into ordinary differential equations (ODEs) by using the Galerkin’s method. The ODEs are solved by incremental harmonic balance method (IHB) in conjunction with the arclength continuation method to obtain the frequency-amplitude response of the shell. The effect of different types of CNT agglomeration models, CNT mass fraction, agglomeration parameters and stacking sequence of laminates on the frequency-amplitude curves corresponding to forced and free nonlinear vibrations of the CNT-FRC shell are studied in detail.

References listed at the end of the paper:
ABSTRACT: Part I [1] of this two-part paper presented the formulation of a novel progressive failure model for pultruded fibre reinforced polymer (FRP) composites, allowing for the 3D simulation of quasi-orthotropic FRP plates as a homogenized material, as well as the model calibration based on a set of standardized material characterization tests. Part II presents the application of that (calibrated) model to the simulation of two case
studies: (i) transverse compact tensile (CT) tests; and (ii) web-crippling tests for two load configurations, external two-flanges (ETF) and internal two-flanges (ITF). The CT test, which is often used to determine the (tensile) fracture energy of FRP materials, is especially interesting as it allows assessing the quality of the simulations for a combination of in-plane transverse tensile and shear stresses in a geometry with a sharp singularity. The web-crippling test, on the other hand, is often used to determine the strength of FRP shapes under concentrated transverse loads, a real structural problem involving combined in-plane compressive and shear stresses. In this paper these two relatively complex case studies are used to assess the quality of the simulation in the presence of combined in-plane stresses. The numerical results showed an excellent agreement with their CT test counterparts; the simulation of these experiments were also used to demonstrate the need for using a mesh regularization scheme when modelling problems with singularities. The models were also well able to simulate both web-crippling load configurations, only slightly underestimating the maximum load – this was likely due to the slight underestimation of shear strength for combined in-plane shear and moderate transverse compressive stresses, as discussed in Part I [1], and/or non-quasi-orthotropic behaviour of the web-flange junction. Overall, the numerical results showed a good agreement with the experimental data, even for relatively coarse meshes, attesting the feasibility and precision of the proposed damage progression model.


ABSTRACT: The present paper addresses the development of bio-inspired composite laminates based on the Fibonacci sequence for impact resistant applications. Four methods such as thickness ratio (FT), incremental angle (FI), hybrid (FY) and Fibonacci helicoidal (FH) are devised to create various sets of laminates to exploit the Fibonacci sequence into the laminate design. These methods include controlling of ply group thickness (FT), rotation fiber angle (FI), both thickness and angle (FY), and direct implementation of Fibonacci based helicoidal laminate sequence (FH). The performance of these proposed laminates is analysed by considering ballistic impact loading with six different impact velocities, out of which three are below the ballistic limit of laminates. The behaviour of these laminates under this loading is investigated using an elastic-plastic progressive damage based numerical model. The results obtained through numerical simulation are validated with experimental results and found to be well correlated. The performance of bio-inspired laminates is compared with conventional cross-ply and quasi-isotropic laminates in terms of various parameters such as residual velocity, displacement, energy absorption, peak load, number of plies damaged and delamination. These parameters are correlated by using a level-based methodology and the most versatile method to design Fibonacci based bio-inspired laminates among all methods considered is estimated for all velocities.


ABSTRACT: The free vibration analysis of functionally graded carbon nanotube reinforced composite (FG-CNTRC) conical shell is carried out by using element-free kp-Ritz method. Based on the first-order shear deformation shell theory, the approximate displacement field is expressed by the shape function of the nuclear particle, and the governing equation is established. The material properties of conical shell plates are determined by rule of mixtures and change with the thickness. In this work, the convergence is studied in terms of the number of nodes, and the accuracy of the proposed method is verified by comparing the current solution with the solution in the literature from different aspects. The effects of volume fraction, boundary conditions, distribution patterns of CNTs, half vertex angle and radius thickness ratio on their free vibration frequency characteristics are discussed in detail.

References listed at the end of the paper:
2 J. Yang, R. Xu, H. Hu, Q. Huang, W. Huang, Structural-Genome-Driven computing for composite structures, Compos Struct, 215 (2019), pp. 446-453
3 H. Hu, S. Belouettar, M. Potier-Ferry, A. Makradi, A novel finite element for global and local buckling analysis of sandwich beams, Compos Struct, 90 (2009), pp. 270-278
4 S.C. Xie, K.K. Jing, H. Zhou, X. Liu, Mechanical properties of Nomex honeycomb sandwich panels under dynamic impact, Compos Struct, 235 (2020), Article 111814
5 X. Liu, Spectral dynamic stiffness formulation for inplane modal analysis of composite plate assemblies and prismatic solids with arbitrary classical/nonclassical boundary conditions, Compos Struct, 158 (2016), pp. 262-280


10 X. Liu, H.I. Kassem, J.R. Banerjee, An exact spectral dynamic stiffness theory for composite plate-like structures with arbitrary non-uniform elastic supports, mass attachments and coupling constraints, Compos Struct, 142 (2016), pp. 140-154

11 X. Liu, C. Xie, H.C. Dan, Exact free vibration analysis for plate built-up structures under comprehensive combinations of boundary conditions, Shock Vib, 530592 (2020), pp. 1-21

12 X. Liu, X. Zhao, C. Xie, Exact free vibration analysis for membrane assemblies with general classical boundary conditions, J Sound Vib (2020)


16 Z.X. Lei, L.W. Zhang, K.M. Liew, Analysis of laminated CNT reinforced functionally graded plates using the element-free kp-Ritz method, Compos B Eng, 84 (2016), pp. 211-221


21 Z.G. Song, L.W. Zhang, K.M. Liew, Aeroelastic analysis of CNT reinforced functionally graded composite panels in supersonic airflow using a higher-order shear deformation theory, Compos Struct, 141 (2016), pp. 79-90


30 K.M. Liew, T.Y. Ng, X. Zhao, Free vibration analysis of conical shells via the element-free kp-Ritz method, J Sound Vib, 281 (2005), pp. 627-645


32 J.E. Jam, Y. Kiani, Buckling of pressurized functionally graded carbon nanotube reinforced conical shells, Compos Struct, 125 (2015), pp. 586-595


Wei Xian (1,2), Wensu Chen (2), Hong Hao (2), Wen-Da Wang (1) and Rui Wang (3)  
(1) School of Civil Engineering, Lanzhou University of Technology, Lanzhou 730050, PR China  
(2) Center for Infrastructural Monitoring and Protection, School of Civil and Mechanical Engineering, Curtin University, Australia  
(3) School of Civil Engineering, Taiyuan University of Technology, Taiyuan 030024, PR China  
“Investigation on the lateral impact responses of circular concrete-filled double-tube (CFDT) members”,  
Composite Structures, Vol. 255 Article 112993, 1 January 2021,  
https://doi.org/10.1016/j.compstruct.2020.112993

ABSTRACT: To meet specific design requirements or achieve superior structural performances, a new type of concrete-filled steel tubular (CFST) composite structure called as concrete-filled double-tube (CFDT) was proposed in recent years. Despite intensive studies on structural performances of CFDT members under various loading conditions, very limited investigations on impact responses of CFDT members can be found in literature. During the service life structural members may be subjected to extreme loads such as impact load, therefore the investigation on impact responses of CFDT members is essential for impact resistant design and assessment. This paper presents experimental study and finite element analysis (FEA) results of lateral impact responses of circular CFDT members. A total of twelve circular CFDT specimens with various parameters are tested by utilizing a drop hammer impact system. The damage modes, impact forces, displacement responses and energy absorption capacities of CFDT members from the impact tests are evaluated and compared, followed by numerical simulations using explicit software ABAQUS. With the verified numerical models, the damage evolution of each component and its contribution to impact loading resistance are extracted and analysed. In addition, the performances of CFDT and common CFST members under impact loading are compared.

References listed at the end of the paper:
1 L.H. Han, W. Li, R. Bjorhovde, Developments and advanced applications of concrete-filled steel tubular (CFST) structures: Members, J Constr Steel Res, 100 (2014), pp. 211-228
2 L.H. Han, G.H. Yao, Z. Tao, Performance of concrete-filled thin-walled steel tubes under pure torsion, Thin-Walled Struct, 45 (2007), pp. 24-36,
47 D. Saini, B. Shafiei, Investigation of concrete-filled steel tube beams strengthened with CFRP against impact loads, Compos Struct, 208 (2019), pp. 744-757
51 R. Wang, L.H. Han, X.L. Zhao, K.J.R. Rasmussen, Analytical behavior of concrete filled double steel tubular (CFDST) members under lateral impact, Thin-Walled Struct, 101 (2016), pp. 129-140
52 W. Li, Y.Z. Gu, L.H. Han, X.L. Zhao, R. Wang, M. Nassirnia, et al., Behaviour of ultra-high strength steel hollow tubes subjected to low velocity lateral impact: Experiment and finite element analysis, Thin-Walled Struct, 134 (2019), pp. 524-536


ABSTRACT: The present investigation deals with the size-dependent analysis of the geometrically nonlinear vibration response of micro/nano-plates with and without a central cutout made of a porous functionally graded material (PFGM) in the presence of nonlocality and strain gradient size dependencies. In accordance with this purpose, a modified porosity-dependent power-law function is put to use to estimate the effective mechanical properties of PFGM micro/nano-plates with various porosity distribution patterns. To solve the constructed nonlinear nonlocal strain gradient problem, the non-uniform rational B-spline (NURBS)-based isogeometric analysis is utilized as an efficient discretization technique having the capability to satisfy C1+ continuity. It is seen that for specific values of the material property gradient index, porosity index and the plate deflection, the enhancement in the nonlinear frequency due to the strain gradient size effect is more than the reduction caused by the nonlocality. Furthermore, it is found that there is a specific value of the length to thickness ratio, corresponding to which the nonlocal strain gradient frequency ratio becomes minimum. This minimum value enhances by increasing the value of the porosity index of PFGM micro/nano-plates. Also, by increasing the value of the material property gradient index, the minimum point of the nonlocal strain gradient frequency ratio shifts to a higher ratio of the length to width ratio.

References listed at the end of the paper:
1 J. Parthasarathy, B. Starly, S. Raman, A design for the additive manufacture of functionally graded porous structures with tailored mechanical properties for biomedical applications, J Manuf Processes, 13 (2011), pp. 160-170
4 C. Han, Y. Li, Q. Wang, S. Wen, Q. Wei, C. Yan, et al., Continuous functionally graded porous titanium scaffolds manufactured by selective laser melting for bone implants, J Mech Behav Biomed Mater, 80 (2018), pp. 119-127
7 K.C. Opiela, T.G. Zielinski, Microstructural design, manufacturing and dual-scale modelling of an adaptable porous composite sound absorber, Compos B Eng, 187 (2020), Article 107833
8. L. Yang, C. Han, H. Wu, L. Hao, Q. Wei, C. Yan, et al., Insights into unit cell size effect on mechanical responses and energy absorption capability of titanium graded porous structures manufactured by laser powder bed fusion, J Mech Behav Biomed Mater, 109 (2020), Article 103843.


ABSTRACT: This paper presents the combination of multiple scale method and modal analysis in order to investigate nonlinear vibration of laminated composite angle-ply cylindrical and conical shells. The shells are modeled considering the shear deformation and rotary inertia while the geometrical nonlinearity is modeled using von Karman approach. Hamilton principle is used for obtaining the basic equations of the system. These equations are converted to nonlinear ordinary differential equations depending on time variable using Ritz method. The results of this study are validated against the results of open literature and good agreement is observed. The effects of several parameters including the layers' angle, the number of the layers, semi-vertex angle, length, radius and also each layer's thickness on nonlinear frequency ratio, fundamental linear frequency and nonlinear frequency are illustrated in details.

References listed at the end of the paper:
4 Ç. Demir, Ö. Civelek, A new nonlocal FEM via Hermitian cubic shape functions for thermal vibration of nano beams surrounded by an elastic matrix, Compos Struct, 168 (2017), pp. 872-884
12 A.H. Sofiyev, N. Kuruoglu, Buckling and vibration of shear deformable functionally graded orthotropic cylindrical shells under external pressures, Thin-Walled Structures, 78 (2014), pp. 121-130
16 H. Lin, D. Cao, C. Shao, An admissible function for vibration and flutter studies of FG cylindrical shells with arbitrary edge conditions using characteristic orthogonal polynomials, Compos Struct, 185 (2018), pp. 748-763
17 J. Zhao, K. Choe, Y. Zhang, A. Wang, C. Lin, Q. Wang, A closed form solution for free vibration of orthotropic circular cylindrical shells with general boundary conditions, Compos B Eng, 159 (2019), pp. 447-460
18 A.H. Sofiyev, D. Hui, On the vibration and stability of FGM cylindrical shells under external pressures with mixed boundary conditions by using FOSDT, Thin-Walled Structures, 134 (2019), pp. 419-427

ABSTRACT: The static/dynamic compressive performances of sandwich panels with density gradient lattice core were investigated by experimental and numerical methods. A three-layer stainless steel lattice sandwich panel was proposed, and the density gradient between core layers of the sandwich panels was achieved by varying the cross-sectional dimensions of truss bar of each layer. A large diameter Hopkinson pressure bar device was employed to carried out the dynamic impact experiment. The three-dimension finite element method was used to investigate the effects of gradient scheme of core layers and the impact velocity on the structural response. The results reveal that, there exists different failure mechanism between non-gradient lattice sandwich panels and gradient lattice sandwich panels, and the ABC gradient configuration is optimal due to its higher impact strength and better energy absorption capacity at a higher impact velocity which can buckle the truss bars of all layers of gradient lattice sandwich panel.

References listed at the end of the paper:

1 Q.H. Qin, T.J. Wang, S.Z. Zhao, Large deflections of metallic sandwich and monolithic beams under locally impulsive loading, Int J Mech Sci, 51 (11–12) (2009), pp. 752-773
7 J. Liu, J. Liu, J. Mei, et al., Investigation on manufacturing and mechanical behavior of all-composite sandwich structure with Y-shaped cores, Compos Sci Technol, 159 (2018), pp. 87-102
8 J. Mei, J. Liu, J. Liu, A novel fabrication method and mechanical behavior of all-composite tetrahedral truss core sandwich panel, Compos A Appl Sci Manuf, 102 (2017), pp. 28-39
ABSTRACT: Improved buckling analysis of stiffened laminated composite plates under axial compressive loads are conducted using spline finite strip method. The stiffened laminated composite plates are modeled as beam-plate structures, where the base plate and the stiffeners are formulated based on the respective first-order shear deformation theory and thin-walled composite beam theory. The eccentricity and torsional rigidity of stiffeners are taken into account, and the beam displacements are expressed by those of plate middle surface according to the compatibility condition between the base plate and stiffeners. The present model is capable of capturing both global and local buckling of stiffened laminated composite plates with stiffeners of any kind of cross-sections, and it is extended to analysis of transversely- and orthogonally-stiffened laminated plates through modification of spline interpolations. The validity of developed buckling analysis is verified by comparisons with the existing solutions and numerical finite element results, while parametric studies are conducted to demonstrate its effectiveness and capabilities in analyzing buckling behavior of stiffened laminated composite plates.

References listed at the end of the paper:

6 M. Madhavan, J.S. Davidson, Buckling of centerline-stiffened plates subjected to uniaxial eccentric compression, Thin-Walled Struct, 43 (8) (2005), pp. 1264-1276


ABSTRACT: Improved buckling analysis of stiffened laminated composite plates under axial compressive loads are conducted using spline finite strip method. The stiffened laminated composite plates are modeled as beam-plate structures, where the base plate and the stiffeners are formulated based on the respective first-order shear deformation theory and thin-walled composite beam theory. The eccentricity and torsional rigidity of stiffeners are taken into account, and the beam displacements are expressed by those of plate middle surface according to the compatibility condition between the base plate and stiffeners. The present model is capable of capturing both global and local buckling of stiffened laminated composite plates with stiffeners of any kind of cross-sections, and it is extended to analysis of transversely- and orthogonally-stiffened laminated plates through modification of spline interpolations. The validity of developed buckling analysis is verified by comparisons with the existing solutions and numerical finite element results, while parametric studies are conducted to demonstrate its effectiveness and capabilities in analyzing buckling behavior of stiffened laminated composite plates.
7 E. Jaberzadeh, M. Azhari, Elastic and inelastic local buckling of stiffened plates subjected to non-uniform compression using the Galerkin method, Appl Math Model, 33 (4) (2009), pp. 1874-1885
8 C. Mittelstedt, M. Beerkorsh, Closed-form buckling analysis of compressively loaded composite plates braced by omega-stringers, Compos Struct, 88 (3) (2009), pp. 424-435
9 C. Mittelstedt, K.-U. Schröder, Local postbuckling of hat-stringer-stiffened composite laminated plates under transverse compression, Compos Struct, 92 (12) (2010), pp. 2830-2844
10 L. Shan, P. Qiao, Explicit local buckling analysis of rotationally restrained composite plates under uniaxial compression, Eng Struct, 30 (1) (2008), pp. 126-140
20 Y.V. Satish Kumar, M. Mukhopadhyay, A new finite element for buckling analysis of laminated stiffened plates, Compos Struct, 46 (4) (1999), pp. 321-331
22 O.K. Bedair, The elastic behaviour of multi-stiffened plates under uniform compression, Thin-Walled Struct, 27 (4) (1997), pp. 311-335


ABSTRACT: The dynamic behavior of radially functionally graded tubes is studied when subjected to axial tensile and compressive forces. Differing from the Euler–Bernoulli/Timoshenko beam theories, a higher-order shear beam deformation model that does neither require a shear correction factor nor need a planar cross-section assumption after deformation. The cross-section’s warping is constructed to meet the shear-free condition on tube’s inner and outer surfaces. A governing partial differential equation is derived. Exact characteristic equations for determining the natural frequencies are given. For typical end supports including hinged-hinged, clamped-clamped, clamped-free, and clamped-hinged ends, the natural frequencies are calculated. By letting the frequency vanish, the critical buckling loads under compression can be exactly determined by solving the
characteristic equation. A comparison of the present buckling loads and the natural frequencies with the classical ones and with finite element results is made and verifies the efficiency of the proposed model. The frequency-load interaction is plotted for typical boundary conditions. Axial tensile force causes the natural frequencies to increase and axial compressive force decreases the natural frequencies. The effects of the radial gradient, tube’s thickness and length, and the cross-sectional warping shape on the buckling loads and the natural frequencies are elucidated.

References listed at the end of the paper:
1 S.P. Timoshenko, J.M. Gere, Theory of elastic stability, Courier Corporation (1963)
8 X.F. Li, A unified approach for analyzing static and dynamic behaviors of functionally graded Timoshenko and Euler-Bernoulli beams, J Sound Vib, 318 (4–5) (2008), pp. 1210–1229
10 S.-R. Li, R.C. Batra, Relations between buckling loads of functionally graded Timoshenko and homogeneous Euler-Bernoulli beams, Compos Struct, 95 (2013), pp. 5–9
12 M. Simšek, Buckling of Timoshenko beams composed of two-dimensional functionally graded material 2D-FGM having different boundary conditions, Compos Struct, 149 (2016), pp. 304–314
13 J. Zhang, L. Chen, Y. Lv, Elastoplastic thermal buckling of functionally graded material beams, Compos Struct, 224 (2019), 111014
16 H.-C. Li, L.-L. Ke, J. Yang, S. Kitipornchai, Y.-S. Wang, Free vibration of variable thickness FGM beam submerged in fluid, Compos Struct, 233 (2020), 115182

ABSTRACT: A full understanding of the mechanical behaviors of a three-dimensional (3D) functionally graded carbon nanotube reinforced composite (FG-CNTRC) cylindrical panel is important for structural design of engineering composite components. In this paper, the buckling and free vibration studies of FG-CNTRC cylindrical panel with different patterns of CNT distribution are investigated using the three-dimensional theory of elasticity. The cylindrical panels are subjected to axial and circumferential initial stresses, which frequently occur in real engine structures. The state space technique along the radial direction and the Fourier series expansion along the in-plane coordinate (are) employed to formulate the problem and solve it analytically. A parametric study is carried out to examine the effects of the CNT distribution pattern, CNT volume fraction, length to mid radius ratio, and mid radius to thickness ratio on the buckling and vibration behaviors of FG-CNTRC cylindrical panels. Some interesting findings are observed, which may help design the CNTRC cylindrical panel structures. Besides, the presented studies may serve as benchmarks for researchers to check the validity of their future research works.


ABSTRACT: Functionally graded porous (FGP) plates have been introduced as modern structural members which open a new window to optimal and functional designs. Despite the need to study the effect of graded porosity on the mechanical behavior of FGP plates, it is necessary to consider the very extensive and valuable literature in plate field, presenting remarkable closed-form solutions. Hence, this paper aims to answer where is possible to implement the available exact solutions for the analysis of FGP plates. The special distinction of FGP plates, graded porosity, is reflected in their stiffnesses and moments of inertia coefficients. Here 12 different functionalities of porosity distribution along the thickness are considered and a set of explicit formulations for evaluating these coefficients are presented to be substituted in already provided analytical solutions. Many examples including bending and free vibration of thin and thick FGP plates are exhibited and
the influence of the type of porosity distribution is discussed in details. This work can be considered as a guideline for designers to evaluate the effect of graded porosity based on the cornerstone of the huge number of solutions in the precious literature of plate theories.

ABSTRACT: With attributes such as high stiffness, high damping and lightweight, laser-welded corrugated-core (LASCOR) sandwich panels with polyurea-metal laminate (PML) face sheets were envisioned as multifunctional sandwich constructions to meet the growing needs of loading bearing and vibration/noise suppression. The sensitivity of vibration damping characteristics of these novel sandwich panels was systematically investigated using a combined finite element-modal strain energy (FE-MSE) method, and their superiority over monolithic panels having equal mass was highlighted. Subsequently, the fidelity of using the surrogate modeling technique to approximate the damping loss factor of the sandwich panel was analyzed. Under the principles of cross-validation, the orthogonal polynomial model was found to provide the most accurate predictions among four widely used surrogate models. A high-efficiency optimization procedure factoring structural stiffness, damping loss, and weight of the sandwich panel was proposed by coupling the surrogate model and an optimization algorithm. For single-objective optimization, the total weight of the optimal sandwich panel decreased by around 7% compared with that of preliminary design. Meanwhile, the Pareto fronts obtained from multi-objective optimizations revealed significant enhancements of both damping loss factor/structural stiffness and specific damping loss factor/structural stiffness.

ABSTRACT: The emergence of automated manufacturing techniques has allowed the realization of the so-called tow-steered composite laminates, in which the fibers are deposited following continuous curvilinear paths. This enables to broaden the design space to satisfy a variety of design objectives. Previous studies have shown that conventional composites can be designed to maximize the modal frequencies and modal damping factors. However, similar investigations have not been devoted to tow-steered composites so far. In this context, the objective of this paper is to investigate the use of multi-objective optimization aiming at simultaneously maximizing the fundamental modal frequency and corresponding specific damping capacity of tow-steered composite laminates. The fiber trajectories are parameterized using two different schemes, and the parameters are taken as design variables. The equations of motion are derived from the combination of the Classical Lamination Theory with the Rayleigh–Ritz method. Damping is modeled by using the Strain Energy Method. Numerical optimization is performed using the evolutionary Direct Multisearch method, which provides optimal solutions forming Pareto fronts. Results obtained from various scenarios, including fully and partially steered laminates, and different boundary conditions, show that fiber steering can indeed improve substantially the dynamic characteristics, including damping, of composite laminates.

ABSTRACT: An analytical solution is obtained for the 3D static deflection of variable stiffness composite beams subject to non-uniformly distributed loads. Governing differential equations with variable coefficients, reflecting the spatially variable stiffness properties, are presented in which four degrees of freedom are fully coupled. The general analytical solution in integral form is derived and closed-form expressions obtained using series expansion approximations. The static deflection of a number of variable stiffness composite beams that can be made by fibre steering are considered with various stacking sequences. The results obtained from the proposed method are validated against numerical results from the Chebyshev collocation method and excellent agreement is observed between the two. While the proposed methodology is applicable for variable stiffness composite beams with arbitrary span-wise variation of properties, it is also an efficient approach for capturing
the complicated 3D static deflection of variable stiffness composite beams subject to non-uniformly distributed
loads.


ABSTRACT: In recent years, composite materials have gained popularity in numerous high-tech and engineering applications, owing to their outstanding physico-mechanical properties. They were initially used as fairings/reinforcements for different structures, but their application has recently shifted from general-purpose structures to primary and secondary load-bearing structures, where structural failures would result in catastrophic safety repercussions. This increased scope of application has prompted the introduction of composite structures featuring significant thickness and complexity. As such, the application of nondestructive testing and evaluation (NDT&E) to localize and characterize flaws in these materials at their incipient initiations could save resources, eliminate unplanned breakdown, and provide a timely window for repair-maintenance activities. Therefore, this paper critically reviews the recent advances in NDT&E as applied to the inspection of thick composite parts and sandwich structures (composites with a thickness ≥15 mm) and determines possible research prospects to address the limitations of the current technologies. A brief overview of defects/damage occurring in composite structures is provided followed by the main NDT&E techniques used to detect these flaws. Since there are many NDT&E techniques available, this work limits its scope on techniques that focus on the detection, localization, and characterization of flaws in thick composites and sandwich structures.


ABSTRACT: In this paper, an analytical integration Legendre polynomial approach (AILPA) is proposed to investigate the guided thermoelastic wave in functionally graded material (FGM) plates in the context of the fractional order Lord-Shulman (LS) thermoelastic theory. Coupled wave equations and fractional order heat conduction equation are solved by the presented approach, which proposes the analytical integral instead of numerical integration in the available conventional Legendre polynomial approach (CLPA). Comparison of the CPU time between two approaches indicates the higher efficiency of the presented approach. Furthermore, a new treatment of the adiabatic boundary condition for the Legendre polynomial is developed, other than the CLPA can only deal with the isothermal boundary condition. Finally, the phase velocity dispersion curves, attenuation curves, the displacement and temperature distributions for functionally graded plates with different fractional orders are analysed. Both the fractional order and relaxation time have weak influence on the elastic mode velocity, but they have considerable influence on the elastic mode attenuation.


ABSTRACT: The experimental and numerical study related to the free vibration characteristics of laminated composite plates with/without cut-out is presented in this paper. The natural frequencies are obtained from the experimental analysis using FFT analyzer. Similarly, these frequencies are also obtained from the finite element analysis employing nine-noded isoparametric plate element. The effects of aspect ratio (0.5, 1.0, 1.5 and 2.0), number of layers (8, 12 and 16), different weight fraction of fibre and epoxy (70:30, 50:50 and 40:60) and different orientations of fibres, i.e. (0/90), (45/−45), and (30/−30), on the natural frequencies of the laminated composite plates are studied for various boundary conditions. The different parameters considered for the free vibration analysis of plate with cut-out are the size of cut-out, location of cut-out, i.e. concentric/eccentric cut-out, and thickness and the ply orientation of the laminated plate. It is observed that the natural frequencies obtained from both the experimental and finite element methods for these cases are in good agreement. Moreover, the above parameters greatly influence the natural frequencies of the laminated composite plate
with/without cut-out. Further, this study will help in providing adequate knowledge and confidence to the designer for the design of laminated composite plates with sufficient accuracy.


ABSTRACT: Despite the accelerated deployment of laminated composites in a wide variety of markets due to their peculiar engineering features, the design of those materials is often restrained by the lack of cost-efficient modeling techniques. In fact, the existing strategies allowing for cheap simulations usually fail to directly capture out-of-plane through-the-thickness stresses, which prove to be typically responsible of delamination failure modes. In this paper, we introduce a fast and accurate stress recovery strategy to model the out-of-plane behavior of Kirchhoff laminated plates. The proposed technique can be regarded as a two-step approach: First, the classical composite plates theory, providing the lowest computational cost among known literature strategies, is applied to obtain a coarse displacement solution; afterwards, this solution is used to compute the necessary in-plane derivatives to recover the out-of-plane stresses directly imposing equilibrium in strong form. Since this a posteriori step relies on high-order in-plane continuity requirements, isogeometric analysis (IGA) represents a natural simulation framework given its accuracy and higher continuity properties. Both isogeometric Galerkin and collocation formulations are herein considered. The effectiveness of the proposed approach is proven by extensive numerical tests.


ABSTRACT: Due to a lack of analytical solution to the issue of dynamics of asymmetric sandwich plates with a periodic microstructure, the only available method of modelling of such structures is FEM. However, such approach is usually a time-consuming process, which additionally requires a lot of computing resources due to a highly refined mesh. In this paper the analytical model of the mentioned structure, based on the tolerance averaging technique, is presented and discussed. The obtained model can be formulated with a system of partial differential equations with constant coefficients, which is relatively simple to solve. As a result, the proposed method is convenient for engineers and accurate. Moreover, unlike the asymptotic homogenisation method, it can be used to investigate the influence of microstructure on the overall behaviour of the plate. Eventually, in the calculation example a comparative simulations were conducted to investigate the influence of certain set of assumptions on the obtained results of free vibration frequencies and to verify the effectiveness and superiority of proposed calculation method over the FEM.


ABSTRACT: In the present study, a displacement based nonlinear finite element model for functionally graded porous micro-plates is developed based on the general third-order shear deformation plate theory and the modified couple stress theory. The developed finite element model accounts for von Kármán nonlinear strains, a power-law variation of two material constituents through the plate thickness, and different distributions of porosity with a constant volume of voids on static bending of micro-plates are analyzed. The length scale dependency is captured using a single parameter of the modified couple stress theory. A power-law distribution is assumed to model the variation of the two material constituents, while the porosity distributions vary according to cosine functions. The temperature-dependent properties are obtained using a cubic-spline interpolation from experimental data. A one-dimensional steady-state heat conduction problem is solved using the effective thermal conductivity of the porous material based on the Maxwell–Eucken model to obtain temperature distribution through the plate thickness. The Newton–Raphson iteration scheme is used to solve the nonlinear system of equations. A parametric study is conducted to demonstrate the effects of material and porosity parameters, temperature and length scale dependencies, and boundary conditions on the deflections and stress distributions.

ABSTRACT: Basalt, as a fiber for reinforcing polymeric composites, is progressively emerging as an alternative to glass, given their comparable mechanical properties and the growing environmental awareness for eco-friendlier solutions in structural engineering. Given the mechanical properties variations that polymers may present depending on the application they are subjected to, experimental results are generally conducted to allow a cost-effective dimensioning of composite structures. As an alternative to these resource and time-costly experimental routines, numerical simulations have become a viable tool to predict the behavior of laminates. However, there might be a technical barrier when dealing with dynamic boundary conditions and explicit codes given the inherently intricate numerical model setups. Hence, the present study describes the calibration of essential constitutive parameters for the creation of a stacked-shell virtual laminate that faithfully reproduces the response of a cross-ply balanced basalt thermoset laminate to low-velocity impact (LVI) in a simplistic and computationally-cheap manner, validating its outcome with experiments. Knowing that most composites must be designed to endure certain environmental variations, the numerical model reproduced the behavior of the composite after accelerated ageing by high temperature and moisture exposure. The accuracy of the numerical output hereby presented was checked by a high correlation coefficient of over 97% and 94% for the force vs. time and force vs. displacement experimental curves, respectively. Furthermore, the final values of the constitutive parameters after calibration pointed out to a predominantly tensile failure in the matrix, which was corroborated by a Scanning Electron Microscopy (SEM) analysis.


ABSTRACT: This approach focuses on the acoustic characteristic of a simply supported doubly curved composite shell subjected to the Pasternak-type elastic foundation. To carry out the sound analysis of a finite shell, displacements and rotation terms and acoustic pressures are developed based on the infinite longitudinal and transversal modes. According to Hamilton's principle, the dynamic equations of the structure equipped with an elastic foundation are extracted. Subsequently, the construction is stimulated using an acoustic wave. Considering infinite modes, the necessity of terminating this process by applying a large number of modes is concerned. Therefore, in addition to the design of the convergence algorithm, some configurations against variations of dimensions and frequencies are proposed. Before presenting the numerical outcomes, the accuracy of the formulation is checked by either natural frequencies or sound transmission spectra. It is realized that although Winkler spring stiffness is impressive to improve the noise property at the low-frequency domain, the positive effects of Shear layer one are specified in the whole region. The outcomes also contain some 3D new shapes for variations of the Winkler spring and Shear layer stiffness.


ABSTRACT: Here, we formulate and study nonlinear vibrations of a thin, polar-orthotropic circular plate subjected to a circularly moving point load at a fixed radius and constant angular velocity. The governing equations and boundary conditions are obtained following Kirchhoff’s plate theory, incorporating von Kármán nonlinearity, and employing extended Hamilton’s principle. The external damping is introduced via Rayleigh dissipation function. The governing equations are solved using mode summation procedure. The mode shapes and the natural frequencies of the polar-orthotropic circular plate are found using Frobenius series method. Mode summation procedure results in coupled nonlinear ordinary differential equations. These equations are solved using the Runge–Kutta method for time response and method of harmonic balance with the arc continuation method for frequency response. The spectrum of the undamped linear vibration response of isotropic and polar-orthotropic plates exhibits natural frequencies of plates and angular velocity of the rotating load. The damped response contains the frequency of the angular velocity of the rotating load only. The nonlinear transverse vibrations of the undamped and damped plate due to rotating point load reveal frequency rich spectrums. The frequency response function shows strong modal interactions.

ABSTRACT: This paper investigates the possibility of triggering ductile modes of failure in a high-performance sandwich structure by employing a multi-core design with dispersed composite plies. Here, two sandwich configurations, based on a carbon fiber reinforced epoxy face sheet and a Nomex® honeycomb core, have been manufactured and their properties evaluated in flexure and compression. The mechanical performance of these multi-layer configurations was then compared with the properties offered by a conventional sandwich panel of similar thickness, manufactured using the same number of carbon/epoxy prepreg plies. The effect of span length on the flexural and compressive properties of the sandwich panels was investigated by performing tests on differently-sized specimens. Theoretical models have been developed to predict the mechanical properties of the sandwich panels. In both theoretical and experimental approaches, superior mechanical properties were obtained in the shorter span length samples. The deviation between the predicted and experimental results was reasonably low.


ABSTRACT: Novel pavement design and size design are important factors to improve the mechanical properties and applicability of composite structures. Based on the multi-coupling of laminates, the universal analytical conditions for multi-coupled laminates are derived. Then four types of laminates with extension-shear coupling capable of forming bending-twisting coupled structure are designed, including three types of multi-coupled laminates. The shape of laminate is no longer limited to rectangular laminate, which is considered as a variable in the design process. Through the combination of theoretical calculation and numerical simulation, the optimal design of trapezoidal laminates with multiple coupling is achieved. The effect of the multi-coupling effect on the stiffness performance has been explored for free-layer laminates, and it has been found that the introduction of the multi-coupling can greatly improve the stiffness performance of laminates. Finally, the hygro-thermal stability performance is verified by numerical simulation and the robust analysis is obtained for stiffness performance.


ABSTRACT: A rotating composite thin-walled beam structure usually works in environment with strong hygrothermal characteristics. Temperature variation and moisture absorption can influence physical properties of composite, and furthermore change mechanical behavior of the structure. Hygrothermal influences depend on composite, layup scheme, geometry and nonlinearity of the beam. However, a comprehensive analytical model including these factors is lacking. This work aims to establish such a model for rotating composite thin-walled beams subjected to hygrothermal effects so that relevant problems can be solved analytically, which can aid numerical simulation and experimental test. Many important factors including hygrothermal effects, nonlinearity, mode coupling, arbitrary layup schemes, rotation, external forces, transverse shear, non-uniformity of cross section, constrained torsion, warping, setting angle and pretwist angle are considered. Governing equations of the coupled vibration are established by using the generalized Hamiltonian principle. Reduction verification, simplification principles and reduced models are discussed. The solution of the model is illustrated and some examples are given. Finally, the influences of temperature, moisture absorption and ply angle on hygrothermal internal forces of constrained thin-walled beams with CUS and CAS configurations are analyzed.


ABSTRACT: Accurate prediction of the thermal stability and durability of composite sandwich materials used in space structures remains a challenge due to the variability of thermal related material coefficients at different
temperatures and the extensive use of adhesively bonded joint fittings. This paper presents an investigation into the thermomechanical performance of complex honeycomb core composite sandwich structures with bonded fittings exposed to extreme temperature ranges. First, detailed analyses are conducted to investigate the failure and predict the intrinsic nonlinear material properties of a specific aerospace-grade aluminum honeycomb core and carbon-epoxy composite face sheet. Sandwich panels with two types of bonded fittings are chosen to investigate nonlinear effects such as shear buckling and plastic deformation in the honeycomb core, and the progressive damage response in composite skins under different loading conditions. The nonlinear properties and modeling strategies are then incorporated in the subsequent analysis of a spacecraft’s thrust tube sandwich structure subject to cyclic thermal loading. The predicted damage and failure in the thrust tube section with an adhesively bonded cup fitting correlated with experimental observations. The current methodology offers a consistent technique for investigating the thermomechanical performance of sandwich structures with other configurations of bonded joints and fittings.


ABSTRACT: The paper presents a new modeling technique for accurately predicting the complex behavior of thin-walled open and closed section beams made of fiber-reinforced laminated composite materials. The new modeling technique is significantly computational-efficient compared to detailed finite element modeling. In this technique, the complete 3D stress analysis problem consisting of all effects and their couplings is systematically decomposed into a 2D problem applicable to the beam section, and a 1D problem applicable along the beam length. The capability of the technique is not only suitable for thin-walled beams but also applicable for modeling beams with solid, thick-walled sections as well as thin/thick-walled composite beams with in-filled materials. To analyze beams with any arbitrary cross-sectional geometry, a 2D finite element (FE) model is used for solving the 2D sectional problem, while the 1D problem for the global load response of the beams is solved by a 1D FE model utilizing the sectional stiffness parameters obtained from the 2D model. The proposed technique is validated using experimental and numerical results, which show the excellent performance of the model. New results for a range of beam sections are developed using the presented method and validated against detailed FE modeling.


ABSTRACT: This study presents an investigation on the low-velocity impact resistance of fibre metal laminates consisting of aluminium layers and a thin-ply carbon fibre reinforced polymer. A thin-ply effect is compared with fibre metal laminates consisting of conventional thickness plies. Low-velocity impact tests are conducted with impact energies ranging from 2.5 J to 30 J. The low-velocity impact behaviour of conventional and thin-ply laminates is estimated and compared by analysis of key characteristics describing impact during the impactor-laminate contact. In addition, impact damage of the laminates is analysed, focusing on the identification of dominant damage modes and locations. Results demonstrate that the use of a thin-ply carbon fibre reinforced polymer neither increases the low-velocity impact resistance of the laminates nor significantly changes their low-impact impact response as compared to the laminates with conventional ply thickness. Results demonstrate that the damage mechanism of the composite thin plies does not significantly differ from that of the conventional carbon plies. Results also confirm that the use of thin-ply fibre metal laminates is an interesting and promising materials solution.


ABSTRACT: Fiber-reinforced polymer (FRP)-steel tubed concrete (FSTC) columns have emerged as a new type of compression members. An experimental program was performed to further demonstrate the axial compressive behavior of FSTC stub columns and to clarify the confinement mechanism in such members. The test results showed that the capacities of the axially loaded FSTC specimens were enhanced with the increase of
the FRP confinement and the decrease of the steel tube’s diameter-to-thickness ($D/t$) ratio. After deducting the steel tube’s axial bearing contribution through elastic–plastic analysis, the concrete cores’ axial load–strain responses had a bilinear shape, which was very similar to the axial load–strain responses of the composite columns. Based on the comparison between steel confinement and FRP confinement, a confinement mechanism was proposed to reveal the interaction between the inner concrete core and the outer FRP-steel composite tube. It was divided into three stages: domination of steel confinement, domination of FRP-steel dual confinement, and domination of FRP confinement. The total confining pressure at the third stage could be considered as a translational motion of the FRP confining pressure, which explained why the second stiffness of the confined concrete was more sensitive to the FRP confinement stiffness than the steel confinement.


ABSTRACT: Fused Deposition Modeling (FDM), as one of the most popular 3D printing methods, has shown great potential in manufacturing customized safety components. However, the materials made by 3D printing show different mechanical properties in different directions due to the inherent anisotropic features of the printing process. In this paper, the axial crushing behavior of Nylon and Al/Nylon hybrid tubes is investigated. Quasi-static axial crushing tests are performed for single-cell and quadruple-cell tubes and energy absorption characteristics of the tubes are investigated. The nonlinear finite element code LS-DYNA is employed to simulate the tests and to further investigate the energy absorption performance of hybrid tubes with various configurations. Results show that Nylon tubes alone are not suitable for energy absorption due to the interlayer fracture during the folding, while Al/Nylon hybrid tubes can avoid the adverse effects of this fracture. The quadruple-cell Al/Nylon hybrid tubes show highly improved energy absorption efficiency. Finally, theoretical expressions are derived to predict the mean crushing forces of the Al/Nylon hybrid tubes, and the predictions compare well with experimental and numerical results.


ABSTRACT: Manufacturing and repair tasks using additive and subtractive laser processing (e.g., paint stripping and drilling) are becoming widely used in ships, aircrafts, and bridge structures. As with fire and exhaust impingement, such low level heat fluxes (<10 W) could negatively impact mechanical properties of composite structures. In this work, thermal excursions were simulated via continuous-wave laser exposure of the center region of a composite sandwich construction (i.e., E-glass fiber-reinforced vinyl ester matrix composite facesheets with a PVC foam core). Sandwich specimens were investigated with different slenderness ratios, facesheet thicknesses, foam core thicknesses and type of core materials. The 3-D temperature history response was measured with the spatially calibrated IR camera technology to map out the resulting damage state across the thickness of the specimens. The morphology of the foam core damage and interfacial debonding were postulated with the temperature profiles and evidenced by the X-ray CT images. Depending on the slenderness ratio and the volume of material heated above $T_c$, the thermally-induced damage significantly affects the edgewise compression strengths and failure modes.


ABSTRACT: We study experimentally the feasibility of using a solitary wave-based diagnostic scheme for the detection of core-skin disbonds in composite sandwich structures comprising of carbon-fiber/epoxy skins and a Nomex™ honeycomb core. Non-destructive tests are conducted using a vertically aligned granular chain of steel beads placed in direct contact with the skin of the sandwich panel containing core-skin disbonds of various sizes. The incident and reflected nonlinear pulses are recorded at a single location in the chain via an embedded piezoelectric sensor, and the effects of disbonds size and skin thickness on the delay and amplitude of the reflected solitary waves are studied. The results show that the existence of a core-skin disbond significantly increases the delay in the formation of reflected solitary waves as compared to the measurements obtained for a pristine panel, and this difference increases with decreasing skin thickness. The proposed method is capable of
detecting defects of 4.9 cm² area or larger in a sandwich panel with skins as thick as 1.2 mm, while disbonds of 1.8 or 3.1 cm² area can only be clearly identified for skin thicknesses up to 0.8 mm. The obtained results demonstrate that the solitary wave-based diagnostic scheme is effective in detecting core-skin disbonds in honeycomb composite sandwich panels, offering a reliable and cost-effective alternative to existing non-destructive test methods.


ABSTRACT: In this paper, a new sandwich beam element is introduced for analyzing sandwich beam structures with a flexible core and partially delaminated regions. In this element, interfaces between the core and face sheets are modeled by two independent layers. The model uses a high-order sandwich panel theory to consider flexibility of the core with nonlinearities associated with geometry and real contact characteristics of the delaminated regions. The proposed motion field takes advantage of both displacement and displacement gradients in the core boundaries. Therefore, the kinematics allow continuity conditions for displacements and rotations at the interfaces to be exactly satisfied in fully bounded and delamination regions. By using finite element (FE) formulation with Hermite shape functions, elemental vectors and matrices are derived in the framework of Hamilton’s principle. FE governing equations are solved by Newton-Raphson iterative scheme. A 2D FE method is also developed to verify predictions of the sandwich model for various delamination cases. Comparison studies show that results from both sandwich and 2D FE models are in a good agreement. They can predict large-deformation results for the sandwich behaviors much better than the simplified model available in the literature. A set of parametric study is devoted to provide an insight into the influence of boundary condition, number and position of delaminated regions on deformations, stresses and instability of fully clamped and cantilever sandwich beams. The developed formulation is not only more computationally efficient than 2D models usually used for such analysis, but also at the same time is accurate, simple and robust. It is also found that modeling of the delaminated zone core and stress distribution at each interface independently is crucial to accurately analyze instability behaviors of sandwich structures.


ABSTRACT: In this work, an investigation of the crush response of a simplified CFRP origami crash box subjected to axial impact is proposed. Crash boxes are thin-walled structural components of the vehicles designed to absorb energy during impact events at low-medium velocity. In particular, the crash boxes must guarantee a progressive and controlled energy absorption, avoiding peak of force (and thus acceleration) that can lead to passenger injury. In recent years, crash boxes made of carbon fibre reinforced polymer (CFRP) have found application in the automotive sector. However, their brittle failure mode leads to an irregular crushing trend characterized by peak of force. Thereafter, the crushing behaviour of the composite material structures can be improved by modifying their geometrical parameters. Among the most promising solutions, the origami structure is increasingly considered for crash boxes. The origami crash box here considered consists of four axially stacked basic structures. Each basic structure is composed of four trapezoidal faces and four triangular faces. The upper cross section is squared, whereas the lower cross section has an octagonal shape. The structural behaviour of the origami component was investigated according to different sizes of the triangular faces. The numerical models were simulated with the finite element commercial code LS-Dyna in its explicit formulation. The optimal shape of the origami structure in terms of maximum energy absorption and limited force peak was defined in LS-OPT environment. The objective function of the shape optimization algorithm was set to maximize the energy absorption, while limiting the peak of force. The optimal shape defined presented larger sizes in the top basic structures than in the bottom parts, resulting in more inclined faces. The result suggested that more inclined faces in the top part can guarantee a fracture-triggering effect in the crash box, which ensured a smaller peak force.

ABSTRACT: In this study, we propose a new IsoGeometric formulation based on Refined Zigzag Theory (RZT), abbreviated as IG-RZT, for static analysis of laminated plates and sandwich panels with curvilinear fiber paths for the first time in literature. The original RZT formulation defines constant, linear, and zigzag deformation contributions of thickness coordinate to the in-plane displacements. This kinematic relation can accurately predict in-plane displacement of composite with straight fibers. However, estimating a realistic variation of in-plane displacements in a variable angle tow (VAT) composite is a more challenging problem as compared to the straight fiber composites. This difficulty has been addressed herein by including a quartic (fourth-order) polynomial thickness expansion that includes the transverse normal strain effects to the kinematic displacement fields of RZT. Moreover, the modelling of VAT composites results in the RZT zigzag functions to depend not only on the thickness coordinate but also on the in-plane positions. The present IG-RZT methodology is free of shear-locking and shear correction factors due to the integration of RZT with Non-Uniform Rational B-Splines (NURBS) functions of isogeometric analysis. The use of NURBS functions also enable the exact geometry data to be taken directly from a computer aided design (CAD) software, e.g., Rhinoceros, into an in-house Mathematica code. The accuracy and efficiency of the present IG-RZT formulation is assessed and validated by solving various examples of curvilinear fiber laminated plates with different aspect and span-to-thickness ratios. Comparison of IG-RZT results with reference solutions available in literature and generated by a commercial software (ANSYS) using 3D finite elements have demonstrated the remarkable benefits of the proposed IG-RZT method for predicting highly accurate both displacement and stress distributions of VAT composite structures.


ABSTRACT: This paper presents an experimental investigation on the damage mechanisms and buckling behaviors of thin composite laminates under low-velocity impact and compression-after-impact (CAI) loading conditions. Barely visible impact damage was introduced into the laminates through drop-weight impact tests. The CAI tests were performed with a non-standard device in order to suppress the global buckling of plates. Three different stacking sequences were compared in this paper. A stage loading method in conjunction with ultrasonic C-scan was adopted to observe the process of delamination propagation and located the position of initial propagation. The 3D digital image correlation technique was employed to monitor the evolution of the out-of-plane displacement of the specimens. The effects of stacking sequences on delamination morphology, the compression damage propagation mode of thin laminates and the influence factors on local buckling were then discussed.


ABSTRACT: Effects of stiffener debonding defects on postbuckling responses and failure behaviors of composite stiffened panels which have extensive applications in aerospace structures attract significantly increasing attention recently. Aiming to this problem, a series of nonlinear analyses comprehensively accounting for multiple failure modes including intra- and inter-laminar damage in composite laminates, adhesive layer damage between stiffeners and skin, as well as buckling and postbuckling responses were carried out via a numerical model. This numerical model is combined with a progressive damage model and a cohesive zone model, and has been validated to be effective for predicting the postbuckling and failure responses of composite stiffened panels. Seventeen computational cases with different parameters including debonding sizes and positions which can affect buckling and postbuckling responses were conducted. It follows that debonding defects can change postbuckling deformation modes of stiffened panels and their development paths, which induce different degrees of inflection and distortion in structures, and change failure behaviors as well as the failure process of composite laminates, and further weaken the ultimate failure strength of the whole composite stiffened panels.
ABSTRACT: In the current research, nonlinear vibration and snap-buckling analysis of long cylindrical panels made of functionally graded (FG) porous materials are studied. The case of cylindrical panels with shallow curvature and long length is analyzed using an approximate nonlocal strain gradient model. Non-homogeneous properties of the cylindrical panel with uniform distributed porosities are graded across the thickness. The interaction of the cylindrical panel with a nonlinear elastic foundation is also included into the formulation. The mathematical formulations are expressed based on the high-order shear deformation theory and the Donnell kinematic assumptions. Three nonlinear motion equations of the cylindrical panel are established by employing the Hamilton principle. These coupled partial differential equations are analytically solved for the case of long cylindrical panels which is immovable pinned on both straight edges. The two-step perturbation technique and Galerkin’s method are implemented to extract the nonlinear free vibration and snap-buckling characteristics of the shell. The natural frequencies and load-deflection curves are first validated for the cases of long plates and shells. Afterwards, novel parametric studies are developed to show the effects of nonlocal and length scale parameters, power law index, porosity coefficient, foundation components, and the geometrical parameters of the shell.

ABSTRACT: The nonlinear forced response of multilayer piezoelectric cantilever microbeams reinforced by carbon nanotubes with a concentrated tip mass is investigated. The geometrically exact formulation based on the Cosserat theory of rods is employed to study large amplitude vibrations. The constitutive law of the nanocomposite layers is based on the Eshelby-Mori-Tanaka homogenization approach while the piezoelectric layers are modeled according to the standard piezoelectric constitutive formulation. The enforced inextensibility and unshearability constraints lead to a partial differential equation (PDE) governing the flexural motion of the multilayer microbeams. The obtained PDE is coupled to the ordinary differential equation for the motion of the shuttle mass. The Faedo-Galerkin approach is implemented to discretize the problem. The method of multiple scales is employed to obtain the frequency response of the system under a primary resonance base excitation. The frequency response highlights the effects of the carbon nanotubes volume fraction, tip mass, and force amplitude. An interesting result is obtained showing the feasibility of the second mode exploitation rather than the first mode for mass sensing purposes.

ABSTRACT: In this study, a simply supported conical shell with distributed piezoelectric sensor and actuator layers is considered and the shell’s vibration reduction is investigated. Four kinds of piezoelectric layer distribution which are upper circumferential, middle circumferential, lower circumferential, and longitudinal distribution are considered. The output voltage of each piezoelectric sensor patch which is proportional to the shell deformation is calculated. A PD controller is considered which magnifies sensor output voltage and applies it on the allocated piezoelectric actuator patch. By this method the amplitude of conical shell vibration reduced. The effect of a distributed sensor and actuator on the conical shell vibration is evaluated. Controller type, controller constant, sensor/actuator distributions effectiveness on the free vibration response, the frequency response is evaluated. The results show that derivative controllers can affect more on natural frequencies of conical shells and it can increase the damping of the structure. The circumferential distribution can change natural frequencies easily and it has more effects on the dynamic of the conical shell than longitudinal distribution, especially the lower circumferential distribution. The maximum voltage for the piezoelectric actuator patch is also calculated and better distribution with lower actuator voltage and higher vibration reduction is chosen.

ABSTRACT: In this study, an efficient numerical procedure is introduced to the solution of the dynamic response of functionally graded porous (FGP) beams. The elastic modulus and mass density of the porous materials are considered to have non-uniform distributions along the thickness direction. The typical open-cell metal foam is assumed to govern the material constitutive law. Within the framework of the first-order shear deformation theory (FSDT) the influence of shear strain is included in the formulations. The impact of damping is also considered. By using the canonically conjugate momentums and their derivatives, the governing canonical equations of motion of FGP beams are derived for the first time. These equations are then transformed into the Laplace space and solved numerically with the aid of the Complementary Functions Method (CFM). Obtained results are retransformed to the time domain by using an efficient inverse transform method. The dynamic response of FGP beams is studied for several boundary and loading conditions. The suggested procedure is verified with the available published literature and the finite element method. Detailed parametric studies are conducted to show the influence of porosity constants, symmetric and asymmetric porosity distributions and damping ratios on the dynamic response of FG porous beams.


ABSTRACT: Sandwich-structured composites are designed to improve through-the-thickness mechanical properties. In this paper, the effect of Z-fiber orientation on the bending behavior of sandwich-structured composites reinforced with weft-knitted spacer fabrics was studied numerically and experimentally. A new mathematical model was generated for geometry of pile yarns. Using the generated model, different orientations of Z-fibers were simulated in ABAQUS software. To investigate the effect of Z-fiber orientation, different structures of pile yarns designed using the gaiting and feeding ratio of pile yarns and layers. Composites with different Z-fiber orientations of reinforcement were fabricated. Three-point bending test was carried out on the prepared samples. The results of experimental and numerical investigations showed that the pattern of reinforcements that creates different orientations of Z-fibers with various heights and angles considerably influences the bending behavior of sandwich-structured composites. The maximum von Mises stress occurs in Z-fibers when the composites are bent in the transverse direction, but the maximum von Mises stress is created in the layers when the composites are bent in the longitudinal direction. Consequently, in the transverse direction, Z-fibers play the major role in the bending behavior of sandwich-structured composites, whereas in the longitudinal direction, the layers play the main role.


ABSTRACT: This work studies the low-velocity impact response of 3D-printed layered structures made of thermoplastic materials (PLA and PETg), which form sacrificial claddings for impact protection. The analyzed structures are composed of crushable cellular cores placed in between terminal stiffening plates. The cores tessellate either honeycomb hexagonal unit cells, or hexagonal cells with re-entrant corners, with the latter exhibiting auxetic response. The given results highlight that the examined PETg protectors exhibit higher energy dissipation ratios and lower restitution coefficients, as compared to PLA structures that have the same geometry. It is concluded that PETg qualifies as an useful material for the fabrication of effective impact protection gear through ordinary, low-cost 3D printers.


ABSTRACT: The present work deals with the dynamics properties of two kinds of multi-layered composite sandwich doubly-curved shells with two-layered viscoelastic cores based on first order shear deformation theory (FSDT). The Hamilton’s principle is adopted to deduce the equations of motion that govern the free
vibrations of the sandwich doubly-curved shells. The vibration frequencies and associated loss factors of shells are obtained by solving these equations as an eigenvalue problem based on the Navier method. Then, the validity of present solutions is confirmed comparing with those available in the published literatures. Next, the change rules of frequencies and loss factors with structural parameters are evaluated and presented graphically. New results for dynamics properties of multi-layered composite sandwich doubly-curved shells with two-layered soft cores are proposed for the first time.


ABSTRACT: This study investigates the non-linear vibrations of stiffened imperfect functionally graded double-curved shallow shells, as rested on nonlinear elastic foundations. The shells are exposed to external harmonic excitation and are placed in the thermal situations. The modeling of shells is derived according to the classical shell theory and the non-linear geometric von Kármán relationships. It is considered that the distribution of material properties changes along the thickness direction based on a power law index. The smeared stiffener technique is considered to model the stiffened shells. An approximation, according to Galerkin’s approach, is utilized to reduction of the shell governing equations into the non-linear coupled ordinary differential relations. The ODE equations are analytically solved and analyzed through the perturbation methodology for investigating the resonance behavior of shells. Simulation results are reported to examine the influences of stiffeners, initial imperfection, foundation coefficients, thermal environment, and geometrical characteristics on the non-linear primary resonance response of doubly curved shallow shells. Also, the nonlinear dynamic behaviors are analyzed by numerical methods through the bifurcation diagrams, and the nonlinear dynamical behaviors of the shell for different value of parameters are examined.

Composite Structures, Vol. 256 Article 113090, 15 January 2021,


ABSTRACT: The paper investigated the dynamic impact response and characteristics of aluminum honeycomb filled with EPP foam (Expanded polypropylene) experimentally and numerically. It was found that the initial peak strength and mean strength of the filled honeycomb were improved significantly attributable to the interaction effect between the aluminum honeycomb and the foam, but the specific energy absorption (SEA) decreased. For the filled specimens with the same foam density, the initial peak strength, mean strength and SEA increased with the increase in impact velocity. Compared with the characteristics in the static compression test, the initial peak strength in the dynamic impact test increased, whereas the mean strength and SEA decreased. The study showed that EPP foam filling was effective to improve the impact characteristics of the bare aluminum honeycomb. Numerical simulation for the dynamic impact of filled honeycombs was also explored. It accurately reproduced the deformation process and addressed the interaction between the wall and EPP foam. By comparison of the properties in different filling types, it showed the single-cell filling was a good choice to improve the load resistance while using the least filling material.

References listed at the end of the paper:
4 L. Yan, B. Yu, B. Han, C. Chen, Q. Zhang, T. Lu, Compressive strength and energy absorption of sandwich panels with aluminum foam-filled corrugated cores, Compos Sci Technol, 86 (2013), pp. 142-148
and loading conditions without any simplifying assumptions such as for strain or stress distribution in plate.

ABSTRACT: In the present research, buckling analysis of composite laminated conical shells reinforced with graphene sheets is investigated. Graphene sheets as reinforcements are distributed in each lamina. Volume fraction of graphene in each layer may be different which results in a piecewise functionally graded conical shell. First order shear deformation shell theory, Donnell kinematic assumptions and von Kármán type of geometrical non-linearity are used to establish the governing equations of the conical shell and the associated boundary conditions. The pre-buckling forces of the shell are obtained employing a membrane analysis. The linear stability equations are developed using the adjacent equilibrium criterion. These equations are discreted by means of the generalised differential quadratures across the shell length and Fourier expansion through the circumferential direction. An eigenvalue problem is obtained which yields the critical buckling pressure of the conical shell in thermal environment and the circumferential mode number at the onset of buckling. Comparison studies are provided for graphene reinforced and conventional composite laminated cylindrical shells and also isotropic conical shells with and without thermal environment. Afterwards parametric studies are given for buckling of functionally graded graphene reinforced composite laminated conical shells in thermal environment with different boundary conditions. It is shown that, temperature elevation decreases the critical buckling pressures of the conical shell significantly. Also buckling pressure of the shell may be enhanced through a piecewise functionally graded distribution of volume fraction of reinforcements.

References listed at the end of the paper:
1 H.S. Shen, Postbuckling of nanotube-reinforced composite cylindrical shells in thermal environments, Part I Axially-loaded shell, Compos Struct, 93 (2011), pp. 2096-2108
2 R. Ansari, J. Torabi, Numerical study on the buckling and vibration of functionally graded carbon nanotube-reinforced composite conical shells under axial loading, Compos B Eng, 95 (2016), pp. 196-208
3 M. Mehri, H. Asadi, Q. Wang, Buckling and vibration analysis of a pressurized CNT reinforced functionally graded truncated conical shell under an axial compression using HDQ method, Comput Meth Appl Mech Eng, 303 (2016), pp. 75-100
4 H.S. Shen, Postbuckling of nanotube-reinforced composite cylindrical shells in thermal environments, Part II Pressure-loaded shells, Compos Struct, 93 (2011), pp. 2496-2503
5 J.E. Jam, Y. Kiani, Buckling of pressurized functionally graded carbon nanotube reinforced conical shells, Compos Struct, 125 (2015), pp. 586-595
6 H.S. Shen, Thermal buckling and postbuckling behavior of functionally graded carbon nanotube-reinforced composite cylindrical shells, Compos B Eng, 43 (2012), pp. 1030-1038
10 F. Scarpa, S. Adhikari, A.S. Phani, Effective elastic mechanical properties of single layer graphene sheets, Nanotechnology, 20 (2009), Art No. 065709
13 Y.Y. Zhang, C.M. Wang, Y. Cheng, Y. Xiang, Mechanical properties of bilayer graphene sheets coupled by sp3 bonding, Carbon, 49 (2011), pp. 4511-4517

ABSTRACT: In this study the dynamic stability of viscoelastic functionally graded cylindrical shells (VEFGCSs) under an axial load with different initial conditions is investigated. Mathematical models are constructed for the problem of dynamic stability of the VEFCSs, which is characterized simultaneously by taking into account both viscoelastic and FGM features. The basic equations of VEFCSs are described by integro-differential equations using the linear viscoelasticity theory. An approach is developed to the determination of the critical times (CTs) for VEFCSs with different initial conditions. Finally, the numerical analyses are performed to demonstrate the influences of the initial conditions, the FGM profiles and the rheological parameter on the critical times for various geometric characteristics of the cylindrical shells.


Corrigendum: In the above article, published in Volume 156, pages 156–165 of Composites Part B Engineering, some typographical errors (erratum) have been identified in Eqs. (15), (16), (19)–(24) and (34), (36), (37). . .

References listed at the end of the paper:
1 S.A. Shesterikov, Criteria for the stability of beams at the moment of flow, Appl Math Mech, 23 (6) (1959), pp. 1101-1106
5 P.M. Ogibalov, V.A. Lomakin, B.P. Kishkin, Mechanics of polymers, MSU, Moscow (1975), [in Russian]
8 V.I. Matyash, Vibrations of isotropic viscoelastic shells, Mech Polymers, 1 (1971), pp. 157-163, in Russian
12 N. Miyazaki, Creep buckling analysis of circular cylindrical shell under both axial compression and internal or external pressure, Comput Struct, 28 (4) (1988), pp. 437-441
16 A.M. Zenkour, Buckling of fiber-reinforced viscoelastic composite plates using various plate theories, J Eng Math, 50 (2004), pp. 75-95
19 A. Alibeigloo, Effect of viscoelastic interface on three-dimensional static and vibration behavior of laminated composite plate, Compos B Eng, 75 (2015), pp. 17-28
25 L. Benchouaf, H. Boutyour, M. Daya, M. Potier-Ferry, Non-linear vibrations of sandwich viscoelastic shells, Compt Rendus Mec, 346 (4) (2018), pp. 308-319
This paper investigated the flexural behavior of composite sandwich beams, composed of glass fiber reinforced polymer (GFRP) skins and a polyurethane (PU) foam core with different kinds of GFRP ribs in flatwise and edgewise positions. The GFRP ribs, consisting of longitudinal, transverse and horizontal ribs, respectively, were embedded inside of the PU foam core. Twenty specimens were tested under four-point bending to verify the influence of the GFRP ribs and beam orientation on the bending stiffness.
ultimate load bearing capacity, and failure modes of sandwich beams. It was found that changing the beam orientation from flatwise to edgewise change the beam failure mode from foam core shear failure to skin compressive failure. The sandwich beam's high stiffness and ultimate load bearing capacity can be efficiently utilized by placing them in edgewise position, and the longitudinal ribs played a major role on the bending stiffness and ultimate load bearing capacity compared with the transverse and horizontal ribs in flatwise position. Furthermore, an analytical model accounting for shear and flexural rigidities was proposed to predict the deflection and ultimate load bearing capacity of composite sandwich beams with different kinds of GFRP ribs in flatwise and edgewise positions. The analytical results were agreed well with test results.

References listed at the end of the paper:
1 V. Birman, G.A. Kardomateas, Review of current trends in research and applications of sandwich structures, Compos B Eng, 142 (2018), pp. 221-240
2 A.K. Haldar, Z.W. Guan, W.J. Cantwell, Q.Y. Wang, The compressive properties of sandwich structures based on an egg-box core design, Compos B Eng, 144 (2018), pp. 143-152
4 A. Manalo, T. Aravinthan, A. Fam, B. Bennokrane, State-of-the-Art review on FRP sandwich systems for lightweight civil infrastructure, J Compos Construct, 21 (1) (2017), pp. 1-16
9 T. Sharaf, W. Shawkatand, A. Fam, Structural performance of sandwich wall panels with different foam core densities in one-way bending, J Compos Mater, 44 (19) (2010), pp. 2249-2263
12 A. Fam, T. Sharaf, Flexural performance of sandwich panels comprising polyurethane core and GFRP skins and ribs of various configurations, Compos Struct, 92 (2011), pp. 2927-2935
19 H. Mathieson, A. Fam, In-plane bending and failure mechanism of sandwich beams with GFRP skins and soft polyurethane foam core, J Compos Construct, 20 (1) (2016), pp. 1-10


ABSTRACT: This work presents a new layerwise mixed model for the static analysis of multilayered plates with embedded functionally graded material (FGM) layers subjected to transverse mechanical loads. This model is capable to fully describe a two-constituent metal-ceramic FGM layer continuous variation of material properties in the thickness direction, using any given homogenization method to estimate its effective properties. The present model is based on a mixed least-squares formulation with a layerwise variable description for displacements, transverse stresses and in-plane strains, chosen as independent variables. This mixed formulation ensures that the interlaminar Co continuity requirements at the layers interfaces, where the
material properties actually change, are fully fulfilled a priori for all independent variables. The order of the in-plane two-dimensional finite element approximations and the order of the z-expansion through each layer thickness, as well as the number of layers, whether FGM layers or not, are considered free parameters. The full description of the FGM effective properties is achieved by applying to the z-continuous elastic coefficients a z-expansion through the layer thickness of a given order, set as an added free parameter, in a similar approach to finite element approximations. The numerical results consider both single-layer and multilayered functionally graded plates with different side-to-thickness ratios, using either Mori–Tanaka or the rule of mixtures estimates for the FGM effective properties with different material gradation profiles. The present model results are assessed by comparison with three-dimensional (3D) exact solutions and closed form solutions, which demonstrate its capability to predict a highly accurate quasi-3D description of the displacements and stresses distributions altogether.

References listed at the end of the paper:
2 N.J. Pagano, S.J. Hatfield, Elastic behavior of multilayered bidirectional composites, AIAA J, 10 (1972), pp. 931-933
5 P.R. Heyliger, D.A. Saravanos, Exact free-vibration analysis of laminated plates with embedded piezoelectric layers, J Acoust Soc Am, 98 (3) (1995), pp. 1547-1557
6 E. Pan, Exact solution for functionally graded anisotropic elastic composite laminates, J Compos Mater, 37 (21) (2003), pp. 1903-1920
12 E. Carrera, Theories and finite elements for multilayered anisotropic, composite plates and shells, Arch Comput Meth Eng, 9 (2) (2002), pp. 87-140
15 D.A. Saravanos, P.R. Heyliger, Mechanics and computational models for laminated piezoelectric beams, plates and shells, Appl Mech Rev, 52 (10) (1999), pp. 305-320
18 A.M. Zenkour, Generalized shear deformation theory for bending analysis of functionally graded plates, Appl Math Model, 30 (2006), pp. 67-84
19 L.F. Qian, R.C. Batra, L.M. Chen, Static and dynamic deformations of thick functionally graded elastic plates by using higher-order shear and normal deformable plate theory and meshless local Petrov-Galerkin method, Compos B Eng, 35 (6–8) (2004), pp. 685-697
20 F. Ramirez, P.R. Heyliger, E. Pan, Static analysis of functionally graded elastic anisotropic plates using a discrete layer approach, Compos B Eng, 37 (1) (2006), pp. 10-20
25 H.-S. Shen, S.-R. Li, Postbuckling of sandwich plates with FGM face sheets and temperature-dependent properties, Compos B Eng, 39 (2) (2008), pp. 332-344

ABSTRACT: The main purpose of this paper is to illustrate the vibration characteristics of functionally graded porous (FGP) shallow shells with general boundary conditions for the first time. The general boundary condition of FGP shallow shells is realized by the virtual spring technique. The imposing procedures of the boundary conditions are simplified so that a certain kind of restraints can be easily achieved by merely setting different stiffness of the springs. It is assumed that the distributions of porosity are uniform or non-uniformly along a certain direction and three types of the porosity distribution are considered, among which material property of two non-uniform porous distributions are expressed as the simple cosine. The size of the pore in a shallow shell is determined by the porosity coefficients. Based on the first-order shear deformation theory (FSDT), all kinetic energy and potential energy of FGP shallow shells are expressed by displacement admissible function. On this basis, the author describes the displacement admissible function of the FGP shallow shells by using the modified Fourier series which increases the auxiliary function, so that the auxiliary function can be used to eliminate the discontinuity or jumping of the traditional Fourier series at the edges. Lastly, the natural frequencies as well as the associated mode shapes of FGP shallow shells are achieved by replacing the modified Fourier series into the above energy expression and using the variational operation for unknown expansion coefficients. Several numerical examples are carried out to demonstrate the validity and accuracy of the present solution by comparing with the results obtained by other researchers. In addition, a series of innovative results are also highlighted in the text, which may provide basic data for other algorithm research in the future.

References listed at the end of the paper:
2 M. Ganapathy, Dynamic stability characteristics of functionally graded materials shallow spherical shells, Compos Struct, 79 (2007), pp. 338-343
3 H. Matsunaga, Free vibration and stability of functionally graded shallow shells according to a 2D higher-order deformation theory, Compos Struct, 84 (2008), pp. 132-146
6 D. Chen, J. Yang, S. Kitipornchai, Elastic buckling and static bending of shear deformable functionally graded porous beam, Compos Struct, 133 (2015), pp. 54-61
7 D. Chen, S. Kitipornchai, J. Yang, Nonlinear free vibration of shear deformable sandwich beam with a functionally graded porous core, Thin-Walled Struct, 107 (2016), pp. 39-48
42 H. Zhang, D. Shi, S. Zha, Q. Wang, Parameterization study on the moderately thick laminated rectangular plate-cavity coupling system with uniform or non-uniform boundary conditions, Compos Struct, 194 (2018), pp. 537-554
44 J. Zhao, F. Xie, A. Wang, C. Shuai, J. Tang, Q. Wang, Vibration behavior of the functionally graded porous (FGP) doubly-curved panels and shells of revolution by using a semi-analytical method, Compos B Eng, 157 (2019), pp. 219-238
47 J. Zhao, K. Choe, F. Xie, A. Wang, C. Shuai, Q. Wang, Three-dimensional exact solution for vibration analysis of thick functionally graded porous (FGP) rectangular plates with arbitrary boundary conditions, Compos B Eng, 155 (2018), pp. 369-381
48 J. Zhao, K. Choe, C. Shuai, A. Wang, Q. Wang, Free vibration analysis of laminated composite elliptic cylinders with general boundary conditions, Compos B Eng (2018)
49 W.L. Li, Free vibrations of beams with general boundary conditions, J Sound Vib, 237 (2000), pp. 709-725


ABSTRACT: An analytical procedure for dynamic stability of CFST column accounting for the creep of concrete core is proposed. The long-term effect of creep of concrete core is formulated based on the creep model by the ACI 209 committee and the age-adjusted effective modulus method (AEMM). The equations of boundary frequencies accounting for the effects of concrete creep are derived by the Bolotin’s theory and solved as a quadratic eigenvalue problem. The effectiveness of the proposed method and the characteristics of time-varying distribution of instability regions are numerically surveyed. It is shown that the CFST column becomes dynamically unstable even when the sum of the sustained static load and the amplitude of the dynamic excitation is much lower than the static instability load. It is also found that due to the time effects of concrete creep under the sustained static load, the same excitation, that cannot induce dynamic instability in the early stage of sustained loading, can induce the dynamic instability in a few days later. The critical amplitude and frequency of the dynamic excitation can decrease by 6% and 3% in 5 days, and 11% and 6% in 100 days.


ABSTRACT: In this article, the authors used two different numerical approaches for frequency response of annular sector and sector plates with functionally graded materials and laminated composite cases. First-order shear deformation (FSDT) and Love’s conical shell theories are used for obtaining the annular sector plate equations via some suitable angles and geometric parameters. The method of harmonic differential quadrature (HDQ) and discrete singular convolution (DSC) have been used for numerical solution of the resulting governing equations for modal analysis. Simple power-law and four-parameter power law distributions in terms of the volume fractions of constituents have been used for FGM composites. Comparison and convergence study for the present numerical methods have been made via existing results available in the literature for sector and annular sector plates. Frequencies values for annular sector/sector plates have been obtained for different material and geometric parameters, boundary conditions and sector angles.


ABSTRACT: The main goal of this article is to provide parameterization study for vibration behavior of functionally graded porous (FGP) doubly-curved panels and shells of revolution by using a semi-analytical method. Distribution of the porosity through the thickness of structure may be uniform or non-uniform and three types of the porosity distributions are performed in this paper. Mechanical properties of materials are determined by open-cell metal foam. Energy expressions, including kinetic energy and potential energy, are
expressed by displacement admissible function. Then, in order to obtain the general boundary conditions including the simply classical boundary conditions, elastic boundary constraint and their combinatorial boundary constraints, each of displacement admissible functions is expanded as a modified Fourier series of a standard cosine Fourier series with the auxiliary functions introduced to eliminate all potential discontinuities of the original displacement function and its derivatives at the edges. Lastly, the natural frequencies as well as the associated mode shapes of FGP doubly-curved panels and shells of revolution are achieved by replacing the modified Fourier series into the above energy expression and using the variational operation for unknown expansion coefficients. The convergence and accuracy of the present modeling are validated by comparing its results with those available in the literature and FEM results. Based on that, a series of innovative results are also highlighted in the text, which may provide basic data for other algorithm research in the future.


ABSTRACT: Large, thin, prestressed membranes known as ‘gossamer’ structures have many applications in space, including light reflection and electromagnetic signal collection. The prestress forces applied to these structures usually causes some wrinkling of the membrane to occur, and the degree of wrinkling affects the reflective performance of the structure. The primary aim was to assess whether solar radiation pressure could affect the wrinkle pattern of gossamer structures, with a particular focus on solar sails. Several prestressed rectangular membranes with dimensions and material properties representative of current and future solar sails, a class of membrane structures typically made of Kapton, were modelled to investigate the effects of pressure on the wrinkle pattern. It was shown that increasing the pressure applied normal to the membrane surface increased the amplitude and decreased the wavelength of the wrinkles. However, no significant change in the wrinkle pattern was found to occur until the magnitude of the applied pressure was much greater than that likely to be experienced by gossamer structures due to solar radiation pressure. Therefore it was concluded that the effects of solar pressure will have no significant impact on the future development of larger and thinner gossamer structures than exist at present.


ABSTRACT: The free and forced vibration of a nonlocal Timoshenko graded nanobeam resting on a nonlinear elastic foundation is investigated in this paper. The Timoshenko beam theory along with the von Kármán geometric nonlinearity is formulated while accounting for Eringen’s nonlocal elasticity differential model. A power-law distribution is used to model the material distribution along the beam thickness. The equations of motion are derived using Hamilton's principle and then solved analytically using the Method of Multiple Scale (MMS) and numerically using the Differential Quadrature Method (DQM) and the Harmonic Quadrature Method (HQM). The considered boundary conditions include both Hinged-Hinged and Clamped-Clamped. The obtained nonlocal nonlinear frequencies of the nanobeam are first validated based on published analytical results that use linear mode shapes. A frequency response analysis is also conducted utilizing both MMS and DQM. The time discretization in DQM solution is performed using Spectral Method (SPM) and HQM. The primary objective of this study is to investigate the effects of the nonlocal parameter, power-law index, linear and nonlinear stiffnesses of the elastic foundation as well as the boundary conditions on the dynamic response of the nanobeam.


ABSTRACT: In this paper, a unified analysis model is proposed for the first time to study the free vibration of laminated composite elliptic cylinders with general boundary conditions including the classical boundary, elastic boundary and their combinations. The theoretical model is established by means of the modified variational principle and multilevel partition technique based on the first-order shear deformation theory. The interface continuity and boundary constraints are enforced by using the coupling and boundary spring technique. On the basis of that, the displacement components of each shell domain are expanded in the form of
double Jacobi polynomials along the meridional and circumferential direction. The convergence and comparison analysis for laminated composite elliptic cylinders subject to different classical boundary conditions is conducted to show the reliability and accuracy of the present method. To make the research topic understood better, some mode shapes are also depicted. The present solutions show stable and rapid convergence characteristics, and the natural frequencies and mode shapes agree well with the Finite Element Analysis results. Some new vibration results and parameterized results are presented and may be as the reference data by other researchers in the future.


ABSTRACT: In the present study, lateral and axial buckling characteristics of the S-glass/epoxy composites were investigated incorporating nano-clay (NC) particles within the common matrix of epoxy resin. Critical axial and lateral buckling loads of the composite samples were experimentally determined for different weight contents of NC particles (1, 1.5, 2 and 3 wt %). The effects of fiber orientation angles on critical buckling loads were investigated for both of axial and lateral buckling analyses, and it was shown that maximum axial and lateral buckling loads were obtained with fiber orientation angle of [0°/90°] and [15°/-75°], respectively. In addition, influence of NC particles on tensile and flexural properties were examined only for NC content of 1 wt %. It is concluded that incorporation of NC particles by 1 wt % in the composites resulted in 8.6% improvement axial buckling load, and further increasing NC content did not significantly effects on axial and lateral buckling values implying poor interfacial stress between NC particles and epoxy resin.


ABSTRACT: Modeling methods for a new type of structural composite – lightweight nap-core sandwich – are presented. The material has its nap-core based on cup-shaped knitted fabric impregnated and cured with a thermosetting resin, which is versatile and possesses noted mechanical properties. However, the complexity of the nap-core's underlying geometries and constituents makes the finite element simulation of it a challenging task. The authors are proposing a number of approaches. At first, the nap-core is modeled at the macroscopic scale as a 3D-shaped thin shell whose input material parameters have been determined through laboratory tests. In the next approach, the nap-core is modeled from the mesoscopic scale whereby its effective material parameters are acquired from a cost-effective homogenization scheme given to its fibrous representative volume element. Ultimately, the analysis of the experimental results and the simulation results proves the appropriateness of the simulation methods.


ABSTRACT: The present works aims at modeling a viscoelastic nanobeam with simple boundary conditions at the two ends with the introduction of the Kelvin-Voigt viscoelasticity in a nonlocal strain gradient theory. The nanobeam lies on the visco-Pasternak matrix in which three characteristic parameters have a prominent role. A refined Timoshenko beam theory is here applied, which is only based on one unknown variable, in accordance with the Euler-Bernoulli theory, whereas the Hamilton's principle is applied to derive the equations of motion. These are, in turn, solved for a carbon nanotube with some fixed material properties. An analytical method has been used to discretize the equations in the displacement field and time, while computing the time-response of the system. For validation purposes, the results based on the proposed formulation are successfully compared to several references. A final parametric investigation focuses on the sensitivity of the time-response of a nanotube under simple boundary conditions, to different parameters such as the length scale, the viscoelasticity coefficients or the nonlocal parameter.

ABSTRACT: This article deals with the free vibration analysis of Carbon Nanotube-reinforced magneto-electro-elastic (CNTMEE) rectangular and skew plates using finite element (FE) methods. The plate kinematics is assumed to follow a higher-order shear deformation (HSDT) theory. The coupled equations of motion are derived with the aid of Hamilton's principle. The material properties of CNTMEE material are estimated using the rule of mixture. The various carbon nanotube (CNT) distribution fashions such as UD, FG-X, FG-O, and FG-V are employed in the present analysis. Further, the FE formulation is extended for skew CNTMEE plates to assess the effect of geometrical skewness on the natural frequencies of the plate. A special emphasize is provided on analyzing the influence of various multi-physical fields such as magnetic, electric and elastic fields on the coupling characteristics of CNTMEE plates. In this article, a detailed parametric study on the effect of boundary conditions, CNT distributions and volume fraction, aspect ratio, length-to-width ratio are considered. The research outcome of this article suggests that these parameters have a significant influence on the coupled free vibration characteristics of CNTMEE plate. It is believed that the results presented in this article may serve as a benchmark in the design and analysis of smart CNTMEE structures for sensors and actuators, energy harvesting application.


ABSTRACT: Triclinic materials are categorized as anisotropic elastic materials with no existence of a symmetry plane. To characterize such materials, 21 elastic constants are required. The previous studies have not investigated triclinic materials due to a high number of material constants considered in the modelling. This paper presents a closed-form 3D piezoelectric model to investigate the free vibration of an arbitrary thick triclinic piezoelectric hollow cylinder. The piezoelectric cylinder is assumed to be infinitely long and short circuit boundary conditions are applied at the inner and outer surfaces of the shell. The natural frequencies of the cylinder are calculated using the transfer matrix approach along with the state space method. The effects of different anisotropic piezoelectric properties including orthotropic, monoclinic, and triclinic materials on the dispersion curve of natural frequencies are studied. The numerical results show that if the value of the axial wave number, the circumferential wave number, or natural frequency increase the resonant frequency of triclinic material deviates from other anisotropic materials such as orthotropic. Finally the validity of the proposed model is confirmed by comparing with simplified cases studied in the literature.


ABSTRACT: A high order theory for functionally graded (FG) beams based on expansion of the two dimensional (2-D) equations of elasticity for functionally graded materials (FGMs) into Legendre's polynomials series has been developed. The 2-D equations of elasticity have been expanded into Legendre's polynomials series in terms of a thickness coordinate. In the same way functions that describe functionally graded relations also has been expanded. Thereby all equations of elasticity including Hook's law have been transformed to corresponding equations for coefficients of Legendre's polynomials expansion. Then system of differential equations in term of displacements and boundary conditions for the coefficients of Legendre's polynomials expansion coefficients has been obtained. Cases of the first and second approximations have been considered in more detail. For the obtained boundary-value problems solution, a finite element method (FEM) has been used and numerical calculations have been done with MATHEMATICA, MATLAB and COMSOL Multiphysics software. Numerical results are presented and discussed.


ABSTRACT: In this paper, the dynamics analysis of functionally graded porous (FGP) circular, annular and sector plates with general elastic restraints is performed in a unified form for the first time. The overall theoretical model is based on the first order shear deformation theory. The kinetic energy and potential energy function of the plates are unified representation of five kinds of displacement admissible function. Then, each of displacement admissible function is expanded as a modified Fourier series to obtain general elastic restraints.
Lastly, the solutions are obtained by using the variational operation. The convergence and accuracy of the present modeling are validated by comparing its results with those available in the literature and FEM results. Based on that, a series of innovative results are also highlighted in the text, which may be as the basic data for other algorithm research in the future.

ABSTRACT: The National Energy Administration of China has promoted the use of wind energy to replace the conventional fossil energy, which provides an inexhaustible and eco-friendly alternative to the increasing energy demand. 10-MW wind turbine is the next-generation turbine with 85-m blade length, which poses great challenges in the engineering design, manufacturing, transportation, installation and maintenance. The paper aims to establish a numerical framework that integrates 3D full-scale modelling, analysis and parametric optimization. Isogeometric Analysis (IGA) enables seamless integration between structural modelling and computational analysis by using NURBS as basis functions. Aerodynamic forces and rotor power of blade subject to wind will be obtained by FAST. The Kirchhoff-Love shell element will be employed for 3D blade modelling to reduce rotational degrees of freedom and alleviate shear locking. The integrated framework residing within Rhino-based Grasshopper will be performed to model and analyse the wind turbine. Parametric optimization using pattern search algorithm targets at a family of turbines that satisfies the Tsai-Wu failure criterion and deformation constraint. The framework is deployed on a 10-MW turbine blade based on the initial design upscaled from the NREL 5-MW baseline model. The optimal blade design with shear webs has gained 20.9% improvement in performance.

ABSTRACT: The present work deals with the free vibration and damping characteristics study of multilayer sandwich spherical shell panels with viscoelastic material core layers and elastic face layers based on first order shear deformation theory. The displacements of the core layers are assumed to vary linearly along the thickness. Longitudinal and transverse deformations of the core layers are taken in to account with the consideration of independent transverse displacements of the elastic layers. The equation of motion is derived using Hamilton's principle in conjunction with the finite element method. Eight number of sandwich shell panels are studied mainly in two groups viz. sandwich panels with laminated base layer and isotropic base layer. Fundamental frequencies and associated system loss factors of different sandwich shell panels are deduced by solving the equation as an eigenvalue problem. The effect of thickness of the constraining layers, thickness of the core layers, viscoelastic material loss factor and aspect ratio on the natural frequencies and system loss factors of the sandwich structures are investigated.

ABSTRACT: This paper investigates the behavior of grid stiffened composite panel (GSCP) subjected to transverse loading by analytical and experimental approach. An improved analytical model is proposed on the basis of smeared method to compute an equivalent stiffness matrix for the isogrid lattice of the GSCP. Hence, the panel can be considered as a laminate with different layers of specific stiffness. In this manner, the global deformation of GSCPs is studied in three types of transverse loading: three-point bending, quasi-static indentation and low-velocity impact. The model is verified by the same experimental tests on some fabricated glass/epoxy GSCPs. The results indicate the good compatibility of analytical model with experiments. Moreover, energy absorbing characterization and damage mechanisms of the tested GSCPs are studied experimentally. Observations indicate that if the skin and the lattice structure are fabricated simultaneously, debonding of ribs and facing would not happen until the main damage (central rib fracture) occurs. Also, micro buckling of skin laminas would not affect the global response significantly. So, the progressive damage and degradation of overall stiffness of the GSCPs have not considerable effect and the prediction of global response on the basis of equivalent stiffness matrix would be a high precision tool to design grid stiffened structures.
Finally, based on the analytical model, a parametric study is performed to investigate the effect of changing some panel's variables and some optimum point is concluded.


ABSTRACT: The aim of this work is to establish a two dimensional (2D) and quasi three dimensional (quasi-3D) shear deformation theories, which can model the free vibration of FG plates resting on elastic foundations using a new shear strain shape function. The proposed theories have a novel displacement field which includes undetermined integral terms and contains fewer unknowns with taking into account the effects of both transverse shear and thickness stretching. The mechanical properties of the plates are assumed to vary through the thickness according to a power law distribution in terms of the volume fractions of the constituents. The elastic foundation parameters are introduced in the present formulation by following the Pasternak (two-parameters) mathematical model. Hamilton's principle is employed to determine the equations of motion. The closed form solutions are derived by using Navier's method and then fundamental frequencies are obtained by solving the results of eigenvalue problems. The efficiency of the proposed theory is ascertained by comparing the results of numerical examples with the different 2D, 3D and quasi-3D solutions found in literature.


ABSTRACT: Intelligent morphing wings have become a research hotspot due to their potential value. This paper is also an innovative basic research work to study it. The deformation performances of the GFRP(glass fiber reinforced polymer) composite beams embedded different pre-strained indented SMA wires were experimentally and numerically studied. The indentation SMA wire made by mechanical indentation method has better interface bonding strength than normal SMA wire. In this paper, the indented SMA wires acting as actuators, were embedded in a symmetrically GFRP laminated composite beam and located at the eccentric position of the laminate. The layering scheme of the laminated plate is as follows: [90°(4:1 fabric)/SMA/0°/0°/90°(4:1)]. The 0° direction is consistent with the direction of the axis of the SMA wire. The Finite element method is adopted to simulate the deformation of the beam with indented SMA wire in which the linear constitutive model of fully constrained SMA wires, together with considering their thermally-induced strain response, is used to describe the recoverable properties of SMA. The prediction from the numerical simulation agrees well with experimental measurements.


ABSTRACT: Fabric membrane, a typical composite material, is widely applied in building structures, agricultural facilities, packaging engineering, and aeronautical engineering, etc. However, it may fail subject to large-amplitude vibration induced by impact due to its lightweight and small stiffness properties. Herein, the nonlinear damped vibration of a pretensioned rectangular orthotropic membrane structure under impact loading is studied by analytical, numerical and experimental methods. The governing equation is derived based on the von Kármán large deflection theory, and the analytical solution is obtained by the Bubnov-Galerkin method and the Krylov-Bogolubov-Mitropolsky (KBM) perturbation method. Meanwhile, the numerical and experimental analysis are carried out for validation of analytical model and good agreement is achieved. Furthermore, parametric study is also performed to find the sensitivity of the design parameters to the vibration response. The results obtained in the paper lay solid foundation for the vibration control and dynamic design of orthotropic membrane structures.

ABSTRACT: A new three-dimensional exact solution for the free vibrations of arbitrary thick functionally graded annular sector plates with arbitrary boundary conditions is presented. The three-dimensional elasticity theory is employed to formulate the theoretical model. According to a power law distribution of the volume of the constituents, the material properties change continuously through the thickness of the functionally graded annular sector plates. Each of displacements of the annular sector plates, regardless of boundary conditions, is expanded as a three-dimensional (3-D) Fourier cosine series supplemented with closed-form auxiliary functions introduced to eliminate all the relevant discontinuities with the displacements and its derivatives at the edges. Since the displacement fields are constructed adequately smooth throughout the entire solution domain, an exact solution is obtained based on the Ritz procedure by the energy functions of plate. The excellent accuracy and reliability of the current solutions are demonstrated by numerical examples and comparison of the present results with those available in the literature, and numerous new results for thick FGM annular sector plates with elastic boundary conditions are presented. The effects of gradient indexes are also illustrated.


ABSTRACT: In the past decades, the exact closed form solutions for the free vibration of thin orthotropic circular cylindrical shells have been merely restricted to some classical boundary conditions. Therefore, the target of the current paper is to present a new exact closed form solution for free vibration of orthotropic circular cylindrical shells with general boundary conditions by means of the method of reverberation-ray matrix (MRRM). Based on the Donnell–Mushtari shell theory, the wave solutions are constructed by the exact closed form solutions of the governing differential equations. The artificial spring technology is introduced to achieve the general boundary conditions of two end edges of shell. Hereby, the reverberation ray matrix can be easily obtained by using the MRRM together with the wave solutions, boundary conditions and dual coordinates of the orthotropic circular cylindrical shells. Then, the vibration results are obtained from the extrapolation method and golden section search (GSS) algorithm. By the comparison with other published methods and the finite element method, the accuracy of the present method is verified. On the basis of that, some new exact nature frequencies of the orthotropic circular cylindrical shells with general elastic restraints are shown which can serve as the benchmark data for the future computing method.


ABSTRACT: This paper quantifies the compound effect of source-uncertainties on low-velocity impact of functionally graded material (FGM) plates following a coupled surrogate based finite element simulation approach. The power law is employed to evaluate the material properties of FGM plate at different points, while the modified Hertzian contact law is implemented to determine the contact force and other parameters in a stochastic framework. The time dependent equations are solved by Newmark's time integration scheme. Insightful results are presented by investigating the effects of degree of stochasticity, oblique impact angle, thickness of plate, temperature, power law index, and initial velocity of impactor following both probabilistic and non-probabilistic approaches along with in-depth deterministic analyses. A detail probabilistic analysis leading to complete probabilistic characterization of the structural responses can be carried out when the statistical distribution of the stochastic input parameters are available. However, in many cases concerning FGM, these statistical distributions may remain unavailable due to the restriction of performing large number of experiments. In such situations, a fuzzy-based non-probabilistic approach could be appropriate to characterize the effect of uncertainty. A surrogate based approach based on artificial neural network coupled with the finite element model for low-velocity impact analysis of FGM plates is developed for achieving computational efficiency. The numerical results reveal that the low-velocity impact on FGM plates is significantly influenced by the effect of inevitable source-uncertainty associated with the stochastic system parameters, whereby the importance of adopting an inclusive design paradigm considering the effect of source-uncertainties in the impact analysis is established.
ABSTRACT: Wave propagation behavior in piezoelectric cylindrical composite shells reinforced with angled and randomly oriented, straight carbon nanotubes (CNTs) is analytically investigated for the first time via the first-order shear deformation shell theory including the transverse shear effects and rotary inertia. The Mori-Tanaka method is used for micromechanical modeling. Dispersion solutions are computed by solving an eigenvalue problem. The effects of CNT orientation, CNT volume fraction, and shell geometry on the dispersion solutions are examined. Various orientations of CNTs lead to different dispersion behaviors; the variation of wave phase velocities is more significant at lower axial wave numbers; and the effects of CNT volume fraction and shell geometry on wave dispersion behaviors are more obvious at higher circumferential wave numbers. The presented model and analytical results of this study can be utilized in the wave propagation analysis of piezoelectric shells reinforced with CNTs for the design of new smart structures used in structural health monitoring and/or energy harvesting applications.

ABSTRACT: Constitutive equations are derived for a 1-D micropolar Timoshenko beam made of a web-core lattice material. First, a web-core unit cell is modeled by discrete classical constituents, i.e., the Euler–Bernoulli beam finite elements (FE). A discrete-to-continuum transformation is applied to the microscale unit cell and its strain energy density is expressed in terms of the macroscale 1-D beam kinematics. Then the constitutive equations for the micropolar web-core beam are derived assuming strain energy equivalence between the microscale unit cell and the macroscale beam. A micropolar beam FE model for static and dynamic problems is developed using a general solution of the beam equilibrium equations. A localization method for the calculation of periodic classical beam responses from micropolar results is given. The 1-D beam model is used in linear bending and vibration problems of 2-D web-core sandwich panels that have flexible joints. Localized 1-D results are shown to be in good agreement with experimental and 2-D FE beam frame results.

ABSTRACT: This paper presents the free vibration analysis of functionally graded carbon nanotube reinforced composite truncated conical panels with general boundary conditions for the first time. Based on the modified Fourier series method for the field variables, the Ritz method is employed to obtain the frequency parameters associated with the mode shapes. The truncated conical panels are reinforced by single-walled carbon nanotubes (SWCNTs) which are assumed to be graded through the thickness direction with different types of distributions. The effective material properties of the FG-CNTRC truncated conical panels are estimated through a micromechanical model based on the extended rule of mixture. In the present study, the artificial spring boundary technique is adopted here to implement the general boundary condition. Several examples are given to demonstrate the convergence, accuracy and flexibility of the present method. The effects of the volume fractions of CNTs, distribution type of CNTs, boundary restraint parameters and geometrical parameters on the vibration behavior of the FG-CNTRC truncated conical panels are presented.

ABSTRACT: In this research, woven spacer fabrics with woven cross-links and having different cell geometries viz. rectangular, trapezoidal and triangular were produced, along with one spacer structure

ABSTRACT: Optimization design assisted with advanced additive manufacturing techniques opens an effective gate for us to create novel, lightweight, mechanically robust cellular materials. Among them, lattice materials with an ordered cellular architecture have been known for their high mechanical properties, low density and energy absorption capacity. Limitedly, what kinds of topologic architecture have the best performance? And how could we obtain the optimized architecture? To answer them, we here took up two challenging tasks to achieve a novel compression-resistant lattice: 1. The topology optimization method was introduced to design the optimized topologic architecture. 2. Metallization was used to form lattice composites to further enhance the mechanical properties of pristine polymer. The topology optimization-guided lattice with only 20% volume of solid materials quite resembles the microstructure of cuttlebone, giving an indication of a good compression-resistant ability. Furthermore, the synthesized composites exhibit high specific compressive modulus of 5417.02 MPa kg⁻¹ and energy absorption efficiency of 78%. By in situ compressive tests, digital image correlation, finite element simulation and fracture analysis, the deformation mechanism, and fracture modes were unambiguously revealed. The design strategies and findings shed light on the realization of advanced materials with tailored mechanical properties.


ABSTRACT: This paper is concerned with the vibration analysis of a rotating tapered axially functionally graded (AFG) nanobeam. The material properties of the nanobeam are assumed to vary along its length. Accordingly, Newtonian method is employed to derive the governing equation of the system considering Euler-Bernoulli beam assumptions. Also, the nonlinear elasticity theory (NET) is used in order to take the small scale effects into account in the modeling. In addition, the differential transformation method (DTM) is hired to solve the obtained differential equation semi-analytically. Therefore, the obtained equations as well as boundary conditions are transformed into algebraic equations by the aid of DTM. Then, the characteristics equation can be solved to gain the non-dimensional frequencies of the system. After presenting the convergence and verification illustrations, some numerical results are discussed in detail to investigate the influences of various parameters namely nonlocal parameter, tapered ratio, angular velocity and FG index on the first three non-dimensional frequencies. As a principal result, it is disclosed that the nonlocal parameter shows both stiffness-hardening and stiffness-softening behavior in different bounds of the angular velocity. Totally, the numerical analysis reveals some important findings which are hoped to be used in efficient design of nano-structures benefited from the rotating nanobeams.

ABSTRACT: This paper aims to investigate the free vibration and bending characteristics of porous functionally graded (FG) plate with two opposite simply supported edges based on a four variable plate theory. Material properties of porous FG plate are defined by rule of the mixture with an additional term of porosity in the through-thickness direction. Equations of motion are derived using Hamilton principle. State-space approach is used to obtain the governing equation of porous FG plate. The effect of porosity parameter, slenderness ratio, and the power-law index is investigated on bending and vibration of porous FG plate. The results are compared with available results in the literature to verify this theory.


ABSTRACT: In this paper, the effect of loading frequency on the dynamic behavior of nanocomposite sandwich plates under periodic thermo-mechanical loadings has been investigated. The utilized sandwich plates are made of an isotropic polymer material and two symmetric face sheets reinforced by functionally graded (FG) distributions of carbon nanotube (CNT) agglomerations. In addition to periodic mechanical loads, these structures are also subjected to thermal gradient loads. Steady state response of the plates under thermal gradient load was assumed like a pre-stress for dynamic equations in conducting timeline vibrations of the structure. The material properties of polymeric matrix and CNTs were assumed to be temperature-dependent and the overall material properties of nanocomposites were estimated using Eshelby-Mori-Tanaka's approach. In order to achieve accurate results, a mesh-free method based on higher order shear deformation theory (HSDT) was utilized. The effects of mechanical loading frequency and thermal gradient load as well as CNTs cluster characterizations, essential boundary conditions and elastic foundation on forced vibration, resonance and phenomenon of beats behaviors were investigated. It was observed that thermal gradient loads and the formation of CNT agglomerations have significant effects on the amplitudes of vibrations in nanocomposite sandwich plates.


ABSTRACT: Composite stiffened structures that are widely used in engineering inevitably produce various defects in manufacturing and service. In order to detect them, a microwave nondestructive testing platform is built in this paper, which simply combines near-field and far-field microwave scanning imaging. 0.4 mm metal hole, 0.5 mm and 1 mm inclusions and 0.1 mm thick debonding are detected by high resolution microwave near-field imaging. Internal poor resin infusions defects in 39 mm thick hat stiffener are detected by high penetration microwave far-field imaging. Far-field microwave images the shape and internal structure of stiffener by adjusting stand-off distance. Detection of the fiber wrinkling defects demonstrates the effectiveness of combining near-field and far-field imaging methods, saving 95% of the scan imaging time. Feature-based image stitching technique is adopted to obtain the full-size image of the large stiffened composite structure.


ABSTRACT: The basic or primitive parameters of composite laminates, such as the constituent materials properties, the thickness of each ply, the ply orientations and the applied loads, exhibit variabilities, hence, the response of the laminated composites also exhibits some degree of variability. Thus, the accuracy and reliability
of the laminates cannot be assured if the variabilities present in the basic parameters are ignored. In the past decades, the probabilistic approach has been used widely to simulate the uncertainties in the macromechanics of composite laminates. However, the exact probability distributions of the primitive parameters are not known in most of the applications. This work, for the first time, models the uncertainties in the macromechanics of composite laminates using the interval analysis and the universal grey system theory by representing the primitive parameters as intervals. Also, for comparison, a probabilistic approach is presented with plus/minus three standard deviations about the mean of the response. Due to the so-called dependency problem, the interval analysis predicts wider and inaccurate ranges. Thus, a truncation-based interval analysis procedure with a suitable truncation parameter is used to overcome the limitation associated with the original interval analysis. Specifically, in this work, the uncertainties in the in-plane and flexural engineering constants and laminae stresses are studied. The environmental effects on the laminae stresses are also investigated. Numerical examples are presented to demonstrate the application of the three interval-based uncertainty methods for the behavior of composite laminates by considering different stacking sequences of graphite/epoxy and glass/epoxy laminates.

ABSTRACT: This paper investigates the static bending and buckling behaviors of functionally graded microplates under mechanical and thermal loads by using isogeometric analysis (IGA) and modified strain gradient theory (MSGT). The material properties are assumed to be temperature-dependent and three different temperature rise patterns including uniform, linear and non-linear are considered. The material properties vary through the plate thickness based on the rule of mixture scheme. A refined hyperbolic shear deformation theory with four independent unknowns is used for analysis, which doesn't need a shear correction factor. For analysis the IGA using B-Spline or Non-Uniform Rational B-Spline (NURBS) functions can easily meet the C-continuity requirement. Various parameters are dealt with including power index, material length scale parameter, temperature rise patterns and material combination. The MSGT results are also compared with those obtained by modified couple stress and classical theories. The obtained results indicate that the two studied types of functionally graded microplates show different behaviors under thermal load and the type of functionally graded material is an important parameter for thermal analysis.

ABSTRACT: The findings of the experimental and numerical investigations on vibration characteristics of laminated skewed shells with cutout are presented in this paper. The shell laminates have been fabricated in the laboratory by adopting resin infusion technique. Experimental analysis is conducted using Photon plus data acquisition system along with accelerometer and impact hammer to identify the influence of skew angle and cutout on the natural frequencies of laminated shell. The results obtained in the present investigation indicate that cutout and skew angle bear remarkable influencing factor to control the frequencies of laminated skewed shells. Additional results obtained from extensive parametric study on various shells with cutout are presented which may be helpful for future researchers.

ABSTRACT: The damping properties analysis of composite sandwich doubly-curved shells (CSDCS) is presented in this paper. First, based on the Hamilton's principle, governing equations of CSDCS are developed by applying the first-order shear deformation shell theory. Because the rotary inertias and shear deformation of all layers are taken into account, thin-to-moderately thick doubly-shells can be studied. Next, these equations are solved by means of the closed-form Navier method. The accuracy of the solution is validated by comparing its results with those available in the literature. Finally, the variation of modal loss factor with system parameters is evaluated and presented graphically, and optimal damping properties of CSDCS are obtained by analyzing the influence of the geometrical parameters as well as the physical parameters on damping properties.

ABSTRACT: The focus of this paper lies on the sensitivity of the nap-core sandwich – a novel kind of structural composite – to changes of its parameters. First, the fabrication, properties, and applications of the nap-core sandwich are briefly presented. This is followed by consideration of the sandwich composite’s mechanical behavior. Finite element based simulation is applied to perform the parametric investigations. The height of the nap-core and the thickness of its knitted fabric as well as the face sheet of the sandwich are changed in order to investigate the dependence of the general mechanical properties of sandwich composites on those parameters. Experiments are used to validate the simulation results. The conducted investigation provides valuable information for the design of nap-core sandwich composites.


ABSTRACT: The beetle has evolved over several hundred million years and possess perfect structure, as well as performance. According to the excellent structure and performance of beetle forewing, a bionic structural material (BSM) was designed and manufactured to improve its low-velocity impact resistance behavior. The surface layer of BSM is carbon-fiber-reinforced plastic (CFRP), and the cores of BSM are aluminum honeycomb. This study aims to investigate the dynamic response, energy absorption, and damage characteristics of BSM in low-velocity and high-cycle impact condition. Results showed that the BSM is superior to single CFRP, with lower peak force, higher energy absorption, and deformation. The damage mechanism of CFRP under cycling low kinetic energy is delamination and then fracture. Meanwhile, the damage of CFRP in sandwich structures is lower than in single CFRP, indicating an excellent impact resistance behavior of BSM, which is useful for practical engineering applications.


ABSTRACT: Geometric configurations in nature could be mimicked in order to develop novel materials and structures with desirable properties. Lots of bio-inspired configurations had been introduced to tubal structures in promoting the energy-absorption performance of thin-walled structures. Nevertheless, these existing studies largely focused on hierarchical hexagonal honeycombs, and the bio-inspired hierarchical circular thin-walled structures under the out-of-plane crushing loads had not been well studied experimentally, numerically and analytically for energy absorption to date. In this study, the bionic honeycomb tubular nested structure (BHTNS) was first inspired by the micro-architecture of bamboo vascular bundles, which could be mimicked by connecting a central circular tube to other six circular tubes in a hexagonal arrangement, regardless of size or choice of materials. The energy-absorption characteristics of BHTNS under axial crushing were systematically studied by drop-weight experiment, numerical simulation, and theoretical analysis. Dynamic drop-weight impact experiments were conducted and the results showed that the specific energy absorption (SEA) of BHTNS was as high as 29.3 J/g. Furthermore, the parametric numerical simulation revealed the influence of diverse mean diameter D of the circular tube and length L of the junction plate on the energy-absorption characteristics. Finally, a theoretical model was also developed to predict the mean crush force Pm, which was in good agreement with the numerical simulation. This work could provide a reference for an energy-absorber design with high efficiency.

ABSTRACT: This paper develops a formulation for displacement-only beam elements based on isogeometric analysis, with intended application to laminated composite members. The main purpose of the current study was to overcome some deficiencies of commonly used beam theories, such as shear-locking, the lacking relevance of isotropic materials for multi-layer composites, the incompatibility with other continuum elements, and the limited continuity in interpolation. A bi-variable non-uniform rational B-spline (NURBS) beam element with complete plane-stress elasticity terms and geometrical expressions was developed. Shear-locking, interlaminar stresses, the deep-beam situation, and vibration features were evaluated for several aspect ratios, ply orientations, and NURBS degrees, in order to verify the efficiency and accuracy. h-, p- and k-refinements were used to improve the displacement field. The validity of the solutions was measured based on results from plane-stress finite element analysis, and compared to the alternative Carrera unified formulation. Results show that the isogeometric displacement-only beam theory can provide the interlaminar stress distribution, gives high accuracy for mid and high-range eigen-frequencies, and avoids the shear-locking phenomenon.


ABSTRACT: Composite materials are becoming the most useful material for aircraft structures. Their main advantage is connected to the possibility of deeply reducing weight and costs by maintaining high performances in terms of strength and security. The second major advantage in using this them depends on the possibility they could be proper designed to guarantee services they are made to. Many ways to combine them lead to the necessity of planning experimental tests in order to evaluate the real both elastic and plastic mechanical properties and to compare their variability as function of the fiber type, matrix type and manufacturing technology involved for realizing them. In this paper, a comparison between two innovative Carbon Fiber Reinforced Plastic materials was done. They differ, one from each other, for the matrix type (PEEK and BENZOXAZINE) and for the manufacturing process used to assemble the matrix with the reinforcement (Compression Molding and Resin Transfer Molding). On the other hand, the resin percentage weight content of both materials is maintained constant for all the tests: it is 42% for PEEK matrix and 64% for BENZOXAZINE matrix. The aim of the work is to critically analyze the results in order to get useful information for choosing the best one intended for designing and making the back section of fuselage of a regional aircraft. The component will consist of a front portion with structural aims (zoom phase) and a back part able to withstand to elevated temperatures.


ABSTRACT: In this paper, the material nonlinearity induced by the high temperature is introduced in the modeling of fiber-reinforced composite thin plate structure, and a nonlinear dynamic model in thermal environment is established using Hamilton's principle in conjunction with the classical laminated plate theory, complex modulus method and strain energy method. The nonlinear relationships between the elastic moduli, Poisson's ratios and loss factors and temperature change are expressed by the polynomial method. Then, the dynamic equations in the high temperature environment are derived to solve the inherent characteristics, dynamic responses and damping parameters with considering temperature dependent property. Also, the identification principle of concerned fitting coefficients in the theoretical model is illustrated. As an example to demonstrate the feasibility of the developed model, the experimental test of a TC500 carbon/epoxy composite thin plate is implemented. The results of the developed model and experimental test show a good consistency, and both indicate that the high temperature has complicated influence on its dynamic characteristics, especially on damping property.
ABSTRACT: Wave propagation problem is solved in smart laminated carbon nanotube (CNT)-reinforced composite cylindrical shells coupled with piezoelectric layers on the top and bottom surfaces in hygrothermal environments for the first time. The motion equations are derived based on the first-order shear deformation shell theory considering the transverse shear effects and rotary inertia. The hygrothermal effects are also included in the mathematical modeling and the effective material properties of a CNT-reinforced composite shell are estimated through the Mori-Tanaka micromechanical model. Dispersion solutions are obtained by solving an eigenvalue problem. Parametric studies are carried out to investigate the effects of temperature/moisture variation, CNT volume fraction and orientation, piezoelectricity, shell geometry, stacking sequence, and material properties of the host substrate laminated composite shell at different axial and circumferential wave numbers. The results show that the temperature/moisture variation influences moderately on the dispersion solutions of smart laminated CNT-reinforced composite shells. The presented methodology and results can be used in wave propagation analysis of smart laminated CNT-reinforced composite shells affected by hygrothermal environmental conditions.

ABSTRACT: This paper presents an investigation into the performance of pultruded glass fibre reinforced polymer (GFRP) square hollow columns subjected to both compression and bending. Eccentric compression experiments were performed on slender GFRP column specimens at different eccentricities. Bolted sleeve joint was employed to connect the GFRP column specimens and loading end plates. The relationship between the load-bearing capacities of GFRP columns and the eccentricities was received and discussed. The interaction curve between compression load and bending moment due to eccentricity (P-M curve) was obtained from experiments and compared with finite element (FE) and design approaches. Results revealed that the compression performance of GFRP columns was significantly affected by the eccentricity and the moment capacity of bolted sleeve joint. Splitting failure developed from the initiative longitudinal cracks in the bolted sleeve joint region at the end of the columns was found as the ultimate failure, after the large lateral deformation. FE analysis presented satisfactory agreements with experimental results; furthermore, the stress analysis in the critical bolted sleeve joint region indicated that the in-plane shear stress was the dominant component leading to the splitting failure.

Levent Pehlivan and Cengiz Baykasoglu (Primarily from: Hitit University, Faculty of Engineering, Department of Mechanical Engineering, Çevre Yolu Avenue, 19030, Çorum, Turkey), “An experimental study of the compressive response of CFRP honeycombs with various cell configurations”, Composites Part B: Engineering, Vol. 162, pp 653-661, 1 April 2019, https://doi.org/10.1016/j.compositesb.2019.01.044
ABSTRACT: The experimental investigation on the compressive response of carbon fiber reinforced polymer (CFRP) honeycombs with various cell configurations was carried out in the present work. The CFRP honeycomb specimens were manufactured by corrugation technique, in which the prepreg CFRP sheets were first corrugated into the certain shape using corrugated aluminum moulds under heat and pressure, and then the corrugated CFRP sheets were glued and stacked to construct honeycomb specimens. Twenty-seven groups of specimens were experimentally tested to examine the effects of cell geometry (i.e., square, circular, and hexagonal), cell wall thickness and height on the quasi-static out-of-plane crushing performance of the honeycombs. The square, circular, and hexagonal honeycomb specimen groups were designed to have almost the same weights. The results showed that the cell wall thickness is an significant parameters on the overall crushing response of the CFRP honeycombs while the out-of-plane compressive strenght of the honeycombs is generally independent of the height. It is observed that the hexagonal specimen groups have generally superior crushing performance in comparison with the square and circular counterparts due to their large double foil bonding surfaces. The experimental results also revealed that the crushing properties of the honeycomb
structures with the core densities of 157–282 kg/m³ could be increased more than two times with the appropriate selection of cell configurations.


ABSTRACT: The quasi-static mechanical properties of re-entrant anti-trichiral honeycombs made from ABS polymer are studied by both experiments and theoretical analysis. The experimental results show that the deformation of honeycomb is dominated by the bending of ligaments, the rotation of ligaments around the plastic hinges and the rigid rotation of cylinders. Based on the deformation mechanism of the cell structures exhibiting in experiments, the collapse process of the honeycomb is divided into several stages. Theoretical formulas are deduced to predict the crushing stress of the re-entrant anti-trichiral honeycombs in each stage, which are functions of the honeycomb's global strain, the cells' geometry parameters and the properties of the base material. The analytical predictions are in good agreement with the experimental results. It is revealed that the crushing stress of the honeycomb increases with the global strain and the cell-wall thickness while decreases with the ligament-length ratio. An optimal value of the cylinders' radius is found which will result in the maximum load-carrying capacity of the honeycomb. The present work is supposed to shed light on the design and fabrication of re-entrant anti-trichiral honeycombs.


ABSTRACT: The nonlinear dynamic responses of a nanocomposite organic solar cell (NCOSC) are developed through the classical plate theory. The investigated NCOSC consists of five layers which are including Al, P3HT: PCBM, PEDOT: PSS, IOT and glass. A uniformly distributed external excitation is exerted on the simply supported NCOSC. The impacts of the Winkler-Pasternak elastic foundation, thermal environment and damping on the nonlinear dynamic responses of the NCOSC are investigated. The equations of motion and geometric compatibility of the NCOSC with the consideration of the von Kármán nonlinearity are derived. The governing equation of the dynamic system is formulated by employing the Galerkin and the fourth-order Runge-Kutta methods. Several numerical experiments are thoroughly presented to report the effects of damping ratio, temperature variations, and elastic foundation parameters on the frequency–amplitude curves and nonlinear dynamic response of the NCOSC. The numerical studies indicate that the existence of the Winkler-Pasternak elastic foundation effectively reduces the dynamic response of the NCOSC. In addition, the damping and thermal variation depress the vibration of the NCOSC but with relatively less efficiency compared with the Winkler-Pasternak elastic foundation.


ABSTRACT: The aim of this paper is to find the magnitudes of velocities of transient waves which could be originated and propagate in thin shells made of Cosserate-type material in the form of surfaces of strong and weak discontinuity. Thus, starting from the 3D Cosserat continuum, the velocities of four transient waves propagating in a thin shell with micro-structure have been determined according to a wave theory for thin-walled plates and shells proposed recently by the authors. Using the expansion ray theory and conditions of compatibility for thin-walled structures, it has been found that (1) the velocities depend only on material constants, and (2) only one micropolar modulus \( \alpha \), which governs the asymmetry of the stress tensor, influences the velocity of the quasi-shear wave, while the Láme moduli \( \lambda \) and \( \mu \) do not affect the velocities of Cosserat waves, which are generated due to micropolar rotations. This results to the fact that the mathematical theory due to Cosserat is not coupled and the knowledge of the velocities of transient waves in thin shells made of
Cosserat-type materials will allow one to solve boundary-value transient dynamic problems resulting in the propagation of surfaces of strong and weak discontinuity.


ABSTRACT: For cylindrical shell structures under axial compression, it is crucial to provide high-fidelity knockdown factors (KDFs) in preliminary design for aerospace and civil structures. In this paper, numerical studies of buckling response for composite cylindrical shell with geometric imperfections and embedded delamination imperfections are performed to predict the lower-bound buckling loads. Results indicate that composite shells with single dimple-shape geometric imperfection exhibit similar lower bound trend and buckling behavior as those with embedded delamination imperfection. It is found that the lower-bound buckling loads are much less conservative than the corresponding design recommendation from NASA SP-8007. And the effect of geometric imperfections can envelope that of delamination imperfections. Therefore, the worst multiple perturbation load approach (WMPLA) is performed to find the worst combination of dimple-shape geometric imperfections to predict the lower-bound buckling load, and the efficient global optimization (EGO) is employed to improve the computational efficiency of WMPLA. It is demonstrated that the improved WMPLA can provide an improved KDF by examples in open literature. Based on the improved KDFs, it is possible to increase the load-bearing efficiency of composite structures in practical engineering.


ABSTRACT: Present research deals with the large amplitude thermally induced vibrations of an annular plate made of functionally graded materials (FGMs). One surface of the plate is subjected to rapid surface heating while the other surface is either thermally insulated or kept at reference temperature. The material properties of the constituents are assumed to be temperature dependent. The rule of mixtures is used to obtain the properties of the graded media. With the aid of the von Kármán kinematic assumptions and first order shear deformation theory, the governing equations of motion and the associated boundary conditions are obtained. With the aid of the generalized differential quadrature (GDQ) method, these equations are transformed into a set of nonlinear algebraic equations which are solved iteratively using the Newton-Raphson method and Newmark time marching scheme. The temperature profile across the plate thickness is also obtained using the iterative Crank-Nicolson and the GDQ methods. Numerical results are devoted to the effects of temperature dependency, plate thickness, power law index, and boundary conditions of the plate on the large amplitude thermally induced vibrations. It is shown that for thin plates thermally induced vibrations take place and the quasi-static response can not be considered as the true response of the plate under thermal shock.


ABSTRACT: Through-the-thickness (TT) confinement of masonry and concrete panels by composite or steel reinforcements, aiming at seismic retrofit of existing structures, has recently growth in popularity. However, structural design of transversal reinforcements, modelled as an homogeneized material, is often performed by neglecting the cyclic nature of seismic actions and by using static approaches. For this reason, a proper strength hierarchy between the confined core material and the confining devices should be accounted for in order to ensure that the retrofit system remains effective until the crisis of the core material is attained. This research introduces strength hierarchy conditions for TT-confinement systems, made of materials exhibiting a nonlinear behavior, aiming at determining the minimum strength required for uniaxial confining devices. The relevant relationships, theoretically derived by assuming a Drucker Prager constitutive model for the confined material and by enforcing equilibrium and compatibility conditions between the core and the confining devices, are
characterized by simple mechanical parameters, usually available in common practice applications, familiar to most of the designers. Numerical examples confirm the effectiveness of the proposed provisions.


ABSTRACT: Composite tubes may be subjected to impact loads during placement or operation. By determining the impact properties of composite tubes and using them in the design process, the accuracy of the behavior of these structures is guaranteed under dynamic and quasi-static loading conditions. In the present study, the effect of changing parameters such as tube diameter, fiber density and fiber layout on the behavior of glass/epoxy composite tubes under dynamic and quasi-static axial loading is investigated. The Force-displacement diagrams were extracted for all experiments and compared with other experiments. Also, the rate of specific energy absorption of each test was calculated for all samples. The results of this study showed the change of parameters mentioned is effective on the energy absorption of composite tubes. In both groups of dynamic and quasi-static axial tests, variations of fiber density and samples diameter caused to change the specific absorbed energy. But the change in fiber layout from [0.90] to [± 45] reduced the specific absorbed energy. In the following, the results of dynamic and quasi-static tests were compared. Comparison of the results showed that for predicting of the average crushing force of the dynamic test for 10-layer samples with a height of 100 mm and [0.90] fiber layout, the average force of the quasi-static test can be used with coefficients of 1.1–1.3. Also, a model was proposed for predicting the average crushing force, maximum force and sample destruction in the dynamic test according to the quasi-static test results. Also, according to the results, in the dynamic and quasi-static impact tests, increasing the fiber density and internal diameter of the samples, increases the amount of specific energy absorption. In the case of changing the fiber orientation for samples made with 200 gr/m and 400 gr/m fibers in the dynamic impact tests, compared to quasi-static tests, have a different effect on the amount of specific energy absorption.


ABSTRACT: This paper aims to investigate analytically the vibrational characteristics of functionally graded (FG) single-walled carbon nanotube (SWCNTs) based on modified Love shell theory. By using Galerkin's technique, the governing carbon nanotube (CNT) dynamics equation of the motion of the considered system is developed. For theoretical point of view, a nanotube problem is framed by amending some physical terms to accommodate the nature of the problem. For the present problem, vibrations of rotating carbon nanotubes with ring supports are examined. The effects of angular velocity, length- and height-to-radius ratios of rotating armchairs and zigzag SWCNTs with ring supports are fully investigated. Rings supports are attached to CNT in the radial direction. Our investigations show that increasing of length- and thickness-to-radius ratios yields decreasing and increasing frequency behaviors for rotating FG-CNT with clamped-clamped (C-C) and clamped-free (C-F) boundary conditions, respectively. It is found that with increasing the angular speed, frequencies of forward waves decrease and backward waves increase. Moreover, the effect of frequency is also performed to place the ring support at different locations of the CNT. Computational software MATLAB is engaged to characterize the frequencies based on CNT model to estimate the accuracy and effectiveness of this model. A few comparisons of analytical results for non-rotating and rotating CNTs are performed to confirm the validity, efficiency and accuracy of the numerical methodology.

M. Shakouri (Department of Aerospace Engineering, Semnan University, P. O. Box 35131-19111, Semnan, Iran), “Free vibration analysis of functionally graded rotating conical shells in thermal environment”, Composites Part B: Engineering, Vol. 163, pp 574-584, 15 April 2019, https://doi.org/10.1016/j.compositesb.2019.01.007

ABSTRACT: Due to the wide applications of functionally graded shells in high temperature conditions, the study of dynamic behavior of these structures in thermal conditions is of the key importance. The vibration of
rotating functionally graded conical shells with temperature-dependency of material properties is studied in this paper. The Donnel shell theory is employed to extract governing equations including initial thermomechanical stresses as well as centrifugal forces, Coriolis forces, and initial hoop tensions due to rotation. The initial thermomechanical stresses are obtained from the nonlinear heat conduction equation with temperature-dependent thermal conductivity for temperature distribution and linear bending equations for initial deflections. The method of generalized differential quadrature is employed to solve the problem. The obtained results are compared with the available literature and finally, the effects of angular velocities, thermal conditions, volume fraction index, semi-vertex angles and lengths of the cone on frequency are investigated.


ABSTRACT: Impact resistance and damage tolerance are of great significance in the design of composite structures. This study investigated the damage and failure mechanism of thin composite laminates under low-velocity impact and compression-after-impact (CAI) loading conditions. Four levels of impact energy were included in the test matrix. Delamination induced by low-velocity impact was captured using ultrasonic C-scan, and a three-dimensional (3D) digital image correlation (DIC) system was employed to measure full-field displacement during the CAI tests. Infrared thermography was also used to online monitor the thermal field variation of the test specimen during the impact and CAI process. The cross sections of typical tested specimens were inspected using an optical microscope and a scanning electron microscope (SEM). A 3D damage model that considers both interlaminar and intralaminar damage was proposed to study the complex damage and failure mechanism. Excellent correlation was obtained between the experimental results and the numerical results. The experimental results obtained from various tests and the results from the numerical simulation were combined to provide a new and deep insight of damage evolution and failure mechanisms under low-velocity impact and CAI loading conditions.


ABSTRACT: Experimental and numerical approaches are used to investigate the effect of impact location and different external patch configurations on the low-velocity impact behaviors of repaired CFRP laminates. Various external patches with different thicknesses (number of layers) and stacking sequences are considered and those patches are used to repair single side of the damaged laminate plates to improve the impact-resistance. To predict the damage initiation and progression of the repaired CFRP laminates under impact loading, a continuum damage mechanics (CDM) model that combines 3D Hashin damage criteria and cohesive zone model (CZM) is proposed. The corresponding drop-weight impact tests are conducted to experimentally obtain the impact response such as impact force and energy. Numerical impact simulations have been performed to study the effect of impact location during the low-velocity impact behaviors of repaired structures. Parametric studies of patch thickness and stacking sequence are also carried out using the low-velocity impact simulation to analyze their effect on the impact-resistance. Finally, this study provides an optimization cafeteria to identify the important design parameter to perform external patch repair based on the simulation results.


ABSTRACT: Present study aims to investigate the influence of material uncertainties on vibration and bending behaviour of skewed sandwich FGM plates. Reddy's higher order shear deformation theory has been employed to model the displacement field. Variational approach has been used to derive the governing differential equations. Effect of material uncertainties in the formulation have been incorporated using first order perturbation technique (FOPT). An efficient stochastic finite element formulation (SFEM) have been used for
the calculation of first and second order statics of natural frequency and transverse deflection. Validation of the results have been performed with the help of available literature and separately developed Monte Carlo formulation (MCS) algorithm. A large number of examples have been solved to quantify the effect of uncertainties on the vibration and bending characteristics of functionally graded skew sandwich plates.


ABSTRACT: Low velocity impact behaviour of laminates made of different reinforcements and matrices was studied in this paper. Impact tests were carried out up to penetration and at increasing energy values on glass fibre reinforced phenolic resin laminates, with different configurations (quasi-isotropic and orthotropic) and thicknesses, in order to correlate the indentation depth with the impact energy. Impact results obtained on basalt fibre reinforced epoxy resin laminates with different thicknesses were compared too. The stacking sequence of the glass fibre specimens was found to have no influence on the penetration energy but revealed lower indentation for the quasi-isotropic ones, under the same impact energy, for all the thicknesses tested. Moreover, basalt laminates showed lower indentation depths, compared to the data from this research and present in literature on other material systems. Finally, the results from the impact tests were used to validate existing semi empirical laws for the evaluation of the indentation and the penetration energy, in which the fibre content assumes the most relevant role.


ABSTRACT: The overall goal of the research is to develop a composite simultaneously able to absorb mechanical shocks. In this paper, carbon nanotubes (CNTs) based polymers were used to enhance the wave absorption capacity against shock load. The material consists of an epoxy polymer reinforced with various concentrations of CNTs: 1%, 2% and 4 wt%. An experimental procedure was developed for material characterization. The specimen was sandwiched between two steel bars (incident and transmitted bars), with 20 mm in the diameter. The shock wave was generated by a launching device drives the striker to hit 1 bar, and then the wave propagates throughout the specimen. Two strain gauges were placed on the surface of each bar with 1 m of the distance from the specimen surface. The wave intensity was recorded using a data acquisition system (HBM GEN3i model). The full histories of strain, force and the energy absorption during the shock time were measured. With 4% mass fraction of CNTs, the shock wave intensity was reduced to 33.34% compared to 0% of CNTs. The results show also that the specimen with CNTs is able to absorb high energy impacts.


ABSTRACT: The fire resistance of lightweight sandwich panels (SW) with carbon fibre/epoxy skins and a poly(methacryl imide) (PMI) foam core is investigated in compression under direct application of a severe flame (heat flux = 200 kW m⁻²). A bench-scale test procedure was used, with the sample held vertically. The epoxy decomposition temperature was quickly exceeded, with rapid flash-over and progressive core softening and decomposition. There is a change in failure mode depending on whether the load is greater or less than 50% of the unexposed failure load, or in other words if one or two skins carry the load. At high loads, failure involved both skins with a single clear linear separation across each face. There is an inflection in the failure time relationship in the ~50% load region, corresponding to the time taken for heat to be transmitted to the rear face, along with a change in the rear skin failure mode from separation to the formation of a plastic hinge. The integrity of the carbon front face, even with the resin burnt out, and the low thermal diffusivity of the core, both
play key roles in prolonging rear face integrity, something to be borne in mind for future panel design. Intumescent coatings prolong the period before failure occurs. The ratio of times to failure with and without protection is proposed as a measure of their effectiveness. Apart from insulation properties, their adhesion and stability under severe fire impact play a key role.


ABSTRACT: The effect of filler shape, volume fraction and high temperature cycle on the dynamic compression behavior of rigid particle filled polymer composite is demonstrated by performing experiments using split-Hopkinson pressure bar (SHPB) setup. Two glass filler variants, spherical particles and milled fibers, are reinforced into epoxy matrix upto 10% volume fraction. Two sets of test specimens are prepared; room temperature cured (RTC) and high temperature exposed (HTE) - the ones prepared by subjecting RTC composites to a temperature cycle beyond their glass transition temperature ($T_g$). The yield stress of milled fiber composites which are consistently higher in HTE cases increases with increasing filler volume fraction whereas it remains nearly constant in all spherical particle composites. While RTC materials exhibit strain softening characteristics, the post-yield strain hardening behavior of HTE composites is attributed to the increased cross-link density of epoxy matrix. Debonded fillers and their foot-prints on the crushed surfaces of HTE composites indicate the relaxation of residual stresses, developed at the filler/matrix interface during curing process. Computational analyses suggest that the average matrix stress in composites remains unaffected by the shape of the inclusions whereas comparatively higher inclusion stresses indicate that slender fillers provide better resistance to deformation when compared to the circular ones. Near constant stresses in circular inclusions at low volume fractions is attributed to the large inter-particle separation. Computational results complement experimental observations where the milled fiber composites consistently exhibited higher yield stress when compared the spherical particle counterparts.


ABSTRACT: The study using numerical methods on porous functionally graded (FG) nanoplates is still somewhat limited. This paper focuses on porosity-dependent nonlinear transient analysis of FG nanoplates using isogeometric finite element approach. In order to capture the small size effects, the Eringen's nonlocal elasticity based on higher order shear deformation theory (HSST) are used to model the porous FG nanoplates. Two distributions of porosities inside FG materials are incorporated and defined via a modified rule of mixture. The nonlinear transient nonlocal governing equations under transverse dynamic loads are formulated by using the von Kármán strains and are solved by Newmark time integration scheme to obtain geometrically nonlinear responses. It is indicated that nonlinear transient deflections of the porous FG nanoplate are significantly influenced by material composition, porosity, nonlocal parameters, volume fraction exponent, porosity distributions, geometrical parameters and dynamic load characteristics.


ABSTRACT: Little research on the dynamic instability of nanobeams caused by parametric resonance has been reported in the literature. This paper presents an accurate and analytical method for investigating the dynamic instability of nanobeams based on the nonlocal continuum mechanics. The governing equation of transverse vibration of nanobeams subject to axial dynamic load is derived using the Hamilton's principle and the nonlocal theory to establish the Mathieu-Hill equation of dynamic stability, based on which the equations of critical excitation frequencies are derived by the Bolotin's theory to determine the regions of dynamic instability. Especially, the matrix singularity problem encountered in solving the equations of critical frequencies is overcome by matrix transformation. For verifying the accuracy of obtained regions of dynamic stability, the
dynamic responses of nanobeams are computed by the fourth-order Runge-Kutta approach. By comprehensively exploring the size dependence of dynamic stability of nanobeams, it is found that the size scale parameter influences the regions of dynamic instability mainly through the nonlocal natural frequency and the nonlocal Euler buckling load. As the size scale parameter increases, the nonlocal natural frequency and the nonlocal buckling load decrease, which leads to the reduction of the value and bandwidth of critical excitation frequencies. Moreover, the size effects are found to decrease with an increase of length of nanobeam.


ABSTRACT: The main purpose of this paper is to provide a new semi analytical method to analyze the free vibration of functionally graded porous (FGP) cylindrical shell with arbitrary boundary restraints. According to the distributions of porous along thickness direction of the structure, two typical types of symmetric and non-symmetric porosity distributions are performed in this paper. The formulations are established on the basis of energy method and first-order shear deformation theory (FSDT). The displacement functions are expressed by unified Jacobi polynomials and Fourier series. The arbitrary boundary restraints are realized by penalty method. The final solutions of FGP cylindrical shell structure are obtained by Rayleigh–Ritz method. To sufficient illustrate the effectiveness of proposed method, some numerical examples about spring stiffness, Jacobi parameters etc. are carried out. In addition, to verify the accuracy of this method, the results are compared with those obtained by FEM, experiment and published literature. The results show that the proposed method has ability to solve the free vibration behaviors of FGP cylindrical shell.


ABSTRACT: Honeycomb sandwich structures are widely employed in the engineering field, due to their light weight, strong rigidity and high strength. In this study, the bending resistance performance of the honeycomb sandwich panel with ceramic tile face-sheet (short as ceramic sandwich) was investigated through three-point bending experiments. Their differences between the present ceramic sandwich and the conventional ones were reported and discussed in terms of deformation mode, load-deflection history and bending resistance. As the experiments turned out that differing from the conventional sandwich panel, the present ceramic one performs different collapse modes when undergoing 3-point bending load. The results demonstrated that the bending behavior of the present ceramic sandwich was largely promoted due to the ceramic tile face-sheet. Besides, the mechanical influence of the ceramic tile face-sheet and the cell edge length of honeycomb core were determined. These achievements pave a way of designing composited superb bending resistant sandwich structures.


ABSTRACT: The transient thermoelastic behavior of functionally graded graphene platelets reinforced composite (FG-GPLRC) spherical shells under thermo-mechanical loadings is studied based on the Lord-Shulman thermoelasticity theory, which includes the coupled as well as the nonlinear terms. The problem formulation is so prepared that both types of commonly used FG-GPLRC in the literature (i.e., multilayer FG-GPLRC, for which the material properties vary in a layerwise or piecewise continuous manner and those with continuously varying material properties) can be analyzed. The modified Halpin-Tsai micromechanical model, rule of mixture and a newly introduced micromechanical model are employed to estimate the effective thermo-mechanical properties of FG-GPLRC shells. The governing equations are discretized in the spatial domain using the layerwise differential quadrature method (LW-DQM). Then, a novel multi-step time integration scheme based on non-uniform rational B-spline (NURBS) in conjunction with Newton-Raphson algorithm are
employed to solve the resulting system of nonlinear ordinary differential equations iteratively. In addition, the Laplace transform is employed to obtain the solution in the time domain. The method is validated by performing the convergence study and comparing the obtained results with available solutions in the limit cases. Afterward, the effects of the GPL distribution pattern, GPLs weight fraction and dimensions ratios, the shell thickness-to-outer radius ratio and suddenly applied thermo-mechanical loadings on the thermoelastic behavior of FG-GPLRC spherical shells are investigated. The results show that adding a very small amount of GPLs into polymer matrix significantly increase the shell stiffness and heat wave speed, and considerably changes the temperature and displacement distributions of the FG-GPLRC spherical shells.


ABSTRACT: A well-posed stress-driven mixture is proposed for Timoshenko nano-beams. The model is a convex combination of local and nonlocal phases and circumvents some problems of ill-posedness emerged in strain-driven Eringen-like formulations for structures of nanotechnological interest. The nonlocal part of the mixture is the integral convolution between stress field and a bi-exponential averaging kernel function characterized by a scale parameter. The stress-driven mixture is equivalent to a differential problem equipped with constitutive boundary conditions involving bending and shear fields. Closed-form solutions of Timoshenko nano-beams for selected boundary and loading conditions are established by an effective analytical strategy. The numerical results exhibit a stiffening behavior in terms of scale parameter.


ABSTRACT: A reliability-based design optimization (RBDO) methodology is first proposed to simultaneously optimize material and thickness distribution of multidirectional functionally graded (MFG) plates for compliance minimization under uncertainties of design variables and system parameters. The modified sequential optimization and reliability assessment (MSORA) method is integrated into the recently suggested adaptive hybrid evolutionary firefly algorithm (AHEFA) to release a novel RBDO approach which is the so-called MSORA-AHEFA. The MSORA is refined from its original for computational cost savings by eliminating the iterative process of finding most probable points (MPPs). An isogeometric multisurface design (IMD) approach is presented to form two separate non-uniform rational B-spline (NURBS) surfaces via the refinement strategy. In which, a coarser NURBS one is employed to define design variables of the ceramic volume fraction and axis coordinate of the top side coincidently assigned at each of control points. A finer analysis NURBS one constructed by the isogeometric analysis (IGA) and a generalized shear deformation theory (GSDT) is used for bending analyses of MFG plates with arbitrary thickness. Applying such two separately defined surfaces dramatically lessens the number of design variables and the computational cost in optimization problems, yet still manifesting optimal profiles properly. Meanwhile, mechanical behavior of the plate in analysis ones is precisely simulated as well. For the validation of the suggested MSORA-AHEFA, its results for the benchmark welded beam are compared with those of formerly published work. Several numerical examples regarding RBDO of MFG plates are then executed to attest the effectiveness of the current paradigm.


ABSTRACT: This paper presents a unified theory of yield and failure criteria for unidirectional polymer-matrix composites (UD PMCs). This interactive unified theory considers the effect of normal stress on the shear strength by introducing a coupling term (math). The coefficient of the coupling term is an empirical value and equals to 0.2. The predictions of the unified theory are well agreeable with present and existing experiments.
Furthermore, Tao theory has been improved by adding the limiting condition that the ratio of compressive strength to shear strength should be greater than two.


ABSTRACT: The size-dependent bending behavior of nano-beams is investigated by the modified nonlocal strain gradient elasticity theory. According to this model, the bending moment is expressed by integral convolutions of elastic flexural curvature and of its derivative with the special bi-exponential averaging kernel. It has been recently proven that such a relation is equivalent to a differential equation, involving bending moment and flexural curvature fields, equipped with natural higher-order boundary conditions of constitutive type. The associated elastostatic problem of a Bernoulli-Euler functionally graded nanobeam is formulated and solved for simple statical schemes of technical interest. An effective analytical approach is presented and exploited to establish exact expressions of nonlocal strain gradient transverse displacements of doubly clamped, cantilever, clamped–simply supported and simply supported nano-beams, detecting thus also new benchmarks for numerical analyses. Comparisons with results of literature, corresponding to selected higher-order boundary conditions are provided and discussed. The considered nonlocal strain gradient model can be advantageously adopted to characterize scale phenomena in nano-engineering problems.


ABSTRACT: The aim of this study is to estimate the mechanical behavior of cured draped fabric structures that have experienced macro and microscopic deformations. The effect of crimp angle variation of tows on compressive properties was considered to evaluate the exact failure behavior of the draped composite structures. Empirical formula for tow modulus degradation was suggested in terms of shear angle (or crimp angle) of the fabric composite. By using the suggested modulus degradation algorithm, the local mechanical properties of the draped fabric hemisphere were predicted, and the corresponding failure mode under compression was successfully estimated.


ABSTRACT: The vibration and stability analyses of functionally graded (FG) reinforced porous plates with piezoelectric layers under supersonic flow are investigated. The plate has a FG core reinforced by nanocomposite graphene platelets (GPLs) which surrounded by two piezoelectric layers. The GPLs are distributed thorough the thickness direction both uniformly and non-uniformly. The first-order shear deformation plate theory (FSDT) and first-order piston theory are applied to analyze the stability of FG porous plates. Using Hamilton's principle and Maxwell's equation, the governing equations of motion as well as electrical and mechanical boundary conditions are obtained. Applying the Galerkin approach, the partial differential governing equations are converted to the ordinary differential equations. The numerical results show that the flutter aerodynamic pressure and natural frequencies decrease as the porosity coefficient increases. Besides, the symmetric porosity distribution together with GPL pattern A predicts the highest flutter aerodynamic pressure and natural frequencies. Also, the best efficient way to increase the stability region is considering GPL pattern A, with dispersing more GPLs fillers near the top and bottom surfaces of FG porous plate along with symmetric porosity distribution. Furthermore, FG porous plate enclosed by piezoelectric layers in open circuit condition predicts higher flutter aerodynamic pressure and natural frequencies than similar plate in closed circuit condition.
ABSTRACT: As a novel class of weight-efficient engineering materials, the functionally graded porous (FGP) beam structures have great potential value. However, the current research on it is relatively small. Based on this research status, the aim of this paper is establishing a unified analytical model to study the vibration behavior of moderately thick functionally graded porous deep curved and straight beam with general boundary conditions. The first-order beam theory which considering the influence of shear deformation, inertia rotary and deepness term are adopted in the formulation. The theoretical solution model is obtained by means of modified series solution which core soul is using the modified Fourier series including a standard cosine Fourier series with two auxiliary terms to expand the admissible function. This fact gives the opportunity to derive the exact solution for FGP beam with general boundary conditions by utilizing a reasonable spring stiffness value at both ends. A series of numerical examples show that the current model has superior convergence characteristics, computational accuracy and stability. On this basis, a series of innovative results are also highlighted in the text, which may be providing basic data for other algorithm research in the future.


ABSTRACT: Given that the thermal stresses mainly at the interface between two different materials are the significant factors of failure of the laminated composite structures, there is an enhanced request to replace laminated composite structures by structures made of micro-composite materials exhibiting the properties of continuously nonhomogeneous continua. In addition to elimination of interface discontinuities, the functional gradation (FG) of material coefficients brings new phenomena in bending of FGM plates as compared with homogeneous ones. There are known coupling effects between the in-plane deformations and bending modes even in plates subjected to stationary mechanical loadings. Another coupling can arise between thermal and mechanical fields in thermoelasticity. In the classical thermoelasticity, the heat conduction is described by the parabolic PDE when the temperature change propagates with infinite velocity. Much more realistic is the non-classical treatment with wave propagation of heat. In this paper, the unified formulation for bending of FGM plates under transient thermal loads is developed within the generalized thermoelasticity with taking into account the assumptions of the Lord-Shulman theory of thermoelasticity and the assumptions of the Kirchhoff-Love theory as well as the 1st and 3rd order shear deformation plate bending theories. Moreover, we can study various coupling effects by changing the parameters of functional gradations of particular material coefficients in numerical simulations. For numerical solution, the strong formulation is developed with meshless approximation of spatial variations of field variables. The time integration is carried out by the Wilson time stepping technique.


ABSTRACT: The attention of the present work is focused on the energy absorption and transformation of carbon fiber reinforced polymer (CFRP) composites under low velocity impact. Moreover, the viscoelastic behavior of composites was explored by observing the changes of dent depths via a micrometer and 3D microscope. In addition, the residual strengths of CFRP specimens were investigated by the compression after impact (CAI) test. The results show that more than 88% of impact energy was absorbed by the CFRPs through reversible deformation, irreversible damage and viscoelastic behavior. The impact damage threshold value and the maximum allowable deformation of the CFRP laminates were 9 J and about half of its thickness respectively. The energy is mainly absorbed by deformation when the impact energy was not larger than the
threshold value. The energy dissipated by viscoelastic behavior increased with the increase in the impact energy and even exceeded $1.4 \, \text{J}$ in the case of $21 \, \text{J}$, which was much higher than the kinetic energy when the impact energy exceeded the threshold value. The residual strength of the CFRP laminates was related to the energy absorbed by irreversible damage.


ABSTRACT: In the present study, the dynamic response of functionally gradient (FG) honeycomb reinforced and viscoelastic material (VEM) embedded composite laminate plates with low-speed impact in the hygrothermal environment is investigated. The equivalent effective mechanical properties of the two-phase macroscopic constructed layers are determined according to Hill's generalized self-consistent model. The Reddy's high-order shear deformation theory (HSDT) is employed to evaluate the in-plane displacement variables. By combining the extended Hamilton's principle with the finite element method and adopting the Rayleigh's proportional damping, the global mass, damping and stiffness matrices are determined first. Then, the central displacement of the FG honeycomb reinforced laminate plate is obtained with the aid of the Newmark's method. Next, several key factors affecting the central displacement in the whole impact duration are analyzed and compared, such as the hygrothermal effects, the radius of the impactor and the functionally gradient factor. Moreover, the finite element method (FEM) is applied to obtain the mode parameters and to verify the convergence of our analysis. Finally, the LS-DYNA explicit solution is employed to validate the present results.


ABSTRACT: The polymeric microporous foams with multi-layer cell structure is prepared via the combination of multi-layer hot melt pressing and supercritical carbon dioxide(SCCO) foaming method. The morphology and compression properties of such foams were detailed studied. The results show that nucleation and directional growth of the cells are promoted by the introduction of multi-layer interface into the polymer matrix. When the distance of the multi-layer interface is smaller than the critical nucleation size of the cell, the microcellular foams with uniform, continuously and directionally multi-layer cell structure can be prepared, and the unit cell shape is well controlled. In addition, the compressive properties of the foams with multi-layer cell structure are different in vertical and horizontal loading direction. The compression strength of the multi-layer foam is up to 20.27 MPa and 11.84 MPa in horizontal and vertical loading direction, respectively, which is much higher than that of the uniform foam.


ABSTRACT: We propose 2-D Cosserat type orthotropic constitutive equations for laminated shells for the purpose of initial failure estimation in a laminate layer. We use nonlinear 6-parameter shell theory with asymmetric membrane strain measures and Cosserat kinematics as the framework. This theory is specially dedicated to the analysis of irregular shells, inter alia, with orthogonal intersections, since it takes into account the drilling rotation degree of freedom. Therefore, the shell is endowed naturally with 6 degrees of freedom: 3
translations and 3 rotations. The proposed equations are formulated from the statement of the generalized Cosserat plane stress with additional transverse shear components and integrated over the shell's thickness using the equivalent single layer approach (ESL). The resulting formulae are implemented into the own Fortran code enabling nonlinear shell analysis. Some numerical results are presented to show the performance of the proposed approach.


ABSTRACT: Present study is devoted to study the nonlinear frequency response of single walled carbon nanotubes, SWCNTs, in the case of primary resonance. Based on the nonlocal Euler-Bernoulli beam theory, the nonlinear geometry, magneto-thermal field, residual stress and surface effects on the governing equation of system are taken into account. The Galerkin technique on the basis of trigonometric mode shape functions and multiple scales method are used to solve the nonlinear governing equations. The effects of the different boundary conditions including the simply supported at two ends, S-S, clamped-clamped, C-C and clamped-simply supported, C-S, longitudinal magnetic field, amplitude of excitation, detuning parameter and surface elasticity on the nonlinear primary frequency response are analytically investigated and discussed.


ABSTRACT: In this study, free axisymmetric vibrations of composite circular sandwich plates with isotropic core and orthotropic facings have been studied using first-order shear deformation theory. The thickness of the core is assumed to vary exponentially in the radial direction and the face sheets is treated as membrane of constant thickness. The effect of shear deformation and rotatory inertia in the core has been taken into account. The governing differential equations of the present model have been obtained by applying Hamilton's principle. Chebyshev collocation technique has been used to obtain the frequency equations for the plate when it is clamped or simply supported or free at the edge. The first three roots of these equations have been reported as the natural frequencies for the first three modes of vibration. The effect of taper parameter, facing thickness and core thickness on the frequency parameter has been investigated. Comparison of results for some special cases with published results obtained by other approximate methods has been presented which shows an excellent agreement. Mode shapes for a specified plate for all the three boundary conditions have been plotted.


ABSTRACT: An atomistic-continuum multiscale approach is used to simulate the nonlinear dynamic behavior of simply-supported single layer graphene sheets subject to a uniformly distributed out-of-plane load. The dynamic equation of motion is derived and solved by the Newmark-β method. The evolution of surface morphology and the nonlinear effects in terms of geometrical and material nonlinearities can be captured by iteratively updating the system stiffness. It is found that the natural frequencies of simply-supported graphene sheets almost remain constant when the external load is in a small range. The present solutions are in good agreement with those results obtained from the linear vibration analysis by a semi-analytical method. As the applied load increases continuously, this gives rise to an elongation of graphene to increase the natural frequency. Based on the numerical approach, the surface morphology evolution of graphene can be visualized and explored.

**ABSTRACT:** Out-of-plane buckling at the inside edge of prepreg tows during steering is one of the major drawbacks of the Automated Fiber Placement (AFP) process, limiting the process application and further optimization of the composite layup. This wrinkle formation is significantly influenced by prepreg tack, which is a property of the viscoelastic prepreg-tool interface. In this paper, an experimental AFP study is performed to gain a deeper understanding of the time-dependent growth of wrinkles. Furthermore, a theoretical model accounting for the viscoelastic properties of the interface is presented. For this purpose, a time-dependent buckling model for an orthotropic plate resting on a generalized viscoelastic Pasternak foundation which is subjected to an in-plane loading is developed. Closed-form solutions for the problem representing individual wrinkles are derived. It is shown that the model can capture the growth of wrinkles with time. Finally, important practical implications of the model are discussed.


**ABSTRACT:** In this study, comprehensive investigations of an innovative compositcd cellular structure—Honeycomb cells filled with circular aluminum tubes (HFCT) are conducted by means of numerical simulation and theoretical analyses. A conventional honeycomb was modeled to calibrate the numerical model and a good agreement between numerical and experimental results was achieved. With the calibrated numerical model, extensive comparisons between mechanical performances considering the deformation modes, nominal stress and energy absorption property were carried out in terms of HFCT, conventional honeycomb, and multi-tubes. The interaction effects between internal filler and outside container of HFTC were discussed through the comparison considering representative volume elements (RVE) of three structures. In addition, obvious matching effects in terms of cell thickness were observed between the filler and container of HFCT. Afterward, a theoretical model based on the minimum energy principle which considering the basic fold element of HFCT was constructed to determine the key compression characteristics (half-wave length and nominal plateau stress). Agreement between them was found in plateau stress and geometrical description of post-deformation mode.


**ABSTRACT:** In this work, the modeling of laminated composite and sandwich beams with a generic cross-section is performed through a variable separation approach. For this purpose, the displacement is approximated as a sum of separated functions of the cross-section coordinates y,z and the axial coordinate x. This choice yields to a non-linear problem that can be solved by an iterative process. This latter consists of solving a 2D and 1D Finite Element problem successively at each iteration. Numerical examples involving several representative sandwich and laminated beams are addressed to show the accuracy of the present method. It is shown that it can provide 3D results and capture local effects for various types of cross-section.


**ABSTRACT:** In this study, for the first time, hygro-thermal behaviour of functionally graded (FG) sandwich microbeams based on nonlocal elasticity theory is investigated. Temperature-dependent material properties are considered for the FG microbeam, which are assumed to change continuously through the thickness based on the power-law form. The equations of motion are obtained on the basis of first-order shear deformation beam theory via Hamilton's principle. The size effects are considered in the framework of the nonlocal elasticity theory of Eringen. The detailed variational and finite element procedure for FG sandwich microbeams are presented with a five-noded beam element and numerical examinations are performed. The influence of several parameters such as temperature and moisture gradients, material graduation, nonlocal parameter, face-core-face and span to depth ratios on the critical buckling temperature and the nondimensional fundamental frequencies of the FG sandwich microbeams are analysed. Based on the results of this study, temperature and moisture rise
soften the FG sandwich microbeam and result in the reduction of the critical buckling load and vibration frequency. In addition, the FG sandwich microbeam with a thicker ceramic core can resist higher temperature and moisture gradients.


ABSTRACT: As a first endeavor, the free flexural vibration behavior of doubly curved complete and incomplete sandwich shells with functionally graded (FG) porous core, FG carbon nanotube reinforced composite (FG-CNTRC) face sheets and integrated piezoelectric layers is investigated. The variable radii shells with the three most common types of geometries, i.e., elliptical, cycloid and parabolic, are considered. The system equations are derived based on the general higher-order shear deformation theory and Maxwell's equation. The generalized differential quadrature (GDQ) method is employed to discretize the governing partial differential equations subjected to different boundary conditions. The accuracy and reliability of the approach are verified by comparing the results with the existing solutions in open literature. The effects of porosity parameter and porosity distribution through the thickness direction, carbon nanotube (CNT) volume fraction, different boundary conditions and various shell geometrical parameters on the flexural vibrational behavior of the smart sandwich shell structures are investigated and useful results are presented.

Mohammad Arefi, Elyas Mohammad-Rezaei Bidgoli, Rossana Dimitri, Michele Bacciochchi and Francesco Tornabene (First author is from: Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan 87317-51167, I.R. Iran), “Nonlocal bending analysis of curved nanobeams reinforced by graphene nanoplatelets”, Composites Part B: Engineering, Vol. 166, pp 1-12, 1 June 2019, https://doi.org/10.1016/j.compositesb.2018.11.092

ABSTRACT: The paper presents a large parametric investigation on the bending response of Functionally Graded (FG) polymer composite curved beams reinforced by graphene nanoplatelets resting on a Pasternak foundation. The theoretical framework is based on the First-order Shear Deformation Theory (FSDT) and the nonlocal elasticity theory. The governing equations are obtained by means of the principle of virtual works. Four different patterns are considered to describe the through-the-thickness distribution of the reinforcing phase. The effective Young's modulus and Poisson's ratio are evaluated through the application of the Halpin-Tsai model and the rule of mixture, respectively. The numerical results are presented in terms of some significant parameters, such as the weight fraction and geometrical features of the graphene nanoplatelets, the total number of layers, the foundation properties and the nonlocal parameter. The effect of these quantities on the kinematic and static behavior is discussed.


ABSTRACT: A novel bended wrinkle structure is proposed for layout design in flexible electronics, which is formed by compressive local buckling of the thin film bonded onto a pre-strained, finite-thickness substrate upon release of the pre-strain. The excellent performance of stretchability of this structure, which could be as high as 309%, is shown according to theoretical analyses and validated by finite element method (FEM). Furthermore, the maximum strain of the proposed design is examined to ensure reliability of application devices. Except for the approach to compressibility based on maximum strain analyses, the bended wrinkle structure is taken as a laminate with geometrical imperfections and buckling analyses are conducted to obtain the critical buckling loads, consequently another evaluation criterion for compressibility is established. It is also revealed that the stretchability can be further enhanced by bonding the two ends of the structure to another pre-strained compliant basal substrate, though the pre-strain for the basal substrate is restricted by the compressibility. In the current work, an alternative to existing planar wavellite layout designs is presented and the results obtained offer important design guidelines for future applications.

ABSTRACT: This paper presents a unique theoretical analysis for the multiple failures of in-plane loaded composite laminates containing a through-width delamination. Under the action of the in-plane load, the delaminated laminates undergo first post-buckling failure, then delamination propagation. The anti-penetrating contact effect occurred at the interfaces of the delamination is identified by analyzing the local transverse deformation and is incorporated into the multiple failure stages. Based on von Karman nonlinear geometric relationships, the post-buckling equilibrium path of the delaminated laminates characterized by the in-plane load vs deflection amplitude curves is solved. Expression of energy release rate is derived from variational principles as the summation of the products of shear forces and deflection slopes at the delamination fronts. With the available solutions from post-buckling analysis, threshold to initiate the delamination to propagate is computed according to Griffith fracture criterion and is calculated for different delamination conditions by developing Matlab program. It is found that the delaminated laminate undergoes a consistently macroscopic deflection with microscopic local buckles on the interfaces of the delamination. For all cases, Mode I delamination propagation can never occur due to the contact behavior. Instead, Mode II delamination propagation prevails regardless of the delamination size and position. The analysis presented in this paper accounts for nonlinear geometric deformation, nonlinear constitutive behavior and anti-penetrating interaction effects and identifies multiscale deformation modes involved in different failure mechanisms, thereby demonstrates the latest research idea for the current frontier problems.


ABSTRACT: The dynamic response and design optimization of clamped sandwich panels comprising two aluminum alloy face-sheets and a layered-gradient closed-cell aluminum foam core subjected to air-blast loading were examined in this study. The numerical approach was first validated by blast test results of sandwich panels with monolithic aluminum foam cores, and then the dynamic responses of layered-gradient core sandwich panels were briefly discussed in terms of deflection response and energy absorption. Two surrogate model methods (i.e., response surface method – RSM, and radial basis function – RBF) were adopted to construct objective response functions, and the single-objective adaptive response surface method (ARSM) and multi-objective genetic algorithm (MOGA) were used for the defined optimization problem. The optimization results show the trade-off relationships among the maximum energy absorption, minimum structural mass and minimum deflection, and the advantage of “Pareto front” in such design circumstances. Furthermore, the applicability and accuracy of RSM and RBF agent models in the multi-objective design optimization (MDO) of sandwich panels with layered-gradient foam cores under air-blast loading were also compared and revealed.

A.I.Aria and M.I. Friswell (First author is from: Tabriz University, Department of Mechanical Engineering, Tabriz, Iran), “A nonlocal finite element model for buckling and vibration of functionally graded nanobeams”, Composites Part B: Engineering, Vol. 166, pp 233-246, 1 June 2019, https://doi.org/10.1016/j.compositesb.2018.11.071

ABSTRACT: In this paper, a nonlocal (strain-driven) finite element model is presented to examine the free vibration and buckling behaviour of functionally graded (FG) nanobeams on the basis of first-order shear deformation theory (FSDBT). The proposed beam element has five nodes and ten degrees of freedom. The material properties of the FG nanobeam are assumed to vary in the thickness direction according to the power-law form. The stretching-bending coupling effect is eliminated by employing the neutral axis concept. Governing equations are deduced with the aid of Hamilton's principle. Buckling loads and natural frequencies are calculated for different nonlocal coefficients, boundary conditions (BCs), power-law indices, and span-to-depth ratios. The accuracy of the proposed element is verified by comparing with available benchmark results in the literature.

ABSTRACT: This study concerns a computational model for the postbuckling failure mechanism of composite T-stiffened panels with different bonding methods. The model is then validated against the available experiments and excellent agreement is obtained. Further, the model is used to predict the postbuckling behavior of the stiffeners co-cured, co-bonded, and secondary bonded to the skin, where the new separation phenomenon including margin cohesive failure, local debonding, and global debonding are captured. Moreover, a parametric study is also carried out to investigate the effect of skin-stiffener interface energy and strength on the postbuckling response of composite panels. The numerical results show that the bonding method has little effect on the uniaxial compressive stiffness of the composite T-stiffened panel, but influences the collapse load and failure process by affecting the skin-stiffener interface behavior. Besides, the collapse load and the failure mode are influenced by the ratio of the interface strength to the interlaminar shear strength. The fiber failure location and shape of load-shortening curve are affected by the ratio of the interface energy to the interlaminar fracture energy.


ABSTRACT: Here, the investigation of thick functionally graded graphene platelets reinforced porous nanocomposite curved beams is carried out considering the static bending and elastic stability analyses based on a higher-order shear deformation theory accounting for through-thickness stretching effect. The formulation is general through which different theories can be realized for various structural applications of beam. The governing equations are developed using the Hamilton's principle and are solved by introducing the Navier's solutions. The formulation is firstly assessed considering problems for that results are available in the literature. The performance of various theories is compared here for the selected problems. The structural characteristics of curved beam, constituting of porous metal foam and graphene platelets as nanofillers for reinforcement, are evaluated considering different dispersion patterns for the graphene and porosity, shallowness of the curved beam, thickness ratio, and platelet geometry. The deflection and stress variations in the thickness direction of the beam are also examined.

Ngoc-Duong Nguyen, Trung-Kien Nguyen, Thuc P. Vo, Thien-Nhan Nguyen and Seunghye Lee (First author is from: Faculty of Civil Engineering, Ho Chi Minh City University of Technology and Education, 1 Vo Van Ngan Street, Thu Duc District, Ho Chi Minh City, Viet Nam), “Vibration and buckling behaviours of thin-walled composite and functionally graded sandwich I-beams”, Composites Part B: Engineering, Vol. 166, pp 414-427, 1 June 2019, https://doi.org/10.1016/j.compositesb.2019.02.033

ABSTRACT: The paper proposes a Ritz-type solution for free vibration and buckling analysis thin-walled composite and functionally graded sandwich I-beams. The variation of material through the thickness of functionally graded beams follows the power-law distribution. The displacement field is based on the first-order shear deformation theory, which can reduce to non-shear deformable one. The governing equations of motion are derived from Lagrange's equations. Ritz method is used to obtain the natural frequencies and critical buckling loads of thin-walled beams for both non-shear deformable and shear deformable theory. Numerical results are compared to those from previous works and investigate the effects of fiber angle, material distribution, span-to-height's ratio, and shear deformation on the critical buckling loads and natural frequencies of thin-walled I-beams for various boundary conditions.

J. Daniel Ronald Joseph, J. Prabakar and P. Alagusundaramoorthy (First author is from: Corrosion and Material Protection Division, CSIR-Central Electrochemical Research Institute, Karaikudi, Tamilnadu, India), “Experimental studies on through-thickness shear behavior of EPS based precast concrete sandwich panels with
Effective use of building materials for achieving sustainable construction is of prime importance today due to fast depletion of the natural resources by the construction industries for obtaining raw materials and aggregates. Precast insulated concrete sandwich panels (CSPs) consisting of two reinforced concrete wythes, an Expanded Poly-Styrene (EPS) core and truss-type shear connectors can be considered as an innovative construction material for acting as load bearing walls and floors in building systems. The two wythes are connected by the shear connectors through the EPS core for transferring shear forces (henceforth called as through-thickness shear) between the wythes and achieving composite action in the panels. In this paper, details of experimental studies conducted on small-scale precast CSP specimens under through-thickness shear loading are presented. The major parameters considered in the experimental program were the thickness of EPS core, gap between the wythes (in CSPs without EPS core), presence/absence of EPS core and number of shear connector lines. The effect of the major parameters on the failure mode, through-thickness shear strength, load vs relative displacement (between top and bottom wythes) behavior and load vs strain behavior of the CSPs are presented and discussed. The test results indicate that the through-thickness shear strength and behavior of the CSPs are significantly influenced by the parameters considered. Reduction in thickness of the EPS core and presence of the EPS core improved the through-thickness shear strength of the CSPs.


ABSTRACT: Nanocomposites are preferred over conventional materials because of their superior mechanical properties. Studies need to be carried out, especially on the dynamic response of the composite material. The objective of the present work is to study the dynamic response of Carbon-Nanotube-Reinforced-Polymer (CNRP) material by developing a 3D multiscale finite-element model of the Representative Volume Element (RVE) of the composite material to determine its dynamic properties, in terms of its natural frequencies and damping properties. A computational model consisting of a Single-Walled Carbon Nanotube (SWCN), an interface region and the polymer matrix is constructed for this purpose. The SWCN is modeled as a space frame structure by using the Morse potential and as a thin shell model based on Donnell's Shell Theory. The polymer matrix is modeled with the Mooney-Rivlin strain energy to calculate its non-linear response and the interface region is modeled via van der Waals links based on the Lennard-Jones Potential. The natural frequencies of CNRP are compared with the natural frequencies of the polymer matrix. A relation between damping ratio and natural frequencies is then obtained. Finally, the analysis of harmonic response is conducted to characterize the effects of the SWCN reinforcement in the polymer material.


ABSTRACT: Engineering structures are often subjected to the conditions of cyclic-loading, which onsets material fatigue, detrimentally affecting the service-life and damage tolerance of components and joints. Carbon fibre reinforced plastics (CFRP) are high-strength, low-weight composites that are gaining ubiquity in place of metals and glass fibre reinforced plastics (GFRP) not only due to their outstanding strength-to-weight properties, but also because carbon fibres are relatively inert to environmental degradation and thus show potential as corrosion resistant materials. The effects of cyclic loading on the fatigue of CFRP are detailed in several papers. As such, collating research on CFRP fatigue into a single document is a worthwhile exercise, as it will benefit the engineering-readership interested in designing fatigue resistant structures and components using CFRP. This review article aims to provide the most relevant and up-to-date information on the fatigue of CFRP. The review focuses in particular on defining fatigue and the mechanics of cyclically-loaded composites, elucidating the fatigue response and fatigue properties of CFRP in different forms, discussing the importance of environmental factors on the fatigue performance and service-life, and summarising the different approaches taken to modelling fatigue in CFRP.

ABSTRACT: Innovative honeycomb-based structures have been paid substantial attention in recent years due to their superb mechanical performances and specific functions. The presented study made a comprehensive overview on the development of the innovative honeycomb-based structures in the past two decades, including filled-type, embedded, tandem, hierarchical, auxetics with Negative Poisson's Ratio (NPR), etc. Mechanical performances of these structures were commented with advantages and disadvantages, related on their geometric configurations, mechanical performance and dynamic response, respectively. The challenges as well as future directions were also analyzed. The achievements provide significant guidelines in designing of new generation light-weight honeycomb-based structures.


ABSTRACT: Honeycomb sandwich structures have been extensively investigated in the past decades. A kind of innovative honeycomb sandwich with ceramic tile (ceramic sandwich), was investigated here for its bending behavior by using finite-element model implemented in Abaqus/Explicit code. In our studies, a series numerical simulations of three-point bending were carried out for the ceramic sandwich and conventional aluminum honeycomb sandwich. Their numerical models were validated by experiments. As confirmed that the ceramic tile largely enhances the stiffness of the structure, which contributes a lot to the promotion of the bending resistance capacity. Parametric studies were performed to further investigate the effects brought from the ceramic tile and honeycomb core in terms of changing the thickness of ceramic tile, the thickness of honeycomb wall, the length of honeycomb cells. It was found that the bending performance heavily relay on the geometric configuration of the present sandwich panel. In addition, the ceramic sandwich with reinforced honeycomb core also shows better mechanical behavior in the simulation. All these achievements provide more likelihood of designing composited high-performance sandwich.


ABSTRACT: This study presents a highly accurate, computationally efficient, and novel isogeometric beam element, named as IG-RZT(m), whose formulation is derived by using the kinematic assumptions and “a priori” transverse-shear stress continuity conditions of mixed form of the refined zigzag theory, known as RZT(m). Both the displacement field and geometry of the beam is approximated by using non-rational B-spline (NURBS) basis functions and the element accommodates only four degrees-of-freedom at each control point. Since the present formulation incorporates isogeometric analysis into the RZT(m) theory, it provides various advantages for displacement and stress analysis of thin/thick composite beams such as high-order continuity representation and simple mesh refinement. Furthermore, the utilization of RZT(m) theory within the current beam formulation enables the calculation of nonlinear transverse-shear stress variations through the thickness of highly anisotropic beams without any post-processing. Various numerical analysis are performed to validate the accuracy of the IG-RZT(m) element and its wide range of applicability including beams with a resin-rich damage zone. Comparisons with analytic solutions and high-fidelity finite element models demonstrate the superior accuracy and practical applicability of the present formulation, especially making the IG-RZT(m) element as an attractive candidate for modelling delamination initiation and propagation in composite structures.

Qingping Sun, Guowei Zhou, Haiding Guo, Zhaoxu Meng, Zhangxing Chen, Haolong Liu, Hongtae Kang and Xuming Su (First author is from: Jiangsu Province Key Laboratory of Aerospace Power System, College of Energy and Power Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China), “Failure mechanisms of cross-ply carbon fiber reinforced polymer laminates under longitudinal compression with

ABSTRACT: This study investigates the failure mechanisms of cross-ply laminates subjected to longitudinal compressive loading. A sequence of failure initiation and propagation process is observed based on optical microscopy images of failed specimens. Specifically, the failure process in the cross-ply laminates involves a combination of four failure mechanisms: fiber kinking, delamination, matrix cracking, and fiber/matrix splitting. We find that the kink-bands in the middle 0° plies of the cross-ply laminates most often show a wedge shape and the angle of matrix cracks in the 90° plies is slightly larger than that of pure 90° plies. The reason has been attributed to the constraining effects by the adjacent plies. The next focus of this study is to propose hybrid micro-macro models to more systematically study the failure mechanisms of the cross-ply laminates. We show that these models accurately predict the combined failure modes of the cross-ply laminates and enable us to closely investigate the interactions of different failure mechanisms. More importantly, the hybrid models achieve great computational efficiency compared to full-scale microstructural models. The combined experimental and computational analyses presented here provide a new level of understanding of the kink-band morphology and damage mechanisms in the cross-ply laminates.


ABSTRACT: In the present paper, the prevention of a probable instability after a sudden change in deformation of thin shallow cylindrical composite panels under impulse loads is pursued using embedded super-elastic SMA wires. A novel and practical framework is proposed to analyze these panels according to the precisely determined super-elastic function of the shape memory alloys. The suggested phase transformation algorithm can deal with the existing deficiencies in the modeling of the super-elastic behaviors. The governing equations of motion are obtained based on a matrix form of the energy equilibrium, using Sanders’ shell theory, and including the in-plane and rotary inertia effects. The resulting nonlinear finite element formulation is programmed in FORTRAN language to solve the time-dependent equations by the Newmark-beta numerical time-integration approach. The Budiansky-Roth criterion is used to determine the stability thresholds of the structures by detecting the abrupt and unexpected deformations under the suddenly imposed transverse concentrated load. Effects of imposing loads with different time durations, types, and characteristics, various amounts of the pre-tension, different viscous damping and volume fractions of the SMA are examined in order to determine the dynamic instability strength of the hybrid composite cylindrical shells and the resulting deformations in a fully non-linear solution. The large magnitudes of the pre-tension loads can change the instability performance of the structures under even small loads. In this study, the viscous damping of the host composite panels is ignored in comparison to the energy absorption due to the hysteresis loops of the stress-strain transformation diagrams of the SMA wires.


ABSTRACT: The objective of the research described in the paper was the structural development of a FRP composite bridge deck intended for manufacturing and application in road bridges in Poland, mainly for redecking the deteriorated bridge slabs. The appropriate shape of the sandwich bridge deck panel, its overall structure, constituent materials and the associated cost-effective manufacturing technology were determined following a comprehensive analysis of the similar solutions recently developed worldwide. In the first stage three different small-scale deck panel prototypes were designed and fabricated, assuming the various core configuration of the sandwich structure. Based on manufacturing tests and initial static tests the feasibility and stiffness of all prototypes were assessed to select the optimal deck solution in terms of material, structure and technology. In the second stage of the research a full-size 2.0 × 5.0 m bridge deck panel was designed taking into account the bridge loading according to Eurocode 1. The full-size bridge deck prototype was subjected to a
series of static load tests simulating the relevant load. The tests confirmed the appropriate stiffness and load carrying capacity of the novel FRP bridge deck panel, quite similar to performance characteristics of other FRP bridge decks implemented worldwide. However, the necessary technological and research works on the novel sandwich bridge deck panel in order to increase its safety level were also outlined.


ABSTRACT: In this article, the influence of the multi-walled carbon nanotube reinforcement on the stiffness of sandwich curved panel is examined theoretically via deflection analysis and compared with own experimental data for the verification of accuracy. The nanotube-reinforced sandwich structural panel model is derived theoretically using the higher-order polynomial functions and displacement finite element steps adopted for the numerical solution purpose. The structural stiffness values are measured from the deflection resistance of the theoretical structural model by computing the structural equilibrium equation with the help of an own customized MATLAB code. Firstly, the numerical solution accuracy and the corresponding reliability of the present solutions are cross-checked through the element sensitivity including the comparison test. Further, the multi-walled carbon nanotube reinforced sandwich plate is fabricated for the required experimentation including the mechanical as well as the material characterization. Finally, the validity of theoretically predicted deflection data of sandwich structure demonstrated by comparing with the own experimental results. In addition, the effect of various design parameters on the stiffness behavior of the own fabricated sandwich construction is computed using the proposed theoretical model and discussed in detail.


ABSTRACT: This study investigated the damage and failure mechanism of composite laminates under low-velocity impact and compression-after-impact (CAI) loading conditions by numerical and experimental methods. Ultrasonic C-scan, DIC and SEM methods were combined to give a new and deep insight of damage evolution and failure mechanisms in composite laminates. A novel three-dimensional damage model based on continuum damage mechanics was developed to investigate the impact and CAI behavior with consideration of both interlaminar delamination damage and intralaminar damage. The maximum-strain failure criterion and an improved three-dimensional Puck criterion, which was physically-based, were employed to capture the initiation of fiber and matrix damage respectively and a bi-linear damage constitutive relation was used for characterization of damage evolution. The interlaminar delamination damage was simulated by the interfacial cohesive behavior. Good correlation between numerical and experimental results demonstrated the effectiveness and rationality of the proposed numerical model. The effects of impact energy level and multiple impacts were discussed.


ABSTRACT: Split Hopkinson Pressure Bar is one of the main methods used to characterize the dynamic behaviour of composite materials. In this study, we performed several impact tests for unstitched (2DWC) and stitched (3DWC) woven composites in order to obtain a reliable comparison between dynamic properties of these materials. On the other hand, an energetic study was carried out during these tests to draw up the energy balance and to quantify the energy dissipation. The impact energy is the kinetic energy of the striker bar and it is the total energy quantity available at the beginning. At the interface bar/sample, some of this energy is absorbed by the specimens and can cause plastic deformation or damage in a different form, which can lead to heat generation. The remaining energy corresponds to the reflected and transmitted energy and can be determined from the measured deformation profile. The test results shows that stitch reinforcement can increase
resistance in comparison with the standard composite. Moreover, the existence of Z-fibres made the fracture more complex and caused several characteristic phenomena, so that the required fracture energy for crack propagation was increased. Stitching does not improve the damage initiation strength but significantly prolongs the duration of the crack propagation phase.


ABSTRACT: The stochastic stability of parametric vibrations of an isolated symmetric cross-ply laminated plate system is investigated in this paper. The mechanical model of the plate system is given as a symmetric cross-ply laminated plate viscoelastically connected with two additional thin plates in order to satisfy necessary isolation (mechanical, thermal, acoustical, etc.) or structural requirements. Several important applications of the model are given in the introduction of the study. The investigated model is new and the adapted procedure is based on the analytical determination of the variable stability conditions as a consequence of the plate system being under the influences of the in-plane stochastic forces. The dynamic equilibrium equations are derived on the basis of the first-order shear deformation theory for laminated plates and Kirchhoff-Love plate theory for thin external plate-isolators. The stochastic stability of the coupled system, under parametric excitation of white noise, is investigated analytically through the moment Lyapunov exponents and Lyapunov exponents. The system of stochastic differential equations of motion is decoupled by using the contact transformation method. Then an intensive analytical procedure is continued through the perturbation method which is used in order to obtain the explicit asymptotic expressions for these exponents for the class of problems with three-degrees-of-freedom stochastic systems. The moment, almost-sure stability boundaries and critical excitation are presented and discussed for varying system parameters. The influences of the laminated plate parameters, damping coefficients and spectral density are taken into consideration in numerical examples. It is shown that thin plate-isolators could improve stochastic stability performances of composite laminated plates.


ABSTRACT: Carbon hollow microspheres with a uniform mesoporous shell (PCHMs) were designed and fabricated using a template-assistant method followed by a pyrolysis-etching process. Through tuning the pyrolysis temperature, PCHMs with various pore size and shell thickness can be obtained. In particular, the PCHMs carbonized at 650 °C (PCHMs-650) are composed of a mesoporous shell (thickness: 52 nm) and an interior void of 153 nm, endowing the materials with large surface area of 925.9 m/g. The unique core-shell structure generated by carbon shell and void core is critical for the attenuation capability of EM energy. The composites containing 20 wt% PCHMs-650 exhibit favorable microwave absorbing performance with the minimum reflection loss (RL_{min}) of −39.4 dB at 3.6 mm. The broadest effective absorption bandwidth (EAB) can extend to 5.28 GHz (9.68–14.96 GHz) at only 2.6 mm. It is believed that PCHMs can be used as a promising absorber with lightweight, impressive bandwidth and strong absorption efficiency.


ABSTRACT: This work studies the agglomeration effect of continuously graded single-walled carbon nanotubes (SWCNTs) on the vibration of SWCNTs/fiber/polymer/metal laminates cylindrical shell. The strain-displacement relations are applied according to the Kirchhoff Love's first approximation shell theory, whereas the dimensionless frequencies of the structure are obtained by means of the beam modal function model. Fiber,
carbon nanotubes (CNTs), polymer matrix and metal are four phases constituting the agglomerated CNTs/fiber/polymer/metal laminate (CNTFPML) cylindrical shell. In the first step, we introduce the CNTs randomly within the matrix, such that the volume fraction can be assumed to be continuously graded in the thickness direction. We determine the effect of the CNTs agglomeration on the elastic properties of CNT-reinforced composites, by means of the Eshelby-Mori-Tanaka approach here applied on an equivalent fiber. In the second step, the fiber is introduced as reinforcement phase in the CNT-reinforced composite. Finally, the adhesive fiber prepreg is combined with the thin metal layers. Thus, we study the sensitivity of the vibration behavior of the cylindrical shell to the following input parameters, namely: the CNTs agglomeration and distribution, the mass and volume fractions of the fiber, the boundary condition and lay-ups.


ABSTRACT: Lightweight sandwich panels with composite facesheets and foam core have high impact energy absorption capability and are widely employed in multifunctional applications such as aircraft and marine structures. The dynamic behaviour of sandwich panels is typically studied for impact loading at normal angle of incidence but the structures are more frequently loaded at some oblique angle or with a complex tri-dimensional trajectory in real engineering situations. The damage area and damage modes for these trajectories are significantly different and it is not sufficient to study only normal impacts. There are well established experimental protocols for normal or oblique impact tests using devices like the drop tower, but impacts with complex trajectory are difficult to characterise experimentally. In this paper, a Gough-Stewart platform with six degrees of freedom has been modified to develop an original tri-dimensional impact device called Hexapod. The trajectory is defined to an impactor attached to the seventh jack of the Hexapod to study the response of sandwich plates to impact loading with complex trajectories. The applicability of the newly developed device is demonstrated by studying parabolic impact with different trajectories on sandwich plates with Kevlar facesheets and Rohacell foam core. The time history of vertical and horizontal components of force is measured using tri-axial load cell and strain history is obtained from Digital Image Correlation of a high speed camera images. The results of the parabolic impact show the importance of shear behaviour of the foam in the progression of damage in the sandwich panels. Additionally, the response of the sandwich panels to parabolic impact was simulated numerically using explicit finite element code LS-DYNA. The results of the FE model are compared with experimental data in terms of the force history and strain contours.


ABSTRACT: The present paper examined the buckling, postbuckling and vibration characteristics of pre-buckled and post-buckled laminated CNT reinforced composite (CNTRC) cylindrical shell panel made up of single walled carbon nanotubes (SWCNTs) and isotropic matrix. The effective material properties of CNTRC panel are computed using extended rule-of mixture (ROM) method. Higher order shear deformation theory (HSDT) with von Kárman type of nonlinearity is adopted to model the CNTRC cylindrical shell panel. Four different boundary conditions are considered. Besides uniform loading, different types of non-uniform in-plane load distribution such as triangular, trapezoidal, parabolic and partial edge loadings are considered. The internal stress distribution within the shell panel due to applied non-uniform loadings is evaluated by prebuckling analysis. Subsequently, via Hamilton's principle the governing partial differential equations of CNTRC laminated cylindrical shell panel are derived. Employing Galerkin's method and by neglecting the inertia terms the partial differential equations are reduced to a set of non-linear algebraic equation for the static problem. However, for dynamic problem the partial differential equations are converted to a set of ordinary differential equations. Beside parametric study the obtained numerical results from the present semi-analytical study illustrates the effects of CNT volume fraction, CNT dispersion profile, non-uniform load distribution and boundary conditions on the stability and vibration characteristics of CNTRC cylindrical panel.
ABSTRACT: In this paper, the free vibrations of functionally graded porous (FGP) rectangular plate with uniform elastic boundary conditions is investigated by means of an improved Fourier series method (IFSM). It is assumed that the distributions of porosity are uniform or non-uniformly along a certain direction and three types of the porosity distribution are considered, among which material property of two non-uniform porous distributions was expressed as the simple cosine. The size of the pore in a rectangular plate is determined by the porosity coefficients. Using the first-order shear deformation theory (FSDT), the energy expression of FGP rectangular plate is created. In order to obtain the admissible function of displacement for functionally graded porous rectangular plate, the IFSM is employed. Then, the Rayleigh-Ritz method is used to solve coefficients in the Fourier series which determine natural frequencies and modal shapes. Convergence and comparative research are performed to prove the convergence, reliability and accuracy of the current method. On this foundation, some new results covering the influence of the geometrical parameters subject to classical and elastic boundary condition are presented, and the parametric studies are also investigated in detail, which can provide a reference for future research by other researchers.


ABSTRACT: A new analytical modelling method for the study of low-velocity impact response in honeycomb sandwich panels with metallic face-sheets is proposed by using Hamilton's principle. A modified Lagrange's function for this model is then proposed by extending the application of Hamilton's principle from elastic bodies to face-sheets with plasticity. The internal physical mechanism in the system is proved to be reasonable by comparing the energy converting history with published data. This study advances the understanding of the role of face-sheet plasticity in low-velocity impact response of honeycomb sandwich panels by having the ability to incorporate either the energy absorption from elastic deformation or the energy dissipation from plastic deformation of the face-sheet depending on the severity of the damage state in the dented region. The predicted maximum deflection and impact force history are compared with published experimental and finite element results, and lower and upper bounds of the maximum dent depth are obtained.


ABSTRACT: The addition of carbon nanotubes (CNTs) in natural fibre based hybrid composites as filler to enhanced low velocity impact (LVI) and compression after impact (CAI) properties of composites are not explored by researchers in literature. In this study, we examined the effect of using multi-walled carbon nanotube material (MWCNT) as nanofillers in LVI followed by ultrasonic wave propagation imaging (UWPI) to visualize the impacted damage and CAI properties of bamboo/glass fibre hybrid composites. Hybrid composites containing 0.5% weight fractions of CNTs were compared with the control hybrid composites. The experimental results revealed that adding CNTs into the hybrid composites show less energy absorption, improved peak force, and increased deflection at maximums of 9.21%, 36.23% and 26.06% respectively in terms of LVI properties. Furthermore, smaller damage size was detected by non-destructive approach for CNTs/hybrid composites as compared to the controls. A maximum of 23.67% increment on CAI strength obtained by addition of CNTs into hybrid composites. We concluded that addition of CNTs into bamboo/glass hybrid composites improved impact and after-impact properties.

ABSTRACT: To improve the anti-blast ability of sheet molding compound (SMC) protective structure, basalt fiber reinforced polymers (BFRPs) are applied to strengthen SMC and improve its stiffness and strength. To simultaneously guarantee the overall and local rigidities, the panel adopts hierarchical orthogrid-stiffened structure. Explosion experiments were carried out to reveal the blast resistance of the BFRP reinforced SMC door. With much lighter mass, the BFRP-SMC protective door exhibits excellent anti-balst ability and would be an ideal substitute for metallic or concrete protective doors. Equivalent method based on identical volume and mode superposition was adopted to build dynamic theory of blast-loaded hierarchical stiffened panels. Equivalent static load method was adopted to predict the maximum displacement of the blast-loaded panel. These two methods are reliable and provide simple ways to design hierarchical stiffened composite protective structures.


ABSTRACT: Porosity of functionally graded materials (FGMs) is usually aroused by fabrication defects. It had been proven that the porosity has a significant influence on the static responses of their structures, but the effects of porosity on buckling behaviors are still worth investigating. To reveal these effects, the thermal-mechanical coupling buckling issue of a clamped-clamped porous FGM sandwich beam is investigated in this paper by employing the high-order sinusoidal shear deformation theory. The modified Voigt mixture rule is used to approximate the temperature-dependent material properties of porous FGMs. The physical neutral plane of FGM sandwich beams is taken into account to reflect the actual condition of the structures and simplify the calculation. The thermal environments are considered as uniform, linear and nonlinear temperature rises, and both the temperature-independent and temperature-dependent material properties are discussed in order to justify the importance of the thermal-mechanical coupling effect. An iterative algorithm is used to solve the thermal-mechanical coupling critical buckling temperature. The present theoretical results are verified by comparing with the literature and ABAQUS results, and the effects of porosity, the physical neutral plane, gradient index, material temperature dependence, sandwich structural parameters are discussed. Results show that for buckling issue excluding the pre-buckling deformation effect, considering either the physical neutral plane or the geometrical middle plane of FGM beams would produce alike critical buckling temperatures. With the rise of porosity, the critical temperature increases greatly, which is quite different from the changing rule observed in the buckling issue of inplane-loaded porous FGM plates in literature. The beam with a smaller face-to-core ratio is more sensitive to the change in porosity. Moreover, to improve the thermal buckling load of FGM beams, ceramic constituents with the lower thermal expansion coefficient would be preferred.


ABSTRACT: The strain gradient nonlocal theory is important to include the size effects of nanostructures in classical continuum theory with the corresponding development of computationally efficient numerical tool such as finite elements for the analysis of such structures with different boundary conditions. However, there is no literature on the finite element formulation of second-order strain gradient elastic plates. The weak form of the governing equation of motion of the Kirchhoff nanoplate using second-order positive/negative strain gradient nonlocal theories requires C1 continuity of transverse displacement. In this paper, a new computationally efficient nonconforming finite element formulation for the modelling of nanoplates using second-order positive/negative strain gradient nonlocal theories is presented. The performance of the developed finite element is compared with conforming finite element for rectangular isotropic Kirchhoff nanoplates with different boundary conditions. Analytical solution for static bending, free vibration, and buckling under biaxial in-plane compressive loading are also obtained for rectangular all edges simply supported isotropic Kirchhoff
nanoplate for the comparison purpose. The nonconforming element is found to be computationally more efficient than the conforming element with better accuracy and convergence rate. The negative strain gradient model predicts results matching with the experimental results available in the literature.


ABSTRACT: Bending analysis of a sandwich plate is studied in this paper based on first order shear deformation theory and nonlocal strain gradient theory. The sandwich nanoplate is including a porous core and two piezomagnetic facesheets. It is assumed that nanoplate is resting on Pasternak's foundation. Power law function is used to describe change of porosity along the thickness direction. To account size dependency, nonlocal strain gradient theory is employed to predict this behavior. The principle of virtual work is used to derive governing equations in terms of primary functions. A nonlocal parameter and a strain gradient parameter are employed to describe both stiffness reduction and stiffness enhancement of nanoplates. The analytical solution is presented to solve seven governing equation using Navier's solution. The numerical results are presented to evaluate the effect of various distribution of porosities, porosity volume fraction, nonlocal and strain gradient parameter, electric and magnetic potentials, geometrical characteristics, and parameters of foundation on the results of problem.

Elsa Piollet, Edith Roland Fotsing, Annie Ross and Guilhem Michon (Primarily from: CREPEC, École Polytechnique, Dep. Mechanical Engineering, P.O. Box 6079, Station Centre-Ville, Montréal, Québec, H3C 3A7, Canada), “High damping and nonlinear vibration of sandwich beams with entangled cross-linked fibres as core material”, Composites Part B: Engineering, Vol. 168, pp 353-366, 1 July 2019, https://doi.org/10.1016/j.compositesb.2019.03.029

ABSTRACT: This article investigates the use of a recently developed fibrous core material to increase vibration damping in sandwich beams. The entangled cross-linked fibre (ECF) material is made of short carbon fibres cross-linked with epoxy resin. Dry friction between fibres provides energy dissipation when the material is deformed. Previous measurements on the material are post-processed to provide a simplified viscoelastic description of the material, for an easier interpretation of subsequent structural testings. Two sandwich beams are compared with reference honeycomb beams: a sandwich beam with an ECF core, and a hybrid beam with a honeycomb core and an ECF insert. Steady-state tests are performed on both types of beams to obtain their frequency responses for different excitation levels, and the corresponding apparent loss factors are computed. The beam with a full ECF core shows an apparent loss factor more than ten times higher than the reference honeycomb beam. The hybrid sandwich beam provides an apparent loss factor four times higher than the reference honeycomb beam. All beams exhibit nonlinear softening responses consistent with a dry friction phenomenon in the material: the resonance frequencies decrease with increasing excitation amplitude, and damping increases then decreases again at very high amplitudes while remaining largely superior to that of the honeycomb beams. Transient impact testings are also presented for a qualitative comparison of the ECF and reference beams, and the ECF beams lead to shorter decay times compared to the reference beams.


ABSTRACT: The present work introduces a numerical approach for the study of the free-edge effects that arise in generic laminated composites with arbitrary geometries. The model is based on the use of a higher-order beam theory that employs only displacement unknowns over the cross-section domain, the so-called Lagrange expansion (LE). This allows for the representation of arbitrary sections of laminated structures through a two-dimensional distribution of mathematical domains, accounting for layerwise (LW) kinematics and high refinements towards the free edges. Subsequently, the finite element method (FEM) is employed to solve the problem along the laminate's length, thus enabling the user to introduce arbitrary boundary conditions. Benchmark solutions of the free-edge stresses in symmetric laminates under extension, bending and twisting are
Mohammad Arefi and Timon Rabczuk (First author is from: Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan, 87317-51167, Iran), “A nonlocal higher order shear deformation theory for electro-elastic analysis of a piezoelectric doubly curved nano shell”, Composites Part B: Engineering, Vol. 168, pp 496-510, 1 July 2019, https://doi.org/10.1016/j.compositesb.2019.03.065

ABSTRACT: Nonlocal higher order electro-elastic bending analysis of a piezoelectric doubly curved nano shell is studied in this paper based on nonlocal elasticity theory and third order shear deformation theory. Nonlocal piezoelectricity relations are used for size-dependent analysis of the piezoelectric structure. One can conclude that combination of important theories such as Reddy's shear deformation theory, nonlocal piezoelectricity theory to a more complicated structure such as doubly curved shells leads to an important and novel work in context of mechanical engineering. The kinematic relations are used based on third order shear deformation theory of Reddy. The doubly curved piezoelectric nano shell is subjected to transverse loads and applied voltage. In addition, the structure is resting on Winkler-Pasternak foundation. The governing equations of nonlocal electro-elastic bending are derived based on principle of virtual work. The nonlocal electro-elastic bending results of doubly curved nano shell are investigated using Navier's method. Influence of nonlocal parameter, applied electric potential, Winkler and Pasternak's parameters of foundation is studied on the mechanical and electrical components of the piezoelectric doubly curved nano shell.


In the above article, published in Volume 156, pages 156–165 of Composites Part B Engineering, some typographical errors (erratum) have been identified in Eqs. (15), (16), (19)–(24) and (34), (36), (37)...


ABSTRACT: The steady state non-linear response of bimodular composite laminated annular sector plates is investigated using the field consistent eight-noded finite element based on the first-order shear deformation theory and Bert's constitutive model. The periodic forced response is obtained using the modified shooting method and arc-length/pseudo arc-length continuation techniques. Within a shooting cycle, the solution of the governing equation is obtained using Newmark's time integration coupled with Newton Raphson method. The effects of bimodularity, geometric nonlinearity, boundary conditions, load amplitude, laminate scheme and sector angle on the response characteristics are presented. Significantly large difference in the peak amplitudes is predicted with and without geometric nonlinearity. The higher harmonic contributions in the steady state displacement/stresses are demonstrated using frequency spectra and phase plane plots. Through the strain energy plots, the participation of even and odd order harmonics is correlated to the quadratic and cubic restoring forces in a cycle. The total number of degrees of freedom for converged results is 805 for CCCC and 865 for CSCS/SCSC plates resulting in a system seldom treated in the literature on nonlinear steady state periodic response and the results presented may serve as reference for validation of approximate solutions.


ABSTRACT: The objective of this work was to prepare a natural fiber reinforced composite product by using nanoparticle technique method. Nanoclay particles were infused into the banana fiber and these modified banana fibers were then reinforced in epoxy polymer composites. A short banana fiber reinforced epoxy polymer composite cylinder was prepared by resin impregnation method, and the compressive, tensile, interfacial and energy absorption characteristics were studied. The properties of nanoclay infused banana fiber...
reinforced composites were compared with alkaline (NaOH) treated and untreated banana fiber reinforced epoxy composites. It was observed that the nanoclay infused banana fiber composites has resulted in 17\%, ~2 times and 43\% improved compressive yield stress, modulus and strength when compared with untreated banana fiber reinforced epoxy composite cylinder. However, nanoclay infusion induces brittleness into the fiber affecting the elongational properties. Tensile, flexural and short beam properties show that the reinforcement effect of nanoclay was higher in flexural and short-beam modes when compared with tensile mode, due to higher level of surface interaction of nanoclay particles in flexural and short-beam modes. About 2 times improved energy absorption properties were obtained in nanoclay infused banana fiber reinforced epoxy composites when compared with untreated banana fiber reinforced epoxy composites. Microscopy examination revealed that the nanoclay infusion in fiber improved fiber-matrix interfacial and load transfer characteristics leading to the higher level of property improvement in nanoclay infused banana fiber reinforced epoxy composites. The outcome of the result suggest that the nano-technique is very much useful and can be simply applied onto the natural fibers to realize the potential application of these materials.


ABSTRACT: In this study, for the first time, a size dependent computational model based on the modified strain gradient theory (MSGT) and higher-order shear deformation theory (HSDT) for free vibration analysis of multilayer functionally graded graphene platelet-reinforced composite (FG GPLRC) microplates is proposed. To capture size effects of microstructures, three material length scale parameters (MLSPs) are considered and used. The effective Young's modulus for each layer of the FG GPLRC microplate is computed according to the Halpin–Tsai model, while the effective density and Poisson's ratio are computed by the rule of mixtures. Four different types of graphene platelets (GPLs) distributions, which are either uniform or functionally graded (FG), are considered. The principle of virtual work is used to derive discretize governing equations which are then solved by an isogeometric analysis (IGA). In addition, thank to continuous higher-order derivatives of NURBS basis functions in IGA, it is suitable for a numerical implementation of the present size dependent model within required third-order derivatives in the weak form. Besides, the present size dependent model can be recuperated into the modified couple stress theory model (MCST) or classical HSDT model when two or all MLSPs in the theory are taken equal to zeros, respectively. The rectangular and circular FG GPLRC microplates with different boundary conditions, distributed types of GPLs and MLSPs are examined to evaluate natural frequencies. Numerical results have shown that the difference of the natural frequency predicted by the MSGT, the MCST and classical HSDT are large when the plate thickness approaches the MLSPs, however, this difference decreases with a rise of the plate thickness.


ABSTRACT: This paper presents an analytical solution for elastic buckling problems of thick, composite prismatic plates subjected to uniaxial or biaxial compressive loads. Based on Reddy's third-order shear deformation theory and the Green-Lagrange deformation measure, the governing equations and natural boundary conditions of the plate are derived using Hamilton's principle, and solved analytically using the Navier and Levy-type solution methods.

A large number of configurations are analyzed, and the effects of geometric and material properties on the buckling of both isotropic and orthotropic prismatic plates, as well as transversely anisotropic sandwich plates, are determined with a reduced computational effort. A comparison with results available in the literature, also determined by considering alternative plate models, shows the accuracy of the proposed approach.

ABSTRACT: The understanding of the damage mechanisms for woven laminate plates under low-velocity impact is challenging as the damage mechanisms at the interface of adjacent layers are dominated by the fibre architecture. This work presents an experimental investigation of the behaviour of woven glass and carbon fibre composite laminates in a matrix of fire retardant resin under low-velocity impact. The performance is evaluated in terms of damage mechanisms and force time history curves. Six impact energy levels were used to test standard plates to identify the type of damage observed at various energy levels. Scanning electron microscopy (SEM) along with C-scans were used to characterise the damage. It has been observed that in woven composites, the damage occurs mostly between the fibre bundles and matrix. As the impact energy increases, the failure involves extended matrix cracking and fibre fracture. Moreover, due to the fibre architecture, both the contact forces between bundles of fibres and stretching of the bundles are responsible for the dominant matrix cracking damage mode observed at the low-impact energy level. As the impact energy increases, the damage also increases resulting in fibre fracture. The experimental evidence collected during this investigation shows that for both the carbon fibre and the glass fibre woven laminates the low-velocity impact behaviour is characterised by extended fibre fracture without a noticeable sudden load drop.


ABSTRACT: Aluminum honeycombs are widely applied in weight sensitive applications, increasing their specific strength and energy absorption capacity are rather important. Thin-walled metallic tube was used to enhance the mechanical properties of aluminum honeycomb and formed a novel tube-reinforced honeycomb structure. Its compressive and three-point bending performances were studied experimentally and numerically. Due to tube filling, the specific compressive strength, elastic modulus and energy absorption have been increased by 16%, 26% and 73%, and the specific bending load and stiffness increased by 42% and 62% respectively. The strengthen mechanism study indicated that the sum of tube and honeycomb caused the increase of compressive properties, and aluminum tube filling changed the stress distribution and expanded the stress concentration region which led to a transformation of bending failure mode. The present reinforcement method will make honeycomb more competitive in light-weight structure applications.


ABSTRACT: This work presents a refined beam model based on the Carrera Unified Formulation for the free-vibration analyses of variable stiffness composite laminate characterized by layers with curvilinear fibers. These models introduce a refined kinematic description over the cross-section to obtain a 3D displacement field. Taylor and Lagrange polynomials have been used to describe the cross-sectional variables that is, equivalent single layer and layer-wise approaches have been considered. Variable stiffness composite materials have been introduced considering a continuous variation of the lamination angle thanks to an ad hoc integration scheme. Extensive validation of the models has been performed including convergence analyses and comparisons with commercial codes. The results obtained using the present models have been compared with those from open literature considering composites with different values of thickness, lamination, and boundary conditions. The results show that the use of refined models is mandatory for the analysis of such structures where complex laminations may create strong mechanical couplings.


ABSTRACT: This paper presents static and dynamic analyses of closed and open cell aluminum foam geometric models using the homogenization technique and the FEA. The RVE models were designed with regard to: the pore size, cell wall and foam porosity of aluminum foam samples. Static analyses of foam cubes were performed in order to obtain the elastic moduli of the analyzed models. The obtained data was afterwards
used for the modal analyses. Two types of models: homogenized beam models and optimized-homogenized beam models; and three types of structures: simple beam, sandwich beam and double sandwich beam were used for these analyses. The purpose of the optimized-homogenized model is to save design and calculation time. The results showed that at lower frequencies the models (homogenized beam and optimized-homogenized beam) reach similar natural frequencies and mode shapes. At higher frequencies the geometric shape and the geometric flaws have a big influence on the results.

ABSTRACT: In this study, energy dissipation characteristics of covalently-bonded stochastic carbon nanotube (CNT) networks are comprehensively studied by means of molecular dynamic simulations. A previously-developed stochastic algorithm is used to generate three distinct numerical specimens which are subjected to two cycles of compression and relaxation for three different compression ratios with varied strain rates. One of the significant findings obtained in this study demonstrates that covalently-bonded stochastic CNT networks exhibit hysteretic stress – strain relationships and dissipate a significant portion of the energy absorbed during compression. Furthermore, it is observed that the hysteretic behavior of the covalently-bonded stochastic CNT network is enhanced by increasing the strain rate. Hence, the amount of energy dissipated by the covalently-bonded stochastic CNT network increases as the strain rate increases.

ABSTRACT: Dynamic stability characteristics of variable stiffness composite plates under periodic in-plane loads are investigated here using a shear-deformable sixteen-node plate bending element. The modal transformation technique is used to reduce the equations of motion for the flexural vibration problem of a rectangular panel into a set of Mathieu-Hill equations. The diagonal and off-diagonal dominance of the parametric coefficient matrix is studied for the representative cases of in-plane loading, i.e., periodic compression/shear in presence or absence of static compression for the isotropic and composite plates. The multi-modal response (participating and accompanying modes) of the shear panels under periodic edge traction is demonstrated through the time history analysis. Then, the method of multiple scales is used to identify the dynamic instability regions corresponding to the simple (single mode flexural vibration) or combination (two mode flexural vibrations) type of resonances in various (isotropic and laminated composite made of straight or curvilinear fibers) shear panels, for which results are not available in the literature.

ABSTRACT: This paper focuses on the dynamics of doubly-curved functionally graded and laminated composite structures with arbitrary geometries and boundary conditions. Integral boundary value problem is obtained following an energy-based approach where the strain energy of the structure is expressed using three-dimensional elasticity equations. The effective properties of functionally graded materials can be described based on Mori–Tanaka or theory of mixtures methods. To simplify the domain of the problem, coordinate transformations are applied to map the curved structure into a straight one; and furthermore, a one-to-one mapping technique is applied to map the (complex) curved geometry to a master geometry in the case of composites with arbitrary geometries. Then, the integral boundary value problem is discretized by means of Gauss–Lobatto sampling and solved using the three-dimensional spectral-Tchebychev approach. In this method, the system matrices are calculated through the exact evaluation of differentiation and integration operations using the derived Tchebychev matrix operators. Finally, if necessary, to impose the essential boundary conditions on the boundary value problem and to assemble multiple layers, the projection matrices approach is used. Various case studies including (i) doubly-curved structures, (ii) doubly-curved laminated composites and (iii) doubly-curved laminated composite structures with arbitrary geometries are analyzed. In each case study, to present the accuracy/precision of the developed solution technique, the predicted (non-dimensional) natural frequencies and mode shapes are compared to those obtained using either a commercial finite element software
and/or to those found in literature. It is shown that the developed three-dimensional spectral-Tchebychev solution technique enables accurately and efficiently capturing the vibration behavior of doubly-curved laminated composite structures having arbitrary geometries under different boundary conditions.


ABSTRACT: The vibrational behavior of bi-directional functionally graded non-uniform Timoshenko nanobeam under linear and nonlinear temperature profiles has been investigated using first order shear deformation theory together with Eringen’s nonlocal elasticity theory. The mechanical properties of beam material are assumed to be temperature dependent and temperature variation is applied across the thickness. The material composition varies according to a power-law distribution in thickness direction and as an exponential function in axial direction. Non-uniformity of beam's cross-section is along thickness and width both. The governing differential equations for such a beam model have been obtained using Hamilton's energy principle and numerically solved for different combinations of clamped, simply supported and free boundary conditions, namely, clamped-clamped, clamped-simply supported, simply supported-simply supported and clamped-free employing generalized differential quadrature method. The effect of temperature profiles, cross-sectional non-uniformity, functionally gradient indices along the thickness and length, slenderness ratio together with nonlocal parameter have been studied on the vibration characteristics of nanobeam for the first three modes of vibration and all the boundary conditions. Results have been validated with published work.


ABSTRACT: The paper investigates free vibration and dynamic responses of smart FG metal foam plate structures reinforced by graphene platelets (GPLs). We then analyze active control of FG metal foam plates with piezoelectric sensor and actuator layers. To provide numerical solution of underlying problems, we develop a computational approach based on a generalized Co-type higher-order shear deformation theory (C-HSDT) polygonal finite element formulation (PFEM), which is suitable for modeling both thick and thin plates. To enhance accuracy of solution, we use in PFEM quadratic serendipity shape functions in combination with a generalized Co-HSDT. The FG core layers are constituted by combining between two porosity distributions and three GPL dispersion patterns distributed along the plate's thickness while two piezoelectric layers are perfectly bonded on the both bottom and top surfaces of host plate. The mechanical displacement field is approximated based on Co-HSDT while the electric potential distribution through the thickness for each piezoelectric layer is assumed to be a linear function. For active control, a constant velocity feedback scheme is employed through a closed loop control with piezoelectric sensors and actuators. The effect of the porosity coefficient, weight fraction of GPLs on the plate's behaviors with various porosity distributions and GPL dispersion patterns are evidently demonstrated through numerical examples.


ABSTRACT: We analyzed the vibration characteristics of single-walled carbon nanotubes (SWCNTs) wrapped with single-stranded DNA (ssDNA) using the finite element method. The SWCNT model was calculated from the 1st-bending mode of 0.98 GHz to the radial breathing mode of 10.2 THz under free boundary conditions. The natural frequency of the SWCNTs was consistent with the well-known Bernoulli-Euler beam theory, and with the experimental relationship between the wave number and diameter of the SWCNTs. Additionally, the vibration modes and conditions for coupling with the 1st-bending mode of the ssDNA-SWCNTs were obtained under vacuum and water conditions.

ABSTRACT: The design of composite members consisting of a tubular column and in-filled conventional concrete has been available and well-defined in the provisions. However, for steel tube members filled with recycled aggregate concrete, there aren't any other special requirements in the current provisions. In this study, the experimental test results are used to model and evaluate the ultimate strength of axially loaded recycled aggregate concrete filled steel tube columns. The test specimens has a length to diameter ratio ranging from 2.0 to 3.5, indicating that they are the stub column and not failing in overall buckling. The proposed model was derived based the technique of gene expression programming. The database utilized contains a total of 97 test results. The predictor variable employed to generate the model are outer diameter, thickness and yield strength of steel tube, length of the column, recycled coarse aggregate replacement ratio, and concrete compressive strength. The experimental data and associated analytical model are examined by four widely used design codes of ACI, Eurocode 4, AIJ, and DL/T. A sensitivity statistical analysis is further conducted to assess the contributions of each parameter affecting the axial capacity. The outcome indicates that the developed model gives reasonable predictions of the axial capacity of recycled aggregate concrete filled circular steel tube stub columns compared to the existing expressions.


ABSTRACT: The nonlinear vibration behavior and dynamic instability of Euler–Bernoulli nanobeams under thermo-magneto-mechanical loads is the main objective of present paper. Firstly, a short Euler–Bernoulli nanobeam is modeled and exposed to an external parametric excitation. Based on the nonlocal continuum theory and nonlinear von Karman beam theory, the nonlinear governing differential equation of motion is derived. Secondly, to transport the partial differential equation to the ordinary differential equation, Galerkin method is applied. Then, multiple scales method, as an analytical approach, is used to solve the equation. At the end, modulation equation of Euler–Bernoulli nanobeams is obtained. Then, to evaluate the dynamic instability of the system, trivial and nontrivial steady-state solutions are discussed. Emphasizing the effect of parametric excitation, for considering the instability regions, bifurcation points are studied and investigated. As a results, it can be observed that the damping coefficient plays an effective role as well as parametric excitation in stability and frequency response of the system.


ABSTRACT: An analytical answer to the natural vibration problem of a composite plate consisted of multi-scale hybrid nanocomposites, is presented here for the first time. In this paper, the constituent material of the structure is made of an epoxy matrix which is reinforced by both macro- and nano-size reinforcements, namely carbon fiber (CF) and carbon nanotube (CNT). The effective material properties like Young's modulus or density are derived utilizing a micromechanical scheme incorporated with the Halpin-Tsai model. To present a more realistic problem, the plate is placed on a two-parameter elastic substrate. Then, on the basis of an energy-based Hamiltonian approach, the equations of motion are derived using the classical theory of plates. Finally, the governing equations will be solved analytically to obtain the natural frequency of the system's oscillation. Afterward, the normalized form of the results will be presented to put emphasis on the impact of each parameter on the dimensionless frequency of nanocomposite plates. It is worth mentioning that the effects of various boundary conditions on the frequency of the plate are covered, too. To show the efficiency of presented modeling, the results of this article are compared to those of former attempts. Numerical results declare that plates fabricated from the hybrid nanocomposites can endure higher frequencies compared with those consisted of conventional composites.
ABSTRACT: The thin-walled polymer liner is widely used to rehabilitate the deteriorated underground pipe. Although the liner is installed close-fitting in the lining procedure, an annular shrinkage gap is inevitable between the liner and the pipe. The grouting technique is commonly employed to eliminate the small gap and often results in a small crown void between the liner and the pipe. Therefore, a pipe-grout-liner system generates. This paper focuses on the structural stability of the pipe-grout-liner system with a crown void subjected to external pressure. It is found that the radially-inward out-of-roundness imperfection results in a single-lobe deformation and the radially-outward out-of-roundness imperfection results in a double-lobe deformation, respectively. The critical buckling pressure is derived and obtained theoretically, and then verified by developing a two-dimensional finite element model. The numerical result shows very close agreement with the analytical solution and other closed-form expressions for both single-lobe and double-lobe cases, respectively. Finally, the effect of the crown void is examined. It is found that the system with a small crown void can sustain the same buckling pressure as the perfectly-confined liner without void. However, a significant reduction of the critical buckling pressure was observed when the crown void is larger than the small size level.

ABSTRACT: The static analysis of Kirchhoff nano plates subjected to uniformly (UDL) and sinusoidally (SSL) distributed load is computed. The strain gradient nonlocal theory has been employed in order to involve the size effects of nanostructures in classical continuum theory. The governing equation of motion of Kirchhoff in weak form are applied to nano plates, involving second-order strain gradient nonlocal theory. Thus, the obtained partial differential equations have an increased order of derivation respect to the classical theory, from the fourth to the sixth. The displacements are carried out following the Navier procedure for simply supported boundary conditions. Isotropic and antisymmetric orthotropic laminates, both cross- and angle-ply are studied, for different layouts involving different material properties. Dimensionless outcomes in terms of transverse displacements, and normal and shear stresses, are given to changing aspect ratio and non local ratio, also making a comparison with the classical theory.

ABSTRACT: Performances of conventional fiber reinforced composites are challenged in thermomechanical loading, when development of interlaminar stresses at the interface becomes the weakest link of the components. Development of functionally graded materials (FGMs) could lead to the reduction of such interlaminar failures, especially at high temperature applications. Therefore, these FGMs have a huge potential for use in many structural applications, particularly under thermomechanical loading. There has been a large number of works already reported on FGM components, starting from manufacturing to stress analysis of such components. Cracks in such FGM components may develop due to variety of reasons during service and need to be addressed while analyzing the performances of such components. This paper reviews the progress made till date on the analysis of structural components made of FGMs with a special emphasis on the analysis of cracked FGM components. In view of the potential use of components made of FGMs in a wide range of applications, it is important to understand the state of the art in this area. This paper thus provides a critical review of works reported in this area with an objective of providing the key challenges and future scopes of development in the direction of analysis of such structure for assessing safety in the presence of cracks.
Mohammed Sobhy and Mohammad Alakel Abazid (Department of Mathematics and Statistics, Faculty of Science, King Faisal University, P.O. Box 400, Hofuf, 31982, Saudi Arabia), “Dynamic and instability analyses of FG graphene-reinforced sandwich deep curved nanobeams with viscoelastic core under magnetic field effect”, Composites Part B: Engineering, Vol. 174, Article 106966, 1 October 2019, https://doi.org/10.1016/j.compositesb.2019.106966

ABSTRACT: Based on the nonlocal strain gradient theory, the effect of an axial magnetic field on the free vibration and mechanical buckling responses of an FG graphene-reinforced sandwich deep curved nanobeam with viscoelastic core embedded in a viscoelastic medium is elucidated in this paper. The curved beam is also assumed to be exposed to axial external compressions. The volume fraction of the constituents of the composite face layers are presumed to be functionally graded through the thickness according to a layer-wise law. The material properties are calculated in the framework of Halpin-Tsai micromechanical scheme. Lorentz magnetic force is deduced employing electro-dynamic Maxwell's relations for a conducting body. According to a refined shear and normal deformations curved beam theory, the motion equations are introduced in the polar coordinates. Analytical solutions are obtained for the natural frequencies and critical buckling load of the viscoelastic sandwich curved nanobeams. By comparing the present results with the available data in the literature, the developed formulations are validated. Furthermore, other several numerical examples are performed to show the effects of different parameters including viscoelastic core thickness, magnetic field, structural and foundation damping factor, opening angle and graphene concentration on the frequency and buckling load of the viscoelastic sandwich curved beams.


ABSTRACT: In this paper, a new effective equivalent analytical approach is presented to compute the global buckling of composite lattice sandwich shells under uniaxial compression based on the first-order shear deformation theory (FSDT). The lattice core was transformed into a solid skin, as the middle skin of the sandwich shell by considering the transverse shear strains and the new force and moment effect analysis on the selected unit cell. The equivalent stiffness of the composite lattice sandwich shells is then calculated by superimposing the stiffness contribution of outer, middle and inner skins. Using the FSDT and Rayleigh-Ritz method, the related eigenvalue equations are solved, and the critical buckling load is obtained. Furthermore, a 3D finite element model is built using ABAQUS software for validation. For various test examples with different slenderness ratio, outer/inner thickness and ply stacking sequence, stiffener thickness and the number of unit cells, the efficiency and accuracy of the presented equivalent approach are confirmed by comparing the obtained results with FE and other work results. It is shown that for thick sandwich shells, the use of FSDT for determining their critical buckling load is necessary, more suitable and can give high computational efficiency.

Phuc Pham Minh (1) and Nguyen Dinh Duc (2)
(1) Faculty of Basic Sciences, University of Transport and Communications, 03 Cau Giay Street, Dong Da, Hanoi, Viet Nam
(2) Infrastructure Engineering Program, VNU Hanoi, Vietnam-Japan University, Luu Huu Phuoc Street, My Dinh 1, Hanoi, Viet Nam


ABSTRACT: In this paper, the stability in a rectangular functionally grade material (FGM) plate with central crack is studied. The plate thickness is changed exponentially following the length of the plate. The properties of the FGM plate are assumed to vary along the thickness direction according to a simple power law distribution. Based on the phase-field theory, the new third order shear deformation plate theory (TSDT) and the finite element method (FEM), the stability of cracked FGM plate is determined. The obtained numerical results are compared with the published articles to ensure credibility. The work also considered effects of changing of the plate thickness ratio, length, crack angle and volume fraction exponent of the functionally graded material on the stability of the plate. Lastly, some visual images of the mechanical instability forms of cracked FGM plates will be introduced.
ABSTRACT: An experimental study of buckling and dynamic response of cenosphere reinforced epoxy composite (syntactic foam) core sandwich beam with sisal fabric/epoxy composite facings under compressive load is presented. Influence of cenosphere loading and surface modification on critical buckling load and natural frequencies of the sandwich beam under compressive load is presented. The critical buckling load is obtained from the experimental load-deflection data while natural frequencies are obtained by performing experimental modal analysis. Results reveal that natural frequencies and critical buckling load increase significantly with fly ash cenosphere content. It is also observed that surface modified cenospheres enhance natural frequencies and critical buckling load of the sandwich beam under compressive load. Vibration frequencies reduce with increase in compressive load. Fundamental frequency increases exponentially in post-buckling regime. Experimentally obtained load-deflection curve and natural frequencies are compared with finite element analysis wherein results are found to be in good agreement.

Mostafa Habibi (1), Alireza Taghdir (2) and Hamed Safarpour (3)
(1) Center of Excellence in Design, Robotics and Automation, School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran
(2) Department of Mechanical Engineering, Qom Industrial University, Qom, Iran
(3) Faculty of Engineering, Department of Mechanics, Imam Khomeini International University, Qazvin, Iran

ABSTRACT: Due to a rapid development of process manufacturing, composite materials with graphene-reinforcement have obtained so much commercially notices in the promoted engineering applications. With this regard, the critical voltage and frequency characteristics of a graphene nanoplatelets (GNP) composite cylindrical nanoshell coupled with the piezoelectric actuator (PIAC) are investigated. The material properties of piece-wise graphene-reinforced composites (GNPRCs) are assumed to be graded through the thickness direction of a cylindrical nanoshell and are estimated based on a nanomechanical model. For the first time, the current study is considering the effects of the piezoelectric layer, GNPRC and size-effects on the natural frequency and critical voltage of the GNPRC cylindrical nanoshell coupled with PIAC. The governing equations and boundary conditions have been developed using minimum potential energy, and have been solved with the aid of generalized differential quadrature (GDQM). In addition, because of the piezoelectric layer, Maxwell's equation is derived. The results show that piezoelectric layer, GNP distribution pattern, length scale parameter and GNP weight function, play important roles on the natural frequency and critical voltage of the GNP cylindrical nanoshell coupled with PIAC. The results of the current study are useful suggestions for the design of materials science, micro-electro-mechanical systems and nanoelectromechanical systems such as nanoactuators and nanosensors.

Mohammad Hossein Jalaei (1) and Huu-Tai Thai (2)
(1) Young Researchers and Elite Club, Islamshahr Branch, Islamic Azad University, Islamshahr, Iran
(2) Division of Construction Computation, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Viet Nam

ABSTRACT: This research is devoted to analyze the dynamic instability of viscoelastic porous functionally graded (FG) nanoplates under biaxially oscillating loading and longitudinal magnetic field using quasi-3D sinusoidal shear deformation plate theory as well as nonlocal strain gradient theory (NSGT). Modified power-law function is developed to show the effective material properties of the porous FG nanoplate that change
uniformly from one surface to another. The motion equations are obtained by employing Hamilton's variational principle. In order to calculate the unstable region of the porous FG nanoplate, Navier as well as Bolotin's methods are utilized. The current theories and formulations are verified by comparing the obtained results with those available in literature. Then, the effects of several remarkable factors like magnetic field, nonlocal parameter (NP), internal damping, power-law index, static load factor, aspect ratio, porosity volume index and length scale parameter (LSP) on the unstable region of viscoelastic porous FG nanoplates are investigated via a comprehensive parametric study which could be utilized as reference results in future research. The numerical results indicated that increasing the porosity volume index, power-law index, internal damping parameter and NP leads to a reduction in the pulsation frequency and thus, unstable region moves to left, whereas magnetic field and LSP have a reverse effect.

Mohammad Hassan Dindarloo (1) and Li Li (2)
(1) Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran
(2) State Key Lab of Digital Manufacturing Equipment and Technology, School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China


ABSTRACT: In this paper, three-dimensional vibrations of carbon nanotubes (CNTs) reinforced isotropic doubly-curved nanoshells using nonlocal elasticity theory based on a new higher-order shear deformation theory (HSDT) is investigated. The considering higher-order shear deformation theory is a combination of sinus and exponential power with cosine function which is one of the most accurate shear deformation theory. One can conclude that combination of important theories such as Reddy's doubly-curved shells theory, nonlocal elasticity theory and higher-order shear deformation theory to a more complicated structure such as doubly-curved shells leads to important and novel work in context of mechanical engineering. The equations of motion and boundary conditions are derived using Hamilton's principle. The equations of motion are solved via Navier-type, closed-form solutions. From the best knowledge of authors, it is the first time that present formulation is used to investigate the vibration of carbon nanotubes reinforced doubly-curved nanoshells based on a new higher-order shear deformation theory. Also, it is the first time that small scale effects are considered in carbon nanotubes reinforced doubly-curved nanoshells made of isotropic materials. The effects of mechanical properties, geometrical properties and the different types of CNTs on the vibration frequencies of doubly-curved nanoshell are investigated. The comparison study is carried out to verify the accuracy of the proposed method. Numerical results indicate that the volume fraction and types of distribution of CNTs have considerable effects on the vibration characteristics of CNTs doubly-curved nanoshells. Presented results for vibrations can minister as benchmarks for future analysis of CNTs doubly-curved nanoshells.

Yong Tao (1,2), Weiguo Li (1,2), Kai Wei (3), Shenyu Duan (4), Weibin Wen (5), Liming Chen (1), Yongmao Pei (6) and Daining Fang (4,6)
(1) College of Aerospace Engineering, Chongqing University, Chongqing, 400044, China
(2) State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University, Chongqing, 400044, China
(3) State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, Hunan, 410082, China
(4) Institute of Advanced Structure Technology, Beijing Institute of Technology, Beijing, 100081, China
(5) School of Civil Engineering, Central South University, Changsha, Hunan, 410083, China
(6) State Key Laboratory for Turbulence and Complex Systems, College of Engineering, Peking University, Beijing, 100871, China


ABSTRACT: Hierarchical structural design was considered as a promising approach to improve the performance of regular cellular materials. In this study, square hierarchical honeycombs (SHHs) were fabricated by employing a commercial 3D printer, and their in-plane mechanical properties and energy absorption were investigated. The SHHs were constructed by replacing each solid cell wall of a regular square honeycomb
(RSH) with different numbers of smaller square substructures. In-plane quasi-static compressive tests were conducted on SHHs, and the effect of substructure number on the deformation mode, mechanical properties and energy absorption performance were studied. The results revealed that the cells of SHHs and RSH collapsed layer-by-layer along the loading direction, while more localized bands and damage were found for SHHs. Enhanced compressive strength, specific energy absorption and crush force efficiency were found for SHHs when compared with RSH of equal mass. Moreover, the reason for the enhancement and the effect of substructure number on the enhancement were also explored. In addition, analytical expressions for the Young's modulus and compressive strength of SHHs were developed, and the results from experiments and simulations were employed to verify the analytical results. This study elucidates the effect of structural hierarchy on the mechanical properties and energy absorption performance of regular cellular materials.

P.K. Karsh (1,2), T. Mukhopadhyay (3), S. Chakraborty (4,5), S. Naskar (6) and S. Dey (1)
(1) Mechanical Engineering Department, National Institute of Technology Silchar, India
(2) Department of Mechanical Engineering, Parul Institute of Engineering & Technology, Vadodara, India
(3) Department of Aerospace Engineering, Indian Institute of Technology Kanpur, Kanpur, India
(4) Center for Informatics and Computational Science, University of Notre Dame, USA
(5) Department of Aerospace and Mechanical Engineering, University of Notre Dame, USA
(6) Whiting School of Engineering, Johns Hopkins University, Baltimore, USA


ABSTRACT: This paper deals with the stochastic sensitivity analysis of functionally graded material (FGM) plates subjected to free vibration and low-velocity impact to identify the most influential parameters in the respective analyses. A hybrid moment-independent sensitivity analysis is proposed coupled with the least angle regression based adaptive sparse polynomial chaos expansion. Here the surrogate model is integrated in the sensitivity analysis framework to achieve computational efficiency. The current paper is concentrated on the relative sensitivity of material properties in the free vibration (first three natural frequencies) and low-velocity impact responses of FGM plates. Typical functionally graded materials are made of two different components, where a continuous and inhomogeneous mixture of these materials is distributed across the thickness of the plate based on certain distribution laws. Thus, besides the overall sensitivity analysis of the material properties, a unique spatial sensitivity analysis is also presented here along the thickness of the plate to provide a comprehensive view. The results presented in this paper would help to identify the most important material properties along with their depth-wise spatial sensitivity for low-frequency vibration and low-velocity impact analysis of FGM plates. This is the first attempt to carry out an efficient adaptive sparse PCE based moment-independent sensitivity analysis (depth-wise and collectively) of FGM plates under the simultaneous susceptibility of vibration and impact. Such simultaneous multi-objective sensitivity analysis can identify the important system parameters and their relative degree of importance in advanced multi-functional structural systems.


ABSTRACT: The present paper attempts to identify the suitability of natural fibre composite as a potential substitute of conventional synthetic fibre reinforced composite materials. Experimental and numerical models are developed to study the variation of vibration characteristics and other engineering properties of both types of laminates in hygrothermal environment. A finite element model based on Green–Lagrange type nonlinear third order shear deformation theory is developed to account for the nonlinear behaviour induced due to hygrothermal effect. A computer code is developed using MATLAB. The laminates are prepared in the laboratory by adopting vacuum bagging technique. The present numerical model is validated by comparing the solutions with experimental results. A comparative study in the perspective of hygrothermal effects on dynamic characteristics of glass fibre reinforced polymer (GFRP) composites and bamboo mat reinforced polymer (BMRP) composites is carried out. The study reveals that the vibration characteristics of BMRP laminates are comparable to glass fibre reinforced plastic (GFRP) laminates even in elevated temperature and moisture.
F. Moleiro (1), E. Carrera (2), G. Li (2), M. Cinefra (2) and J.N. Reddy (3)
(1) LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
(2) Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
(3) Texas A&M University, College Station, TX 77483-3123, USA
ABSTRACT: A new layerwise mixed model is developed for the coupled hygro-thermo-mechanical static analysis of multilayered plates, addressing hybrid composite laminates, fibre metal laminates and sandwich plates under hygro-thermo-mechanical loadings. This model is based on a mixed least-squares formulation, i.e. a strong form model, with a layerwise variable description for displacements, transverse stresses and in-plane strains, along with temperature, transverse heat flux and in-plane components of the thermal gradient, as well as moisture, transverse moisture flux and in-plane components of the moisture gradient, all taken as independent variables. This mixed formulation ensures that the interlaminar Co continuity requirements, where the material properties change, are fully fulfilled a priori by all independent variables. The effects of hygrothermal environments in the behaviour of multilayered plates are here demonstrated considering hybrid composite laminates, fibre metal laminates and sandwich plates with different side-to-thickness ratios under a series of hygro-thermo-mechanical loadings. Three-dimensional (3D) exact solutions are used to assess the results by the present model and some further by an alternative weak form model in the framework of Carrera Unified Formulation (CUF). The present model is shown to predict a highly accurate quasi-3D hygro-thermo-mechanical description of the through-thickness distributions of displacements and stresses, temperature and heat flux, moisture and moisture flux, all together.

Zhejian Li, Wensu Chen and Hong Hao (Centre for Infrastructural Monitoring and Protection, School of Civil and Mechanical Engineering, Curtin University, Australia), “Functionally graded truncated square pyramid folded structures with foam filler under dynamic crushing”, Composites Part B: Engineering, Vol. 177, Article 107410, 15 November 2019, https://doi.org/10.1016/j.compositesb.2019.107410
ABSTRACT: Dynamic crushing responses and energy absorption of functionally graded folded structures with foam fillers are investigated in this study. The proposed structure consists of multiple layers of folded truncated square pyramid (TSP) foldcore with foam fillers added inside each unit cells and the interlayer plates to separate each layer of foldcore and its foam filler. The foldcores are folded using pre-patterned thin aluminium sheets. Two types of foam including cubic shape expanded polystyrene (EPS) foam fillers with density of 13.5, 19 and 28 kg/m$^3$ and rigid polyurethane (PU) foam of 35 kg/m$^3$ with two shapes. Two sets of functionally graded multi-layer structures are achieved by varying the densities of EPS foam fillers (positively/negatively graded EPS) and varying the shapes of PU foam fillers (positively/negatively graded PU) inside each layer of TSP foldcore. These specimens are then crushed under 1 and 10 m/s. Under 1 m/s crushing, excellent crushing responses as energy absorber are observed for both negatively graded and positively graded multi-layer structures with low initial peak force and low fluctuation in resistance throughout deformation. Under 10 m/s crushing, however, positively graded structures show much more uniform load-displacement response with significantly reduced peak crushing force, increased energy absorption than negatively graded structures. Up to 60% increase in specific energy absorption is shown for folded structure with positively graded PU foam as compared to the uniform structure without foam filler under 10 m/s crushing.

ABSTRACT: A finite element (FE) modelling methodology is presented to analyse the dynamic response of carbon fibre reinforced polymer laminates when loaded by the shock wave generated by an airborne explosive blast. An FE model is developed to calculate the out-of-plane deformation of laminates over the entire duration of an explosive blast loading event. The FE model can also predict the initiation and propagation of delamination cracking and ply rupture in laminates. The response of the composite target plates to explosive
blasts loading was modelled in the FE program Abaqus using an explicit solver. The explosive air blast load was modelled using the ConWep algorithm. The accuracy of the FE model is assessed using experimental data obtained from small-scale far-field and near-field explosive blast tests performed on carbon-polyester and carbon-vinyl ester laminates. The FE model can predict the dynamic deformation of the laminates to within an accuracy of ~10%. The model can also accurately determine delamination cracks and broken plies.


ABSTRACT: The current study is focused on the compressive strength of composite materials containing non-crimp fabric (NCF) reinforcement, and how ply stacking sequence and fibre waviness influence onset and growth of damage in such materials. Experiments reveal significant effects from stacking sequence, both on the compressive strength as such, and on the underlying failure mechanisms. The fibre waviness also has a strong influence on the strength. Fibre kinking is seen before ultimate failure for all configurations but some of them also show local delamination prior to kinking. A finite element simulation methodology is developed and used for the studied cases. It handles local variations of fibre orientations by corresponding re-orientation of stiffness matrices at element level. The simulations provide good predictions of intra- and inter-laminar failure considering both in-plane and out-of-plane fibre bundle waviness. The model is further used in a parametric study of the influence from bundle waviness on the compressive strength.

Sha Yin (1,2), Haitian Wang (1,2), Jianxing Hu (1,2), Yaobo Wu (1,2), Yongbin Wang (3), Shiqing Wu (3) and Jun Xu (1,2)
(1) Department of Automotive Engineering, School of Transportation Science & Engineering, Beihang University, Beijing, 100191, China
(2) Vehicle Energy & Safety Laboratory (VESL), Beihang University, Beijing, 100191, China
(3) Beijing Institute of Space Mechanics & Electricity, Beijing, 100098, China

ABSTRACT: Honeytubes were architectured materials formed by the hybrid of honeycomb and lattice microstructures, which exhibited great energy absorption capability. In this work, thin-walled hollow honeytubes (HHTs) were further designed, and fabricated using different 3D printing methodologies and electro-chemical deposition technique. The compression results indicated that HHTs could possess smaller relative density and their specific strength be 2.4 and 1.5 times greater than that of solid-walled honeytubes and honeycombs, respectively. Geometrical effects on compressive performance of HHTs were examined, and tube configurations that determined the interactions with ribs were proved to be vital for the specific performance. Meanwhile, foam filled honeytubes could exhibit additional enhancement after properly designed. The specific energy absorption of HHTs especially steel HHTs was proved to have superiority among cellular materials. Hollow honeytubes (HHTs) in the present study had indicated the guidelines to tailor mechanical properties by microstructure design, which would also provide opportunities for artificial intelligence to speed up the development of novel materials.


ABSTRACT: Wrapping the structures with composites and adopting multi-cell sections are two typical methods to improve the crashworthiness of thin-walled beams. However, the effects of combining these two methods on crashworthiness are not clear. This paper aims to investigate the bending collapse and crashworthiness of the multi-cell aluminum/carbon fiber reinforced plastic (Al/CFRP) hybrid tubes under quasi-static and dynamic loading. Three-point bending tests are firstly conducted for the CFRP, Al and Al/CFRP square tubes with single or multi-cell sections. The deformation characteristics and crushing force responses of the tubes are analyzed, and the energy absorption performances are evaluated. The bending resistance of the Al
tubes is increased by up to 41% attributed to the CFRP enhancement. The non-linear finite element software ABAQUS/Explicit is then employed to simulate the tests and help analyze the deformation mechanisms. Parametric studies are performed to investigate the influence of the Al wall thickness, the number of CFRP plies, loading velocity, partial wrapping and sectional shape on the crashworthiness of Al/CFRP tubes. Results show that the Al wall thickness, partial wrapping, and sectional shape have a significant influence on the deformation pattern and force response of Al/CFRP tubes, while the number of CFRP plies and the loading velocity have a relatively small influence. The specific energy absorption of Al/CFRP tubes can be increased by 11% by introducing partial CFRP wrapping, and in all cases, the multi-cell Al/CFRP tubes outperform the single-cell counterparts in crashworthiness performances.

Jinbong Kim (1), Mungyu Jeong (1), Holger Böhm (2), Jonas Richter (2) and Niels Modler (2)
(1) Composite Structures and System Laboratory, Korea Institute of Materials Science, 797 Changwondaero, Seongangan, Changwon, Gyeongnam, 51508, South Korea
(2) Institut für Leichtbau und Kunststofftechnik (ILK), TU Dresden, Holbeinstrasse 3, Dresden, 01307, Germany

ABSTRACT: In this paper, the results are present of an experimental investigation into quasi-static and dynamic crushing responses and crashworthiness characteristics of round-hat-shaped crash tubes made with glass long-fiber-mat/PA6 laminates of around 45 vol%. These characteristics were explored using a high-dynamic hydraulic test machine. The crash tubes failed by the progressive splaying mode except for some tubes in the quasi-static tests, which failed by the mid-length collapse mode. The specific energy absorption (SEA, 42.0 J/g) in the quasi-static tests increased to around 52 J/g in the dynamic tests. The increased energy absorption at the higher test speed was analyzed through the microscopic behavior of the small bending radius of the splayed laminar bundles and fragmentation of the lamina bundles. The drop-tower tests show that the dependency of the performance of the crash tubes on the test speed appears only at relatively low speed (1 m/s in the limited tests reported in this paper), but the performance becomes relatively steady at much higher impact speeds. The impactor mass and tube length had almost no effect on the crash characteristics of the mean crushing load, SEA, and peak load.

ABSTRACT: It is widely known that the availability of lightweight structures with excellent energy absorption capacity is essential for numerous engineering applications. Inspired by many biological structures in nature, bio-inspired structures have been proved to exhibit a significant improvement over conventional structures in energy absorption capacity. Therefore, use of the biomimetic approach for designing novel lightweight structures with excellent energy absorption capacity has been increasing in engineering fields in recent years. This paper provides a comprehensive overview of recent advances in the development of bio-inspired structures for energy absorption applications. In particular, we describe the unique features and remarkable mechanical properties of biological structures such as plants and animals, which can be mimicked to design efficient energy absorbers. Next, we review and discuss the structural designs as well as the energy absorption characteristics of current bio-inspired structures with different configurations and structures, including multi-cell tubes, frusta, sandwich panels, composite plates, honeycombs, foams, building structures and lattices. These materials have been used for bio-inspired structures, including but not limited to metals, polymers, fibre-reinforced composites, concrete and glass. We also discussed the manufacturing techniques of bio-inspired structures based on conventional methods, and adaptive manufacturing (3D printing). Finally, contemporary challenges and future directions for bio-inspired structures are presented. This synopsis provides a useful platform for researchers and engineers to create novel designs of bio-inspired structures for energy absorption applications.

Hanfeng Yin (1), Zhipeng Liu (1), Jinle Dai (1), Guilin Wen (1) and Chao Zhang (2)

ABSTRACT: Sheet-based 3D periodic cellular structures attract great attentions due to their lightweight and excellent mechanical properties. Unlike other traditional honeycombs and lattice structures, sheet-based cellular structures consist of triply periodic minimal surface (TPMS) cores, which are continuous through space with a porous cavity surrounded by continuous surfaces. In this study, the crashworthiness of four types of TPMS sheet structures (i.e., Primitive, FRD, IWP, and Gyroid) under axial loading was investigated. According to the results obtained by the nonlinear finite element analysis, the level-constant in the implicit form of TPMS and the shell thickness of TPMS sheet structures were found to affect the crashworthiness significantly. To achieve an optimal design, a metamodel-based multi-objective optimization method was developed to optimize the four types of TPMS sheet structures. Three different metamodels, i.e., Kriging (KRG), polynomial response surface (PRS) and radial basis function (RBF), were compared to identify the most accurate model, which was then utilized for the optimization. Followed by the multiobjective optimization, four Pareto fronts of these TPMS sheet structures were plotted and compared, of which the FRD-sheet structure was found to have the best energy absorption capacity. Moreover, the crashworthiness of the TPMS sheet structures was compared with that of the other materials or structures in nature and engineering, and an Ashby plot was given. Overall, TPMS sheet structures possess excellent specific energy absorption and specific strength and show great potential for engineering applications.


ABSTRACT: In this work, an approach based on the Virtual Crack Closure Technique, included in the commercial finite element code ABAQUS, is adopted to study the propagation of delamination in composite structures under quasi-static and fatigue loads. The methodology, originally capable of simulating only delamination under quasi-static loads, has recently been extended introducing the possibility to analyze damage progression under fatigue load condition. The approach is assessed on simple specimens, Double Cantilever Beam and Mixed Mode Bending test, comparing the results with literature data. Afterwards, the behavior of a single-stringer specimen with an initial delamination is numerically investigated considering compressive loading conditions. At first, the single-stringer specimen is analyzed under quasi-static compressive load showing a clear correlation between local buckling phenomena and delamination growth. Then, a cyclic compressive load is applied such that the specimen switches between pre- and post-buckling conditions in a single load cycle. The outcomes of the numerical analyses are compared with the experimental data obtained from an experimental test campaign previously performed, showing the advantages of the adopted numerical technique but also the limitations that need to be addressed to properly analyze this phenomenon.

Krzysztof Kamil Żur (1), Mohammad Arefi (2), Jinseok Kim (3) and J.N. Reddy (4)
(1) Faculty of Mechanical Engineering, Bialystok University of Technology, Bialystok, 15-351, Poland
(2) Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan, 87317-51167, Iran
(3) Department of Mechanical and Aerospace Engineering, Western Michigan University, Kalamazoo, MI, 49008-5343, USA
(4) Department of Mechanical Engineering, Texas A&M University, College Station, TX, 77843-3123, USA


ABSTRACT: In this study, the free vibration and buckling responses of functionally graded nanoplates with magneto-electro-elastic coupling are studied for the first time using a nonlocal modified sinusoidal shear deformation plate theory including the thickness stretching effect. The constitutive relations for these kind of
structures are defined. The equations of motion for rectangular sandwich plates in macro and nano scale are derived using a modified dynamic version of Hamilton's principle including a contribution of the electric and magnetic fields. The closed-form analytical solution to simply supported plates is obtained using Navier solution technique. A power-law distribution and a half cosine variation are used to model the variation of materials properties and electric/magnetic potentials, respectively. The analytical solutions are verified with well-known solutions in the literature. A parametric study was conducted to show the effect of nonlocal parameter, power-law index, predefined electric and magnetic fields, axial compressive and tensile forces, the aspect ratio of plates, and volume ratio of functionally graded and piezomagnetic layers on mechanical behaviors of nanoplates. Obtained numerical results can be used as benchmark values for validation of correctness of diverse analytical and numerical methods applied for design and analysis of composite nanoelectromechanical systems.

Behrouz Karami (1), Maziar Janghorban (1) and Timon Rabczuk (2)
(1) Department of Mechanical Engineering, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran
(2) Institute of Research and Development, Duy Tan University, Da Nang, Viet Nam


ABSTRACT: In this contribution, we study the free vibration of non-uniform nano-size beams in thermal environment. In order to capture the size-dependent effects, we adopt nonlocal strain gradient theory within a Timoshenko beam model. The nanobeam is made of functionally graded materials, which properties are both temperature and porosity dependent and vary continuously along the length and thickness directions. The governing equations as well as boundary conditions are obtained according to a variational approach, which is solved numerically using the generalized differential quadrature method. We compute the natural frequencies and analyze the sensitivity of the vibration response for different non-uniformity, power indices along x and z-directions, porosity coefficients, small-scaling parameters, thermal effect, and geometry conditions. We also study the influence of various boundary conditions including simply-supported, clamped or a combination of them. We find for all boundaries that an increasing nonlocal (strain gradient) parameter leads to decreasing (increasing) natural frequencies.


ABSTRACT: Hybrid Composite laminates have been widely regarded as a family of highly damage tolerant materials with a high weight-saving potential. The main hindrance to full utilization of Hybrid Composite System in the automotive industry is their structural response as compared to monolithic materials like Steel or Aluminum (AL). The main goal of this research is to investigate the stiffness, weight savings, load-carrying capacity, failure Modes of AL/carbon fiber reinforced polymer (CRFP) hybrid composite system and validate the experimental results with computational Model. The multi-material hybrid composite system comprises of single hat section aluminum material adhesively bonded to woven carbon fiber plies by curing them under temperature and pressure. The effect of interface bonding between AL and CFRP layers on flexural behavior of the multi-material hybrid system was studied by developing three different types of specimens. The first category of specimens was manufactured by using epoxy from the prepreg only to provide adhesion between constituents, second ones were developed by using externally applied an extra layer of epoxy between AL-CFRP layers and finally the third type of samples utilizes 3 M adhesive tape to bond the CFRP and Aluminum sheet. The failure modes of these distinct specimens are studied under flexural loading. The effect of metal volume fraction (MVF) on the failure modes of the hybrid composite beam was also studied. It was found that the failure mode changes from rupture in the load-carrying area to gradual deformation as we increase the metal volume fraction in these hybrid composite specimens. Calculations were performed for the weight savings for these hybrid systems with respect to reference aluminum material having the same thickness as that of the multi-material hybrid system. Weight saving of 15–25% is documented for the multi-material hybrid system as compared to the weight of reference Aluminum material system. Stiffness and progressive damage failure result obtained from experimental three-point bending test are validated with the use of LSDYNA Finite Element
Analysis (FEA) for specimens using the only epoxy from the prepreg to provide adhesion between constituents and for samples using externally applied an extra layer of epoxy between AL-CFRP layers for adhesion. Explicit finite element results were found in good agreement with the experimental results.

Ashutosh Pandey (1), Dilip Muchhala (1), Rajeev Kumar (1,2), Sriram S (1,2), A.N. Ch Venkat (1,2) and D.P. Mondal (1,2)
(1) Academy of Scientific and Innovative Research (AcSIR), India
(2) CSIR-Advanced Materials and Processes Research Institute, Bhopal, 462026, India

ABSTRACT: Aluminium hybrid foam (HF) core sandwich structures with carbon fiber-cold setting resin as face sheets have been made. The flexural properties and energy absorption of these sandwich structures have been analyzed through three-point bending (3 PB) test. It is found that with the use of a double-layer carbon fiber sheet, the flexural load carrying capacity of the sandwich structure increases up to eight times as compared to that of bare foam (BF) structure. Whereas, the bending stiffness of the structure is nine times to that of BFs and energy absorption is 58% more than that of BF. It is also found that with the increase in foam core thickness the flexural load carrying capacity, bending stiffness and energy absorption capacity of the sandwich structure increases significantly. The specific strength and bending stiffness increase as compared to that of face sheet due to the addition of foam at the core. The deformation behavior of different sandwich structures was analyzed to investigate the different modes of failure during bending.


ABSTRACT: Nowadays, thin-walled structures are recognized for their significance in numerous technical fields particularly in automotive, aeronautics, and structural engineering. State-of-the-art studies reveal various techniques for improving energy absorptions of thin-walled structures, and each technique has its pros and cons. This paper proposes a combination of two energy absorption techniques to attain a high-level energy absorber component applicable to a wide range of blast-resistant design and crashworthiness applications. Thus, experimental and numerical investigations have been conducted to study the influence of applying internal stiffeners and stacking composite layers on the behavior of aluminum (AL) thin-walled tubes. Single, double, and quadruple thin-walled metallic and hybrid tubes were tested under axial quasi-static compression test. The specimens were fabricated from unidirectional CFRP, epoxy resin and aluminum alloy T6061-T6. Various crashworthiness parameters were assessed such as the absorbed crash energy, specific energy absorption, crush force efficiency, average crushing load and peak load absorbed in order to highlight the behavior of the novel configurations. The hybrid quadrable multi-cell structure showed the highest energy absorption capabilities between the other proposed configurations. Its energy absorption improved by 116% compared to the solo hollow AL tube. In addition, nonlinear finite element analysis (FEA) using the commercial ANSYS-LSDYNA Workbench software was utilized to verify the experimental results. Numerical simulations showed very good decent agreement with the experimental results. The energy absorption of the proposed techniques has been significantly improved, with the most effective configuration (Hybrid quadruple-cell) showed 131.70% more than the control single-cell AL tube.


ABSTRACT: This paper discusses a semi-analytical method to the determination of three-dimensional stress fields in cylindrically curved orthotropic symmetrically or unsymmetrically laminated composite shells under bending load under consideration of free-edge effects. The analysis method incorporates a plane-strain analysis in the innermost regions of the shell (the so-called inner solution) in conjunction with a free-edge solution which enables the accurate determination of the interlaminar stress field at the free shell edges. The free-edge
solution employs a discretization of the laminated shell into a number of mathematical layers with respect to the thickness direction wherein in each layer interface approximate and a priori unknown displacement functions are introduced. Lagrangian shape functions are used to interpolate between the displacement functions in the interfaces, and various orders of shape functions are investigated in this paper. The differential equations and boundary conditions that describe the current stress problem are derived from the principle of minimum elastic potential of the laminated shell. The resultant differential equations allow for an exact solution for the displacement functions whereas the boundary conditions at the free shell edges are satisfied in an integral sense. The results of the developed analysis method are verified by comparison with detailed finite element computations, and it is found that the semi-analytical approach works with comparable accuracy, however only at a fraction of the required computational effort.

Hamid Daghigh (1), Vahid Daghigh (2), Abbas Milani (3), Dwayne Tannant (1), Thomas E. Lacy Jr. (4) and J.N. Reddy (4)
(1) School of Engineering, The University of British Columbia, Kelowna, BC V1V 1V7, Canada
(2) Department of Aerospace Engineering, Mississippi State University, USA
(3) Composites Research Network-Okanagan Laboratory, School of Engineering, The University of British Columbia, Kelowna, V1V1V7, Canada
(4) Department of Mechanical Engineering, Texas A&M University, College Station, TX, 77843-3123, USA

ABSTRACT: The study presents a nonlocal bending and buckling analysis of agglomerated carbon nanotube-reinforced composite nanoplates resting on a Pasternak foundation. A two-parameter micromechanics model incorporating agglomeration is used to obtain the effective mechanical properties of the nanoplates. Using Hamilton's principle, the governing differential equations are derived based on the Eringen's nonlocal elasticity theory and the sinusoidal shear deformation theory. The deflection and critical buckling load of the nanoplates are obtained by Navier's analytical solution. To verify the approach, the results are compared with experimental, analytical, and numerical findings in the literature. Detailed parametric studies are then performed to discuss the influences of the following parameters on the static bending and buckling response of the nanoplates with agglomerated CNTs: degree of agglomeration, nonlocal material scale parameter, temperature, foundation properties, volume fraction of CNTs, and length-to-thickness aspect ratio for the plate.

Zhenyu Huang (1,2), Xudong Qian (2), Zhoucheng Su (3), Dinh Chi Pham (3) and Narayanaswamy Sridhar (3)
(1) Guangdong Provincial Key Laboratory of Durability for Marine Civil Engineering, Shenzhen University, Shenzhen, 518060, China
(2) Department of Civil and Environmental Engineering, National University of Singapore, 1 Engineering Drive 2, 1175762, Singapore
(3) Engineering Mechanics Department, Institute of High Performance Computing, A*STAR Research Entities, 1 Fusionopolis Way, 138632, Singapore

ABSTRACT: This paper investigates the progressive collapse of filament wound Toray T700/Epotech X4201 composite pipes with various layups via a combined experimental and numerical study. The experimental program examines the flexural behavior of full-diameter T700/X4201 pipes under four-point bending and the tensile behavior of filament wound coupon specimens cut from the pipes. The tests show that the composite layup significantly influences the deformation, flexural resistance, and failure mechanisms of the composite pipes. The CFRP pipe with the optimal complex layup [(90±15/90±45)/±45] design has higher ultimate resistance in bending than other designs with layups of [±45], and [90]. Coupon tests show similar effects of composite layup on the tensile behavior of coupon specimens. The numerical effort evolves a three-dimensional progressive damage model to predict the failure in the CFRP coupons and pipes. The damage model incorporates a nonlinear in-plane shear behavior of the T700/X4201 composite material prior to damage initiation and uses a continuum damage mechanics approach to model the matrix and fiber damage progression in the composite pipes. The combined experimental-numerical work provides a more complete understanding of the bending behavior of large-scaled composite pipes, showing distinct failure modes for filament wound pipes.
with different layups. The load-displacement curves, ultimate bending resistance and failure modes of the composite pipes with different layups are accurately captured using the proposed damage model, demonstrating the capability for the failure analysis of large-scaled composite pipes such as composite risers in offshore applications.

Mahmoud M. Osman (1), Mostafa Shazly (2), Ehab A. El-Danaf (1), Parastoo Jamshidi (3) and Moataz M. Attallah (3)

(1) Mechanical Design and Production Department, Cairo University, Giza, 12613, Egypt
(2) Mechanical Engineering Department, Faculty of Engineering, The British University in Egypt, Al-Shorouk City, Cairo, 11873, Egypt
(3) School of Metallurgy and Materials, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK


ABSTRACT: A new proposed truss lattice metamaterial is introduced and compared with the conventional octet truss lattice (OTL) material with regards to specific energy absorption (SEA) and energy absorption efficiency (EAE). The proposed lattice architecture resembles the Face-Centered Cubic (FCC) metamaterial with a mesostructural unit cell with an aspect ratio of 1:1:2, referred to as the stretched cell lattice (SCL). SCL and OTL samples were fabricated from stainless steel 316L by selective laser melting (SLM). Quasi-static compression experiments on the SLM fabricated metamaterials revealed an unstable twisting deformation mode for the SCL, whereas a stable crushing behavior was observed for the OTL. SCL samples provided higher SEA and EAE than OTL by 26% and 17%, respectively. Additionally, it was shown analytically, numerically and experimentally that the yield strength of the proposed SCL is ~80% higher than that of the OTL metamaterials of the same base material and relative density. A hybrid composite lattice structure based on acrylic matrix and the additively manufactured microlattice metamaterials was produced to enhance the struts buckling resistance. The hybrid composite showed a 47% higher specific strength while the SEA and EAE dropped by 31.5% and 30.7%, respectively, when compared to the bare stainless steel microlattice. Dynamic compression experiments using Split Hopkinson Pressure Bar (SHPB) at strain rates in the order of 10^3/s demonstrated a similar deformation plateau as the static compression experiments with a dynamic increase factor (DIF) of ~1.3 for the bare stainless steel metamaterials and ~2 for the acrylic-stainless steel hybrid composite material.

Patrick Kendall (1), Mengqian Sun (1), Diane Wowk (2), Christopher Mechefske (1) and Il Yong Kim (1)

(1) Queen's University, Canada
(2) Royal Military College, Canada


ABSTRACT: Aluminum hexagonal honeycomb panels are commonly used in the aerospace industry to reduce weight due to their high stiffness to mass ratio. The panels are commonly involved in incidents where they are dented in the out-of-plane direction which causes plastic deformation in the face-sheet and buckling collapse of the thin repeating cell-walls in the core. This paper investigates the responses to barely-visible-impact-damage (BVID) in aluminum honeycomb sandwich panels in the out-of-plane direction with attention to the structural adhesive. The structural adhesive forms a fillet shape between the face-sheet and the aluminum core during the curing process and in some cases can encompass over 50% of the honeycomb core thickness. The adhesive fillets become stiff after curing and are able to brace the thin metallic cell-walls and prevent buckling in sections of the core enclosed in adhesive. It was shown that larger fillets cause the damage to occur deeper in the core. Force-displacement data collected from quasi-static experiments showed that as the amount of adhesive used in honeycomb panels was increased, the peak force required to produce a specified maximum dent depth increased as well. Absorbed energy positively correlated with an increasing quantity of adhesive; showing improvements of up to 50% when comparing panels with the largest amount of adhesive and no adhesive. This paper provides relationships between the quantity of adhesive used to fabricate metallic honeycomb sandwich panels and the damage resistance and energy absorption under BVID conditions.

Itay Odessa (1), Yeoshua Frostig (2) and Oded Rabinovitch (3)
Discussed in detail. Effects of repeated impact on the damage characteristics and expansions of matrix and delamination were summarized by the changes of impact force, displacement, energies. The qualitative conclusions about the effects of repeated impact on global mechanical response were model was adopted to investigate the first-order shear deformation theory kinematic assumptions for the face sheets along with a geometrically nonlinear behavior. The high-order small deformations kinematic assumptions that account for out-of-plane compressibility are considered for the core layer. The two interfaces link the three components of the panel together and the nonlinear traction-displacement laws introduce the interfacial nonlinearity into the model. The model considers dynamic effects in order to assess the influence of the inertial terms on the interfacial debonding mechanism and to examine the coupling between the two. The results of the dynamic analysis are compared with results of a static analysis for two cases: a sandwich panel with a pre-existing delamination subjected to an end-shortening loading and an intact sandwich panel subjected to three-point-bending. In the second case, the interfacial debonding triggers a dynamic response that substantially affects the structural behavior. The dynamic results, the assessment of the time scales of the process, and the comparison with the static results shed light on the significance of the dynamic nature of the interfacial debonding failure mechanism.


ABSTRACT: Due to the multiple dimensional and embeddable characterizations, the three-dimensional woven structure is of great potential as a platform for multifunctional composites. As an example of this concept, we proposed a light-weight and high-gain three-dimensional woven spacer microstrip antenna (3DWS-MA) for the first time by integrating microstrip antenna into 3D woven spacer composites. The single-element 3DWS-MA showed superb electromagnetic performance with the gain value of 7.1 dB, which is more than four orders of magnitude higher than traditional microstrip antenna (2.5 dB). Furthermore, the 3DWS-MA maintained proper resonant frequency and impedance matching after the impact of 18 J, exhibiting excellent structural integrity.

Junjie Zhou (1,2), Pihua Wen (2) and Shengnan Wang (1)
(1) School of Aeronautics, Northwestern Polytechnical University, Xi’an, 710072, China
(2) School of Engineering and Materials Science, Queen Mary University of London, London, E1 4NS, UK

ABSTRACT: The dynamic mechanical responses and damage development of cross-ply composite laminates under repeated low-velocity impact are investigated through finite element simulations with ABAQUS/Explicit. A progressive damage model for laminates, consisting of the continuum damage model, the 3D Hashin failure criterion and the damage evolution model based on equivalent displacement, is integrated with the bilinear traction-separation relationship cohesive model to simulate the damage initiation, evolution and propagation behavior of different damage modes in composite laminates. Compared with the experimental results, the established finite element model was validated through the global mechanical response and damage distribution contours. Besides, a mesh refinement study was performed by using three different element sizes. The validated model was adopted to investigate the repeated impact behaviors of composite laminates under three different energies. The qualitative conclusions about the effects of repeated impact on global mechanical response were summarized by the changes of impact force, displacement, contact time and energy absorption. Moreover, the effects of repeated impact on the damage characteristics and expansions of matrix and delamination were discussed in detail.
ABSTRACT: Sandwich structures are extensively utilized as a structural component in different engineering applications such as aircraft, automotive and construction industries. For this reason, vibration damping behavior comes into prominence for structural health. Shear thickening fluid (STF) is a candidate smart material for vibration isolation in structural members due to its viscoelastic properties. In this work, we fabricated a novel concept by filling an STF into the extruded polystyrene (XPS) foam core of an aluminum face sheet sandwich structure to take advantage of STF rheology during vibrational loadings. In addition to consideration of temperature effect on STF based structures for the first time, STF usage has been extended to foam core sandwich systems with this design. The vibrational characteristics in these smart composites were analyzed by using modal analysis and therefore, natural frequencies and damping ratios were calculated for the structures. According to the results, STF inclusion in the sandwich structures leads to a significant development in the vibration attenuation properties whereas increasing temperature exhibits a disruption in the damping behavior.

V. Keryvin (1), A. Marchandise (1,2), P.-Y. Mechin (3) and J.-C. Grandidier (4)  
(1) Univ. Bretagne Sud, UMR CNRS 6027, IRDL, F-56321 Lorient, France  
(2) Avel Robotics, F-56100 Lorient, France  
(3) Dassault Systèmes, Catia Composites, F-78140 Velizy-Villacoublay, France  
(4) ISAE-ENSMA, UPR CNRS 3346, PPrime, F-86360 Chasseneuil-du-Poitou, France  
ABSTRACT: A method for extracting the axial non linear elastic behaviour and compressive strength of unidirectional plies from bending tests on carbon fibres laminates is proposed. It is first based on a procedure using the axial elastic non linearity to describe the observed shift of the neutral axis position during loading. This procedure extracts four axial elastic parameters by identification. It is validated via numerical analyses. The compressive strength is then calculated and lower values (15%) than those obtained by ignoring these elastic non linearities are found. This emphasises the necessity of using such a method to get proper elasticity description and compression strength values for the design of composite structures.

Chao Quan (1,2,3), Bin Han (2,4,5), Zhanghao Hou (6), Qi Zhang (2,4), Xiaoyong Tian (6) and Tian Jian Lu(3,7)  
(1) Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an, 710049, China  
(2) Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an, 710049, China  
(3) Department of Mechanical Engineering, Xi'an Jiaotong University, Xi'an, 710049, China  
(4) Department of Mechanical Engineering, Xi'an Jiaotong University, Xi'an, 710049, China  
(5) Aeronautical Research Laboratories, Guangdong University of Technology, Guangzhou, 510006, China  
(6) Department of Mechanical Engineering, Xi'an Jiaotong University, Xi'an, 710049, China  
(7) Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an, 710049, China  
ABSTRACT: A method for extracting the axial non linear elastic behaviour and compressive strength of unidirectional plies from bending tests on carbon fibres laminates is proposed. It is first based on a procedure using the axial elastic non linearity to describe the observed shift of the neutral axis position during loading. This procedure extracts four axial elastic parameters by identification. It is validated via numerical analyses. The compressive strength is then calculated and lower values (15%) than those obtained by ignoring these elastic non linearities are found. This emphasises the necessity of using such a method to get proper elasticity description and compression strength values for the design of composite structures.
ABSTRACT: Continuous fiber reinforced thermoplastic composite (CFRTPC) auxetic honeycomb structures were fabricated using the 3D printing technology with a specific printing path planning. For comparison, auxetic honeycombs were also fabricated with pure polylactic acid (PLA). In-plane compression tests were conducted, with corresponding damage types explored using Scanning Electron Microscopy (SEM) images. A printing path-based finite element (FE) method was developed to mimic both small and large deformations of CFRTPC auxetic honeycombs, while analytical model was proposed to predict their effective stiffness and Poisson ratio. Good agreement was achieved among analytical predictions, FE simulation results and experimental measurements. A systematic parametric study was subsequently carried out to quantify the dependence of in-plane mechanical properties on geometrical parameters. Compared with pure PLA structures, the presence of continuous fibers efficiently prohibited crack propagation in the matrix for each ligament of CFRTPC auxetic honeycombs. Adding continuous fibers increased the mass only by 6%, but led to dramatic increase in compressive stiffness and energy absorption by 86.3% and 100% respectively and smaller Poisson ratios. The proposed 3D printing technology has great potential in integrated fabrication of continuous fiber reinforced composite lightweight structures having complex shapes, attractive mechanical properties, and multifunctional attributes.

Hossein Bisheh (1,2), Timon Rabczuk (3) and Nan Wu (1)
(1) Department of Mechanical Engineering, University of Manitoba, Winnipeg, Manitoba, R3T 5V6, Canada
(2) Institute of Structural Mechanics, Bauhaus-Universität Weimar, Marienstr. 15, 99423, Weimar, Germany
(3) Institute of Research and Development, Duy Tan University, Da Nang, Viet Nam

ABSTRACT: Dynamics of wave propagation in carbon nanotube (CNT)-reinforced piezocomposite cylindrical shells affected by nanotube agglomeration is investigated in this study for the first time by developing an analytical approach incorporating existing theories and models. The Mori-Tanaka micromechanics model in combination of the first-order shear deformation shell theory and wave propagation solution are employed to determine wave propagation characteristics of piezocomposite cylindrical shells reinforced with agglomerated CNTs. The effects of both partial and complete nanotube agglomerations on the effective elastic properties and wave dynamics are examined within various axial and circumferential wave numbers for different wave modes by solving an eigenvalue problem. It is found that nanotube agglomeration leads to the reduction of wave phase velocity as a result of decrease in the effective elastic properties. The developed methodology in this study can be used for analysis of the data of structural health monitoring by the non-destructive testing (NDT) in estimating the degree of nanotube agglomeration in nanocomposites.

John Holmes (1), Youssef Hafiz (1), Zbigniew Stachurski (1), Raj Das (2) and Shankar Kalyanasundaram (1)
(1) Research School of Electrical, Energy and Materials Engineering, Australian National University, North Road, ACT 2601, Australia
(2) Aerospace Engineering and Aviation, RMIT University, Plenty Road, VIC 3082, Australia

ABSTRACT: The evolution of architectural distortion of woven composites can significantly influence the deformation behaviour but is challenging to measure experimentally. In this paper, two techniques are proposed to examine the out-of-plane topography of composites under deformation measured using stereo Digital Image
Correlation (DIC). The primary method relies on fitting a surface to the data to compensate for global sample distortion and reveal local topography while the supplementary method uses local curvatures calculated for each data point on the surface. These methods have been applied to thermoplastic composites with different weave architectures, matrix and fibre materials. Topography results show good agreement in magnitude and form with mesoscale Finite Element Analysis (FEA). The methods improve existing experimental techniques to examine local effects with multiple applications regarding deformation, defect detection and failure analysis of composites.

Z.W. Xu (1), Y.H. Chen (2), W.J. Cantwell (3) and Z.W. Guan (1,4)
(1) Department of Civil Engineering, University of Liverpool, Liverpool, L69 3GH, UK
(2) Department of Engineering Science, University of Oxford, Oxford, OX1 3PJ, UK
(3) Department of Aerospace Engineering, Khalifa University, Abu Dhabi, United Arab Emirates
(4) School of Mechanical Engineering, Chengdu University, Shiling Town, Chengdu, PR China


ABSTRACT: This paper presents a multiscale model developed to predict scaling effects in plain woven carbon fibre-reinforced polymer (CFRP) composites. The model contains a parameter-segmented unit cell (UC) developed to account for the contribution of the fabric architecture to the macroscopic response. The behaviour of constituent materials was considered by employing the models that have been established for characterising the nonlinearity and rate-dependence of the polymer matrix and the damage of the yarn material. A user subroutine was developed to numerically implement the parameterised UC and the material models for multiscale analyses. Based on the multiscale model, numerical examples were performed to investigate scaling effects in the impact response of a plain woven composite by simulating scaled panels subjected to projectile impact. It is shown that the proposed model is capable of predicting both scalable and non-scalable effects in this composite with reasonable success. The simulation results highlighted an evident variation of the load-displacement curves with scale size at the post-elastic stage, insensitivities of the primary failure modes and their appearance to scale size, as well as a clear trend of increased capability of energy absorption with scale size, which all agree well with those observed in experiments. The significance of this research is the development of a numerical tool capable of capturing the influence of microscopic features on macroscopic scaling effects in plain woven composites.

References listed at the end of the paper:
2 K.E. Jackson, S. Kellas, J. Morton, Scale effects in the response and failure of fiber reinforced composite laminates loaded in tension and in flexure, J Compos Mater, 26 (18) (1992), pp. 2674-2705
4 L.S. Sutherland, R.A. Shenoi, S.M. Lewis, Size and scale effects in composites: II. Unidirectional laminates, Compos Sci Technol, 59 (2) (1999), pp. 221-233
10 S.R. Swanson, Scaling of impact damage in fiber composites from laboratory specimens to structures, Compos Struct, 25 (1) (1993), pp. 249-255
12 S. McKown, W.J. Cantwell, N. Jones, Investigation of scaling effects in fiber-metal laminates, J Compos Mater, 42 (9) (2008), pp. 865-888
ABSTRACT: Gradual and localised changes in mechanical properties can be exploited to design composites with mixed properties. In this work, dynamic compression on functionally graded gyroid and sandwich composite panels constructed from functionally graded gyroid core and metallic facets are numerically investigated and compared to evaluate the dynamic behaviours when subjected to extreme loadings. The Finite Element Analysis (FEA) is employed to investigate the deformation behaviours of proposed structures considering the rate-dependent properties, elastoplastic response and nonlinear contact. The Johnson-Cook model is utilised to capture the rate-dependent dynamic responses of the gyroid panels. The numerical model is then validated with experimental results under quasi-static compression. Due to the symmetry, only a quarter of the gyroid panel is modelled using shell elements, which offers significantly reduction in computational cost. Parametric studies are conducted to demonstrate the influences of different functionally graded cores on the blast resistances of gyroid composite panels. Reaction forces and critical stress extracted from underneath protected structure are assessed.
Fuctionally graded gyroid sandwich structures clearly demonstrate unique dynamic crushing responses, impact energy mitigation & dissipation mechanisms, which leads to enhancement of the blast resistance.


ABSTRACT: As promising materials, the NS mechanical metamaterials bring new alternatives for energy-absorbing materials, but also research challenges in performance prediction considering their large, local deformation. In this paper, numerical and experimental methods were employed to investigate the mechanical properties of the truncated-conical shell element. Also, empirical formulas, which can well predicate the element's response, were developed based on the simulated data. Mechanical responses of the metamaterials, consisted of truncated-conical shells in a periodic arrangement, were investigated through the multilinear model. These prediction models were all verified through the simulations and experiments, and the comparison results indicated that the presented models were applicable in wide parameter range, attributed to a piecewise fitting method. Generally, a comprehensive approach, of general applicability, is presented in this paper to study the NS metamaterial's mechanical response from local to global, and it can be a reference to researches on novel NS metamaterials.


ABSTRACT: Multi-layered thermoplastic composite (TPC) corrugated sandwich panels (CSPs) were designed and fabricated from glass fiber reinforced polypropylene prepregs by hot-pressing and hot-melting bonding methods. Quasi-static compressive response including failure deformation modes of TPC CSPs were experimentally and numerically investigated to reveal the effect of layer numbers and core configurations namely regular, perpendicular and symmetrical. For two-layered CSPs, core layers of the regular configuration panels were firstly compressed to overlapping and then failed together, core layers of the perpendicular ones failed step by step. But for the symmetrical configuration, assembly deviations were found to affect the deformation modes sensitively by comparing the experimental and numerical results. Among three configurations, the perpendicular one has the optimal specific energy absorption (SEA) and crushing force efficiency (CFE), while the regular one has the biggest peak crushing force (PCF). Increasing layer number can enhance the SEA and MCF due to the bending of the interlayer face sheets.


ABSTRACT: This paper describes the design and testing of a shock absorber with an inward-folding composite tube that can be used as a structural component in its normal working state. Although more energy can be absorbed when the hollow of the tube is filled with composite debris, a higher load relative to the initial peak load will be produced. A variable structure based on two inclined energy absorbers was then proposed, and impact tests used to verify the reaction load calculation for two models experimentally. Results indicate that the variable structure had a greater compression ratio and a flatter load curve, demonstrating its potential for use in the struts of an aircraft cargo floor.

Yuwen Wei (1), Tolendra Kshetri (2), Priyanuj Bhuyan (1), Changwoon Nah (1) and Sungjune Park (1,2) (1) BK21 Plus Haptic Polymer Composite Research Team, Department of Polymer-Nano Science and Technology, Jeonbuk National University, Jeonju, 54896, South Korea (2) Department of BIN Convergence Technology, Jeonbuk National University, Jeonju, 54896, South Korea

ABSTRACT: This study describes buckling instabilities mediated via surface roughness to generate hierarchical structures on a metal (aluminum)/polymer (polystyrene) laminated composite bilayer film on a rigid substrate. Buckling instability is a non-lithographic approach to generate microscale features in thin films. Metals can buckle over the surface due to compressive stress arising from differences in thermal expansion of the individual layers. The topographies of the buckles characterized by wavelength and amplitude can be manipulated by varying the thickness of the layers and the extent of thermal annealing time. Here, the pre-buckled surface on the laminated composite bilayer film formed via two-step molding resulted in hierarchical patterns via surface roughness-mediated buckling instability. The negative replica of the buckles was generated by poly(dimethyl siloxane) (PDMS) and the positive replica of the buckles was fabricated via molding using a PDMS negative replica onto the PS film. The metal layer was subsequently formed on the PS film and the laminated composite bilayer film enabled patterns with hierarchical topography following thermal treatment. The hierarchically structured surfaces exhibit moderately enhanced hydrophilicity and the elastomeric replica with hierarchical buckles showed stretchable hydrophobicity up to 120% stretching due to partial preservation of the pre-structured buckles on the surface.

M.H. Nagaraj (1), J. Reiner (2), R. Vaziri (3), E. Carrera (1) and M. Petrolo (1)
(1) MUL Group, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino, Italy
(2) School of Engineering, Deakin University, Geelong, Australia
(3) Composites Research Network, Departments of Civil Engineering and Materials Engineering, The University of British Columbia, Vancouver, Canada


ABSTRACT: The objective of the current work is the development of a numerical framework for the simulation of damage in composite structures using explicit time integration. The progressive damage is described using a Continuum Damage Mechanics (CDM) based material model, CODAM2, in which the damage initiation and progression are modelled using Hashin's failure criteria and crack-band theory, respectively. The structural modelling uses higher-order theories based on the Carrera Unified Formulation (CUF). The current work considers 2D-CUF models where Lagrange polynomials are used to represent the displacement field through the thickness of each ply, resulting in a layer-wise element model. Numerical assessments are performed on coupon-level specimens, and the results are shown to be in good agreement with reference numerical predictions and experimental data, thus verifying the current implementation for progressive tensile damage. The capability of the proposed framework in increasing the polynomial expansion order through the ply thickness, and its influence on the global behaviour of the structure in the damaged state, is demonstrated. The advantages of using higher-order structural models in achieving significant improvements in computational efficiency are highlighted.

Naresh Reddy Kolanu (1), Gangadharan Raju (2) and M Ramji (1)
(1) Engineering Optics Lab, Department of Mechanical and Aerospace Engineering, IIT Hyderabad, India
(2) NDT & E Lab, Department of Mechanical and Aerospace Engineering, IIT Hyderabad, India


ABSTRACT: Thin-walled composite structures operating in the post-buckling regime needs a thorough understanding of their stability behavior and failure mechanisms. For the accurate prediction of the collapse loads, one needs to account for the damage evolution precisely. In the current study, we have proposed a unified and generic numerical modeling approach that accounts for both the intra and inter-laminar damage modes in stiffened CFRP panels. A 3D finite element based progressive damage model (PDM) is proposed to simulate the collapse behavior of the single blade stiffened composite (SSC) CFRP panels with and without embedded de-bonding defects under uniaxial compression loading. A user-defined material subroutine based on 3D Hashin failure criteria is developed in Abaqus software to study the evolution of intra-laminar damages in SSC panel.
Further, the skin-stiffener bonded interface, the inter-laminar interfaces in the skin, stiffener, including the noodle region, is modeled using the cohesive zone elements to simulate the de-bonding/delamination growth. The stability response and collapse load results obtained using the proposed PDM are compared with the experimental observations. Also, the damage evolution, failure mechanisms, the ultimate load, and the corresponding displacement data obtained from the developed PDM are validated with the experimental estimates. A comprehensive damage assessment involving the ultrasonic C-scans, infrared thermograms, and micrographic study is also carried out to supplement the PDM predictions. Thus, the proposed PDM is generic in terms of damage studies and can be used for investigating the collapse behavior of CFRP panels with multiple stiffeners.


Geoffrey Neale (1), Monali Dahale (1), Sanghyun Yoo (2), Nathalie Tos (2), Cormac McGarrigle (3), Justin Quinn (3), John Kelly (1), Alistair McIlhagger (1), Edward Archer (1) and Eileen Harkin-Jones (1) (1) Engineering Research Institute, Ulster University, Shore Road, Newtownabbey, BT37 0QB, United Kingdom (2) Institute of Structures and Design, German Aerospace Centre (DLR), Stuttgart, Germany (3) Centre for Engineering and Renewable Energy, Ulster University, Magee Campus, BT48 7JL, United Kingdom


ABSTRACT: Although 3D woven composites have exceptional out-of-plane properties, there is a lack of understanding for these materials in crash application in automotive and aerospace industries. To encourage the use of 3D wovens in crashworthy automotive structures, knowledge must be gained so that designers can adjust the highly flexible weave parameters to create tailor-made performance materials. Here we show that fabric pick density causes large changes in progressive failure modes and associated energy absorption, particularly in the dynamic regime, where the quasi-static to dynamic energy absorption loss typical of composites is completely removed. Compression and flexure properties, which are known to be linked to crash performance in composites, are also investigated for these 3D woven layer-to-layer interlock carbon-epoxy composite structures. 3D fabric preforms are manufactured in three different pick densities: 4, 10 & 16 wefts/cm. With a constant warp density of 12 warps/cm from carbon fibres. Increasing the pick density improved specific energy absorption (SEA) even in relatively inefficient progressive failure modes like folding, which has not previously observed in composite materials. SEA values up to 104 J/g (quasi-static) and 93 J/g (dynamic) are recorded. This work shows that minor weft direction (transverse) weave changes can lead to sizeable improvements in warp direction (axial) energy absorption without fundamentally redesigning the weave architecture.


ABSTRACT: The results, findings, and analytical investigation of an experimental study conducted on the hydrostatic implosion of filament wound carbon fiber epoxy composite tubes within partial confinement are presented. Implosion in geometries varying in length and diameter is initiated within a tubular confining structure with one end closed and one end open to a free-field, hydrostatic environment. Structural deformation behavior is captured and quantified using high speed cameras in conjunction with 3D digital image correlation (DIC). Water hammer pulses resulting from implosion are measured at various locations in the confining chamber and are shown to behave as a damped harmonic oscillator. Water hammer behavior is thus experimentally characterized for each geometry by determining average values of amplitude, frequency of
The fatigue life prediction of post-buckled composite structures represents still an unresolved issue due to the complexity of the phenomenon and the high costs of experimental testing. In this paper, a novel numerical approach, called “Min-Max Load Approach”, is used to analyze the behavior of a composite single-stringer specimen with an initial skin-stringer delamination subjected to post-buckling fatigue compressive load. The proposed approach, based on cohesive zone model technique, is able to evaluate the local stress ratio during the delamination growth, performing, in a single Finite Element analysis, the simulation of the structure at the maximum and minimum load of the fatigue cycle. The knowledge of the actual value of the local stress ratio is crucial to correctly calculate the crack growth rate. At first, the specimen is analyzed under quasi-static loading conditions, then the fatigue simulation is performed. The results of the numerical analysis are compared with the data of an experimental campaign previously conducted, showing the capabilities of the proposed approach. References listed at the end of the paper:

2. K.N. Anyfantis, N.G. Tsouvalis, Post buckling progressive failure analysis of composite laminated stiffened panels, Appl Compos Mater, 19 (3-4) (2012), pp. 219-236
10. I. Di Memmo, C. Bisagni, Fatigue simulation for damage propagation in composite structures, Proceedings of 32nd technical conference of the American society for composites, West Lafayette (October 2017), Paper number 135472
16. B. Landry, G. LaPlante, Modeling delamination growth in composites under fatigue loadings of varying amplitudes, Compos B Eng, 43 (2) (2012), pp. 533-541
18. A. Pironi, G. Giuliese, F. Moroni, Fatigue debonding three-dimensional simulation with cohesive zone, J Adhes, 92 (7-9) (2016), pp. 553-571
ABSTRACT: Due to the intimate contact between the fluid-like liquid nanofoam (LN) filler and the tube wall, the filler-tube wall interaction in LN-filled tube (LNFT) is enhanced, leading to a much-improved performance of the composite structure. However, a comprehensive understanding of the energy mitigation performance and the underlying working mechanism of LNFT is still lacking. This study aims to explore the crushing behavior of LNFT subjected to quasi-static compression and dynamic impact and reveal the working mechanism of LNFT at different strain rates and the selection criteria for LN filler and tube wall material. A series of quasi-static compression tests are conducted on LNFTs with various LN fillers. The strengthening coefficient of LNFTs is larger than 3.5. Micro-CT images show that the LN-tube interaction improves the performance of LNFT through extended plastic deformation of the tube wall. Under dynamic impacts, the energy absorption capacity of LNFT shows 54% increase compared to that under quasi-static tests, leading to a remarkable strengthening coefficient of 8.0. The strain rate effect is due to the different energy mitigation mechanisms of the LN-filler, i.e. energy dissipation at lower strain rate and energy capture at higher strain rate. To optimize the impact...
mitigation performance of LNFT, the most critical system parameters are the infiltration pressure and total pore volume of the LN-filler and the stiffness and ductility of the tube wall. These findings and research outcomes expedite the understanding of the impact mitigation mechanism of LNFT and provide design guidance for the LN-based composite structures.

Bart P.H. van den Akker (1,2), Mauricio V. Donadon (1), Richard Loendersloot (2), Lucas A. de Oliveira (1) and Mariano A. Arbelo (1)
(1) Department of Aeronautical Engineering, Instituto Tecnológico de Aeronáutica, Praça Marechal Eduardo Gomes 50, 12228-900, São José dos Campos, SP, Brazil
(2) Faculty of Engineering Technology, University of Twente, De Horst 2, 7522, LW, Enschede, The Netherlands
ABSTRACT: Adhesively bonded composite structures, if designed properly, have proven to be stiffer and to possess a higher specific strength than their mechanically fastened counterparts. To increase the applicability of these bonded joints in the aircraft industry, a study was performed to investigate the influence of hygrothermal aging on co-bonded composite stiffened panels with an initial disbond under cyclic compression loading. Experiments showed that hygrothermal aging led to a decrease in disbond growth throughout cyclic loading. The decreased disbond growth was likely caused by the increased ductility of the bond due to the presence of moisture. A higher ductility can lead to crack blunting and stress relaxation, resulting in higher fracture toughness of the bond. Furthermore, it was shown that hygrothermal aging did not influence the residual strength and stiffness of the panels after cyclic loading. The experiments were simulated numerically to gain a better understanding of the crack growth behavior and to aid future numerical crack growth predictions.

ABSTRACT: The additive-manufacturing process generally fabricates lattices with geometries that depart from their as-designed counterparts and some inherent geometric imperfections exist within the fabricated lattice samples. In this paper, mechanical responses of the lattice structures with stochastic geometric defects originated from additive-manufacturing were examined. Here, X-ray Computed tomography (CT) was employed to capture the morphology and distribution of process-induced defects in order to study their role in the elastic response, damage initiation, and failure evolution under quasi-static compression. Testing results indicated that more geometric imperfections exist in the horizontal struts than in the diagonal or vertical struts. Then, extracted from the X-ray CT images, the process-induced defects (i.e. strut porosity, strut thickness variation and strut waviness) were introduced into the ideal finite element (FE) model for establishing the statistical FE model. A much more agreement is observed between the statistical FE model predicted results and experimental results. Finally, the roles of the single geometric defect on the mechanical responses and energy absorption of the lattices were investigated. It was indicated that strut thickness variation in the lattice structures has a larger impact in energy absorption than strut porosity or strut waviness.

ABSTRACT: Test and simulation of low-velocity impact and residual strength of composite structures is usually limited to relatively thin laminates. However, numerous applications in the aerospace and automotive industry exist, such as high-lift devices and pressure vessels that have thick laminates with notably different damage mechanisms to thin laminate. This paper investigates the influence that laminate thickness has on damage initiation and propagation during low-velocity impact, and on residual strength after impact. An enhanced cohesive zone model is presented that accounts for i) internal friction, ii) crack surface enlargement
due to through-the-thickness compression, iii) strain rate effects and iv) different damage initiation stresses in the traction separation law of undamaged and damaged delamination layers. The effect of each feature is discussed and the model is validated on 2 mm–12 mm thick laminates. For residual strength prediction after impact, a strategy is proposed that maps impact damage and residual deformations to a new residual strength model, to avoid mesh distortions and improve computational costs while retaining a high level of accuracy. The mapping strategy is validated through compression after impact simulations and these studies are accompanied by an exploratory study of tension after impact for 2 mm thick laminates. The results show that the proposed modelling improvements are necessary to enable accurate prediction impact damage in thick laminates. Prediction of tensile and compressive residual strength, as well as deformation and failure modes, are also shown to closely agree with test measurements for the range of laminate thicknesses investigated.

ABSTRACT: With increasing terrorist attacks in recent years, many researchers paid special attention to investigate the responses and failure behaviors of reinforced concrete (RC) structures subjected to blast loads. Generally, RC structures would demonstrate brittle damages and localized spallation along with ductile failure modes due to high-rate actions of explosions. Hence, the vast majority of the studies in the literature focused on recognizing the damage mechanisms and the material behaviors of RC structures under high-rate blast loads. This paper aims to comprehensively review on existing analytical, numerical, and experimental studies in the literature investigating the loading mechanisms, dynamic responses and failure behaviors of various concrete structures subjected to blast loads. In addition, the sensitivity of the blast responses of RC structures to various structural- and loading-related parameters are reviewed based on the findings of previous studies.

ABSTRACT: Among a variety of defects associated with composite technology, fibre wrinkles are known to be a major source of failure for fibre reinforced plastic and closely associated with the ever popular automated fibre placement technique. In the present work, with the aim to investigate their influence on the failure of carbon fibre reinforced plastics (CFRP), composite laminates containing fibre wrinkles of varying architectures have been designed and prepared utilizing gaps and overlaps based on the understanding of wrinkle formation mechanisms. The effects of these engineered wrinkles with different combination of gaps and overlaps on the mechanical performance of CFRP were systematically investigated. A maximum of 21% and 37% drop in the tensile and compressive strength were recorded for the most severe combination of gaps and overlaps. A simple analytical model was proposed to relate the wrinkle angle to the defect characteristic parameters and a good agreement with experimental results was obtained. Furthermore, numerical simulations were conducted to inform the failure mechanisms where different wrinkle models were generated using previously developed pre-processing tools. Good agreements with experimental observations were obtained in terms of ply waviness, strength and failure modes. These findings provide certain practical insights for controlling defects in composite manufacturing processes.

ABSTRACT: Aluminum foam, carbon fiber reinforced plastics (CFRP) and foam-filled structures have been drawn growing attention for their outstanding lightweight and energy absorption capacity; therefore, crushing characteristics of a hybrid system involving these components would be of particular interest. In this study, quasi-static compression tests were carried out to experimentally investigate the crushing behaviors of foam-filled aluminum/CFRP hybrid tube subject to transverse loading condition. Based upon the experimental tests and numerical modeling, the interactive effects in between the aluminum foam filler and aluminum/CFRP
hybrid tube was explored. It is found that the load carrying and energy absorption capacities of foam-filled hybrid tube were significantly improved in comparison with the summation of net foam filler and empty hybrid tube. The parametric study was carried out for exploring the effects of the aluminum foam density, aluminum tube thickness and ply number of CFRP tube on the crushing behaviors of foam-filled hybrid tube. It is found that both the total energy absorption (EA) of foam-filled hybrid tubes and the EA contributions of the aluminum foam (or aluminum tube, or CFRP tube) were enhanced with increase in density (or thickness, or ply number). The specific energy absorption (SEA) of foam-filled hybrid tubes increased from 3.45 J/g to 9.24 J/g with the foam density changed from 0.23 g cm⁻³ to 0.70 g cm⁻³; nevertheless, increase in aluminum tube thickness (or ply number of CFRP tube) has no evident influence on the of foam-filled hybrid tubes. Finally, discrete design optimization was further performed to obtain the best possible foam-filled hybrid configuration for the transverse crushing characteristics. The optimum results showed that the was largely improved by 213% in comparison with the baseline design.


ABSTRACT: In this work, the synergistic effect of 3D orthogonal woven structure and asymmetric carbon/glass hybridization on impact response was studied by experimental and numerical methods. The hybrid 3D orthogonal woven (H3DOW) composite plates were manufactured on a home-made 3D weaving machine. Impacts with various energies 42.9, 54.9, 66.9 and 78.9 J were applied to carbon (CG) and glass (GC) sides. The impact response was examined using fracture morphology observation and mechanical curves. Yarn-level finite element models including failure criteria and progressive damage law were established in ABAQUS/Explicit to compare the structural deformation and damage behavior. The impact side significantly influences the failure modes of H3DOW materials. GC specimen failed through delamination between carbon layers at non-impact side and subsequent fiber tensile breakage, whereas the crushing damage in the carbon yarn located in the impact-side and large area debonding between yarn and matrix resin in superficial layers was the dominant failure mode in CG specimen. This caused the CG configuration to exhibit better impact resistance with respect to the perforation threshold energy.


ABSTRACT: Honeycombs with re-entrant (RE) unit cells were found to have negative Poisson ratios (NPRs) and enhanced energy absorption capacities than regular hexagon honeycombs. For further improved energy absorption capacity, a novel re-entrant circular (REC) honeycomb configuration is proposed in this work by replacing the sloped cell wall of the regular re-entrant honeycomb with double circular arc cell walls, which can dissipate extra energy due to more formed plastic angles during the crushing process. The in-plane quasi-static crushing response of the REC honeycomb with large deformation was investigated theoretically and numerically. The numerical modeling methods in LS-DYNA software were validated by using the quasi-static crush test data of 3D-printed REC honeycomb specimens. Experiment and numerical simulations both revealed that quasi-static load can result in an “X” mode deformation of the REC honeycomb. Based on the simulated deformation profiles of the representative unit, theoretical models were derived to predict the REC honeycomb's crushing strength, i.e. plateau stress. Good agreements were found between the theoretical and the numerical results within a relative error about 9%. Parametric analyses further showed that the unit cell configuration has a great effect on the crushing strength of the REC honeycomb. The REC honeycomb presents a varied Poisson's ratio with the global strain of the honeycomb; smaller radius to height ratio and length to height ratio were found to yield more pronounced NPR effect. Moreover, compared with the regular RE honeycomb, the specific energy absorption of the REC honeycomb is much higher due to the introduction of the double circular arc cell walls.

ABSTRACT: In this paper, the complex phenomena of the elastic and elastoplastic indentation responses of functionally graded materials (FGMs) are studied in the framework of frictional contact mechanics using finite element method. The proposed model accounts for the continuous gradation of all the elastic and plastic properties of the indented material along its thickness using power law function and Tamura, Tomota and Ozawa (TTO) model. Classical Coulomb's friction law is utilized to model the friction effect throughout the contact interface. The model is implemented in ANSYS FE software and utilized to simulate the axisymmetric frictional contact of an FGM substrate and a rigid spherical indenter. Parametric studies are performed to investigate the effects of friction coefficient, gradient index, and FGM-constituent materials on the frictional indentation behaviors of elastic and elastoplastic FGMs under loading/unloading pattern. Results show that the frictional contact response of elastoplastic FGMs can be controlled by appropriate choice of the gradient index. Using obtained numerical results, an empirical equation is derived to predict the normalized residual indentation depth for elastoplastic FGMs by knowing the gradient index and a single material parameter under frictional spherical indentation.


ABSTRACT: How sand filling affects the dynamic response of metallic corrugated sandwich beams under shock loading was characterized, both experimentally and numerically, with shock loading simulated by high-speed impact of aluminum foam projectiles at beam mid-span. To facilitate evaluating the effects of sand filling, both empty and sand-filled corrugated core sandwich beams were assessed and compared for shock resistance. Representative deformation processes, deformation and failure modes, and beam deflections were experimentally obtained and analyzed. Sand-filled sandwich beams exhibited much higher shock resistance than the empty ones. Numerical simulations were subsequently conducted using a coupled discrete particle/finite element approach that takes into account the coupling interaction between the sand grains and corrugation members. The simulations predicted reasonably well the primary features (permanent mid-span deflections and deformation modes) of both the empty and sand-filled sandwich beams observed experimentally. The validated numerical model was employed to evaluate how the properties of the filling sand and other granular filling materials, e.g., density, stiffness, friction and damping, affect the shock resistance of sandwich beams. The results indicated that the shock resistance was sensitive to, firstly, the density and stiffness of sand and, secondly, the friction between sand particles. In contrast, the damping between sand particles had little effect.


ABSTRACT: In order to solve the problems of poor mechanical properties and incapable reuse for single cellular foam, this study proposed low-cost spring-like sandwich flexible foam composites (SFFCs) with a 3D resilient concave–convex structured fabric core (RCFC) and two gradient-structured styrene-ethylene/butene–styrene copolymer (SEBS)-g-maleic anhydride (MAH)-filled polyurethane (PU) foam faces through two-step foaming. RCFC plied with different sizes and distances constituted warp-knitted spacer fabrics (WKSF) sealed between two layers of low-melting polyester nonwovens through thermal bonding. The effects of SEBS-g-MAH content and volume content of RCFC cubes on compression and dynamic low-velocity impact properties were explored at different impact energy levels. At 3:4 (wt%) ratio of the upper-to-lower SEBS-g-MAH content faces and at 0.4 ratio of WKSF-to-PU volume ratio, the resultant SFFCs showed a compression stress of 68.4 kPa (40%) and absorbed up to 98% of impact energy under 16 J. After five cycles of impact, this sandwich foam composite maintained 98% absorption of impact energy, demonstrating excellent spring-like dynamic-
impact-recovery property. Overall, this study provided a novel structure design for lower cost, higher-performance recycling cushion materials in industrial construction, transport packaging, and sports fields.


ABSTRACT: Structural insulated panels (SIPs), which consist of a composite of an insulating polymer foam sandwiched between two layers of structural skins, are widely used in residential and commercial buildings. Such panels, in the regions prone to hurricanes and tornadoes, are often exposed to the risk of windborne debris impact. Despite the consequences associated with damage to SIPs, the studies on their perforation resistance and design variables have been rather limited. To address this gap, the current study develops a computational framework to assess the vulnerability of the SIPs of various configurations subjected to a range of windborne debris impact scenarios. For this purpose, impact simulations are conducted to quantify the response and evaluate the extent of damage to the SIPs. The study is further extended to evaluate the effect of various structural details and material properties on the perforation resistance of the SIPs. Based on the simulation results, a set of vulnerability curves are developed to capture the risk of failure of the SIPs under the windborne debris hazard. This is expected to improve the design of this important category of wall panels, especially to ensure their safety and performance during severe windstorms.


ABSTRACT: Novel fiber-metal hybrid tubes with overlapped fiber reinforced plastics (FRP) and aluminum layers were proposed in this paper. By combining progressive failure behavior of composites and large plastic deformation of metal materials, the structure was hybridized at mesoscopic scale. To this end, circular fiber/aluminum hybrid tubes with various inner diameters (40, 60, and 80 mm) combined with parent materials (Al-1060, carbon fiber, and glass fiber) were fabricated using vacuum bag molding process. Quasi-static uniaxial compressive tests were conducted to comprehensively explore the effects of geometric factors and failure patterns on energy absorption capability. The experimental results revealed that the pristine FRP and CF/Al (carbon fiber and aluminum) hybrid tubes collapsed in a progressive failure mode and generated abundant intra- and inter-laminar cracks during crushing. The GF/Al (glass fiber and aluminum) hybrid tubes with large diameters collapsed in an unstable and inefficient mode due to local buckling and delamination. Compared with bare aluminum tubes (Al 6061-T6), the specific energy absorption (SEA) and crushing force efficiency (CFE) of CF/Al hybrid structures were improved significantly by respectively 54.3% and 40.4% for tubes with 40 mm inner diameter. Furthermore, the CFE of CF/Al hybrid structures improved by more than 40% when compared to their bare CFRP counterparts, though the SEA reduced by more than 5.5%. In sum, the proposed hybrid design efficiently reduced the peak crushing force with desirable SEA, which has great potential for low-cost and lightweight energy absorber applications.


ABSTRACT: In this paper, an innovative bio-inspired multi-layered graded foam-filled structure (MGFS) mimicking the characteristics of the human skeleton was proposed in an attempt to improve the energy absorption. The proposed structures consisted of three layers of aluminum foam with different densities filled in three concentric aluminum circular tubes. To find out the optimal foam-filled combination and demonstrate the superior energy absorption performance of the proposed structures, a series of quasi-static compression tests were experimentally and numerically carried out. The results showed the proposed structures had higher energy absorption efficiency than that of both uniform foam-filled structures and the empty tubes, and Model-1 with the foam density increasing from the inner tube to the outer tube was the best combination mode. Furthermore, parametric numerical studies on Model-1 revealed that the diameter and thickness of the aluminum tube and the density of the aluminum foam had significant effects on the energy absorption characteristics. Finally, a
theoretical model was developed to predict the mean crushing force of the bioinspired MGFS, which was in good agreement with the experimental results. This study provides an effective guideline for designing a foam-filled energy absorber with high energy absorption efficiency.

ABSTRACT: One of the best nondestructive techniques to evaluate the buckling behavior of imperfection-sensitive structures is the vibration correlation technique (VCT). This paper presents an analytical formulation for the free vibration of axially loaded composite lattice sandwich cylinders (CLSC) and numerical and experimental validations of the VCT applied to such structures. From an analytical point of view, the equations are obtained through the Rayleigh-Ritz method considering first-order shear deformation theory (FSDT). For the numerical verification of the VCT, three types of linear and nonlinear finite element analyses are performed. At first, numerical results for the critical buckling load and the first natural frequency at different load levels are compared with the corresponding analytical ones, validating the numerical models. Then, the numerical models are extended considering geometric nonlinearities and imperfection to simulate the variation of the first natural frequency of vibration with the applied load. As well, a nonlinear buckling analysis is also performed using the Riks method for a better comparison of the VCT results. In the last section, four specimens are fabricated using a new rubber mold and a filament winding machine. Additionally, the experimental buckling test is carried out, verifying the results of the VCT approach. The results demonstrate that the maximum difference between the estimated buckling load using the VCT approach and the corresponding nonlinear and experimental buckling loads is less than 5%, being the VCT result more accurate than the numerical one. Moreover, the proposed VCT provided a good estimation of the buckling load of the CLSC, considering a maximum load level of at least 62.1% of the experimental buckling load.

ABSTRACT: A sandwich panel based on upcycled bottle caps core and sustainable components is investigated to contribute to advances in lightweight and environmentally friendly structural solutions. Ecological alternatives to the panel skin and adhesive, such as a recycled PET-bottle foil and a castor oil bio-polyurethane, respectively, are tested and compared to commercial components (aluminium skin and epoxy polymer). Bottle caps are characterised using a small punch test specially developed to obtain the properties of the bottle caps. Additionally, low-cost reinforcement (Portland cement) is added to adhesives to enhance the mechanical behaviour of the panel. The sustainable panels achieve enhanced efficiency compared to aluminium-based panels for core shear strength and stiffness, besides having similar specific flexural properties compared to those of epoxy-based PET panels. Despite their higher strength and stiffness, epoxy polymer-based panels show visible adhesive peeling off to bottle caps core and aluminium skin. In contrast, the biopolymer exhibits larger deformation and debonding of both substrates, indicating a progressive and ductile failure. The satisfactory efficiency of sustainable panels confirms the promising reuse of recycled bottle caps in structural applications.

ABSTRACT: Since the carbon nanotube (CNT) technology was invented in 1991, it has attracted widespread attention from researchers owing to the excellent properties and wide applications. However, the easy agglomeration of CNTs in composite materials severely restricts large-scale applications. The problem of CNT distributing in composites has been solved, since the buckypaper (BP) called ‘carbon nanotube film or carbon nanotube paper’ was first prepared in 1998. Because porous structure of BP is beneficial to impregnation of matrix materials, preparation methods and applications of BP composites have been widely reported. With
porous structure, low density, anti-corrosion and excellent properties, BP and its composites could be applied in the electrically conductive fields. This paper is intended to provide a comprehensive review of BPs, including a fundamental understanding of the technology, methods of fabrication, related properties of BPs, various BP composites and their potential applications in aeronautics. The first section presents a brief introduction of BPs, then the descriptions of preparation methods, morphology and related properties of BPs and BP composites are introduced in detail. BP composites, which have been developed for improving related properties of BPs as functional materials, are briefly described. Specially, BP composites are fabricated for conductive applications in aeronautics, such as in deicers, electromagnetic interference (EMI) shielding and lightning striking protection (LSP).


ABSTRACT: This study aims to explore the crushing characteristics and failure modes of multiple filament winding hybrid tubes. Two types of hybrid tubes, namely Glass fiber reinforced plastics (GFRP)/carbon fiber reinforced plastics (CFRP)/aluminum (Al) hybrid tubes and CFRP/Al, were fabricated by the filament winding process. The typical load-displacement curves, failure modes, effects of winding plies, winding angle and interaction on crashworthiness were explored. It showed that the failure modes of hybrid specimens were predominated by progressive brittle crack, delamination mode in CFRP layers and diamond failure mode in aluminum tube. Increasing hybrid plies increased the specific energy absorption (SEA), energy absorption (EA) and peak crushing force (PCF). The PCF of the hybrid tubes decreased with increasing CFRP winding angle from 30° to 60° (winding angle of 0° was along the axial direction of the tube) while the hybrid tubes with the winding angle of 45° showed the highest SEA and EA. A theoretical analysis was conducted on the effect of interaction on load bearing capacity and it is showed that the interactions between different materials can effectively enhance energy absorption. A comparison among the filament winding, vacuum bag forming and nested manufacturing processes was performed and the filament winding technique exhibited the highest improvement in crashworthiness of CFRP/Al hybrid tubes.


ABSTRACT: This paper presents the details and results of a series of follow-up experimental and numerical investigations that were conducted to establish the buckling behaviour of special three-dimensional fiber metal laminates (3D-FMLs). This FML is made of a special 3D fiberglass fabric (3DFGF)-epoxy composite, which also hosts a two-part liquid urethane foam within its core cavities and further reinforced with basalt and E-glass bidirectional fabrics. 3D-FML panels with six different configurations were fabricated and beam-like specimens were extracted from the panels. The specimens were subjected to uniaxial compression loading. This follow-up study focuses on investigating the effects and level of improvement in the performance of the 3D-FMLs by utilizing magnesium and stainless steel as the face-sheet materials and the enhancement gained by the basalt and E-glass fabrics. The responses of the 3D-FMLs are also simulated numerically. By comparing the numerical and experimental results, it will be explicitly demonstrated that the developed FE framework could serve as an effective and accurate means for establishing the performance of such FMLs, including those with more complex geometries and loading conditions. In addition, the most effective 3D-FMLs are identified and ranked based on their buckling capacity with respect to their cost and weight.


ABSTRACT: Accurate debonding identification is essential for subsequent structural repair, however, the research on debonding identification on both sides of the symmetrical honeycomb sandwich structures by means of the vibration-based method faces certain challenges. To address this, a two-step strategy based on the
uniform load surface (ULS) curvature method is presented. Specifically, the potential debonding area is first identified through the global debonding detection of the entire sandwich structure. Then, the specific debonding information on both sides is identified by introducing the local constraint to the boundary of the above potential debonding area. The corresponding mechanism is that the local constraint improves the relative vibration amplitude of debonded skin. On this basis, further study on the applicable scope of the ULS curvature method indicates that the debonding of Nomex honeycomb sandwich structures with relatively low-modulus skin and large honeycomb core phenolic resin thickness is relatively easy to be identified. This work is helpful to guide the precise debonding detection of honeycomb sandwich structures.


ABSTRACT: A novel crush testing approach is presented to obtain crush properties of flat-plate fibrous materials. To validate the proposed approach, fully constrained specimens of different materials were crushed. The inevitable component, the splitting force, included in the measured force, emanating from shearing, tearing, and friction at specimen edges, is isolated and deducted, resulting in the crushing force. An approximately linear relationship between the energy associated with the measured force and the specimen width was observed, suggesting width independent splitting energy. Consistent specific energy absorption (SEA) properties of fully supported flat-plate specimens were obtained using the proposed approach.


ABSTRACT: Origami has received significant interest from the science and engineering community as a design method and used to construct expandable mechanical metamaterials by folding and unfolding along the crease line. Here, we adopted a 4D printing method with shape memory polymer to create a smart origami metamaterial with tunable stress-strain curves, controllable compression twist deformation, shape programming and self-expansion, and develop its deformation theory model. The effects of unit structure parameters and temperature field on the mechanical properties and functional deformation of the metamaterial are analyzed using experiments, theory model and finite element method. The origami structure can realize the shape programming, self-expansion and mechanically tunable by control temperature, and switch between monostability and bistability by adjusting the parameters. The structure parameters, temperature field, and series combination method are used to adjust and control the stress-strain curves and compression twist deformation behavior of the metamaterials. This multifunctional metamaterial may find a wide range of applications, such as, mechanical storage, tunable shock absorption interface and soft robots.


ABSTRACT: Simulations and experiments for automated fiber placement (AFP) of prepreg slit tape (tow) on a flat surface with different radii of curvature are presented, with emphasis on characterization of wrinkle formation. Bonding of the slit tape to the substrate surface is modelled through a sticky contact definition in Abaqus. Subsequent delamination and wrinkling are predicted through incorporation of measured mixed mode cohesive TSL for contact and bonding of the slit tape and substrate. Comparisons of predicted wrinkle shape, amplitude and wavelength to experimental measurements show excellent agreement for a 6.35 mm wide IM7/8552-1 prepreg tow placed on a flat surface using four different radii of curvature. In addition, simulations are demonstrated to be capable of capturing the mechanisms of wrinkle formation using a generally accepted damage model. Careful inspection of the stress and deformation conditions at the tow-substrate interface under the compaction roller reveals a combination of Mode II and Mode III tractions, with significant damage predicted under the roller due to the Mixed Mode II/III traction conditions. After passage of the roller, nearly
instantaneous initiation and growth of wrinkles occur with relatively consistent spacing under predominantly Mode I condition at the interface.

ABSTRACT: This paper focuses on structural collapse of fully clamped and simply supported hybrid sandwich beams of geometrically asymmetric carbon fiber-reinforced composite face sheets and an aluminum foam core under three-point bending. Both bending behavior and collapse mechanism have been explored and identified through the collapse mechanism map. Limit analyses have been conducted and these predictions are validated by experimental results. Experimental results show two active failure modes: face fracture and core shear. Effect of fully clamped boundary condition is to make bending deformation mechanism towards stretching of face sheets and core and strengthen the structural load-carrying capacity. Geometric parameters have significant influence on the initial failure load of hybrid sandwich beams under different boundary conditions. The initial failure modes are significantly affected by the mass distributions of face sheets with the same core thickness. The fully clamped sandwich beams with thick front face sheet have better fracture-resistance. For the similar failure modes, the load-carrying capacity of the simply supported sandwich beam with thick front face sheet is higher than that with thin front face sheet. The initial failure load of face fracture increases with increasing the front face sheet thickness and the initial failure load of core shear increases with increasing the core thickness.

ABSTRACT: A three-dimensional (3-D) Finite Element Analysis (FEA) model incorporating an elastic-plastic (EP) damage model, which was implemented as a user-defined material (‘VUMAT’) sub-routine in a FEA code (‘Abaqus/Explicit’), is developed to simulate the impact response of carbon-fibre reinforced-plastic (CFRP) composites. The model predicts the load versus time and the load versus displacement responses of the composite during the impact event. Further, it predicts the extent, shape and direction of any intralaminar damage and interlaminar delaminations, i.e. interlaminar cracking, as a function of the depth through the thickness of the impacted CFRP test specimen, as well as the extent of permanent indentation caused by the impactor striking the composite plate. To validate the model, experimental results are obtained from relatively low-velocity impact tests on CFRP plates employing either a matrix of a thermoplastic polymer, i.e. poly(ether-ether ketone), or a thermosetting epoxy polymer. The 3-D EP model that has been developed is shown to model successfully the experimentally-measured impact behaviour of the CFRP composites.

ABSTRACT: Current methods for designing Formula One (F1) crash structures are mainly based on costly iterative experiments, aimed at minimising the component mass and maximising driver safety. This paper assesses the simplified block approach used in F1 to computationally predict crashworthiness. Quasi-static and dynamic crush experiments of flat and tubular coupons are presented, to generate data for the modelling of a F1 Side Impact Structure (SIS). The crushing efficiency of these coupons is found to be dependent on geometry, ply orientation, and crushing velocity. This modelling strategy yields results which compare favourably with those obtained from the quasi-static and dynamic experimental testing of a full-scale SIS, but also highlight areas which require further work to improve accuracy.

ABSTRACT: Different from conventional materials, materials with negative Poisson's ratios expand laterally when stretched longitudinally. Known as ‘auxetic’ materials, the effect means they possess particularly fascinating properties, which have recently attracted considerable attention in the literature. A range of auxetic materials has been discovered, theoretically designed and fabricated. Developments in additive manufacturing (AM) techniques enable fabrication of materials with intricate cellular architectures. This paper outlines recent progress in the development of auxetic materials and structures, and their mechanical properties under quasi-static and dynamic loading are analysed and summarised. Limited experimental studies on 3D printed auxetic materials and structures are given more attention, ahead of extensively finite element (FE) simulations. A special focus is dedicated to their large, plastic deformation behaviour and energy absorption performance, which should be stressed in their engineering applications; no review paper has yet been found regarding this. Finally, this paper provides an overview of current study limitations, and some future research is envisaged in terms of auxetic materials and structures, nano-auxetics and additive manufacturing.


ABSTRACT: We studied the crashworthiness performance of thin-walled ultralight braided lattice composites (UBLCs) under quasi-static compressive loading experimentally and numerically. The lattice structures were initially preformed on mandrels with various cross-sectional geometries, including circular, octagonal, hexagonal, and rectangular. The effects of cross-section type and perimeter were also investigated. Our results showed that the square-shaped sample exhibited the highest specific absorbed energy (SAE) and absorbed energy per length. We also investigated the effect of the number of lattice layers. The concentric multi-layer samples absorbed more energy than single-layer samples due to interactions between the embedded layers. Furthermore, the crushing force efficiency (CFE) was improved by the use of multi-layer samples. Finite element (FE) modeling was used to predict and analyze the energy absorption behavior of UBLC samples. Both structure buckling and material failure were included in the simulations. The results of the FE simulation were in good agreement with our experimental results. The SAEs of single-layer and multi-layer UBLCs are significantly higher than those of expanded metal tubes. Considering SAE and CFE simultaneously, we can conclude that the energy absorption behavior of UBLC structures is more promising than that of similar tubular lattice structures.


ABSTRACT: We present a nonlinear multiscale modeling and simulation framework for the mechanical design of machine-knitted textiles with functionally graded microstructures. The framework operates on the mesoscale (stitch level), where yarns intermesh into stitch patterns, and the macroscale (fabric level), where these repetitive stitch patterns are composed into a fabric. On the mesoscale, representative unit cells consisting of single interlocked yarn loops, modeled as geometrically exact, nonlinear elastic 3D beams, are homogenized to compute their effective mechanical properties. From this data, a B-Spline response surface model is generated to represent the nonlinear orthotropic constitutive behavior on the macroscale, where the fabric is modeled by a nonlinear Kirchhoff–Love shell formulation and discretized using isogeometric finite elements. These functionally graded textiles with locally varying properties can be designed and analyzed by parameterizing the stitch value, i.e., the loop length of a single jersey stitch, and the knitting direction as mesoscopic design variables of the macroscopic response surface constitutive model. To validate the multiscale simulation and design approach, numerical results are compared against physical experiments of different tensile loading cases for various grading scenarios. Furthermore, the versatility of the method for the design of functionally graded textiles is demonstrated.

ABSTRACT: Structures used in space applications demand the highest levels of stiffness for their mass whilst also performing in a hostile environment. To partly address these requirements and so as to also pack efficiently for stowage during launch we propose a new type of compact telescopic morphing lattice space boom. This boom stows within a 1U Cubesat volume and is lightweight being only 0.4 kg. The boom has a total length of 2 m in its deployed state which is 20 times its stowed height. The device comprises two multi-stable cylindrical composite lattices that are joined telescopically. These lattices nest inside one another in the stowed configuration, with the objective of improving packaging efficiency. Notably, prestress and lamina orientation are used to smoothly change shape from being compact when stowed to being extended when deployed. The lattices in the boom have been designed to maximise deployment force and to be self-deploying by tuning manufacturing parameters. As a result, only a small, lightweight mechanism is required to regulate deployment speed of the lattice boom. By reversing its direction, this mechanism can be used to retract the lattice boom to its stowed configuration, thereby enabling two-way reconfigurability.

References listed at the end of the paper:
1 H.W. Jones, The recent large reduction in space launch cost, 48th international Conference on environmental systems (2018), Albuquerque, New Mexico
6 F. Royer, S. Pellegrino, Ultralight ladder-type coilable space structures, AIAA spacecraft structures conference, Kissimmee, Florida (2018)
8 T.J. King, E.L. Kuhl, Structural performance of the nanosat deployable truss, AIAA SciTech (2018), Kissimmee, Florida, 8-12 January
11 J. Reveles, M. Lawton, V. Fraux, V. Gurusamy, The development of a low mass extendible composite boom for small satellite applications, Small satellite conference (2015), Logan, Utah
14 C. McHale, S. Carey, D.A. Hadjiloizi, P.M. Weaver, Morphing composite cylindrical lattices: thermal effects and actuation. AIAA scitech forum and exposition (2020), Orlando, Florida


ABSTRACT: This paper presents a general mesh smoothing method for finite elements. The method deals with two and three-dimensional meshes with virtually any type of element. To evaluate the quality of different element types, the paper also introduces a broad quality function. The proposed method works by solving a standard deformation analysis where nodal forces aim to deform each element into an optimally placed reference element. A detailed algorithm of the proposed smoothing method is presented which is suitable for a straightforward computer implementation. Several application examples in two and three-dimensions are presented and analyzed in order to demonstrate the capabilities of the proposed algorithm. In all cases very good quality improvements were obtained with very few iterations. Also, the proposed method provided greater improvements when compared to conventional Laplacian-based methods.


ABSTRACT: We consider the two-dimensional numerical approximation of the fluid-structure interaction problem over unfitted fluid and structure meshes. In particular, we consider a method where the fluid mesh (on the background) is fixed, apart from the interface with the moving immersed structure, where general polygonal elements of arbitrary shape and changing in time are generated. The new idea of this work is to handle the discretization on such polygons by using the Discontinuous Galerkin method on polyhedral grids (PolyDG), which has been recently developed for different differential equations and here adapted for the first time to a heterogeneous problem. We prove a stability result of the proposed semi-discrete formulation and discuss how to deal with the partial or total covering of a fluid mesh element due to the structure movement. We finally present some numerical results with the aim of showing the effectiveness of the proposed method.


ABSTRACT: Thin piezoelectric bimorph cantilever is increasingly employed throughout the field of actuator and sensor applications in the microelectromechanical system (MEMS). Generally for finite element analysis of piezoelectric bimorph cantilever, three–dimensional (3D) solid element can accurately takes into account a linear or quadratic distribution of electric potential over the thickness for various electric configurations of the actuator and sensor applications. As the MEMS structures usually are quite thin and undergo large deformations, shell elements are very well suited for the structural discretization. This paper is focused on the development of a novel coupled algorithm to analyze the electromechanical coupling in a piezoelectric bimorph actuator and sensor using the shell and solid elements to simulate the structural and electric fields, respectively. The electric force induced by the inverse piezoelectric effect is transformed from the solid elements to the shell elements as an equivalent external force and moment, and the resultant displacements are transformed from the shell elements to the solid elements to evaluate the direct piezoelectric effect. Two different approaches were developed to analyze the electric field–structure interaction. In the first approach, for each block Gauss–Seidel (BGS) iteration, multiple full Newton–Raphson (N–R) iterations are executed until the tolerance criteria are satisfied. In the second approach, the BGS and N–R loops are unified into a single loop. A piezoelectric bimorph actuator and sensor were analyzed for various electrical configurations to demonstrate the accuracy of the proposed method.


ABSTRACT: A numerical procedure to analyze bifurcation and post-bifurcation of a finite deformation boundary-value problem for a residually-stressed elastic body is studied. In particular, the problem is the combined extension and inflation of a circular cylindrical tube subject to radial and circumferential residual stresses. The material model, given by a residual-stress dependent nonlinear elastic constitutive law in terms of invariants, is implemented in a finite element code. A numerical procedure to analyze the bifurcation and post-
bifurcation of the finite deformation boundary-value problem at hand is developed based on the modified Riks method. The dependence of bifurcation and post-bifurcation behavior of tubes under the loading at hand on residual stresses is shown and compared with results when there is no residual stress. The finite deformation boundary-value problem is described mainly in terms of the inflation pressure, as well as the axial and azimuthal stretches of the tube. The dependence of these quantities on bifurcation is illustrated graphically for different values of the parameters (in dimensionless form) involved, in particular, the strength of the residual stress. It is found that bulging bifurcation is expected for sufficiently large values of the axial stretch. On the other hand, for small values of the axial stretch (close to the non-extended configuration), the onset of bifurcation is found to be the bending mode. Furthermore, for the latter case in subsequent motion, i.e. post-bifurcation, it is shown that bending triggers bulging as opposed to the situation in which bending is not allowed and the onset of bifurcation is associated with bulging. In addition, the bulge, or the abnormal enlargement, that is formed during post-bifurcation after the onset of bending bifurcation appears on one side of the tube showing an irregular shape which is consistent with the development of abdominal aortic aneurysms (AAA).

ABSTRACT: Metal wind turbine support towers are very tall and slender shell structures designed to exhibit a stepwise varying distribution of optimised wall thicknesses, with strakes in the upper regions of the tower usually being much thinner than those in the lower regions. Each strake is an individual shell and potentially a critical location for failure, and as the failure location is rarely obvious in advance each strake in the tower must be carefully meshed in a finite element analysis. It is not unusual for over twenty individual strakes to be present in a design, and the computational cost involved in modelling such a structure with finite elements, particularly in nonlinear analyses, can quickly become prohibitive for execution on a personal workstation. Compromises in mesh resolution must often be made, usually to the detriment of the quality of the global solution. This paper explores a simple hybrid beam-shell modelling technique that permits an efficient and insightful analysis of multi-strake wind turbine support towers. It consists of modelling all but a handful of the strakes with beam elements or rigid bodies which have a negligible computational cost compared to shell elements, and to focus the deployment of expensive shell elements only on strakes of interest as part of a resistance assessment. As only strakes meshed with shell elements participate in a failure mechanism, the technique allows the realistic exploration of the relative criticality of all tower strakes. The technique is illustrated on a real design of a 1.5 MW 25-strake wind turbine tower.

ABSTRACT: Higher-order strain-gradient models are relevant for engineering materials which exhibit size-dependent behaviour as observed from experiments. Typically, this class of models incorporate a length scale -related to micro-mechanical material properties - to capture size effects, remove stress singularities, or regularise an ill-posed boundary value problem resulting from localisation of deformation. The higher-order continuity requirement on shape functions can be met using NURBS discretisation, as is considered herein. However, NURBS have a tensor-product nature which makes selective refinement cumbersome. To maintain accuracy and efficiency in analysis, a finer mesh may be required, to capture a localisation band, certain geometrical features, or in regions with high gradients. This work presents strain-gradient elasticity and strain-gradient plasticity, both of second-order, with hierarchically refined NURBS. Refinement is performed based on a multi-level mesh with element-wise hierarchical basis functions interacting through an inter-level subdivision operator. This ensures a standard finite-element data structure. Suitable marking strategies have been used to select elements for refinement. The capability of the numerical schemes is demonstrated with two-dimensional examples.
This paper introduces a novel hybrid finite element (FE) formulation of shell element to enable assembly process simulation of compliant sheet-metal parts with higher efficiency and flexibility. Efficiency was achieved by developing both new hybrid quadrilateral and triangular elements. Quadrilateral element (QUAD+) was formulated by combining area geometric quadrilateral 6 (AGQ6) nodes and mixed interpolated tensorial components (MITC) to model membrane and bending/shear component respectively. Triangular element (TRIA+) was formulated by merging assumed natural deviatoric strain (ANDES) for membrane and MITC for bending/shear component. Flexibility was addressed by developing an open-source C++ code, enhanced by the OpenMP interface for multiprocessing programming. Tests and benchmarks were compiled and executed within Matlab using the MEX API interface. Extensive benchmark studies were accomplished to evaluate the performance of the proposed hybrid formulation and the shell formulations used in three FEM packages - ABAQUS, ANSYS and COMSOL- under static linear elastic condition with small strain.

ABSTRACT: Sheet metal forming is a very important process in industry to create a wide variety of goods. The analysis of local ductility and residual stresses is important both to assess the viability of the manufacturing process and the reliability of the resulting elements in service. An example is crash-worthiness, where remaining ductility and residual stresses govern the safety of the overall structure during the impact. A main ingredient of finite element simulations for sheet metal forming in industry is a robust continuum-based computational algorithm for large strain elastoplasticity which includes both elastic and plastic anisotropy, as well as mixed hardening. The theory should use exactly-integrable (conservative) elastic and hardening behaviors based on physically motivated proper state variables and, if possible, result in a simple integration algorithm. In this work we implement a novel large strain formulation for anisotropic hyperelasticity in a user subroutine of the commercial program ADINA to perform sheet metal forming simulations, testing the robustness and suitability of the model for industry, as well as its accuracy. The formulation is based on a new approach to the treatment of large strain kinematics, using logarithmic elastic corrector rates instead of plastic rates. Furthermore, kinematic hardening is formulated without an explicit backstress. We compare and discuss the results with those in the literature which use alternative frameworks.

ABSTRACT: It is well known that the mechanical properties of extrusion blow molded plastic bottles are influenced by the process conditions, which leads to local orthotropic process-dependent material parameters. In this study, these parameters as well as local orientation effects are for the first time considered in the structural analysis of extrusion blow molded products. Furthermore, an integrative simulation concept has been worked out which combines process simulation and structural analysis to take the process history of the plastic bottle into account. The elastic modulus is described as a function of process parameters like the local degrees of stretching and the mold temperature. Because the local degrees of stretching differ considerably, a new algorithm was developed which identifies the local degrees of stretching as well as their orientation using the results of the process simulation. For the data mapping between the process mesh and the structural analysis mesh, the self-developed MpCCI Mapper software was used. In a simulation of a top load test, the integrative simulation model was compared with the conventional model as well as with experimental data. Although in this particular case the influence of the orthotropic material model with respect to the local degrees of stretching is rather low, the general use of process dependent material parameters leads to much better results.
assumption. It was observed that the proposed QUAD+ and TRIA+ elements performed better amongst the FE packages, especially when there was in-plane mesh distortion, with errors below 3%. It was also identified that the best efficiency is obtained by adopting dominant QUAD+ elements compared to the TRIA+ when working on complex geometries. This paper also contributes to present a wide set of benchmark studies required to verify new release of FE packages using shell element or evaluate the performance of new shell formulations.


ABSTRACT: In this paper and in the framework of the Asymptotic Numerical Method (ANM), we investigate numerically improved vectorial Padé Approximants. The ANM is a branch-by-branch continuation algorithm, each branch is represented by a vectorial Taylor series with respect to a path parameter. In the ANM, the vectorial Padé approximants have been introduced to increase the validity range of vectorial Taylor series. In a recent work, we have introduced a new matrix generalized definition of vectorial Padé approximants of vectorial Taylor series truncated at order $N$. By using this definition, the vectorial Padé approximants of type $[L, M] \ (N = L + M)$ have been investigated. We show also numerically, in this paper, that the vectorial Padé approximants $[1, N − 1]$ when the coefficients $b$ are computed from the Gram-schmidt orthogonalization technique make it possible to reduce the number of ANM steps compared to the classical vectorial Padé approximant. The effectiveness of these vectorial Padé approximants will be demonstrated on numerical examples of post-buckling of shells.


ABSTRACT: In the present study, the ability of the classical solid-shell element to satisfy the membrane patch test is examined. Theoretical and numerical investigations showed that the classical solid-shell element fails to satisfy the membrane patch test when the elements' referential covariant basis vectors in the thickness directions are coordinate-dependent. This deficiency has motivated the development of a new solid-shell formulation in the present study for modeling elastic thin structures and shell-like applications. Within the new solid-shell element, a modified Green-Lagrange strain tensor is constructed by adopting both the assumed natural inhomogeneous strain (ANIS) and the enhanced assumed strain (EAS) methods. The developed formulation is implemented in the commercial finite element software Abaqus for numerical simulations. An extensive numerical study is carried out for testing the accuracy of the developed finite element. To this end, the accuracy of the ANIS solid-shell element incorporating the proposed set of 21 EAS parameters is compared to the classical ANS solid-shell element with the same set of the EAS parameters. It is shown that the ANIS solid-shell element combined with the set of 21 EAS parameters is of great accuracy and excellent performance considering both the linear and the non-linear regimes.

References listed at the end of the paper:
2 E. Ventset, T. Krauthammer, Thin Plates and Shells, Marcel Dekker, New York (2001)
ABSTRACT: An approach to improve the membrane behaviour of the four-node shell element with 24 degrees of freedom DKMQ24 proposed by Katili et al. (2015) is presented. This improvement is based on a different approximation of drilling rotations, based on Allman's shape functions. Further, the element formulation is enhanced by the use of selective reduced integration of shear terms and by the proportional scaling of the penalty constant to the shell thickness. Additionally, nodal moment corrections for the approximation of distributed normal loads are proposed. This element, called DKMQ24+, was tested on nine standard benchmark applications.
problems for the case of linear elasticity. The element is free of shear and membrane locking and shows lower numerical errors for membrane and membrane-dominated problems.


ABSTRACT: This paper introduces the inverse finite element method using simple brick elements that can be used for shell analysis. The proposed element is the inverse counterpart of an existing Lagrangean-based “direct” trilinear hexahedral finite element that uses the approaches of reduced integration, assumed natural strains and enhanced assumed strain to prevent locking defects in shell modeling. Like the standard trilinear hexahedral element, this locking-free element has eight vertex nodes and three displacement degrees-of-freedom per node. It also has one scalar enhanced-strain degree-of-freedom, which is eliminated at the element level. Both inverse and direct finite element formulations are identical up to the definition of the Lagrangean-based equilibrium equations. For the inverse approach, these equations have as unknowns the positions of the nodes in the undeformed configuration. The current approach is particularly well suited for a category of inverse problems where a given shape must be attained after large elastic deformations. This is the case in the design of turbine blades, to be developed here.


ABSTRACT: Almost all the mesh-free methods are restricted to 2-D problems owing to the difficulty in generating 3-D grids. One effective way to overcome this limitation is to utilize the concept of hierarchical modeling for elastic structures. It was introduced originally for the dimensionally-reduced analysis of 3-D structures, but it can be used for the reverse purpose. By assuming the displacement field in the thickness direction with polynomials, the in-plane displacement could be approximated by 2-D mesh-free method. Inspired this motivation, this paper intends to demonstrate the numerical analysis of plate-like structures by 2-D natural element method (NEM). The polynomial order in the thickness direction is defined by the model level, and a number of hierarchical models are constructed by sequentially increasing the model level. The mid-surface of structure is discretized into a NEM grid and the corresponding in-plane displacement field is approximated according to a locking-free selectively reduced integration technique. The numerical experiments are performed to illustrate and validate the proposed method. Both the central deflection and the stress resultants are investigated with respect to the model level and compared with the full 3-D elasticity. In addition, the modeling error of hierarchical models is examined with respect to the thickness and the model level, and the convergence characteristic to the total number of grid points is compared with FEM.

http://www.sciencedirect.com/science/journal/00457825


ABSTRACT: This article firstly presents a novel numerical methodology to concurrently optimize material distribution (size) and thickness variation (shape) of multidirectional functionally graded (MFG) plates under free vibration within the isogeometric analysis (IGA) framework. An isogeometric multimesh design (IMD) approach is proposed to generate two distinct non-uniform rational B-spline (NURBS) surfaces via the refinement strategy. A finer analysis one relied upon a combination of the IGA and a generalized shear deformation theory (GSDT) is utilized for the unknown solution approximation in finite element analyses.
(FEAs). Whilst the other coarser design one is employed for the exact geometry representation as well as the optimal material and thickness depiction. Size and shape design variables are in turn the ceramic volume fraction and -axis coordinate of the top side of the MFG plate coincidentally assigned to each of control points on this surface. Flexibly utilizing such two surfaces helps diminish a large number of design variables and considerably save the computational cost in optimization problems, yet still appropriately manifesting optimal material and thickness profiles. Additionally, this definition accurately simulates mechanical behavior of MFG plates in analysis ones as well. A recently developed derivative-free adaptive hybrid evolutionary firefly algorithm (AHEFA) is used to solve constrained frequency maximization problems. Several numerical examples are executed to verify the effectiveness and robustness of the present paradigm.

References listed at the end of the paper:
1 Koizumi M., FGM activities in Japan, Compos. B. Eng., 28 (1997), pp. 1-4
2 Ebrahimí F., Saleri E., Thermo-mechanical vibration analysis of nonlocal temperature-dependent FG nanobeams with various boundary conditions, Compos. B. Eng., 78 (2015), pp. 272-290
3 Şimşek M., Al-shujairi M., Static, free and forced vibration of functionally graded (FG) sandwich beams excited by two successive moving harmonic loads, Compos. B. Eng., 108 (2017), pp. 18-34
7 Panyatong M., Chinnaboo B., Chuecheepsakul S., Free vibration analysis of FG nanoplates embedded in elastic medium based on second-order shear deformation plate theory and nonlocal elasticity, Compos. Struct., 153 (2016), pp. 428-441
9 Mehrfian F., Beni Y.T., Size-dependent torsional buckling analysis of functionally graded cylindrical shell, Compos. B. Eng., 94 (2016), pp. 11-25
15 Şimşek M., Bi-directional functionally graded materials (BDFGMs) for free and forced vibration of Timoshenko beams with various boundary conditions, Compos. Struct., 133 (2015), pp. 968-978
16 Şimşek M., Buckling of Timoshenko beams composed of two-dimensional functionally graded material (2D-FGM) having different boundary conditions, Compos. Struct., 149 (2016), pp. 304-314
17 Karamanli A., Bending behaviour of two directional functionally graded sandwich beams by using a quasi-3D shear deformation theory, Compos. Struct., 174 (2017), pp. 70-86
21 Xiang T., Natarajan S., Man H., Song C., Gao W., Free vibration and mechanical buckling of plates with in-plane material inhomogeneity–A three dimensional consistent approach, Compos. Struct., 118 (2014), pp. 634-642
23 Alinaghizadeh F., Shariati M., Geometrically non-linear bending analysis of thick two-directional functionally graded annular sector and rectangular plates with variable thickness resting on non-linear elastic foundation, Compos. B. Eng., 86 (2016), pp. 61-83
46 Tsiatas G.C., Charalampakis A.E., Optimizing the natural frequencies of axially functionally graded beams and arches, Compos. Struct., 160 (2017), pp. 256-266
52 Icardi U., Ferrero L., Optimisation of sandwich panels with functionally graded core and faces, Compos. Sci. Technol., 69 (2009), pp. 575-585
ABSTRACT: We extend the analysis and discretization of the Kirchhoff–Love plate bending problem from Führer et al. (in press) in two aspects. First, we present a well-posed formulation and quasi-optimal DPG discretization that include the gradient of the deflection. Second, we construct Fortin operators that prove the well-posedness and quasi-optimal convergence of lowest-order discrete schemes with approximated test functions for both formulations. Our results apply to the case of non-convex polygonal plates where shear forces can be less than L2-regular. Numerical results illustrate expected convergence orders.

References listed at the end of the paper:

https://doi.org/10.1016/j.cma.2018.09.011

ABSTRACT: The eigenproblem for thin shells of revolution under uncertainty in material parameters is discussed. Here the focus is on the smallest eigenpairs. Shells of revolution have natural eigenclusters due to symmetries, moreover, the eigenpairs depend on a deterministic parameter, the dimensionless thickness. The stochastic subspace iteration algorithms presented here are capable of resolving the smallest eigenclusters. In the case of random material parameters, it is possible that the eigenmodes cross in the stochastic parameter space. This interesting phenomenon is demonstrated via numerical experiments. Finally, the effect of the chosen material model on the asymptotics in relation to the deterministic parameter is shown to be negligible.

References listed at the end of the paper:
2 Andreev R., Schwab C., Sparse Tensor Approximation of Parametric Eigenvalue Problems, Lecture Notes in Computational Science

ABSTRACT: A strain gradient elasticity model for shells of arbitrary geometry is derived for the first time. The Kirchhoff–Love shell kinematics is employed in the context of a one-parameter modification of Mindlin’s strain gradient elasticity theory. The weak form of the static boundary value problem of the generalized shell model is formulated within an $H^3$ Sobolev space setting incorporating first-, second- and third-order derivatives of the displacement variables. The strong form governing equations with a complete set of boundary conditions are derived via the principle of virtual work. A detailed description focusing on the non-standard features of the implementation of the corresponding Galerkin discretizations is provided. The numerical computations are accomplished with a conforming isogeometric method by adopting $C^1(p-1)$-continuous NURBS basis functions of order $p \geq 3$. Convergence studies and comparisons to the corresponding three-dimensional solid element simulation verify the shell element implementation. Numerical results demonstrate the crucial capabilities of the non-standard shell model: capturing size effects and smoothening stress singularities
ABSTRACT: A bio-inspired concept of non-uniform curved grid-stiffened composite structures with embedded stiffeners (embedded NCGCs) is proposed in the paper. Shallow curved stiffeners are embedded in the laminate skin to form an integrated structure to improve the skin–stiffener deformation compatibility. A method named streamline stiffener path optimization (SSPO) based on multiscale modeling is proposed for curved stiffener layout design of embedded NCGCs. Firstly, the homogenization-based global/local analysis is used to calculate structural responses on a global unstiffened model with the equivalent material properties obtained from local representative cell configurations (RCCs). Secondly, the discrete distribution of 2D curved stiffener paths is transformed into a continuous distribution of the streamline function values (SFVs) on a 3D level set surface. The stiffener path description using the streamline function is similar as the level set method with specific constraints. Projections of points with the same integral SFVs will form one stiffener path. Thirdly, optimal curved stiffener layout is achieved using shape design of local parallelogram representative cell configurations with analytical sensitivities calculated using the affine mapping from the square master domain to the parallelogram RCCs. Fourthly, stiffener spacing and angle constraints are added for manufacturing considerations and local buckling resistance, and optimization design is implemented to maximize the buckling load within a given weight. Finally, numerical examples of a square laminated panel under uniaxial and biaxial compressions validate the effectiveness of the proposed SSPO method and indicate the significant improvement of the buckling loads by steering the stiffener paths.


ABSTRACT: In the size-dependent continuum theories such as the strain gradient theory, the higher-order derivatives of displacement field appear in the energy functional of the structure which leads to the employment of C1 continuous shape functions within the finite element discretization procedure. Although a wide range of one- and two-dimensional small-scale finite elements were developed to analyze the structural behavior of micro- and nano-structures, a few studies can be found on the development of size-dependent three-dimensional (3D) finite elements. Hence, the main purpose of this work is the introduction of a four-node tetrahedral element to analyze the size-dependent mechanical behavior of micro- and nano-structures based on the three-dimensional strain gradient theory (SGT). In the proposed element, the values of displacement components and their related first-order derivatives are considered as degrees of freedom at each node. To present the governing equations, the matrix form of kinetic and strain energies and the work of external forces are derived based on the 3D elasticity theory and strain gradient model. To show the efficiency of the proposed model, the size-dependent linear vibration analysis of circular and elliptical micro- and nano-plates is presented. Various numerical results including comparative and convergence studies are reported to check the accuracy and performance of the introduced finite element.


ABSTRACT: Straight beams, rods and trusses are common elements in structural and mechanical engineering, but recent advances in additive manufacturing now also enable efficient freeform fabrication of curved, deformable beams and beam structures, such as microstructures, metamaterials and conformal lattices. To exploit this new design freedom for applications with nonlinear mechanical behavior, we introduce an isogeometric method for shape optimization of curved 3D beams and beam structures. The geometrically exact Cosserat rod theory is used to model nonlinear 3D beams subject to large deformations and rotations. The initial and current geometry are parameterized in terms of NURBS curves describing the beam centerline and an isogeometric collocation approach is used to discretize the strong form of the balance equations. Then, a nonlinear optimization problem is formulated in order to optimize the positions of the control points of the NURBS curve that describes the beam centerline, i.e., the geometry or shape of the beam. To solve the design problem using gradient-based algorithms, we introduce semi-analytical, inconsistent analytical and fully analytical approaches for calculation of design sensitivities. The methods are numerically validated and their
performance is investigated, before the applicability and versatility of our 3D beam shape optimization method is illustrated in various numerical applications, including optimization of an auxetic 3D metamaterial.


ABSTRACT: In this paper, we propose an enhanced isogeometric analysis (IGA) collocation method. It is well known that the location of the collocation points plays an important role in the accuracy and stability of IGA collocation methods. This is particularly true for non-uniform meshes and domains generated from multi-patch geometries. We present an enhanced collocation method based on Gauss points, which has improved accuracy as compared to using C1 splines and a recovery-based error estimator that can be derived by sampling the solution at particular points in the domain. Adaptivity is implemented using a hierarchical spline basis, which satisfies the C1 continuity requirement. The proposed approach has been tested by several benchmark problems, including multipatch domains and geometries with re-entrant corners.


ABSTRACT: Stress integration algorithm based on finite difference method (FDM) was proposed to effectively deal with both first and second derivatives of yield and potential functions which are the lengthiest component in stress integration procedure. With the proposed numerical algorithm, both first and second derivatives of yield function are approximated by central difference method, so that finite element modeling using advanced constitutive model could be easily performed no matter how complicated its derivatives are. For the verification purpose, the algorithm was applied for advanced constitutive models: Plastic anisotropy model under associated (AFR) and non-associated flow rule (non-AFR), the homogeneous anisotropic hardening (HAH) model under associated (AFR) and non-associated flow rule (non-AFR). The proposed algorithm was verified with single element loading–unloading and cup-drawing simulations. The Euler backward method based on both the proposed numerical algorithm and analytical derivatives were employed for verification purpose. The accuracy and time efficiency of the proposed numerical algorithm were evaluated by comparing the simulation results from analytical derivatives. In addition, the applicability of the proposed numerical algorithm for the HAH models was estimated with single element loading–unloading, loading–reloading, and deep-drawing/springback simulations. Non-associated flow plasticity for the HAH model is newly proposed to improve numerical efficiency with finite difference method by keeping the same level of accuracy as associated flow rule plasticity. All the simulation results proved that the proposed numerical algorithm can be widely used for the implementation of advanced constitutive models.


ABSTRACT: We present a finite element (FE) formulation based on an efficient layerwise (zigzag) theory for stress and vibration analysis of highly inhomogeneous composite and sandwich plates with multiple delaminations using the region method. The delaminations are assumed to be present at multiple interfacial and/or planar locations, and are not allowed to change in size during the deformations. Following the free mode model, the delaminated faces are assumed to have no mutual interaction during deformations. Using a hybrid method, the continuity of inplane displacements at the delamination front is satisfied exactly at the midplanes of the sublaminates separated by delaminations, while the deviations of their through-thickness variations in the intact and delaminated segments are minimized with respect to the rotation variables, using the least squares method. The formulation is shown to yield accurate results with reference to the full-field three dimensional FE solutions, for the deflection, stresses, natural frequencies and mode shapes for delaminated composite as well as highly inhomogeneous single- and double-core sandwich plates. The conventional point and least squares
continuity methods, however, show large error for moderately thick plates and for higher than fundamental vibration modes. The smeared third order theory, which has the same number of degrees of freedom as the zigzag theory, is shown to yield grossly inaccurate results for delaminated sandwich plates. The present formulation is more computationally efficient than the layerwise theories that are usually used for such analysis, but is at the same time accurate, simple and robust.


ABSTRACT: It is important to account for inherent variability in the material properties in the design and analysis of engineering structures. These properties are typically not homogeneous, but vary across the spatial coordinates within a structure, as well as from specimen to specimen. This form of uncertainty is commonly modelled using random fields within the Stochastic Finite Element Method. Simulation within this framework can be complicated by the dependence of a random field’s correlation function upon the geometry of the domain over which it is defined. In this paper, a new method is proposed for simulating random fields over a general two-dimension curved surface, represented as a finite element mesh. The covariance function is parametrised using the geodesic distance, evaluated using the solution to the ‘discrete geodesic problem,’ and a point discretisation approach is subsequently applied in order to sample the random field at the nodes of the model. The major contribution of the present work is the development of a methodology for simulating random fields over curved surfaces of arbitrary geometry, with a focus upon non-intrusive application to industrial finite element models using ‘off the shelf’ commercial software. In order to demonstrate the potential impact of the proposed approach, the algorithm is applied in an uncertainty quantification case study concerning vibration and buckling of an industrial composite aircraft wing model.


ABSTRACT: The integrity of engineering structures is often compromised by embedded surfaces that result from incomplete bonding during the manufacturing process, or initiation of damage from fatigue or impact processes. Examples include delaminations in composite materials, incomplete weld bonds when joining two components, and internal crack planes that may form when a structure is damaged. In many cases the areas of the structure in question may not be easily accessible, thus precluding the direct assessment of structural integrity. In this paper, we present a gradient-based, partial differential equation (PDE)-constrained optimization approach for solving the inverse problem of interface detection in the context of steady-state dynamics. An objective function is defined that represents the difference between the model predictions of structural response at a set of spatial locations, and the experimentally measured responses. One of the contributions of our work is a novel representation of the design variables using a density field that takes values in the range [0, 1] and raised to an integer exponent that promotes solutions to be near the extrema of the range. The density field is combined with the penalty method for enforcing a zero gap condition and realizing partially bonded surfaces. The use of the penalty method with a density field representation leads to objective functions that are continuously differentiable with respect to the unknown parameters, enabling the use of efficient gradient-based optimization algorithms. Numerical examples of delaminated plates are presented to demonstrate the feasibility of the approach.


ABSTRACT: As a soft material with an almost negligible bending stiffness, a membrane may easily lose its mechanical stability. To capture its entire instability process, intensive computation is required, especially in the
case of short wave length. The objective of this paper is to construct an efficient model to simulate and study the instability phenomena of circular membranes. By using the method of Fourier series with slowly variable coefficients in the circumferential direction, a new family of one-dimensional reduced finite elements are developed to study the three-dimensional problems. The nonlinear system is solved by the Asymptotic Numerical Method (ANM), which is reliable and efficient for tracing the bifurcation points and post-buckling equilibrium path compared with other classical non-linear solution algorithms. The accuracy and efficiency of the reduced model is verified by simulating the instability phenomena in stretched annular membranes and a compressed circular plate. The relation between critical loads and bifurcation patterns and the evolution of stress components in the entire wrinkling process are discussed. This study provides new simulation schemes to explore the instability in circular membranes under complex loadings and boundary conditions.


ABSTRACT: We extend a recently-developed framework for isogeometric analysis of composite laminates to drive material damage evolution with a smoothed strain field. This builds on ideas from gradient-enhanced continuum damage modeling, and is intended to limit the dependence of damage predictions on the choice of discrete mesh. The resulting enhanced framework models each lamina of a composite shell structure as a Kirchhoff–Love thin shell. To account for the anisotropic damage modes of laminae, we smooth a tensor-valued strain by solving an elliptic partial differential equation (PDE) system on each lamina. This strain-smoothing PDE system is formulated to be independent of the choice of coordinates and is applicable to general manifold shell geometries. Numerical examples illustrate the enhanced damage model’s validity, mesh-independence, and applicability to complex industrial geometries.


ABSTRACT: For Kirchhoff–Love shell problems a new mixed formulation solely based on standard H1 spaces is presented. This allows for flexibility in the construction of discretization spaces, e.g., standard Co-coupling of multi-patch isogeometric spaces is sufficient. In terms of solution strategies, efficient methods for standard second-order problems like multigrid methods can be used as building blocks of preconditioners for iterative solvers. Furthermore, a combination of the proposed mixed formulation of the bending part with a popular mixed formulation of the membrane part in order to avoid membrane locking is considered. The performance of both mixed formulations is demonstrated by numerical benchmark studies.


ABSTRACT: We propose a method to obtain diagonal mass matrices for NURBS-based approximation spaces by a “dual lumping” method. The use of lumped mass matrices is of great importance in elastodynamics problems, as they can be employed in explicit time integration schemes which do not require the solution of a linear system. In finite elements, several well-established methods, such as row-sum, diagonal scaling, or nodal quadrature methods have been used to obtain lumped mass matrices for different applications. However, for higher-order and higher continuity approximation spaces such as those derived from NURBS, these approaches have only limited (second-order) accuracy. In this work, we derive a dual basis which has optimal approximation and dispersion properties, while maintaining local support. The dual space has discontinuities at the element boundaries (knots) and it is used to provide the test functions in the context of a Petrov–Galerkin method. This results in a general framework for the study of lumped mass matrices which can be employed in explicit time integration schemes with high-order accuracy. Numerical experiments are presented to demonstrate the applicability of the method to problems with smooth solutions as well as to wave propagation problems with reduced regularity.
ABSTRACT: Isogeometric analysis (IGA) has been a particularly impactful development in the realm of Kirchhoff–Love thin-shell analysis because the high-order basis functions employed naturally satisfy the requirement of C1 continuity. Still, engineering models of appreciable complexity, such as wind turbine blades, are typically modeled using multiple surface patches and, often, neither rotational continuity nor conforming discretization can be practically obtained at patch interfaces. A penalty approach for coupling adjacent patches is therefore presented. The proposed method imposes both displacement and rotational continuity and is applicable to either smooth or non-smooth interfaces and either matching or non-matching discretization. The penalty formulations require only a single, dimensionless penalty coefficient for both displacement and rotation coupling terms, alleviating the problem-dependent nature of the penalty parameters. Using this coupling methodology, numerous benchmark problems encapsulating a variety of analysis types, geometrical and material properties, and matching and non-matching interfaces are addressed. The coupling methodology produces consistently accurate results throughout all tests. Furthermore, the suggested penalty coefficient of alpha = 1000 is shown to be effective for the wide range of problem configurations addressed. Finally, a realistic wind turbine blade model, consisting of 27 patches and 51 coupling interfaces and having a chordwise-and-spanwise-variant composite material definition, is subjected to buckling, vibration, and nonlinear deformation analyses using the proposed approach.


ABSTRACT: In the present study, a geometrically nonlinear theory for circular cylindrical shells made of incompressible hyperelastic materials is developed. The 9-parameter theory is higher-order in both shear and thickness deformations. In particular, the four parameters describing the thickness deformation are obtained directly from the incompressibility condition. The hyperelastic law selected is a state-of-the-art material model in biomechanics of soft tissues and takes into account the dispersion of collagen fiber directions. Special cases, obtained from this hyperelastic law setting to zero one or some material coefficients, are the Neo–Hookean material and a soft biological material with two families of collagen fibers perfectly aligned. The proposed model is validated through comparison with the exact solution for axisymmetric cylindrical deformation of a thick cylinder. In particular, the shell theory developed herein is capable to describe, with extreme accuracy, even the post-stability problem of a pre-stretched and inflated Neo–Hookean cylinder until the thickness vanishes. Comparison to the solution of higher-order shear deformation theory, which neglects the thickness deformation and recovers the normal strain from the incompressibility condition, is also presented.


ABSTRACT: A quadrilateral bi-cubic G1-conforming finite element for the analysis of Kirchhoff plates is presented. The rational version of the Gregory patch proposed by Loop et al. (2009) is the starting point of our formulation. This version of the Gregory patch consists in rational enhancement of the bi-cubic Bézier interpolation representing a suitable tool for designing G1-conforming quadrilateral element on Co-conforming un-structured meshes. The element includes as additional degrees of freedom the edge rotations like in the Loop-formulations but is only displacement based. Because of the presence of the rational functions, the second derivatives of the interpolation present a finite discontinuity at the corners of the element, that prevent the element from passing the bending patch test. The element so formulated does not present optimal rate of convergence under h-refinement operation. The formulation is enhanced enforcing these discontinuities to be zero by means of Lagrange multipliers. It is shown that with these constraints the element passes the patch test and presents optimal rate of convergence for unstructured mesh. In this way the rational conforming
approximation collapses into a conforming re-arrangement of the complete bi-cubic Bézier interpolation. Some examples and benchmarks are presented in order to test the performance of the element for the Kirchhoff plate model.


ABSTRACT: The contribution herein proposes an isogeometric generalized nth order perturbation-based stochastic method for exactly modeling/representing composite structures comprising of different materials with particular attention to both static and dynamic analysis of structures with random material characteristics. Herein, we exactly represent the geometric model via isogeometric analysis (IGA), such as exactly modeling the interfaces in composite structures with dissimilar materials and also continuous variable thicknesses that cannot be achieved by existing traditional methods such as FEM. Besides, only a limited or scant work has been conducted thus far with IGA and stochastic methods. We consider the uncertainties of elastic modulus and mass density into account as stochastic inputs in static and dynamic isogeometric stochastic analyses. Moreover, we derive and expand the IGA based random-input parameter and all state functions included in static and dynamic equilibrium equations around their expectations via a generalized nth order Taylor series using a small perturbation parameter epsilon. In addition, we determine the probabilistic moments of the stochastic solution that satisfy the given accuracy requirement by expanding to nth order. The results obtained by the proposed method, the finite element method (wherever feasible), and Monte Carlo simulations for both benchmark and engineering applications verify the following: (a) the proposed methodology can achieve more accurate determinstic solutions with improved efficiency, thereby strengthening the effectiveness and efficiency brought by the stochastic method. This is in contrast to the FEM based method which weakens them, (b) on the other hand, it can more efficiently acquire reliable and more accurate stochastic results, both for expected values and standard deviations in the static and dynamic (free vibration) analyses. Note that the larger the problem size is, the more efficient the proposed method will be.


ABSTRACT: Nanowire based semiconductors are promising for nanogenerators. However, there exist limited numerical tools to analyze these type of structures taking into account effects which are of particular importance at nanoscale. Therefore, we present a finite deformation NURBS based formulation to model a multifunctional material that couples strain, strain gradient, polarization and free charge carriers simultaneously. Specifically, the weak form and consistent linearization of the piezoelectric semiconductor including flexoelectricity and non-local elasticity are introduced. The nonlinear equations are then discretized and solved by utilizing isogeometric analysis (IGA) which fulfills the C1 continuity requirement. Several numerical examples are performed to investigate the influence of flexoelectricity and non-local elasticity in ZnO piezoelectric semiconductor nanowires under large deformation. The formulation developed in this work can contribute to the development of novel nanoelectromechanical coupling devices such as flexoelectric nanogenerators.


ABSTRACT: The structures in thermal environment often suffer from severe thermal expansion, potentially leading to buckling failure. This study aims to address this issue by proposing multi-material topology optimization for thermomechanical buckling problems. The density-based model with the rational approximation of material properties (RAMP) is adopted here for parameterization of multiple materials. The
sensitivities of thermomechanical compliance and buckling are derived through the adjoint technique. The globally convergent version of the method of moving asymptotes (GCMMA) is employed to solve the non-monotonic topology optimization problem. In this study, two numerical examples are presented to illustrate the effectiveness of the proposed method, in which the total volume of multi-materials is minimized subject to thermoelastic compliance and buckling constraints. The examples exhibit significant difference in the final topologies for mechanical buckling and thermomechanical buckling optimization. The study demonstrates the importance of thermomechanical buckling criteria for the design of structures operating in a temperature-varying environment.


ABSTRACT: We consider the numerical approximation of lipid biomembranes at equilibrium described by the Canham–Helfrich model, according to which the bending energy is minimized under area and volume constraints. Energy minimization is performed via L2-gradient flow of the Canham–Helfrich energy using two Lagrange multipliers to weakly enforce the constraints. This yields a highly nonlinear, high order, time dependent geometric Partial Differential Equation (PDE). We represent the biomembranes as single-patch NURBS closed surfaces. We discretize the geometric PDEs in space with NURBS-based Isogeometric Analysis and in time with Backward Differentiation Formulas. We tackle the nonlinearity in our formulation through a semi-implicit approach by extrapolating, at each time level, the geometric quantities of interest from previous time steps. We report the numerical results of the approximation of the Canham–Helfrich problem on ellipsoids of different aspect ratio, which leads to the classical biconcave shape of lipid vesicles at equilibrium. We show that this framework permits an accurate approximation of the Canham–Helfrich problem, while being computationally efficient.


ABSTRACT: The contribution is concerned with a numerical element formulation in boundary representation. It results in a polynomial element description with an arbitrary number of nodes on the boundary. Scaling the boundary description determines the interior domain. The scaling approach is adopted from the so-called scaled boundary finite element method (SBFEM), which is a semi-analytical formulation to analyze problems in linear elasticity. Within this method, the basic idea is to scale the boundary with respect to a scaling center. The boundary, which is denoted as circumferential direction, and the scaling direction span the parameter space. In the present approach, interpolations in scaling direction and circumferential direction are introduced. The interpolation in circumferential direction is independent of the scaling direction. The formulation is suitable to analyze problems in nonlinear solid mechanics. The displacement degrees of freedom are located at the nodes on the boundary and in the interior element domain. The degrees of freedom located at the interior domain are eliminated by static condensation, which leads to a polygonal finite element formulation with an arbitrary number of nodes on the boundary. The element formulation allows per definition for Voronoi meshes and quadtree mesh generation. Numerical examples give rise to the performance of the present approach in comparison to other polygonal element formulations, like the virtual element method (VEM). Some benchmark tests show the capability of the element formulation. A comparison to standard and mixed element formulations is presented. The present approach is perfectly suitable to model heterogeneous structures with inclusions and voids. It avoids also staircase approximation of curved boundaries.


ABSTRACT: In this paper, we investigate the construction and identification of a new random field model for representing the constitutive behavior of laminated composites. Here, the material is modeled as a random hyperelastic medium characterized by a spatially dependent, stochastic and anisotropic strain energy function.
The latter is parametrized by a set of material parameters, modeled as non-Gaussian random fields. From a probabilistic standpoint, the construction is first achieved by invoking information theory and the principle of maximum entropy. Constraints related to existence theorems in finite elasticity are, in particular, accounted for in the formulation. The identification of the parameters defining the random fields is subsequently addressed. This issue is attacked as a two-step problem where the mean model is calibrated in a first step, by imposing a match between the linearized model and nominal values proposed in the literature. The remaining parameters controlling the fluctuations are next estimated by solving an inverse problem in which principal component analysis and the maximum likelihood method are combined. The whole framework is illustrated considering an experimental database where multi-axial measurements are performed on a carbon-epoxy laminate. This work constitutes a first step towards the development of an integrated framework that will support decision making under uncertainty for the design, certification and qualification of composite materials and structures.


ABSTRACT: This paper presents a new formulation of the coupled reduced-order modeling technique for fluid–structure interaction problems. The problem addressed here is a classical vibro-acoustic issue, which is a coupled vibration of an acoustic fluid in an elastic structure. Discretization of the problem yields a model having many degrees of freedom, which may impede rapid simulation and analysis. Projection-based model reduction is thus the most popular way to handle this problem. Conventionally, structure and fluid modes are independently employed to reduce their own degrees of freedom, and the Schur complement is then used to make a weak coupling between the two domains. In this work, we suggest a new coupled formulation to build a strong connection between the fluid and structure, which is mathematically a sequential projection from structure to fluid. The proposed strongly coupled formulation provides insight into the way that the structural vibration energy is transmitted to the fluid domain. Consequently, it can offer more precise reduced-order modeling of the fluid–structure interaction problems than conventional approaches. Numerical results herein demonstrate improved accuracy of the proposed method.


ABSTRACT: This work makes a first attempt to conduct a geometrically non-linear analysis of functionally graded carbon nanotube reinforced composites (FG-CNTRC) structures, with surface-bonded active layers, based on Kirchhoff shell theory. Uniform and three different distribution types of functionally graded nanocomposites are presented. These distributions are assumed to be uniaxially aligned in the axial direction and functionally graded in the shell thickness direction, while the electric potential through the thickness of the active layers is assumed to be linear. A comparison study is carried out in order to show the applicability of the current formulation applied to various shapes of shell structures. The effects of various parameters as volume fraction, distribution of nanotubes, geometrical characteristics as well as load boundary on non-linear behavior of the smart FG-CNTRC structures are investigated.


ABSTRACT: This article presents application of rational triangular Bézier splines (rTBS) for developing Kirchhoff–Love shell elements in the context of isogeometric analysis. Kirchhoff–Love shell formulation requires high continuity between elements because of higher order PDEs in the description of the problem. Non-uniform rational B-spline (NURBS)-based IGA has been extensively used for developing Kirchhoff–Love shell elements, as NURBS-based IGA can provide high continuity between and within elements. However, NURBS-based IGA has some limitations; such as, analysis of a complex geometry might need multiple NURBS patches and imposing higher continuity constraints over interfaces of patches is a challenging issue. Addressing
these limitations, isogeometric analysis based on rTBS can provide C1 continuity over the mesh including element interfaces, a necessary condition in finite elements formulation of Kirchhoff–Love shell theory. Based on this technology, we use Cr smooth rational triangular Bézier spline as the basis functions for representing both geometry and solution field. In addition to providing higher continuity for Kirchhoff–Love formulation, using rTBS elements we can achieve three significant challenging goals: optimal convergence rate, efficient local mesh refinement and analysis of geometric models of complex topology. The proposed method is applied on several examples; first, this technique is verified against multiple plate and shell benchmark problems; investigating the convergence rate on the benchmark problems demonstrates that the optimal convergence rate can be obtained by the proposed technique. We also apply our method on geometric models of complex topology or geometric models in which efficient local refinement is required. Moreover, a car hood is modeled with rTBS and structurally analyzed by using the proposed framework.


ABSTRACT: A superconvergent isogeometric formulation is presented to accurately analyze the natural frequencies for elastic continua. This formulation is realized by a set of superconvergent quadrature rules which are designed for the numerical integration of isogeometric mass and stiffness matrices. In order to obtain these quadrature rules, a natural frequency error measure for elastic continua is systematically deduced using the quadratic basis functions, where the mass and stiffness matrices are formulated by the assumed quadrature rules. In contrast to the quadrature-based superconvergent isogeometric formulation for the scalar-valued wave equations, it is shown that herein different quadrature rules are required for the mass and stiffness matrices to achieve the superconvergence of natural frequency computation for the vector-valued elastic continuum problems. Consequently, the superconvergent quadrature rules are established through optimizing the natural frequency accuracy. It turns out that with these quadrature rules, the accuracy of natural frequencies for elastic continua is improved by two orders compared with the standard isogeometric formulation employing the consistent mass matrix. Meanwhile, it is found that the superconvergent quadrature rules involve the wave propagation angle and consequently simplified quadrature rules without the angle dependence are further proposed for straightforward practical applications. Numerical results reveal the superconvergence of the proposed method regarding the natural frequencies for elastic continua.


ABSTRACT: An investigation into the postbuckling and geometrically nonlinear behaviors of functionally graded carbon nanotube-reinforced composite (FG-CNTRC) shells is carried out in this study. The discrete nonlinear equation system is established based on non-uniform rational B-Spline (NURBS) basis functions and the first-order shear deformation shell theory (FSDT). The nonlinearity of shells is formed in the Total Lagrangian approach considering the von Karman assumption. The incremental solutions are obtained by using a modified Riks method. In the present formulation, the rule of mixture is used to estimate the effective material properties of FG-CNTRC shells. Effects ofCNTs distribution, volume fraction and CNTs orientation on the postbuckling behavior of FG-CNTRC shells are particularly investigated. Exact geometries of shells are modeled by using NURBS interpolation. Several verifications are given to show the high reliability of the proposed formulation. Especially, some complex postbuckling curves of FG-CNTRC panels and cylinders are first provided that could be useful for future references.


ABSTRACT: We present a multiscale plate element for the analysis of solid, waffle and hollowcore reinforced concrete slabs based on the higher order computational continua (HC) formulation. The salient features of the
proposed formulation are: (i) the ability to consider large representative volume elements (RVE) characteristic to waffle and hollowcore slabs, (ii) versatility stemming from the ease of handling damage and prestressing, and (iii) computational efficiency resulting from model reduction, combined with the well-established damage law rescaling method that yields simulation results nearly mesh-size independent. The multiscale formulation has been validated against experimental data for solid, hollowcore and waffle reinforced concrete slabs with and without prestressing.


ABSTRACT: We present a systematic study on higher-order penalty techniques for isogeometric mortar methods. In addition to the weak-continuity enforced by a mortar method, normal derivatives across the interface are penalized. The considered applications are fourth order problems as well as eigenvalue problems for second and fourth order equations. The hybrid coupling, which combines mortar and penalty methods, enables the discretization of fourth order problems in a multi-patch setting as well as a convenient implementation of natural boundary conditions. For second order eigenvalue problems, the pollution of the discrete spectrum – typically referred to as “outliers” – can be avoided. Numerical results illustrate the good behaviour of the proposed method in simple systematic studies as well as more complex multi-patch mapped geometries for linear elasticity and Kirchhoff plates.


ABSTRACT: A new finite element procedure for thin plates and shells is presented. It combines a geometrically non-linear, rotation-free Kirchhoff–Love formulation with triangular and quadrilateral Bernstein–Bézier elements and C and G inter-element continuity conditions, as well as boundary conditions for clamping and for symmetry. The formulation is free from transverse-shear locking and relies on a high polynomial degree to mitigate membrane locking. Bernstein–Bézier elements are, as opposed to NURBS, suitable for arbitrary triangulations. Unlike with Hermite elements, no stress concentrations occur if the boundary is partially clamped and the formulation can be potentially extended to stiffened plates and shells and to step-wise changes of thickness and material properties. The convergence behaviour is demonstrated and the computational efficiency is compared with that of C° Reissner–Mindlin elements on several numerical examples.


ABSTRACT: Over the recent decades, Topology Optimization (TO) has become an important tool in the design and analysis of mechanical structures. Although structural TO is already used in many industrial applications, it needs much more investigation in the context of vehicle crashworthiness. Indeed, crashworthiness optimization problems present strong nonlinearities and discontinuities, and gradient-based methods are of limited use. The aim of this work is to present an in-depth analysis of the novel Kriging-Assisted Level Set Method (KG-LSM) for TO. It is based on an adaptive optimization strategy using the Kriging surrogate model and a modified version of the Expected Improvement (EI) as the update criterion, which allows for embedding opportune constraints. The adopted representation using Moving Morphable Components (MMCs) significantly reduces the dimensionality of the problem, enabling an efficient use of surrogate-based optimization techniques. A minimum compliance cantilever beam test case of different dimensionalities is used to validate the presented strategy, as well as identify its potential and limits. The method is then applied to a 2D crash test case, involving a cylindrical pole impact on a rectangular beam fixed at both ends. Compared to the state-of-the-art Covariance Matrix Adaptation Evolution Strategy (CMA-ES), the KG-LSM optimization algorithm demonstrates to be efficient in terms of convergence speed and performance of the optimized designs.
ABSTRACT: We formulate a methodology to enforce interface conditions preserving higher-order continuity across the interface. Isogeometrical methods (IGA) naturally allow us to deal with equations of higher-order omitting the usage of mixed approaches. For multi-patch analysis of Kirchhoff–Love shell elements, $G_1$ continuity at the interface is required and serve here as a prototypical example for a higher-order coupling conditions. When working with this class of shell elements, two different types of constraints arise: Higher-order Dirichlet conditions and higher-order patch coupling conditions. A basis modification approach is presented here, based on a least-square formulation and the incorporation of the constraints into the IGA approximation space. An alternative formulation using Lagrange multipliers which are statically condensed via a discrete Null-Space method provides additional insight into the proposed formulation. A detailed comparison with a classical mortar approach shows the similarities and differences. Eventually, numerical examples demonstrate the capabilities of the presented formulation.


ABSTRACT: Structural stochastic analysis is vital to engineering. However, current material related uncertainty methods are mostly limited to low dimension, and they mostly remain unable to account for spatially uncorrelated material uncertainties. They are not representative of realistic and practical engineering situations. In particular, it is more serious for composite structures comprised of dissimilar materials. Therefore, we propose a novel model order reduction via proper orthogonal decomposition accelerated Monte Carlo stochastic isogeometric method (IGA-POD-MCS) for stochastic analysis of exactly represented (composite) structures. This approach particularly enables high-dimensional material uncertainties wherein the characteristics of each element are independent. And the novelties include: (1) the structural geometry is exactly modeled thanks to isogeometric analysis (IGA), as well as providing more accurate deterministic and stochastic solutions, (2) we innovatively consider high-dimensional and independent material uncertainties by separating the stochastic mesh from the IGA mesh, and modeling different stochastic elements to have different (independent) uncertainty behaviors, (3) the classical Monte Carlo simulation (MCS) is employed to universally solve the high-dimensional uncertainty problem. However, to circumvent its computational expense, we employ model order reduction via proper orthogonal decomposition (POD) into the IGA coupled MCS stochastic analysis. In particular, we observe that this work decouples all IGA elements and hence permits independent uncertainty models easily, thereby the engineering problem is modeled to be more realistic and authentic. Several illustrative numerical examples verify the proposed IGA-POD-MCS approach is effective and efficient; and the larger the scale of the problem is, the more advantageous the method will become.


ABSTRACT: In this study, a new polygonal shell element is developed to provide greater flexibility in mesh design of complex shell structures. Wachspress coordinates are used to construct shape functions for polygonal shell elements. An assumed covariant shear strain field with respect to the element natural coordinate system is defined by employing the mixed interpolation of tensorial components approach to avoid transverse shear locking in polygonal shell elements. Moreover, an assumed covariant membrane strain field is constructed by using characteristic geometry and displacement vectors defined on quadrilateral subdomains of polygonal shell elements to alleviate membrane locking due to the element curvature. Some benchmark shell problems are...
solved to evaluate the performance of the proposed polygonal shell elements. Numerical experiments show that they converge much better than triangular shell elements and comparable to quadrilateral shell elements.


ABSTRACT: We present a combination of techniques to improve the convergence and conditioning properties of partition of unity (PU) enriched finite element methods. By applying these techniques to different types of enrichment functions, namely polynomial, discontinuous and singular, higher order convergence rates can be obtained while keeping condition number growth rates similar to the ones corresponding to standard finite elements.


ABSTRACT: Isogeometric shape optimization uses a unique model for the geometric description and for the analysis. The benefits are multiple: in particular, it avoids tedious procedures related to mesh updates. However, although the analysis of complex multipatch structures now becomes tractable with advanced numerical tools, isogeometric shape optimization has not yet been proven to be applicable for designing such structures. Based on the initial concept of integrating design and analysis, we develop a new approach that deals with the shape optimization of non-conforming multipatch structures. The model is built by employing the Free-Form Deformation principle. Introducing NURBS composition drastically simplifies the imposition of the shape updates in case of a non-conforming multipatch configuration. In the case of stiffened structures, the use of embedded surfaces enables to tackle the geometric constraint of connecting interfaces between the panel and the stiffeners during shape modifications. For the analysis, we introduce the embedded Kirchhoff–Love shell formulation. The NURBS composition defines the geometry of the shell while the displacement field is approximated using the same spline functions as for the embedded surface. We also formulate a new mortar method to couple non-conforming Kirchhoff–Love shells which intersect with any angle. We apply the developed method on different examples to demonstrate its efficiency and its potential to optimize complex industrial structures in a smooth manner.


ABSTRACT: A differential quadrature hierarchical finite element method (DQHFEM) using Fekete points was formulated for triangles and tetrahedrons and applied to structural vibration analyses. First, orthogonal polynomials on triangles and tetrahedrons that can be used as bases of the hierarchical finite element method (HFEM) were derived and simple formulas of transforming one dimensional non-uniform nodes to simplexes were presented. Then the non-uniform nodes were used as initial guesses to solve the Fekete points on simplexes through Newton–Raphson’s method together with the orthogonal polynomials. New differential quadrature (DQ) rules on simplexes were formulated using the HFEM bases and the Fekete points. The numbers of nodes or bases on different edges and faces and inside the body of the new DQ elements do not relate with each other like the HFEM that can freely assign different numbers of bases on different edges and faces and inside the body. So the new DQ method was named as a differential quadrature hierarchical (DQH) method that uses either interpolation functions or orthogonal polynomials as bases inside the element. Its weak form was named as the DQHFEM. Besides the DQH method and its weak form, a simple method of generating high quality linear and high order triangular and tetrahedral meshes from a single NURBS patch was presented. Numerical tests of the DQHFEM through structural vibration analyses showed that high accuracy results can be
obtained using only a few nodes even on curvilinear domains using the DQH bases on both physical and geometric fields. It was concluded that wide applications of the DQH method and the DQHFEM to science and engineering are possible and commercial codes based on them are deserved to be developed.


ABSTRACT: A novel spectral stochastic isogeometric analysis (SSIGA) is proposed for the free vibration analysis of engineering structures involving uncertainties. The proposed SSIGA framework treats the stochastic free vibration problem as a stochastic generalized eigenvalue problem. The stochastic Young’s modulus and material density of the structure are modelled as random fields with Gaussian and non-Gaussian distributions. The basis functions, the non-uniform rational B-spline (NURBS) and T-spline, within Computer Aided Design (CAD) system are adopted within the SSIGA, which can eliminate geometric errors between design model and uncertainty analysis model. The arbitrary polynomial chaos (aPC) expansion is implemented to investigate the stochastic responses (i.e. eigenvalues and eigenvectors) of the structure. A Galerkin-based method is freshly proposed to solve the stochastic generalized eigenvalue problems. The statistical moments, probability density function (PDF) and cumulative distribution function (CDF) of the eigenvalues can be effectively obtained. Two numerical examples with irregular geometries are investigated to illustrate the applicability, accuracy and efficiency of the proposed SSIGA for free vibration analysis of engineering structures.


ABSTRACT: Many interface formulations, e.g. based on asymptotic thin interphase models or material surface theories, involve higher-order differential operators and discontinuous solution fields. In this article, we are taking first steps towards a variationally consistent discretization framework that naturally accommodates these two challenges by synergistically combining recent developments in isogeometric analysis and cut-cell finite element methods. Its basis is the mixed variational formulation of the elastic interface problem that provides access to jumps in displacements and stresses for incorporating general interface conditions. Upon discretization with smooth splines, derivatives of arbitrary order can be consistently evaluated, while cut-cell meshes enable discontinuous solutions at potentially complex interfaces. We demonstrate via numerical tests for three specific nontrivial interfaces (two regimes of the Benveniste–Miloh classification of thin layers and the Gurtin–Murdoch material surface model) that our framework is geometrically flexible and provides optimal higher-order accuracy in the bulk and at the interface.


ABSTRACT: The use of modified couple stress theory to simulate the size-dependent phenomenon of composite laminate microplate is commonly limited to simple boundary conditions and mechanical bending load. The small-scale effects on bending and buckling on composite laminate microplate under complex boundary conditions in thermal environment have not been understood fully in the literature. Hence, this research develops, for the first time, a model to overcome the above limitation through the combination of a new modified couple stress theory and isogeometric analysis (IGA). By solving the governing equation using IGA, the thermal displacement, stress and thermal buckling load for various material length scale parameters are obtained. To satisfy the continuous shear stress condition at the layer interfaces, the equilibrium equations as integrated in-plane stress derivatives over the thickness are imposed. In addition, the non-uniform rational B-splines (NURBS) satisfy the higher-order derivative of shape function using the equilibrium equation. Furthermore, to show the effectiveness of presented model for capturing the size effect on thermal bending and
thermal buckling of multi-ply laminate microplate, the influences of fiber orientation, thickness ratio, boundary condition and the variation in material length scale parameter are investigated.


ABSTRACT: Soft, active materials have been widely studied due to their ability to undergo large, complex shape changes in response to both mechanical and non-mechanical external stimuli. However, the vast majority of such studies has focused on investigating the forward problem, i.e. determining the shape changes that result from the applied stimuli. In contrast, very little work has been done to solve the inverse problem, i.e. that of identifying the external loads and stimuli that are needed to generate desired shapes and morphological changes. In this work, we present a new inverse methodology to study residual thermal expansion induced morphological changes in geometric composites made of soft, thin shells. In particular, the method presented in this work aims to determine the prescribed external stimuli needed to reconstruct a specific target shape, with a specific focus and interest in morphological changes from two-dimensional (2D) to three-dimensional (3D) shapes by considering the external stimuli within a thermohyperelastic framework. To do so, we utilize a geometrically exact, rotation-free Kirchhoff–Love shell formulation discretized by NURBS-based shape functions. We show that the proposed method is capable of identifying the stimuli, including cases where thermal expansion induced shape changes involving elastic softening occur in morphing from the initially flat 2D to non-planar 3D shapes. Validation indicates that the reconstructed shapes are in good agreement with the target shape.


ABSTRACT: This work focuses on fluid–structure interaction (FSI) between a curved (tortuous) coronary artery with an implanted stent, pulsatile blood flow, and heart contractions. The goal is to understand which geometric distribution of stent struts, given by four different, commercially available stent geometries, is least likely to be associated with parameters correlated with pathobiologic responses leading to restenosis, in the case of curved coronary arteries, whose curvature changes significantly with each heart contraction. The stent geometries considered in this study correspond to a Palmaz-like stent, an Express-like stent, a Cypher-like stent, and a Xience-like stent. The biomechanical environment induced by each implanted stent is evaluated in terms of displacement magnitude, Von Mises stress, normal stress experienced by the intimal layer with implanted stent, and wall shear stress. Arterial walls are modeled as multi-layered structures: the intimal layer with the internal elastic laminae is modeled as a nonlinearly elastic membrane, while the media–adventitia complex is modeled as a 3D linearly elastic material. The Navier–Stokes equations for an incompressible, viscous fluid, are used to model the blood flow. Full, two-way coupling between the fluid and the structure, and between the thin and thick structure, is considered. To include the effects of the force exerted by the pericardium and heart muscle contractions, external force is applied to the coronary artery walls. Pulsatile boundary conditions were imposed at the inlet and outlet of the coronary segment, approximating measured diastolic coronary flow. The presence of an implanted stent was modeled by its impact on the mass and elasticity properties of the intimal layer where the stent is located. The stent material is modeled as a 316L stainless steel. A novel, loosely coupled partitioned scheme combined with an ALE approach was used to solve this nonlinear FSI problem. It was found that the Cypher-like stent geometry outperforms the other three stent geometries. The ranking from best to worst is as follows: Cypher-like stent, Express-like stent, Xience-like stent, Palmaz-like stent. It is conjectured that the sinusoidal horizontal stent struts and large cells associated with open-cell design, give rise to a stent geometry that conforms best to the native curved coronary artery, with smallest deviations in Von Mises stress and displacement from the nonstented curved coronary artery both during systole and diastole. To the best of our knowledge, this is the first computational study in which the behavior of different stent geometries implanted in curved coronary arteries is studied using full FSI capturing the behavior of multi-layered, curved, stented coronary arteries contracting on a beating heart.

ABSTRACT: Membranes have been extensively used for the design of architectural and general structural models due to their low cost and high load carrying capacity. Traditionally such models were discretized using the standard low order Finite Element Method (FEM) which typically results in a compromised description of the geometry. However, the accurate geometric description of membrane structures is essential as for instance bifurcation points in geometrically nonlinear analysis may be inaccurately predicted when the geometric description of the model is not accurate enough. Moreover, the design of membrane structures typically requires several cycles of form-finding and subsequent structural analysis under various loads which can benefit from a direct connection to the Computer-Aided Design (CAD) environment using its exact geometric description. In this contribution, the form-finding analysis using the Updated Reference Strategy (URS) and the geometrically nonlinear transient analysis of membranes is extended to Isogeometric Analysis (IGA) on multipatch surfaces with Non-Uniform Rational B-Splines (NURBS). As typical in IGA for real CAD geometries, multiple patches with non-matching parametrizations are considered and therefore the continuity of the solution field along with the application of weak Dirichlet boundary conditions need to be addressed. Thus, four different constraint enforcement methods are elaborated and compared, namely, the Penalty, the Lagrange Multipliers, the augmented Lagrange Multipliers and a Nitsche-type method. For the latter method, a solution dependent stabilization approach is employed in order to render the Nitsche-type method coercive. All methods are elaborated and systematically compared in both form-finding analysis, whenever necessary, and subsequently in geometrically nonlinear transient analysis. It should be noted that the Nitsche-type method is more computationally demanding amongst these methods due to the additional nonlinear terms. However, the results suggest that the Nitsche-type method is advantageous for these kinds of problems as no parameter or discretization other than the isogeometric discretization within each patch needs to be specified prior to the analysis.


ABSTRACT: In this paper, using an isogeometric approach, a continuum-based adjoint configuration design sensitivity analysis (DSA) method is presented for three-dimensional finite deformation shear-deformable beam structures. A geometrically exact beam model together with a multiplicative update of finite rotation by an exponential map of a skew-symmetric matrix is utilized. The material derivative of the orthogonal transformation matrix can be evaluated at final equilibrium configuration, which enables to compute design sensitivity using the tangent stiffness at the equilibrium without further iterations. We also present a procedure of explicit parameterization of initial orthonormal frame using the smallest rotation (SR) method within the isogeometric analysis framework. Furthermore, it is shown that for curve entities embedded to a smooth surface, the convected basis of the surface can be effectively utilized for reference orthonormal frames in the SR method. Various numerical examples including pressure loads and nonhomogeneous kinematic boundary conditions in built-up structures demonstrate the effectiveness of the developed DSA method.


ABSTRACT: In this research, the dynamic instabilities of nanocomposite truncated conical shells containing a quiescent or a flowing inviscid fluid are scrutinized. Nonlinear dynamic equations are established according to the Novozhilov nonlinear shell theory along with Green’s strains and Hamilton principle. The velocity potential and Bernoulli’s equations are adopted to calculate fluid pressure acting on the conical shell. The nonlinear governing equations are discretized using trigonometric expansion through the circumferential direction and generalized differential quadrature method (GDQM) through the meridional direction. A detailed parametric
study is directed to provide an insight into the influence of volume fraction of carbon nanotubes (CNTs), CNT dispersion, geometrical parameters, and boundary conditions on the divergence and flutter instabilities of nanocomposite truncated conical shells. This study shows the superb efficiency of the outlined solution procedure in reducing computational costs and virtual storage. The simulation indicates that the beginning of divergence and flutter instabilities can be significantly postponed by selecting an appropriate dispersion of CNTs through the thickness of the conical shell. Furthermore, the onset of flutter and divergence instabilities are found to be very sensitive to the semi-vertex angle and thickness-to-radius ratio. The results of this research shed light into using ultra-high-strength and low-weight nanocomposite for pressure vessels applications.


ABSTRACT: Isogeometric B-Rep Analysis (IBRA) was the first approach that enabled a full integration of Computer Aided Design (CAD) and Computer Aided Engineering (CAE) based on trimmed NURBS B-Rep models ubiquitous in industrial CAD. However, the applicability of IBRA to explicit dynamic problems such as vehicle crash simulations and especially the effect of trimming and penalty coupling on the critical time step were not systematically investigated in the literature. To fill this gap, we developed Explicit IBRA, a combination of the patch coupling capabilities of IBRA with the explicit dynamic features of the FE solver LS-DYNA. For Explicit IBRA, we particularly (i) developed a new penalty-based B-Rep element formulation for the application to a Reissner–Mindlin shell with six degrees of freedom, (ii) formally extended the IBRA theory to explicit time integration schemes, (iii) showed that the common stability criterion and the maximum eigenvalue-based time step estimation from FE still hold, and (iv) used the IBRA exchange format to implement a closed design workflow between the CAD program Rhinoceros and the solver LS-DYNA. We solved selected benchmark problems, from quasi-static linear elastic to highly dynamic elasto-plastic with large deformations, and obtained accurate results with penalty factors that cause no or only a minor decrease in stable time step size. That is, we found that penalty coupling does not have a severe impact on the critical time step in explicit analysis, making Explicit IBRA practically applicable. Finally, we studied an industrial BMW engine bonnet model under dynamic loading and observed good agreement with reference finite element simulations.


ABSTRACT: A novel surface interrogation technique is proposed to compute the intersection of curves with spline surfaces in isogeometric analysis. The intersection points are determined in one-shot without resorting to a Newton–Raphson iteration or successive refinement. Surface-curve intersection is required in a wide range of applications, including contact, immersed boundary methods and lattice-skin structures, and requires usually the solution of a system of nonlinear equations. It is assumed that the surface is given in form of a spline, such as a NURBS, T-spline or Catmull–Clark subdivision surface, and is convertible into a collection of Bézier patches. First, a hierarchical bounding volume tree is used to efficiently identify the Bézier patches with a convex-hull intersecting the convex-hull of a given curve segment. For ease of implementation convex-hulls are approximated with k-dops (discrete orientation polytopes). Subsequently, the intersections of the identified Bézier patches with the curve segment are determined with a matrix-based implicit representation leading to the computation of a sequence of small singular value decompositions (SVDs). As an application of the developed interrogation technique the isogeometric design and analysis of lattice-skin structures is investigated. Although such structures have been common in large-scale civil engineering, current additive manufacturing, or 3d printing, technologies make it possible to produce up to metre size lattice-skin structures with designed geometric features reaching down to submillimetre scale. The skin is a spline surface that is usually created in a computer-aided design (CAD) system and the periodic lattice to be fitted consists of unit cells, each containing a small number of struts. The lattice-skin structure is generated by projecting selected lattice nodes onto the surface after determining the intersection of unit cell edges with the surface. For mechanical analysis, the skin is modelled as a Kirchhoff–Love thin-shell and the lattice as a pin-jointed truss. The two types of structures are coupled with a standard Lagrange multiplier approach.

ABSTRACT: A spectral stochastic isogeometric analysis (SSIGA) scheme is proposed for the stochastic linear stability analysis of plate with uncertain material properties. Within the proposed SSIGA scheme, the first-order shear deformation theory of plate is adopted for modelling the kinematic relationship. Both homogeneous and functionally graded material (FGM) models can be incorporated. The considered spatially dependent uncertainties (i.e., Young's modulus and Poisson's ratio) are modelled as random fields with Gaussian and lognormal distributions, and the spatially independent uncertainty (i.e., gradient index of FGM) is modelled as random variable. The generalized isogeometric basis function is adopted for both the random field geometry representation and random field discretization through the Karhunen–Loève (K–L) expansion. An extended support vector regression (X-SVR) with a new generalized Gegenbauer polynomial kernel is developed to model the nonlinear relationship between the structural uncertainties and the buckling load. By further implementing various nonparametric statistical inference methods, the mean, standard deviation, probability density function (PDF), and cumulative distribution function (CDF) of the buckling load can be effectively established to determine the strength limit of the plate. The accuracy, efficiency, and applicability of the proposed approach are illustrated through two numerical examples.


ABSTRACT: The linear Reissner–Mindlin shell theory is reformulated in the frame of the tangential differential calculus (TDC) using a global Cartesian coordinate system. The rotation of the normal vector is modelled with a difference vector approach. The resulting equations are applicable to both explicitly and implicitly defined shells, because the employed surface operators do not necessarily rely on a parametrization. Hence, shell analysis on surfaces implied by level-set functions is enabled, but also the classical case of parametrized surfaces is captured. As a consequence, the proposed TDC-based formulation is more general and may also be used in recent finite element approaches such as the TraceFEM and CutFEM where a parametrization of the middle surface is not required. Herein, the numerical results are obtained by isogeometric analysis using NURBS as trial and test functions for classical and new benchmark tests. In the residual errors, optimal higher-order convergence rates are confirmed when the involved physical fields are sufficiently smooth.


ABSTRACT: Vibroacoustic performance of the doubly curved thick shell is explored based on the three dimensional sound propagation approach as well as state space solution. In fact, the main aim is particularly focused on inspecting the influence of using three-dimensional theory through sound transmission loss (STL) of the structure which includes more reliable and accurate results especially for relatively thick and thick shells even in high frequency domain in comparison with other theories. In order to achieve this end, firstly stress and strain components are developed to present the governing equations of thick shell. This procedure is carried out by dividing the shell into layers. Then, a solution technique is provided on the basis of state vector methodology wherein approximate layer model along with local transfer matrix are performed. Moreover, this method is followed by global transfer matrix method for the all layers of structure. As an outcome, in results section, not only the accuracy of the offered results is proved but also the importance of employing the current theory in high frequencies is revealed. Another remarkable achievement of this work is related to nominate the dip points of STL diagram. On contrary to panels, doubly curved shells contain two dips, because of their both radii of curvatures. In this work, the first dip is nominated as curvature frequency. The second dip is similar to that of panels at high frequency zone. Thus, it is called as coincidence frequency. Finally, the behavior of the transmitted pressure and the effect of curvatures on the position of curvature frequency are discussed.

ABSTRACT: We present a 3D hybridizable discontinuous Galerkin (HDG) method for nonlinear elasticity which can be efficiently used for thin structures with large deformation. The HDG method is developed for a three-field formulation of nonlinear elasticity and is endowed with a number of attractive features that make it ideally suited for thin structures. Regarding robustness, the method avoids a variety of locking phenomena such as membrane locking, shear locking, and volumetric locking. Regarding accuracy, the method yields optimal convergence for the displacements, which can be further improved by an inexpensive postprocessing. And finally, regarding efficiency, the only globally coupled unknowns are the degrees of freedom of the numerical trace on the interior faces, resulting in substantial savings in computational time and memory storage. This last feature is particularly advantageous for thin structures because the number of interior faces is typically small. In addition, we discuss the implementation of the HDG method with arc-length algorithms for phenomena such as snap-through, where the standard load incrementation algorithm becomes unstable. Numerical results are presented to verify the convergence and demonstrate the performance of the HDG method through simple analytical and popular benchmark problems in the literature.


ABSTRACT: The general framework for growth and remodeling (G&R) of soft biological tissues shows a great potential for expanding our current understanding of biochemical and biomechanical processes, and to predict disease progression. Yet, its use is held up by the lack of a reliable and verified 3D finite element (FE) implementation capable of describing G&R processes of soft biological tissues. Thus, in this study we present the implementation of a 3D constrained mixture G&R model in a FE analysis program. In contrast to traditional finite strain FE formulations, we show that the volumetric–isochoric decomposition not only introduces numerical problems and instabilities, it also provides unphysical results. As a verification of the implementation we present adaptations of realistic aorta models to changes in the hemodynamics, i.e. changes in blood flow and pressure. The obtained results show a correspondence with the membrane theory and with clinical expectations. Application to a fusiform aneurysm model provided realistic growth rates, evolution of thickness and stress, whereas changes in the kinetic parameters show good agreement to animal models. Finally, we present simulated expansions of an asymmetric fusiform aneurysm. Non-axisymmetric elastin degradation increased the curvature of the aorta, which is characteristic for abdominal aortic aneurysms.


ABSTRACT: This paper presents a nonlinear numerical model, which is based on the modified couple stress theory (MCST), and trigonometric shear deformation theory coupled with isogeometric analysis. The present approach captures the small scale effects on the geometrically nonlinear behaviors of functionally graded carbon nanotube reinforced composite (FG-CNTRC) micro-plate with four patterns distribution. The equations of motion are established based on a Galerkin weak form associated with von-Kármán nonlinear strains. The MCST utilizes only one material length scale parameter to predict the size effect in FG-CNTRC micro-plate, for which its material properties are derived from an extended rule of mixture. The solutions of nonlinear static equation are obtained by using the Newton–Raphson technique and the Newmark time iteration procedure in association with Picard method is assigned to get responses of the nonlinear dynamic problems. In addition, the Rayleigh damping is applied to consider the influence of damping characteristic on the oscillation of FG-CNTRC micro-plates. Comparisons are performed to verify the proposed approach. Afterward, the numerical examples are used to show the effects of the distribution of carbon nanotubes (CNT), their volume fraction, the material length scale parameter and the boundary conditions on the nonlinear static and dynamic behaviors of FG-CNTRC micro-plates.

ABSTRACT: Self-supporting surfaces are widely used in contemporary architecture, but their design remains a challenging problem. This paper aims to provide a heuristic strategy for the design of complex self-supporting surfaces. In our method, non-uniform rational B-spline (NURBS) surfaces are used to describe the smooth geometry of the self-supporting surface. The equilibrium state of the surface is derived with membrane shell theory and Airy stresses within the surfaces are used as tunable variables for the proposed heuristic design strategy. The corresponding self-supporting shapes to the given stress states are calculated by the nonlinear isogeometric analysis (IGA) method. Our validation using analytic catenary surfaces shows that the proposed method finds the correct self-supporting shape with a convergence rate one order higher than the degree of the applied NURBS basis function. Tests on boundary conditions show that the boundary’s influence propagates along the main stress directions in the surface. Various self-supporting masonry structures, including models with complex topology, are constructed using the presented method. Compared with existing methods such as thrust network analysis and dynamic relaxation, the proposed method benefits from the advantages of NURBS-based IGA, featuring smooth geometric description, good adaption to complex shapes and increased efficiency of computation.


ABSTRACT: This study presents a novel multi-scale computational method to analyze the dynamic thermo-mechanical performance of heterogeneous shell structures with orthogonal periodic configurations. The heterogeneities of heterogeneous shell structures are taken into account by periodic layouts of unit cells on the microscale in orthogonal curvilinear coordinate system. The new second-order two-scale approximate solutions for these multi-scale problems are constructed based on the multi-scale asymptotic analysis. Furthermore, the error estimates for the second-order two-scale (SOTS) solutions are obtained under some hypotheses. And then, a novel SOTS numerical algorithm based on finite element method (FEM), finite difference method (FDM) and decoupling method is brought forward in detail. Finally, some numerical examples are presented to verify the feasibility and validity of our multi-scale computational method. They also demonstrate that our multi-scale computational method can accurately capture the micro-scale dynamic thermo-mechanical responses in heterogeneous block structure, plate, cylindrical and doubly-curved shallow shells. In this paper, a unified multi-scale computational framework is established for dynamic thermo-mechanical problems of heterogeneous materials and structures with orthogonal periodic configurations. The asymptotic homogenization theory in Cartesian coordinate system and cylindrical coordinate system can be directly obtained based on the results in this paper.


ABSTRACT: Composite shells with complex geometry are widely used in aerospace structures. Due to the complexity of geometry and curvilinear fiber path, the analysis and optimization based on finite element analysis (FEA) for complex variable-stiffness (VS) shells is extremely time-consuming. By comparing with FEA, isogeometric analysis (IGA) exhibits higher prediction efficiency of buckling load. In this work, the formula of geometric stiffness matrix for complex VS shells is derived for the first time based on degenerated shell method using IGA, which is the basis of performing linear buckling analysis. Then, a new variable curvature quasi-linear function (VCQLF) to describe curvilinear fiber path is proposed, which can further expand the design space of VS shells. After that, two frameworks for shape optimization of complex shells are put forward and then compared, and it is found that the one based on LOFT function can provide representative control variables of shape and effectively reduces the number of design variables for complex shells. Finally, a novel collaborative optimization framework of fiber path and shell shape using IGA is established. By
A comparison of traditional methods, it is demonstrated that the proposed framework can greatly improve the efficiency of optimization and fully explore the buckling load of complex VS shells.


ABSTRACT: Isogeometric Kirchhoff–Love elements have received an increasing attention in geometrically nonlinear analysis of elastic shells. Nevertheless, some difficulties still remain. Among the others, the highly nonlinear expression of the strain measure, which leads to a complicated and costly computation of the discrete operators, and the existence of locking, which prevents the use of coarse meshes for slender shells and low order NURBS, are key issues that need to be addressed. In this work, exploiting the hypothesis of small membrane strains, we propose a simplified strain measure with a third order polynomial dependence on the displacement variables which allows an efficient evaluation of the discrete quantities. Numerical results show practically no difference to the original model, even for very large displacements and composite structures. Patch-wise reduced integrations are then investigated to deal with membrane locking in large deformation problems. An optimal integration scheme for third order C2 NURBS, in terms of accuracy and efficiency, is identified. Finally, the recently proposed Newton method with mixed integration points is used for the solution of the discrete nonlinear equations with a great reduction of the iterative burden with respect to the standard Newton scheme.


ABSTRACT: This paper presents a variable cutting (VCUT) level set based topology optimization method to design functionally graded cellular structures (FGCS). A variable and continuous cutting function by interpolating with a set of height variables is proposed to generate functionally graded cellular structures, which offers a novel tool to optimize the macroscopic graded pattern. Due to the continuity of the cutting function, perfect geometric connections between adjacent cells are guaranteed without imposing extra constraints in the optimization. In addition, a solid covering skin can be easily attached to the FGCS by means of the variable cutting function. Three FGCS design problems, including graded density control, compliance minimization and layered cellular structure design, are presented to demonstrate the effectiveness and applicability of the proposed method. The optimized 2D and 3D macroscopic FGCS designs exhibit well-performing structural layout with fully connected micro-scale geometries.


ABSTRACT: Lattice structures have been widely studied due to their advantage of low stiffness-to-weight ratio or sometimes auxetic properties. This paper presents a topology optimization method for structures with functionally-graded infill lattices with buckling constraints, which minimizes compliance while ensuring a prescribed level of structural stability against buckling failures. To realize topologically-optimized structures filled with functionally-graded lattices, Helmholtz PDE-filter with a variable radius is applied on the density field in Solid Isotropic Material with Penalization (SIMP) method. Buckling load factors based on the linear buckling analysis is employed as buckling constraints. Numerical examples show that proposed method can generate stiff structures comparable to the ones by the SIMP, with functionally-graded infill lattices that improve the structural stability by avoiding long, slender features under compression.


ABSTRACT: Additively manufactured lattice structures enable the realisation of light-weight, multi-functional, structures. For example, lattices can be used for high stiffness and buckling resistance in sandwich structures or
ABSTRACT: Stiffness degradation due to matrix cracks is the main initial form of damage in composite structures. Topology optimisation and additive manufacturing are two technologies that allow the design, optimisation and manufacture of complex lattice designs. In this work, a new lattice optimisation methodology is presented that tailors the size, shape and orientation of individual lattice trusses in three-dimensional space by using principal strain fields obtained from topology optimisation. This new method of generating functionally graded lattices is shown both numerically and experimentally to be capable of generating lattice structures with greatly improved stiffness and strength when compared to lattice structures with a uniform lattice infill. Upper and lower relative density thresholds and minimum truss member sizes are included in the optimisation workflow to ensure that the optimised lattice designs are compatible with additive manufacturing process constraints. The functional grading method is also shown to be capable of generating conformal lattice structures in three dimensions, even for complex loading conditions and arbitrary volume boundaries.


ABSTRACT: Transverse shear locking is an issue that occurs in Reissner–Mindlin plate and shell elements. It leads to an artificial stiffening of the system and to oscillations in the stress resultants for thin structures. The thinner the structure is, the more pronounced are the effects. Since transverse shear locking is caused by a mismatch in the approximation spaces of the displacements and the rotations, a field-consistent approach is proposed for an isogeometric degenerated Reissner–Mindlin shell formulation. The efficiency and accuracy of the method is investigated for benchmark plate and shell problems. A comparison to element formulations with locking alleviation methods from the literature is provided.


ABSTRACT: The stability analysis of elastic structures strongly coupled to incompressible viscous flows is investigated in this paper, based on a linearization of the governing equations formulated with the Arbitrary-Lagrangian–Eulerian method. The exact linearized formulation, previously derived to solve the unsteady non-linear equations with implicit temporal schemes, is used here to determine the physical linear stability of steady states. Once discretized with a standard finite-element method based on Lagrange elements, the leading eigenvalues/eigenmodes of the linearized operator are computed for three configurations representative for classical fluid–structure interaction instabilities: the vortex-induced vibrations of an elastic plate clamped to the rear of a rigid cylinder, the flutter instability of a flag immersed in a channel flow and the vortex shedding behind a three-dimensional plate bent by the steady flow. The results are in good agreement with instability thresholds reported in the literature and obtained with time-marching simulations, at a much lower computational cost. To further decrease this computational cost, the equations governing the solid perturbations are projected onto a reduced basis of free-vibration modes. This projection allows to eliminate the extension perturbation, a non-physical variable introduced in the ALE formalism to propagate the infinitesimal displacement of the fluid–solid interface into the fluid domain.


ABSTRACT: Stiffness degradation due to matrix cracks is the main initial form of damage in composite laminates. This paper presents a framework to model geometrically nonlinear large deformation behaviors of matrix cracked hybrid composite double-curved deep shell containing carbon nanotube reinforced composite (CNTRC) layers. Two types of structures, namely Structure-I and Structure-II, are investigated. The CNTRC layers in Structure-I are considered with CNTs arranged in uniformly distributions, while Structure-II is arranged in functionally graded distributions. The degraded stiffness of cracked layers is modeled via the self-consistent model (SCM) micromechanical framework. To describe the geometrically nonlinear large deflection behaviors and account for deep and moderate thick shells, the von Kármán geometric nonlinearity assumptions and the term 1/(1+R) are considered in the relationship between displacement and strain. The IMLS-Ritz method is employed to discretize the non-linear partial differential equations. The modified Newton–Raphson
method in combination with the arc-length iteration technique is adopted to solve the discretized equations. Comparison studies indicate that the proposed predictive model can furnish very accurate results for linear and nonlinear behaviors of thin to moderately thick as well as shallow and deep laminated doubly-curved shells. Parametric studies on the effect of CNT distribution, matrix crack density, load type, length-to-thickness ratio, radius-to-length ratio, aspect ratio, boundary condition, and fiber ply-angle on the geometrically nonlinear large deformation behaviors of spherical hybrid composite shells are investigated.


ABSTRACT: The application of carbon nanotubes (CNTs) to improve postbuckling characteristics of T-section nanocomposite strut is the subject of this research. A solution procedure according to the layerwise theory along with the first-order shear deformation theory (FSDT) by taking into account the von Karman geometrical nonlinearity is proposed. Nonlinear governing equations are developed in regard to the minimum total potential energy principle, and solved by the aid of the Rayleigh–Ritz method in conjunction with Newton–Raphson method. A comprehensive parametric study is conducted to provide an insight into effects of CNT volume fraction and dispersion, geometrical parameters and boundary conditions on the bifurcation points and paths, in-plane displacement, normal stress and strain, and bending moment of T-section nanocomposite struts. A three dimensional finite element analysis using the ABAQUS commercial software is carried out to verify the obtained results, which shows close agreement. Results indicate that dispersion of CNTs plays a dominant role in bifurcation behavior of nanocomposite struts. The results also show that volume fraction of CNTs has a significant effect on the load-carrying capacity of open section nanocomposite struts. The results of this research shed light into using ultra-high-strength and light-weight open section nanocomposite struts for civil and aerospace applications.


ABSTRACT: Auxetic materials with negative Poisson’s ratio have potential applications across a broad range of engineering fields. Several FE based design techniques have been developed to achieve auxetic materials with targeted effective properties, mostly in linear deformation regime. In this paper, an isogeometric shape optimization framework for designing 2D auxetic materials with prescribed deformation over large strain intervals is presented. Taking into account practical manufacturing considerations, a minimum thickness for each member is imposed via a spline-based geometric constraint. The capability of the framework is demonstrated through two examples. First, the paper considers shape optimization of smoothed hexa-petals in plane strain condition to achieve constant Poisson’s ratios ranging from a null value to -0.5 to an effective tensile strain of 50%. The second example showcases the shape optimization of smoothed tri- and hexa-petals in plane stress condition for targeted nonlinear deformation behaviour of cat’s skin up to 90% tensile strain.


ABSTRACT: Two triangular G1-conforming elements, based on the triangular Gregory patch, suitable for the analysis of the Kirchhoff plate model are presented. Both have cubic normal derivative along the sides, so that they can be effectively used in combination with generalized Hermitian elements.

The Gregory patch consists in a rational enhancement of the base-polynomial spaces useful to design G1-conforming elements on general Co-conforming unstructured meshes.

Because of the presence of the rational functions, the second derivatives at the corners of the element present finite discontinuities, that prevent the elements from passing the bending patch test. The discontinuities are
removed using a constrained version of the Gregory patch, with Lagrange multipliers. In this way, the rational conforming space collapses into a conforming rearrangement of the original polynomial interpolant spaces. The proposed formulation design elements that pass the bending patch test and present optimal rate of convergence on general unstructured meshes.

Chiu Ling Chan (3), Cosmin Anitescu (3) and Timon Rabczuk (1,2)
(1) Chiu Ling Chan, Cosmin Anitescu, Timon Rabczuk
(2) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(3) Institute of Structural Mechanics, Bauhaus Universität Weimar, Germany

“Strong multipatch C1-coupling for isogeometric analysis on 2D and 3D domains”, Computer Methods in Applied Mechanics and Engineering, Vol. 357, Article 112599, 1 December 2019,
https://doi.org/10.1016/j.cma.2019.112599

ABSTRACT: The solution spaces of isogeometric analysis (IGA) constructed from degree basis functions allow up to C-super-p-1 continuity within one patch. However, for a multi-patch domain, the continuity is only C0 at the boundaries between the patches. In this study, we present the construction of basis functions of degree p gte 2 which are C1 continuous across the common boundaries shared by the patches. The new basis functions are computed as a linear combination of the C0 basis functions on the multi-patch domains. An advantage of the proposed method is that for the new basis functions, the continuity within a patch is preserved, without additional treatment of the functions in the interior of the patch.

We apply continuity constraints to the new basis functions to enforce C1 continuity, where the constraints are developed according to the concept of “matched G-super-k-constructions always yield C-super-k-continuous isogeometric elements” discussed in Groisser and Peters, (2015). However, for certain geometries, the over-constrained solution space will lead to C1 locking (Collin and Sangalli, 2016). We discuss and show the usage of partial degree elevation to overcome this problem. We demonstrate the potential of the C1 basis functions for IGA applications through several examples involving biharmonic equations.

T. Hirschler (1), R. Bouclier (2,3), D. Dureisseix (1), A. Duval, T. Elguej (1) J. Morlier (3)
(1) Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F69621 Villeurbanne, France
(2) Univ Toulouse, INSA-Toulouse, CNRS UMR5219, IMT, F31077 Toulouse, France
(3) Univ Toulouse, ISAE Supaero-INSa-Mines Albi-UPS, CNRS UMR5312, Institut Clément Ader, F31055 Toulouse, France

https://doi.org/10.1016/j.cma.2019.112578

ABSTRACT: Originally, Isogeometric Analysis is aimed at using geometric models for the structural analysis. The actual realization of this objective to complex real-world structures requires a special treatment of the non-conformities between the patches generated during the geometric modeling. Different advanced numerical tools now enable to analyze elaborated multipatch models, especially regarding the imposition of the interface coupling conditions. However, in order to push forward the isogeometric concept, a closer look at the algorithm of resolution for multipatch geometries seems crucial. Hence, we present a dual Domain Decomposition algorithm for accurately analyzing non-conforming multipatch Kirchhoff–Love shells. The starting point is the use of a Mortar method for imposing the coupling conditions between the shells. The additional degrees of freedom coming from the Lagrange multiplier field enable to formulate an interface problem, known as the one-level FETI problem. The interface problem is solved using an iterative solver where, at each iteration, only local quantities defined at the patch level (i.e. per sub-domain) are involved which makes the overall algorithm naturally parallelizable. We study the preconditioning step in order to get an algorithm which is numerically scalable. Several examples ranging from simple benchmark cases to semi-industrial problems highlight the great potential of the method.

Alessandro Tasora, Simone Benatti, Dario Mangoni and Rinaldo Garziera (Università degli Studi di Parma, Department of Engineering and Architecture, Parco Area delle Scienze, 181/A, 43124 Parma, Italy), “A geometrically exact isogeometric beam for large displacements and contacts”, Computer Methods in Applied Mechanics and Engineering, Vol. 358, Article 112635, 1 January 2020,
https://doi.org/10.1016/j.cma.2019.112635
ABSTRACT: This work discusses an efficient formulation of a geometrically exact three-dimensional beam which can be used in dynamical simulations involving large displacements, collisions and non-linear materials. To this end, we base our model on the shear-flexible Cosserat rod theory and we implement it in the context of Isogeometric Analysis (IGA). According to the IGA approach, the centerline of the beam is parameterized using splines; in our work the rotation of the section is parameterized by a spline interpolation of quaternions, and time integration of rotations is performed using the exponential map of quaternions. Aiming at an efficient and robust simulation of contacts, we propose the adoption of a non-smooth dynamics formulation based on differential-variational inequalities. The model has been implemented in an open-source physics simulation library that can simulate actuators, finite elements, rigid bodies, constraints, collisions and frictional contacts. This beam model has been tested on various benchmarks in order to assess its validity in non-linear static and dynamic analysis; in all cases the model behaved consistently with theoretical results and experimental data.

References listed at the end of the paper:
19 Weeger Oliver, Wever Utz, Simeon Bernd, Isogeometric analysis of nonlinear EulerBernoulli beam vibrations, Nonlinear Dynam., 72 (4) (2013), pp. 813-835
32 Weeger Oliver, Narayanan Bharath, Dunn Martin L., Isogeometric collocation for nonlinear dynamic analysis of Cosserat rods with frictional contact, Nonlinear Dyn., 91 (2) (2018), pp. 1213-1227
40 Negrut Dan, Tasora Alessandro, Mazhar Hammad, Heyn Toby, Hahn Philipp, Leveraging parallel computing in multibody dynamics, Multibody Syst. Dyn., 27 (2012), pp. 95-117
Hao Deng (1), Lin Cheng (1), Xuan Liang (1), Devlin Hayduke (2) and Albert C. To (1)

(1) Department of Mechanical Engineering and Materials Science, University of Pittsburgh, Pittsburgh, PA 15261, United States of America

(2) Materials Sciences Corporation, 135 Rock Rd. Horsham, PA 19044, United States of America


ABSTRACT: Topology optimization for damping design of lattice structures is proposed in this work. Compared to metal lattice or viscoelastic materials, lattice structures made of soft materials composed of bistable elements show exceptional energy dissipation properties with fully recoverable capacity. Theoretical energy absorption capacity is a key concept to describe damping properties of architectured metamaterials, which reflects the maximum energy absorption per element if a bi-stable chain contains infinite buckling elements. To achieve extreme damping design, topology optimization algorithm is formulated to achieve extreme theoretical energy absorption capacity within a prescribed design domain. An approximate mathematical expression for the energy absorption capacity is formulated with rigorous derivation of sensitivities. Element strain energy in P-norm formulation is constrained at limit points to alleviate material softening failure under large strain. Four design cases are presented and discussed in detail. Results demonstrate that the optimal bi-stable elements achieved by topology optimization algorithm show programmable properties with desired energy dissipation capacity.

References listed at the end of the paper:

ABSTRACT: After space discretization employing traditional dynamic isogeometric analysis of structures (composite type) with/without dissimilar materials, the issues that persist include either using numerically non-dissipative time integration algorithms that induces the high frequency participation (oscillations) in solution, or using dissipative algorithms that can dampen the high frequency participation but simultaneously induce significant loss of total energy of the system. To circumvent this dilemma, we instead develop a novel approach via a proper orthogonal decomposition (POD) based dynamic isogeometric methodology/framework that eliminates (significantly reduces) high-frequency oscillations whilst conserving the physics (e.g., total energy) for dynamic analysis of (composite or hybrid) structures comprising of dissimilar materials. This proposed framework and contributions therein are comprised of three phases, namely, (1) it successfully filters the high-frequency part via first simulating the original IGA semi-discretized structure with dissimilar materials for a few time steps using numerically dissipative type integration schemes, and then obtain the reduced IGA system via POD. (2) We then simulate the reduced IGA system (high-frequency oscillations being eliminated) with instead a numerically non-dissipative algorithm to conserve the underlying physics. As consequence, we successfully preserve the physics (energy) associated with the low frequency modes whilst eliminating/reducing the high-frequency oscillations. (3) Three illustrative examples, with/without dissimilar materials demonstrate the advantages of IGA for applications to structures with dissimilar materials over FEM, in particular, in modeling complex geometries and providing more accurate dynamic solutions with less number of degrees of freedom. Furthermore, we show the effectiveness and efficiency of the proposed approach in further advancing the dynamic isogeometric analyses for both linear, and material and/or geometrically nonlinear cases.

ABSTRACT: The proposed work fills a gap of investigation on forced resonant vibration analysis of graphene nanoplatelets (GNPs) reinforced functionally graded polymer composite (FG-PC) doubly-curved nanoshells. For the first time, forced resonant vibration of the nanoshells including four different geometries of the shells namely spherical, elliptical, hyperbolic and cylindrical has been studied here. The Halpin–Tasi model and a rule of mixture are adopted to estimate the effective material properties due to distribution patterns of GNPs (UD, FG-O and FG-X) The governing equations are obtained through the Hamiltonian principle for general third-order shear deformation shell theory in conjunction with the nonlocal strain gradient theory, and then solved for simply-supported boundaries. Using this work, it is possible to accurately analyze the roles of weight fraction, total number of layers as well as distribution pattern of GNPs, nonlocal parameter, strain gradient parameter, type of doubly-curved nanoshell and geometrical parameters on the resonant phenomena of GNPs reinforced FG-PC nanoshells. The results indicate that resonant phenomenon will occur firstly in the hyperbolic type of the nanoshell, followed by cylindrical, elliptical and spherical ones. In addition, the resonant phenomenon will occur sooner in flat structures compared to curved ones.

F. Moleiro (1), E. Carrera (2), E. Zappino (2), G. Li (2) and M. Cinefra (2)
(1) LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
(2) Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

ABSTRACT: Carrera Unified Formulation (CUF) is taken a step further to render node-dependent kinematics (NDK) capabilities to new layerwise finite elements based on Reissner’s Mixed Variational Theorem (RMVT), especially suited for global–local stress analysis of multilayered plates, ensuring high numerical accuracy and computational efficiency, all together. In the framework of CUF, as introduced originally for multilayered structures, any degree of kinematic refinement can be considered in agreement with Equivalent Single-Layer (ESL) or Layer-Wise (LW) theories to develop advanced finite element models, whether based on the Principle of Virtual Displacements (PVD) or RMVT. The degree of kinematic refinement, which usually holds equally for the entire element, can be taken a step further, by being assigned locally to each of its nodes, making full use of CUF to render NDK capabilities to the elements. Besides, even though the elements can adopt any type of nodal shape functions, high–order hierarchical Legendre expansions (HLE) can also be combined with NDK, achieving excellent convergence rates. These capabilities combined, explored first under the PVD, are for once integrated in the proposed elements under RMVT to further benefit accurate stress analysis. These elements can be applied throughout the entire mesh, adapting to local, transitional and global regions straightforwardly, providing high numerical accuracy, locally, with minimal computational efforts, globally. The numerical results focus on stress analysis of multilayered composite plates, including local effects, to demonstrate the predictive capabilities of the proposed RMVT-based LW elements with NDK and HLE combined, considering well-known benchmark three-dimensional exact solutions for assessment.

Shirko Faroughi (1), Erfan Shafei (2) and Timon Rabczuk (3)
(1) Faculty of Mechanical Engineering, Urmia University of Technology, Urmia, Iran
(2) Faculty of Civil Engineering, Urmia University of Technology, Urmia, Iran
(3) Institute of Research and Development, Duy Tan University, Da Nang, Viet Nam

ABSTRACT: We proposed an IGA formulation for free vibration, buckling and divergence analyses of generally anisotropic solid-like composite shells. Recently developed Rayleigh–Ritz based methods are not accurate enough for curved shells since they are not able to capture twisting mode shapes. Here, we use the advantages
of isogeometric analysis (IGA) and develop a three-dimensional higher-order continuous solid-like shell (SLS) model. Since the continuity of material orientation is crucial in numerical analysis of anisotropic shells, non-uniform rational B-splines (NURBS) are used to establish a smooth interpolation through the thickness and on the middle surface of the shell for both the geometry and displacement fields. The developed isogeometric SLS is coupled with Bézier extraction operators to represent continuity between multi-patch anisotropic domains. Numerical solutions for composite laminated shells with different boundary conditions are compared with analytical solutions or other solutions from the literature. In this context, we study the influence of span-to-thickness ratios, different shapes, modulus ratios, member aspect ratios and various layouts on the mechanical response. With the presented model, we were able to obtain the twisting mode shapes, which are not frequently observed in orthotropic and isotropic ones. We also study the influence of the polynomial order of the IGA formulation on the results.

Hugo Casquero (1), Xiaodong Wei (1), Deepesh Toshniwal (2), Angran Li (1), Thomas J.R. Hughes (3), Josef Kiendl (4) and Yongjie Jessica Zhang (1)
(1) Department of Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, USA
(2) Delft Institute of Applied Mathematics, Delft University of Technology, Van Mourik Broekmanweg 6, XE Delft 2628, The Netherlands
(3) Oden Institute for Computational Engineering and Sciences, 201 East 24th Street, C0200, Austin, TX 78712-1229, USA
(4) Department of Marine Technology, Norwegian University of Science and Technology, O. Nielsens veg 10, 7052 Trondheim, Norway


ABSTRACT: Analysis-suitable T-splines (ASTS) including both extraordinary points and T-junctions are used to solve Kirchhoff–Love shell problems. Extraordinary points are required to represent surfaces with arbitrary topological genus. T-junctions enable local refinement of regions where increased resolution is needed. The benefits of using ASTS to define shell geometries are at least two-fold: (1) The manual and time-consuming task of building a new mesh from scratch using the CAD geometry as an input is avoided and (2) C1 or higher inter-element continuity enables the discretization of shell formulations in primal form defined by fourth-order partial differential equations. A complete and state-of-the-art description of the development of ASTS, including extraordinary points and T-junctions, is presented. In particular, we improve the construction of C1-continuous non-negative spline basis functions near extraordinary points to obtain optimal convergence rates with respect to the square root of the number of degrees of freedom when solving linear elliptic problems. The applicability of the proposed technology to shell analysis is exemplified by performing geometrically nonlinear Kirchhoff–Love shell simulations of a pinched hemisphere, an oil sump of a car, a pipe junction, and a B-pillar of a car with 15 holes. Building ASTS for these examples involves using T-junctions and extraordinary points with valences 3, 5, and 6, which often suffice for the design of free-form surfaces. Our analysis results are compared with data from the literature using either a seven-parameter shell formulation or Kirchhoff–Love shells. We have also imported both finite element meshes and ASTS meshes into the commercial software LS-DYNA, used Reissner–Mindlin shells, and compared the result with our Kirchhoff–Love shell results. Excellent agreement is found in all cases. The complexity of the shell geometries considered in this paper shows that ASTS are applicable to real-world industrial problems.

David Mora (1,2) and Iván Velásquez (2)
(1) GIMNAP, Departamento de Matemática, Universidad del Bío-Bío, Concepción, Chile
(2) CIIMA, Universidad de Concepción, Concepción, Chile


ABSTRACT: In this paper, we develop a virtual element method (VEM) of high order to solve the fourth order plate buckling eigenvalue problem on polygonal meshes. We write a variational formulation based on the Kirchhoff–Love model depending on the transverse displacement of the plate. We propose a C1 conforming virtual element discretization of arbitrary order $k \geq 2$ and we use the so-called Babuška–Osborn abstract
spectral approximation theory to show that the resulting scheme provides a correct approximation of the spectrum and prove optimal order error estimates for the buckling modes (eigenfunctions) and a double order for the buckling coefficients (eigenvalues). Finally, we report some numerical experiments illustrating the behavior of the proposed scheme and confirming our theoretical results on different families of meshes.

Hui-Shen Shen (1,2), Chong Li (1) and J.N. Reddy (3)
(1) School of Aeronautics and Astronautics, Shanghai Jiao Tong University, Shanghai 200240, People’s Republic of China
(2) School of Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, People’s Republic of China
(3) Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843-3123, USA


ABSTRACT: This paper presents an investigation on the nonlinear flexural vibrations of carbon nanotube-reinforced composite (CNTRC) laminated cylindrical shells with negative Poisson’s ratios in thermal environments. The material properties of the CNTRCs are temperature-dependent and the functionally graded (FG) in a piece-wise pattern in the thickness direction of the shell. An extended Voigt (rule of mixture) model is employed to estimate the CNTRC material properties. The motion equations for the nonlinear flexural vibration of FG-CNTRC laminated cylindrical shells are based on the Reddy’s third order shear deformation theory and the von Kármán-type kinematic nonlinearity, and the effects of thermal environmental conditions are included. The nonlinear vibration solutions for the FG-CNTRC laminated cylindrical shells can be obtained by applying a singular perturbation technique along with a two-step perturbation approach. The effects of material property gradient, the temperature variation, shell geometric parameter, stacking sequence as well as the end conditions on the vibration characteristics of CNTRC laminated cylindrical shells are discussed in detail through a parametric study. The results show that negative Poisson’s ratio has a significant effect on the linear and nonlinear vibration characteristics of CNTRC laminated cylindrical shells.


ABSTRACT: A new approach to model shell structures is proposed. It is based on the scaled boundary finite element method in three dimensions. Thus, the solution is sought analytically in the through-thickness direction while the surface of the domain is discretized in a finite element sense. Since no kinematic assumptions are made, the proposed method can be applied to thick spherical shells and thin shells. Very good agreement with reference solutions is demonstrated or classical benchmark problems of shell analyses. No membrane locking induced by mesh distortion is observed. The potential of the proposed method is particularly evident when p-refinement is employed. Furthermore, the applicability of the proposed method to shells with non-spherical geometry is discussed in detail.


ABSTRACT: Different strategies based on rotation vector and exact strain measure have been proposed over the years for analyzing flexible bodies undergoing arbitrary large rotations. To avoid the singularity of the vector-like parametrization, the interpolation of the incremental rotation vector is the most popular approach in this context, even if this leads to path dependence and numerical instability, i.e. error accumulation. It is also non objective, although both objectivity and path independence are recovered with and refinement. Corotational approaches do not have these drawbacks, even though the geometrically exact model is achieved by mesh refinement. In this work, we develop a novel strategy which uses the incremental nodal rotation vectors to define corotational nodal rotations, which are then interpolated for the evaluation of the nonlinear strains. This

ABSTRACT: This paper proposes a coupling scheme for isogeometric elements, which is valid for large rotations and displacements. Two elements can be coupled not only at interpolated control points but also inside the parametric domain of a NURBS patch. Furthermore, each cross section may be arbitrarily oriented in space. The formulation is applicable for all structural elements, where an orthogonal system of base vectors can be derived. An Euler–Bernoulli beam is used as an example in order to illustrate the demands on the coupling conditions in the proposed approach. Moreover, the conditions are chosen such that different types of joints, e.g. scissor joints, can be modeled and such that they are easy and fast to implement. The coupling is incorporated by an additional term in the Principle of Virtual Work which is here computed using a penalty approach. The Euler–Bernoulli beam is summarized in order to introduce the notations in this contribution. This is followed by the proposed coupling conditions in the weak form. Subsequently, alternatives for the coupling conditions are briefly introduced. Eventually, benchmark and demonstrator examples validate and illustrate the proposed coupling methodology.

Hayoung Chung (1), Oded Amir (2) and H. Alicia Kim (3,4)
(1) School of Mechanical, Aerospace and Nuclear Engineering, Ulsan National Institute of Science and Technology, Ulsan, 44919, Republic of Korea
(2) Civil and Environmental Engineering, Technion, Technion City, Haifa, 32000, Israel
(3) Structural Engineering Department, University of California San Diego, 9500 Gilman Drive, San Diego, CA 92093, USA
(4) Cardiff School of Engineering, Cardiff University, The Queen’s Buildings, 14-17 The Parade, Cardiff, CF24 3AA, United Kingdom


ABSTRACT: At elevated temperature environments, elastic structures experience a change of the stress-free state of the body that can strongly influence the optimal topology of the structure. This work presents level-set based topology optimization of structures undergoing large deformations due to thermal and mechanical loads. The nonlinear analysis model is constructed by multiplicatively decomposing thermal and mechanical effects and introducing an intermediate stress-free state between the undeformed and deformed coordinates. By incorporating the thermoelastic nonlinearity into the level-set topology optimization scheme, wider design spaces can be explored with the consideration of both mechanical and thermal loads. Four numerical examples are presented that demonstrate how temperature changes affect the optimal design of large-deforming structures. In particular, we show how optimization can manipulate the material layout in order to create a counteracting effect between thermal and mechanical loads, even up to a degree that buckling and snap-through are suppressed. Hence the consideration of large deformations in conjunction with thermoelasticity opens many new possibilities for controlling and manipulating the thermo-mechanical response via topology optimization.

Claire Lestringant (1), Basile Audoly (2) and Dennis M. Kochmann (1,3)
(1) Mechanics & Materials, Department of Mechanical and Process Engineering, ETH Zürich, 8092 Zürich, Switzerland
ABSTRACT: We present an extension of a discrete, geometrically exact beam formulation based on discrete framed curves and discrete parallel transport originally introduced in the computer graphics community. In combination with variational constitutive updates, our numerical scheme decouples the kinematics from the material behavior, and can handle finite rotations as well as a wide class of constitutive laws depending on the stretching, flexural and torsional strain and strain rates. We demonstrate its capabilities through a suite of benchmark problems involving elastic, viscous and visco-elastic beams. The method fits naturally in existing finite element frameworks and is well suited to engineering applications. It can efficiently and accurately simulate the nonlinear deformation of slender beams featuring complex material behavior, such as those found in the topical design of flexible structural metamaterials.

Yan Zhang (1), Mi Xiao (1), Xiaoyu Zhang (2) and Liang Gao (1)
(1) Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, Wuhan 430074, China
(2) Beijing Institute of Spacecraft System Engineering, China Academy of Space Technology, Beijing 100094, China

ABSTRACT: Exploring ultralight sandwich structures with superior load-bearing performance is one of the important topics in structural optimization. This paper proposes a novel multiscale topology optimization method to achieve the design of high-performance sandwich structures with graded cellular cores (SSGCCs). In this method, the thicknesses of two solid face-sheets, the graded distribution of cellular sandwich cores at a single layer and their configurations are optimized to well suit for loading conditions, where the single layer is arrayed periodically at its height direction to obtain sandwich layers. Specifically, at macroscale, the variable thickness sheet (VTS) method with the capacity of generating an overall free material distribution pattern, is applied to optimize the thicknesses of two solid face-sheets and achieve the graded distribution of cellular sandwich cores at a single layer. At microscale, a progressive optimization scheme is employed to topologically optimize multiple representative cellular cores (RCCs) at a single layer, so as to achieve their similar topological configurations. With a shape interpolation method, the configurations of graded cellular cores (GCCs) with essential interconnections can be obtained by interpolating the shapes of these RCCs with similar topological features. In order to reduce the computational burden on evaluating effective properties of GCCs by the homogenization method, a Kriging metamodel is constructed based on some key cellular cores as sample points, and adopted to predict the effective properties of all the GCCs. Both 2D and 3D numerical examples are provided to test the validity and advantages of the proposed method for designing SSGCCs.

Javier Videla (1,3), Felipe Contreras (1), Hoang X. Nguyen (2) and Elena Atroshchenko (1,3)
(1) Department of Mechanical Engineering, University of Chile, Santiago 8370448, Chile
(2) Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne NE1 8ST, United Kingdom
(3) University of New South Wales, School of Civil and Environmental Engineering, Sydney, Australia

ABSTRACT: In this work, we present an eXtended Geometry Independent Field approximaTion (X–GIFT) formulation for cracked Kirchhoff–Love plates. The plate geometry is modeled by Non-Uniform Rational B-Splines (NURBS) while the solution is approximated by Polynomial Splines over Hierarchical T-meshes (PHT-splines) and enriched by the Heaviside function and crack tip asymptotic expansions. The adaptive refinement is driven by a recovery-based error estimator. The formulation is employed for bending and vibration analysis. We
compare different strategies for refinement, enrichment and evaluation of fracture parameters. The obtained results are shown to be in a good agreement with the reference solutions.

Peng Hao (1), Yu Wang (1), Zhangming Wu (2), Xuanxiu Liu (1), Bo Wan (1) and Wei Huang (3)
(1) Structural Analysis for Industrial Equipment, Department of Engineering Mechanics, International Research Center for Computational Mechanics, Dalian University of Technology, Dalian, 116023, China
(2) Impact and Safety Engineering, Ministry of Education of China, Ningbo University, Ningbo, 315211, China
(3) Beijing Institute of Astronautical Systems Engineering, Beijing, 100076, China


ABSTRACT: Thin-walled shells with cutouts are widely used as primary structures in the aerospace field. The mechanical analysis of shell structures using the Finite Êlement Analysis (FEA) method often needs very fine meshes to achieve a high-fidelity simulation. The advent of isogeometric analysis (IGA) method provides an alternative, yet efficient and accurate means to model complex shell structures with cutouts. In this paper, the trimmed surface analysis (TSA) method is applied in IGA to perform the trimmed elements integration of linear buckling analysis of shell structures. In the shape optimization process, the analytical formulae for the design sensitivities of IGA based shell buckling model are derived, and the sensitivity propagation from the design model to the analysis model is computed using a $h$-refinement method. Moreover, a novel smart design domain (SDD) method is proposed and implemented to reduce the number of design variables and further enhance the shape optimization efficiency, substantially. SDD can provide useful reference information to guide the selection of control points as design variables. Later, the comparison of optimization examples approve that the SDD method can provide a very efficient means to perform the local shape optimization for the complex shells. Finally, a multi-level progressive optimization framework based on the SDD method is developed, in which the design model and the analysis model are separated and implemented independently. In doing so, the design model is able to provide enough parameterization for optimization, and, in the meantime, the analysis model ensures efficiency and accuracy for simulation. Finally, the numerical examples on the buckling analysis and optimization of complex shells with cutouts demonstrate the greatly improved capacity and efficiency of the design framework proposed in this paper.

E. Samaniego (3), C. Anitescu (4), S. Goswami (4), V.M. Nguyen-Thanh (5), H. Guo (5), K. Hamdia (5), X. Zhuang (5) and T. Rabczuk (1,2)
(1) Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(2) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(3) School of Engineering and Departamento de Recursos Hidricos y Ciencias Ambientales, Universidad de Cuenca, Av. 12 de Abril s/n., Cuenca, Ecuador
(4) Institute of Structural Mechanics, Bauhaus-Universität Weimar, Marienstraße 15 99423 Weimar, Germany
(5) Institute of Continuum Mechanics, Leibniz Universität Hannover, Appelstraße 11, 30167 Hannover, Germany


ABSTRACT: Partial Differential Equations (PDEs) are fundamental to model different phenomena in science and engineering mathematically. Solving them is a crucial step towards a precise knowledge of the behavior of natural and engineered systems. In general, in order to solve PDEs that represent real systems to an acceptable degree, analytical methods are usually not enough. One has to resort to discretization methods. For engineering problems, probably the best-known option is the finite element method (FEM). However, powerful alternatives such as mesh-free methods and Isogeometric Analysis (IGA) are also available. The fundamental idea is to approximate the solution of the PDE by means of functions specifically built to have some desirable properties. In this contribution, we explore Deep Neural Networks (DNNs) as an option for approximation. They have shown impressive results in areas such as visual recognition. DNNs are regarded here as function approximation machines. There is great flexibility to define their structure and important advances in the architecture and the efficiency of the algorithms to implement them make DNNs a very interesting alternative to approximate the solution of a PDE. We concentrate on applications that have an interest for Computational Mechanics. Most
contributions explore this possibility have adopted a collocation strategy. In this work, we concentrate on mechanical problems and analyze the energetic format of the PDE. The energy of a mechanical system seems to be the natural loss function for a machine learning method to approach a mechanical problem. In order to prove the concepts, we deal with several problems and explore the capabilities of the method for applications in engineering.


ABSTRACT: Repeatedly solving the generalized eigenvalue problems by far dominates the computational cost in large-scale topology optimization involving natural frequency constraints. This study proposes a method for dynamic topology optimization problems considering natural frequencies using successively executed iterations for the structural analysis and design. By using the Rayleigh quotients as approximations of the natural frequencies and achieving sequential approximation of the eigenpairs through inverse iteration-like procedures to improve the eigenvectors along with the topological evolution of the structure, the method avoids solving the time-consuming eigenvalue problem in each design iteration. This makes the method particularly suitable for large-scale frequency-constrained topology optimization problems. The convergence property of the method is analyzed under the assumption of sufficiently small design changes between two successive design iterations. Numerical examples regarding frequency and frequency gap constraints show that this method is able to realize concurrent convergence of the eigenvalue analysis and design optimization, and is more efficient than the conventional double-loop approach.

Andreas Hessenthaler (1), Maximilian Balmus (2), Oliver Röhrle (1) and David Nordsletten (3,2)
(1) Institute for Modelling and Simulation of Biomechanical Systems, University of Stuttgart, Pfaffenwaldring 5a, 70569 Stuttgart, Germany
(2) School of Biomedical Engineering and Imaging Sciences, King’s College London, 4th FL Rayne Institute, St. Thomas Hospital, London, SE1 7EH, United Kingdom of Great Britain and Northern Ireland
(3) Department of Biomedical Engineering and Cardiac Surgery, University of Michigan, NCRC B20, 2800 Plymouth Rd, Ann Arbor, 48109, United States of America

ABSTRACT: Fluid-structure interaction (FSI) problems are pervasive in the computational engineering community. The need to address challenging FSI problems has led to the development of a broad range of numerical methods addressing a variety of application-specific demands. While a range of numerical and experimental benchmarks are present in the literature, few solutions are available that enable both verification and spatiotemporal convergence analysis. In this paper, we introduce a class of analytic solutions to FSI problems involving shear in channels and pipes. Comprised of 16 separate analytic solutions, our approach is permuted to enable progressive verification and analysis of FSI methods and implementations, in two and three dimensions, for static and transient scenarios as well as for linear and hyperelastic solid materials. Results are shown for a range of analytic models exhibiting progressively complex behavior. The utility of these solutions for analysis of convergence behavior is further demonstrated using a previously published monolithic FSI technique. The resulting class of analytic solutions addresses a core challenge in the development of novel FSI algorithms and implementations, providing a progressive testbed for verification and detailed convergence analysis.

Srdjan Simunovic (1), Lee P. Bindeman (2) and Abhishek Kumar (3)
(1) Oak Ridge National Laboratory, P.O. Box 2008-6164, Oak Ridge, TN 37831-6164, USA
(2) Livermore Software Technology, an ANSYS company, 7374 Las Positas Road, Livermore, CA 94551, USA
(3) Northeastern University, 360 Huntington Avenue, Boston, MA 02115, USA
ABSTRACT: We describe a new approach for modeling nonlinear deformation and stress distribution of battery cells using a new thick shell finite element formulation with a through-thickness calculation of stresses and strains that satisfy equilibrium conditions. Battery cells are transversely layered materials that contain numerous thin layers in a repeating sequence. The layers are made of materials with significantly different mechanical responses. Explicit discretization of the layers is computationally impractical except for very small domains, while homogenized material models cannot account for stress and strain variations and partition through the thickness. The new formulation allows for calculation of the transverse and interlayer stresses based on the material properties of the individual cell layers. The application to problems where the transverse stresses have strong influence is also possible.

J. Schulte (1), M. Dittmann (1), S.R. Eugster (3), S. Hesch (2), T. Reinicke (2), F. dell’Isola (4) and C. Hesch(1)
(1) Chair of Computational Mechanics, University of Siegen, Siegen, Germany
(2) Chair of Product Development, University of Siegen, Siegen, Germany
(3) Institute for Nonlinear Mechanics, University of Stuttgart, Stuttgart, Germany
(4) Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy


ABSTRACT: A second gradient theory for woven fabrics is applied to Kirchhoff–Love shell elements to analyze the mechanics of fiber reinforced composite materials. In particular, we assume a continuous distribution of the fibers embedded into the shell surface, accounting for additional in-plane flexural resistances within the hyperelastic regime. For the finite element discretization we apply isogeometric methods, i.e. we make use of B-splines as basis functions omitting the usage of mixed approaches. The higher gradient formulation of the fabric is verified by a series of numerical examples, followed by suitable validation steps using experimental measurements on organic sheets. A final example using a non-flat reference geometry demonstrates the capabilities of the presented formulation.


ABSTRACT: In this paper, we discuss cloth simulation using the splitting technique used in extended isogeometric analysis. We claim that splitting techniques can provide more flexible and diverse expressions than existing ones. We use a custom-designed enrichment function and apply it to three static test problems: Scordelis-Lo roof, pinched cylinder, and pinched hemisphere. We also show that local splitting is applicable to simple multi-patch problems. For these problems, we obtain results closer to the reference solution, despite using less control points. We also use the custom-designed enrichment function to simulate the folding and wrinkling of clothes without changing mesh. In addition, a discontinuous enrichment function can be used to express cutting cloth. We demonstrate it is possible to express clothes movement more accurately and variously by locally adding an enrichment function to existing isogeometric analysis based static and dynamic simulations.

Jie Gao (1,3,4), Mi Xiao (1), Liang Gao (1), Jinhui Yan (2,3) and Wentao Yan (4)
(1) Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan, Hubei 430074, China
(2) Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign, 205 North Mathews Ave, Urbana, IL 61801, USA
(3) Advanced Digital Sciences Center, University of Illinois Urbana-Champaign, 205 North Mathews Ave, Urbana, IL 61801, USA
(4) Department of Mechanical Engineering, National University of Singapore, 117575, Singapore

ABSTRACT: Auxetic composites, a kind of rationally artificial materials, possess superior multifunctional properties due to a mixture of materials. In this paper, an Isogeometric Topology Optimization (ITO) method is proposed for computational design of both the re-entrant and chiral auxetic composites in both 2D and 3D. The homogenization is numerically implemented using isogeometric analysis (IGA) to predict macroscopic effective properties of microstructures, where the periodic boundary formulation is imposed. An effective Non-Uniform Rational B-splines (NURBS)-based Multi-Material Interpolation (N-MMI) model is applied to compute material properties of all points in composite microstructures, mainly including the Fields of Design Variables (DVFVs), Fields of Topology Variables (TVFs), and multi-material interpolation. A unified ITO formulation is developed for 2D and 3D auxetic composites, where an appropriate objective function with a weight parameter is defined to control the generation of different deformation mechanisms. Finally, several numerical examples are performed to demonstrate the effectiveness of the proposed ITO method, and a series of 2D and 3D auxetic composites with the re-entrant and chiral deformation mechanisms are found. The optimized composite structures are simulated using ANSYS to show the auxetic behavior.

Yang Guo (1), Qian Ye (2), Xiaopeng Zheng (3), Shikui Chen (2), Na Lei (3), Yuanqi Zhang (4) and David Xianfeng Gu (1)
(1) Department of Computer Science, State University of New York at Stony Brook, USA
(2) Department of Mechanical Engineering, State University of New York at Stony Brook, USA
(3) DUT-RU International School of Information Science & Engineering, Dalian University of Technology, China
(4) Division of Engineering and Applied Sciences, Harvard University, USA

ABSTRACT: This paper presents a framework for computational generation and conformal fabrication of woven thin-shell structures with arbitrary topology based on the foliation theory which decomposes a surface into a group of parallel leaves. By solving graph-valued harmonic maps on the input surface, we construct two sets of harmonic foliations perpendicular to each other. The warp and weft threads are created afterward and then manually woven to reconstruct the surface. The proposed computational method guarantees the smoothness of the foliation and the orthogonality between each pair of leaves from different foliations. Moreover, it minimizes the number of singularities to theoretical lower bound and produces the tensor product structure as globally as possible. This method is ideal for the physical realization of woven surface structures on a variety of applications, including wearable electronics, sheet metal craft, architectural designs, and conformal woven composite parts in the automotive and aircraft industries. The performance of the proposed method is demonstrated through the computational generation and physical fabrication of several free-form thin-shell structures.


ABSTRACT: This paper presents an isogeometric formulation and the corresponding algorithm to predict the mechanical behaviors of swellable soft materials by the high-order NURBS elements. To deal with the difficulties aroused from the growth and incompressibility of soft materials, a numerical scheme based on two multiplicative decompositions of deformation gradient is developed. For introducing the growth effect, the deformation gradient is decomposed into a growth tensor and an elastic deformation gradient. For circumventing the volumetric locking caused by incompressibility of soft materials, the elastic deformation gradient is further decomposed into its volume-preserving and volumetric-dilatational parts. Meanwhile, the volumetric-dilatational part is modified by a linear projection operator. Then, the incremental equations of the weak form are derived by an effective linearization method for this nonlinear problem. After introducing the discrete technique in isogeometric analysis, the formulations for numerical calculations, i.e., the stiffness matrices and the force vectors, are derived. The efficiency and accuracy of the proposed isogeometric method are demonstrated by several examples discretized by the high-order NURBS elements exactly, including conic
sections and other complex geometries. The proposed method is also proved to have great potentials for analyzing the mechanical behaviors of swellable soft materials as well as bionic structures and designing the bionic devices.

ABSTRACT: This paper studies quadrature rules for simulating large deformations of shells using isogeometric analysis. Several recently proposed rules and their effects on a real-world application known as incremental sheet forming are investigated. It is observed that, when tackling real-world applications, unexpected problems arise and, therefore, theoretical studies only with manufactured solutions are not enough for a complete verification of a method. The chosen application reveals problems with certain quadratures and that some simple stabilization strategies cannot completely suppress hourglass modes. Additionally, the effects of quadrature rules on the total computational costs are demonstrated and the influence of the maximum stable time step is assessed using a highly demanding simulation.

ABSTRACT: This work presents a multilevel approach to large-scale topology optimization accounting for linearized buckling criteria. The method relies on the use of preconditioned iterative solvers for all the systems involved in the linear buckling and sensitivity analyses and on the approximation of buckling modes from a coarse discretization. The strategy shows three main benefits: first, the computational cost for the eigenvalue analyses is drastically cut. Second, artifacts due to local stress concentrations are alleviated when computing modes on the coarse scale. Third, the ability to select a reduced set of important global modes and filter out less important local ones. As a result, designs with improved buckling resistance can be generated with a computational cost little more than that of a corresponding compliance minimization problem solved for multiple loading cases. Examples of 2D and 3D structures discretized by up to some millions of degrees of freedom are solved in Matlab to show the effectiveness of the proposed method. Finally, a post-processing procedure is suggested in order to reinforce the optimized design against local buckling.

Hesaneh Kazemi (1), Ashkan Vaziri (2) and Julián A. Norato (1)
(1) Department of Mechanical Engineering, The University of Connecticut, 191 Auditorium Road, U-3139, Storrs, CT 06269, USA
(2) BioSensics, 57 Chapel St #200, Newton, MA 02458, USA
ABSTRACT: This work presents a computational method for the design of architected truss lattice materials where each strut can be made of one of a set of available materials. We design the lattices to extremize effective properties. As customary in topology optimization, we design a periodic unit cell of the lattice and obtain the effective properties via numerical homogenization. Each bar is represented as a cylindrical offset surface of a medial axis parameterized by the positions of the endpoints of the medial axis. These parameters are smoothly mapped onto a continuous density field for the primal and sensitivity analysis via the geometry projection method. A size variable per material is ascribed to each bar and penalized as in density-based topology optimization to facilitate the entire removal of bars from the design. During the optimization, we allow bars to be made of a mixture of the available materials. However, to ensure each bar is either exclusively made of one material or removed altogether from the optimal design, we impose optimization constraints that ensure each size variable is 0 or 1, and that at most one material size variable is 1. The proposed material interpolation scheme readily accommodates any number of materials. To obtain lattices with desired material symmetries, we design only a reference region of the unit cell and reflect its geometry projection with respect to the appropriate planes of symmetry. Also, to ensure bars remain whole upon reflection inside the unit cell or with respect to the
periodic boundaries, we impose a no-cut constraint on the bars. We demonstrate the efficacy of our method via numerical examples of bulk and shear moduli maximization and Poisson’s ratio minimization for two- and three-material lattices with cubic symmetry.

Pablo Antolin (1), Annalisa Buffa (1,2) and Luca Coradello (1)
(1) Institute of Mathematics, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
(2) Istituto di Matematica Applicata e Tecnologie Informatiche ‘E. Magenes’ (CNR), Pavia, Italy
“Adaptive isogeometric analysis on two-dimensional trimmed domains based on a hierarchical approach”
Computer Methods in Applied Mechanics and Engineering, Vol. 364, Article 112925, 1 June 2020,
https://doi.org/10.1016/j.cma.2020.112925
ABSTRACT: The focus of this work is on the development of an error-driven isogeometric framework, capable of automatically performing an adaptive simulation in the context of second- and fourth-order, elliptic partial differential equations defined on two-dimensional trimmed domains. The method is steered by an adaptive error estimator, which is computed with the aid of an auxiliary residual-like problem formulated onto a space spanned by splines with single element support. The local refinement of the basis is achieved thanks to the use of truncated hierarchical B-splines. We prove numerically the applicability of the proposed estimator to various engineering-relevant problems, namely the Poisson problem, linear elasticity and Kirchhoff–Love shells, formulated on trimmed geometries. In particular, we study several benchmark problems which exhibit both smooth and singular solutions, where we recover optimal asymptotic rates of convergence for the error measured in the energy norm and we observe a substantial increase in accuracy per-degree-of-freedom compared to uniform refinement. Lastly, we show the applicability of our framework to the adaptive shell analysis of an industrial-like trimmed geometry modeled in the commercial software Rhinoceros, which represents the B-pillar of a car.

Raphaël Charrondière (1), Florence Bertails-Descoubes (1), Sébastien Neukirch (2) and Victor Romero (1,2)
(1) Univ. Grenoble Alpes, CNRS, Inria, Grenoble INP, LJK, Grenoble, France
(2) Sorbonne Université, CNRS, UMR 7190, Institut Jean le Rond d’Alembert, Paris, France
“Numerical modeling of inextensible elastic ribbons with curvature-based elements”,
Computer Methods in Applied Mechanics and Engineering, Vol. 364, Article 112922, 1 June 2020,
https://doi.org/10.1016/j.cma.2020.112922
ABSTRACT: We propose a robust and efficient numerical model to compute stable equilibrium configurations of clamped elastic ribbons featuring arbitrarily curved natural shapes. Our spatial discretization scheme relies on elements characterized by a linear normal curvature and a quadratic geodesic torsion with respect to arc length. Such a high-order discretization allows for a great diversity of kinematic representations, while guaranteeing the surface of the ribbon to remain perfectly inextensible. Stable equilibria are calculated by minimizing the sum of the gravitational and elastic energies of the ribbon, under a developability constraint. Our algorithm compares favorably to standard shooting and collocation methods, as well as to experiments. It furthermore shows significant differences in behavior compared to numerical models for thin elastic rods, while
yielding a substantial speed-up compared to a more general thin elastic shell simulator. These results confirm the benefit of designing a special numerical model dedicated to ribbons.

Alessandro Nitti (1), Josef Kiendl (2), Alessandro Reali (3) and Marco D. de Tullio (1)
(1) Department of Mechanics Mathematics and Management, Polytechnic University of Bari, Via Re David 200, 70125, Bari, Italy
(2) Institute of Mechanics and Structural Analysis, Bundeswehr University Munich, Werner-Heisenberg-Weg 39, 85577, Neubiberg, Germany
(3) Department of Civil Engineering and Architecture, University of Pavia, Via Ferrata 3, 27100, Pavia, Italy

ABSTRACT: A computational framework is designed to accurately predict the elastic response of thin shells undergoing large displacements induced by local hydrodynamic forces, as well as to resolve the complex fluid pattern arising from its interaction with an incompressible fluid. Within the context of partitioned algorithms, two different approaches are employed for the fluid and structural domain. The fluid motion is resolved with a pressure projection method on a Cartesian structured grid. The immersed shell is modeled by means of a NURBS surface, and the elastic response is obtained from a displacement-based isogeometric analysis relying on the Kirchhoff–Love theory. The two solvers exchange data through a direct-forcing immersed-boundary approach, where the interpolation/spreading of the variables between Lagrangian and Eulerian grids is implemented with a Moving Least Squares approximation, which has proven to be very effective for moving boundaries. In this scenario, the isoparametric paradigm is exploited to perform an adaptive collocation of the Lagrangian markers, decoupling the local grid density of fluid and shell domains and reducing the computational expense. The accuracy of the method is verified by refinement analyses, segregating the Eulerian/Lagrangian refinement, which confirm the expected scheme accuracy in space and time. The effectiveness of the method is then validated against different test-cases of engineering and biologic inspiration, involving fundamentally different physical and numerical conditions, namely: (i) a flapping flag, (ii) an inverted flag, (iii) a clamped plate, (iv) a buoyant seaweed in a free stream. Both strong and loose coupling approaches are implemented to handle different fluid-to-structure density ratios, providing accurate results.

Mahyunirsyah Mahjudin (1,2), Pascal Lardeur (1), Frédéric Druesne (1) and Irwan Katili (3)
(1) Sorbonne Universités, Université de Technologie de Compiègne, CNRS FRE2012, Laboratoire Roberval, 60203 Compiègne, France
(2) Department of Civil Engineering, Institut Teknologi Medan, Medan 20217, Indonesia
(3) Department of Civil Engineering, Universitas Indonesia, Depok 16424, Indonesia

ABSTRACT: The paper presents an extension of the Certain Generalized Stresses Method (CGSM) for the static finite element analysis of homogeneous and laminated shells with variability. The basic assumption is that the generalized stresses do not depend on input parameters perturbation. The CGSM is a non-intrusive method that requires only one finite element analysis with some load cases to calculate the variability of mechanical quantities of interest. The uncertain input parameters are material and physical properties. Uniform random parameters as well as random fields are considered. The displacements statistical results: mean value, standard deviation and distribution are obtained by Monte Carlo simulations, using a semi-analytical formula. Two examples are treated: the Scordelis–Lo shell roof and an automotive windscreen. The method provides results of good quality and is very economical from a computational time point of view.

Dan Wang (1), Si-Yong Yeo (1,2), Zhoucheng Su (1), Zhen-Pei Wang (1) and Mostafa M. Abdalla (3)
(1) Institute of High Performance Computing (IHPC), Agency for Science, Technology and Research (A*STAR), 1 Fusionopolis Way, 138632, Singapore
(2) Information Systems Technology and Design (ISTD), Singapore University of Technology and Design (SUTD), 8 Somapah Road, 487372, Singapore
(3) Zewail City of Science and Technology, Sheikh Zayed District, Giza, 12588, Egypt
ABSTRACT: The homogenization-based streamline stiffener path optimization (SSPO) method was previously proposed by the authors for stiffener layout design of non-uniform curved grid-stiffened composite (NCGC) structures. The applications are limited to densely distributed stiffeners with no significant scale effect in the homogenization process, which is revealed in this work. A data-driven SSPO method, which is inspired by the popular principal component analysis (PCA) in data processing, is proposed for sparse stiffener layout design. With several referential layouts as input, the PCA generates a sequence of principal layouts. Together with weighting factors and distortion techniques, using only a small number of dominant principal layouts is enough to represent most possible synthesized layouts, which significantly reduces the number of design variables while preserving and extending a large design space. This strategy is further enhanced with a detailed modeling technique based on multiple point constraints (MPCs) to automate the modeling process. The data-driven SSPO method can be integrated with either gradient-based or artificial intelligence (AI) algorithms due to the small number of design variables. A flexible objective target, to maximize the critical buckling load or minimize the structural weight, can be used since the structural responses are evaluated on the detailed model. Numerical examples demonstrate the effectiveness of the proposed method in optimizing the layout of sparsely distributed stiffeners.

Weisheng Zhang (1,2), Shan Jiang (1), Chang Liu (1), Dingding Li (1), Pilseong Kang (3), Sung-Kie Youn (1,4) and Xu Guo (1)
(1) Structural Analysis for Industrial Equipment, Department of Engineering Mechanics, International Research Center for Computational Mechanics, Dalian University of Technology, Dalian, 116023, PR China
(2) Strength and Vibration of Mechanical Structures, Department of Engineering Mechanics, School of Aerospace Engineering, Xi’an Jiaotong University, Xi’an, 710049, PR China
(3) Center for Space Optics, Korea Research Institute of Standards and Science, 267 Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea
(4) KAIST, 291-Daehak-ro, Yuseong, Daejeon 34141, Republic of Korea

ABSTRACT: There have been quite a few research works on the topology optimization under stress constraints. However, most of them only treated two dimensional (2D) cases. In the present work, a new approach for topology optimization of three dimensional (3D) shell structures under stress constraints is presented. This approach is constructed by combining the Moving Morphable Void (MMV) approach with trimming technique-based Isogeometric analysis (IGA), where the shell geometry is described using Non-Uniform Rational B-Spline (NURBS) and a set of trimming curves. The proposed approach not only shares the same advantages of MMV approach for topology optimization (e.g., involving small number of design variables, linking with CAD system seamlessly, etc.), but also has the capability of providing high accuracy stress analysis results using much smaller number of degree of freedoms with the help of trimming surface analysis (TSA) technique. Several numerical examples are also presented to demonstrate the effectiveness and advantages of the proposed approach.

Chao Wang (1,2), Jin Ming Koh (3), Tiantang Yu (2), Neng Gang Xie (1) and Kang Hao Cheong (3)
(1) Department of Mechanical Engineering, Anhui University of Technology, Maanshan 243002, PR China
(2) Department of Engineering Mechanics, Hohai University, Nanjing 211100, PR China
(3) Science and Math Cluster, Singapore University of Technology and Design (SUTD), 8 Somapah Road, S487372, Singapore

ABSTRACT: In the design of functionally graded materials, bi-directional design offers greater design freedom than the typical single-direction approach. This paper studies the shape and size design of variable-thickness bi-directional functionally graded plates (2D-FGPs) with multi-objective optimization. A method integrating
generalized iso-geometrical analysis (GIGA) and an improved multi-objective particle swarm optimization algorithm (IMOPSO) is proposed, with numerous technical advantages. B-spline basis functions in two dimensions are used to robustly represent the volume fraction distribution, with volume fraction and shape profile at control points located along the plane set to be design variables. The mechanical behavior of the 2D FGP is treated with a third-order shear deformation theory and a non-uniform rational basis spline (NURBS)-based GIGA scheme. The IMOPSO algorithm incorporates chaotic sequence mapping, a diversity feedback mechanism, and a hybrid mutation mechanism to mitigate premature convergence and enhance evolution of the Pareto frontier. A number of test examples are provided, on square, circular, and gear FGP with various loading configurations, optimizing for natural frequency and mass.

Li Chen (1,2), Lars A.A. Beex (2), Peter Z. Berke (1), Thierry J. Massart (1) and Stéphane P.A. Bordas (2,3,4) (1) Building Architecture and Town Planning Department, Université Libre de Bruxelles (ULB), Avenue F.D. Roosevelt 50, 1050 Brussels, Belgium (2) Faculté des Sciences, de la Technologie et de la Communication, Université de Luxembourg, Maison du Nombre, Avenue de la Fonte 6, L-4364 Ésch-sur-Alzette, Luxembourg (3) Department of Mechanics and Advanced Materials, School of Engineering, Cardiff University, Cardiff CF10 3AT, UK (4) Department of Medical Research, China Medical University Hospital, China Medical University, Taichung, Taiwan


ABSTRACT: We propose a generalized quasicontinuum method to model the mechanical response of 3D lattice structures. The method relies on the spatial coupling of fully-resolved domains and coarse-grained domains. In the fully-resolved domain, the full micro-structure is taken into account. In the coarse-grained domain, the kinematics of the micro-structure are individually interpolated based on their connectivity. On top of that, the contributions of the microstructure to the governing equations in the coarse-grained domain are sampled using only a few unit cells. In both domains, geometrical and material variability along the strut can be naturally taken into account using a 3D co-rotational beam finite element with embedded plastic hinges. We verify the approach for BCC lattices, demonstrating that the new method can capture both material and geometrical non-linearities of single struts at a fraction of the cost of a direct numerical simulation.


ABSTRACT: This study proposes a novel isogeometric beam formulation for thin, elastic, planar curved beams subjected to large displacements. The Euler–Bernoulli beam theory is employed. In the formulation, a two-dimensional continuum beam is entirely described by its axis and a convective frame rigidly attached to the beam axis. Rational B-spline basis functions are used to construct the geometrical approximation of the beam axis, and the translational displacements of the beam axis are considered as the unknown kinematics. A property of NURBS curves is used to introduce rotational degrees of freedom at both ends of the beam. With the end rotational degrees of freedom, applying rotational boundary conditions and concentrated moments are straightforward. In addition, rigid connections between beams can be easily simulated. The accuracy and efficiency of the proposed beam formulation are verified by several well-established problems.


ABSTRACT: The isogeometric boundary element method (IGABEM) has great potential for the simulation of elasticity problems because of its exact geometric representation and good approximation properties. These advantages can be extended to thin structures, including coatings, but the development of an accurate and efficient method to deal with the large number of nearly singular integrals existing in the IGABEM presents a
great challenge for very thin sections. In this paper, we propose a new sinh scheme for weakly, strongly and hyper near-singular integrals arising in 3D IGABEM for thermoelastic problems, based on the sinh transformation method and adaptive integral method. The presented scheme is efficient, since it combines the advantages of both methods: (1) when the thickness of coatings/thin structures is moderately small, an accurate and efficient integral result will be obtained by the adaptive integral method; (2) when is very small, the nearly singular integrals are computed by the sinh scheme efficiently. With the introduction of NURBS in IGABEM, truncation errors arising in the Taylor expansion cannot be ignored. Based on the values of these errors, the computed knot spans are further divided into several sub-knot spans and different methods will be used to evaluate the integral over each sub-knot span in the new scheme. In addition, based on the analytical extension of the NURBS surface, an adaptation of the sinh transformation method is proposed which can evaluate the near-singular integrals accurately for cases in which the projection point lies outside of the considered knot span. Several numerical examples are presented to validate the accuracy and efficiency of the 3D IGABEM based on the sinh scheme in the analysis of thermoelastic problems. (Math symbols not printed. Please do not use math symbols in your abstracts.)

ABSTRACT: One of the defining properties of thin shell problems is that the solution can be viewed as a linear combination of local features, each with its own characteristic thickness-dependent length scale. For perforated shells it is thus possible that for the given dimensionless thickness, the local features dominate, and the problem of deriving effective material parameters becomes ill-posed. In the general case, one has to account for many different aspects of the problem that directly affect the effective material parameters. Through a computational study we derive a conjecture for the admissible thickness-ranges. The effective material parameters are derived with a minimisation process over a set of feasible instances. The efficacy of the conjecture and the minimisation process is demonstrated with an extensive set of numerical experiments.

ABSTRACT: A novel varying-order based NURBS discretization method is proposed to enhance the performance of isogeometric analysis (IGA) technique within the framework of computational contact mechanics. The method makes use of higher-order NURBS for the contact integral evaluations. The minimum orders of NURBS capable of representing the complex geometries exactly are employed for the bulk computations. The proposed methodology provides a possibility to refine the geometry through controllable order elevation for isogeometric analysis. To achieve this, a higher-order NURBS layer is used as the contact boundary layer of the bodies. The NURBS layer is constructed using different surface refinement strategies such that it is accompanied by a large number of additional degrees of freedom and matches with the bulk parameterization.

ABSTRACT: The main motivation for hierarchical B-Splines in Isogeometric Analysis is to perform a local refinement that is globally not a tensor product. Compared to standard knot insertion, this allows to increase refinement locality. Moreover, the implementation of hierarchical refinement on existing codes can be facilitated by Bézier extraction. This approach was initially developed for unrefined patches and then extended to local refinement. In case of B-Spline patches that are not locally refined, extraction and projection algorithms can be optimized by leveraging the tensor structure. However, these optimizations are not straightforwardly applicable to hierarchical B-Splines. In this contribution, we show an approach where all extraction operations are formulated to work directly on the univariate extraction operators, without explicitly computing and storing
the full tensor product. In particular, we consider the extraction of functions, and projection of degrees of freedom for refinement and coarsening. A slightly modified Bézier projection is proposed to fully exploit the developed algorithms. We finally compare our approach to an explicit computation of the extraction operator in both a linear transient and a nonlinear example.


ABSTRACT: This work presents a Fluid–Structure Interaction framework for the robust and efficient simulation of strongly coupled problems involving arbitrary large displacements and rotations. We focus on the application of the proposed tool to lightweight membrane-like structures. Nonetheless, all the techniques we present in this work can be applied to both volumetric and volumeless bodies. To achieve this, we rely on the use of embedded mesh methods in the fluid solver to conveniently handle the extremely large deflections and eventual topology changes of the structure. The coupling between the embedded fluid and mechanical solvers is based on an interface residual black-box strategy. We validate our proposal by solving reference benchmarking examples that consider both volumetric and volumeless geometries. Whenever it is possible, we also compare the embedded solution with the one obtained with our reference body fitted solver. Finally we present a real-life application of the presented embedded Fluid–Structure Interaction solver.


ABSTRACT: Based on a formulation on the special Euclidean group, a geometrically exact thin-walled beam with an arbitrary open cross-section is proposed to deal with the finite deformation and rotation issues. The beam strains are based on a kinematic assumption where warping deformation and Wagner effects are included such that the nonlinear behavior of a thin-walled beam is predicted accurately, particular under large torsion. To reduce the nonlinearity of rigid motion, static and dynamic equations are derived in the SE(3) framework based on the local frame approach. As the value of the iteration matrix, including the Jacobian matrix of inertial and internal forces, is invariable under arbitrary rigid motion, the number of updates required during the computation process decreases sharply, which drastically improves the computational efficiency. Furthermore, the isogeometric analysis (IGA) based on the non-uniform rational B-splines (NURBS) basis functions, which promotes the integration of computer-aided design (CAD) and computer-aided engineering (CAE), is adopted to interpolate the displacement, rotation, and warping fields separately. The interpolated strain measures satisfy the objectivity by removing the rigid motion of the reference point. To obtain the symmetric Jacobian matrix of internal forces, the linearization operation is conducted based on the previously converged configuration. A Lie group SE(3) extension of the generalized-time integration method is utilized to solve the equations of motion for thin-walled beams. Finally, the proposed formulation is successfully tested and validated in several static and dynamic numerical examples.


ABSTRACT: Modal metamodels can be effectively used as surrogates for expensive simulations in structural dynamics analysis with parametric variations. However, in the case of a system with clustered eigenvalues, e.g., a structure exhibiting symmetry or periodicity, mode interactions due to parametric variations are challenging to handle. Clustered eigenvalues are potentially associated with high sensitivity in eigenvectors. That is, a small perturbation to clustered eigenvalues may lead to significant changes in the corresponding eigenvectors. Neglecting the effect of mode interactions may produce large errors for modal metamodels in this case. To meet this challenge, we develop a novel automated mode tracking method (AMTM) for structures with clustered eigenvalues. Specifically, the changes in corresponding eigenvectors due to parametric variations are characterized by a transformation matrix representing a rotation in the subspace spanned by the reference
eigenvectors. Modal metamodels are subsequently trained to predict both eigenvalues and eigenvectors in the presence of mode interactions. The effectiveness of the proposed method is demonstrated using a four-edge clamped symmetric plate structure. In addition, an application of the proposed approach to uncertainty propagation (UP) of modal properties is presented using an example with a multi-dimensional parametric space.


ABSTRACT: Different from large deflection analyses of plates and shells, for analysis of an isotropic membrane structure a form finding procedure is first performed to find the new geometry of membrane. With this new geometry, large deflection analysis is conducted and the membrane works in a pure membrane state. In the conventionally numerical approaches for analysis of membranes, form finding and large deflection analysis are performed separately and quite complexly by different techniques. To overcome this difficulty, this paper proposes a unified adaptive approach (UAA) for analysis of membranes in the framework of isogeometric analysis (IGA). In UAA, both form finding and large deflection analysis are simultaneously and simply performed based on a modified Riks (M-R) nonlinear solver. As another advantage of UAA, it can be applied to various types of structures without any limitation or modification. For membranes, the proposed approach performs both form finding and large deflection analysis naturally. It is convenient that UAA automatically performs large deflection analysis without form finding when plates or shells are considered. Based on the adaptation of UAA, nonlinear responses of plates/shells and membranes are first obtained at the same time in this paper. Especially, a new type of equilibrium path of membranes is first proposed via UAA. The path includes two parts: one is obtained by form finding and another is from large deflection analysis. High accuracy and efficiency of the proposed approach and the present formulation are verified via some benchmark problems. Effects of slenderness ratio, curvature and boundary condition on form finding and nonlinear responses of membranes are rigorously investigated. Some new equilibrium paths of square and cylindrical membranes are first provided.


ABSTRACT: This study focuses on the efficient computational model for predicting the structural vibration induced underwater acoustic radiation in shallow marine environment. In the proposed model, the finite element method (FEM) is used to calculate the vibration response of the shell structures and the singular boundary method (SBM) with near-field and far-field Green’s functions is used to simulate the underwater acoustic radiation excited by shell structural vibration in shallow water marine environment, namely, the hybrid FEM–SBM solver. For axisymmetric shell structures, the axisymmetric numerical formulation of the FEM–SBM solver is derived to save the computational cost. For general shell structures, the fast direct solver based on the recursive skeletonization factorization is introduced into the FEM–SBM solver to accelerate the computation of the underwater acoustic field. Numerical results demonstrate that the proposed FEM–SBM solver provides more efficient and reliable solutions in comparison with the coupled FEM/FEM solver (COMSOL software). The effect of the sound velocity profiles on the underwater acoustic radiation field in shallow water marine environment is numerically investigated.


ABSTRACT: This work presents numerical techniques to enforce continuity constraints on multi-patch surfaces for three distinct problem classes. The first involves structural analysis of thin shells that are described by general Kirchhoff–Love kinematics. Their governing equation is a vector-valued, fourth-order, nonlinear, partial differential equation (PDE) that requires at least C1-continuity within a displacement-based finite
element formulation. The second class are surface phase separations modeled by a phase field. Their governing equation is the Cahn–Hilliard equation – a scalar, fourth-order, nonlinear PDE – that can be coupled to the thin shell PDE. The third class are brittle fracture processes modeled by a phase field approach. In this work, these are described by a scalar, fourth-order, nonlinear PDE that is similar to the Cahn–Hilliard equation and is also coupled to the thin shell PDE. Using a direct finite element discretization, the two phase field equations also require at least a C1-continuous formulation. Isogeometric surface discretizations – often composed of multiple patches – thus require constraints that enforce the C1-continuity of displacement and phase field. For this, two numerical strategies are presented: A Lagrange multiplier formulation and a penalty method. The curvilinear shell model including the geometrical constraints is taken from Duong et al. (2017) and it is extended to model the coupled phase field problems on thin shells of Zimmermann et al. (2019) and Paul et al. (2020) on multi-patches. Their accuracy and convergence are illustrated by several numerical examples considering deforming shells, phase separations on evolving surfaces, and dynamic brittle fracture of thin shells.


ABSTRACT: This study presents a computational strategy to address the challenge associated with the emergence of spurious modes in topology optimization with global stability considerations. In a discrete setting these modes pertain to the very low stiffness regions of the design domain occupied by hair-like elements with vanishing cross-sections and often surface when the computational optimizer tries to make dramatic changes to the topology. We demonstrate the inability of the classical approach to discrete topology optimization in capturing and repositioning these modes, and provide an elegant alternative which rests on the idea of expanding the set of design variables to include an “indicator” set, that similar to element densities in continuum domain, allow for quick clustering of contributing and non-contributing elements. The interplay between the set of basic design variables and the “indicator” set is shown to have the ability to identify the dominant eigenpairs that get pushed away in the presence of spurious modes and to effectively reposition them back to their original place where accurate values for the objective, constraints and the associated eigen-sensitivities are needed. A set of 2D frame structural topology optimization problems are used to demonstrate the effectiveness of the proposed methodology as well as the impact of parameters that affect the size of the design space, such as minimum to maximum thickness ratio and constraint bounds, on the optimized topology.


ABSTRACT: We develop a mixed geometrically nonlinear isogeometric Reissner–Mindlin shell element for the analysis of thin-walled structures that leverages Bézier dual basis functions to address both shear and membrane locking and to improve the quality of computed stresses. The accuracy of computed solutions over coarse meshes, that have highly non-interpolatory control meshes, is achieved through the application of a continuous rotational approach. The starting point of the formulation is the modified Hellinger–Reissner variational principle with independent displacement, membrane, and shear strains as the unknown fields. To overcome locking, the strain variables are interpolated with lower-order spline bases while the variations of the strain variables are interpolated with the corresponding Bézier dual bases. Leveraging the orthogonality property of the Bézier dual basis, the strain variables are condensed out of the system with only a slight increase in the bandwidth of the resulting linear system. The condensed approach preserves the accuracy of the non-condensed mixed approach but with fewer degrees of freedom. From a practical point of view, since the Bézier dual basis is completely specified through Bézier extraction, any spline space that admits Bézier extraction can utilize the proposed approach directly.

Chuong Nguyen, Xiaoying Zhuang, Ludovic Chamoin, Xianzhong Zhao, H. Nguyen-Xuan and Timon Rabczuk, “Three-dimensional topology optimization of auxetic metamaterial using isogeometric analysis and
ABSTRACT: We present an approach for designing material micro-structures by using isogeometric analysis and parameterized level set method. Design variables, which are level set values associated with control points, are updated from the optimizer and represent the geometry of the unit cell. The computational efficiency is further improved in each iteration by employing reduced order modeling when solving linear systems of the equilibrium equations. We construct a reduced basis by reusing computed solutions from previous optimization steps, and a much smaller linear system of equations is solved on the reduced basis. Two- and three-dimensional numerical results show the effectiveness of the topology optimization algorithm coupled with the reduced basis approach in designing metamaterials.


ABSTRACT: Isogeometric analysis (IGA) has become a strong tool for analysis of shell structures, which can be considered as a powerful alternative to the standard finite element method (FEM). Besides several advantages of IGA over FEM in geometric nonlinear analysis of the shells, it has some drawbacks corresponding to tensor-product of B-spline and NURBS surfaces. One of the solutions to eliminate or at least reduce the effects of the mentioned shortcomings is to combine IGA with the other methods, such as FEM. In the present paper, a novel version of the finite strip method (FSM) is developed to carry out the geometric nonlinear analysis, which employs a combination of FEM and IGA in the transversal and longitudinal directions, respectively and is named isogeometric B-spline finite strip method (IG-SFSM). The strip elements have been formulated based on the Degenerated-Shell method for Updated-Lagrangian (UL) approach. Then, it is examined by some examples incorporating various geometries, boundary conditions (BCs), and material properties, such as laminated composites and sandwich FGMs. The results exhibited that, to achieve the complicated nonlinear equilibrium paths of the shells, IG-SFSM requires a lower number of degrees of freedom (DOFs) and, consequently, computational efforts comparing to the other common methods, such as finite element and mesh-free methods.


ABSTRACT: Isogeometric Kirchhoff–Love elements have been receiving increasing attention in geometrically nonlinear analysis of thin shells because they make it possible to meet the requirement in the interior of surface patches and to avoid the use of finite rotations. However, engineering structures of appreciable complexity are typically modeled using multiple patches and, often, neither rotational continuity nor conforming discretization can be practically obtained at patch interfaces. Simple penalty approaches for coupling adjacent patches, applicable to either smooth or non-smooth interfaces and either matching or non-matching discretizations, have been proposed. Although the problem dependence of the penalty coefficient can be reduced by scaling factors which take into account geometrical and material parameters, only high values of the penalty coefficient can guarantee a negligible coupling error in all possible cases. However, this can lead to an ill conditioned problem and to an increasing iterative effort for solving the nonlinear discrete equations. In this work, we show how to avoid this drawback by rewriting the penalty terms in an Hellinger–Reissner form, introducing independent fields work-conjugated to the coupling equations. This technique avoids convergence problems, making the analysis robust also for very high values of the penalty coefficient, which can be then employed to avert coupling errors. Moreover, a proper choice of the basis functions for the new fields provides an accurate coupling also for general non-matching cases, preventing overconstrained solutions. The additional variables are condensed out and then not involved in the global system of equations to be solved. A highly efficient approach based on a mixed integration point strategy and an interface-wise reduced integration rule makes the condensation inexpensive preserving the sparsity of the condensed stiffness matrix and the coupling accuracy.
ABSTRACT: Reliability-based optimization (RBO) offers the possibility of finding the best design for a system according to a prescribed criterion while explicitly taking into account the effects of uncertainty. Although the importance and usefulness of RBO is undisputed, it is rarely applied to practical problems, as the associated numerical efforts are usually extremely large due to the necessity of solving simultaneously a reliability problem nested in an optimization procedure. To alleviate this issue, this contribution proposes an approach for solving a particular class of problems in RBO: the minimization of the failure probability of a linear system subjected to an uncertain load. The main characteristic of this approach is that it is fully decoupled. That is, the solution of the RBO problem is reduced to the solution of a single deterministic optimization problem followed by a single reliability analysis. Such an approach implies a complete change of paradigm with respect to the more classical double-loop and sequential methods for RBO. The theoretical basis for the proposed approach lies in the application of the operator norm theorem. The application and capabilities of the proposed approach are illustrated by means of three examples.

ABSTRACT: In this paper, an efficient element-free modeling framework for variable stiffness composite laminates with cutouts is developed. In comparison with other numerical methods or semi-analytical methods, element-free meshless methods offer many advantages in modeling variable stiffness materials and structures, e.g. complex geometries with cut-outs, providing accurate stress computations and stable nonlinear behavior modeling. In this study, an element-free Galerkin (EFG) method based modeling framework is developed to model variable stiffness composite plates containing circular holes, specifically for buckling and post-buckling analysis. Weighted orthogonal basis functions are used to further reduce the computational costs of the meshless method. Modeling accuracy for variable stiffness composite structures using node-based fiber angle definitions in this element-free framework are validated against FEM results obtained from ABAQUS. The critical buckling loads of linearly varying fiber composite laminates with different sizes of central circular holes are then computed. Based on the proposed element-free modeling scheme, nonlinear post-buckling equilibrium paths of variable stiffness composite plates are traced using an incremental loading step control method, which enables efficient post-buckling analysis. Changes in both critical buckling loads and nonlinear post-buckling performance with respect to hole size and the linear variation of fiber angles are investigated with the results presented in the form of parametric studies. The numerical results show that stress redistribution remains the major factor driving improvements in the buckling and post-buckling performance of variable stiffness composite plates with cut-outs. The research work presented in this paper for composite plates with linearly varying stiffness provides a basis for the analysis of general variable stiffness soft materials in the future.

S.E.H.M. van Bree (1), O. Rokoš (1,2), R.H.J. Peerlings (1), M. Doškář (2) and M.G.D. Geers (1)
(1) Mechanics of Materials, Department of Mechanical Engineering, Eindhoven University of Technology, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands
(2) Department of Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic
ABSTRACT: Mechanical metamaterials feature engineered microstructures designed to exhibit exotic, and often counter-intuitive, effective behaviour such as negative Poisson’s ratio or negative compressibility. Such a specific response is often achieved through instability-induced transformations of the underlying periodic microstructure into one or multiple patterning modes. Due to a strong kinematic coupling of individual repeating microstructural cells, non-local behaviour and size effects emerge, which cannot easily be captured by
classical homogenization schemes. In addition, the individual patterning modes can mutually interact in space as well as in time, while at the engineering scale the entire structure can buckle globally. For efficient numerical predictions of macroscale engineering applications, a micromorphic computational homogenization scheme has recently been developed (Rokoš et al., J. Mech. Phys. Solids 123, 119–137, 2019). Although this framework is in principle capable of accounting for spatial and temporal interactions between individual patterning modes, its implementation relied on a gradient-based quasi-Newton solution technique. This solver is suboptimal because (i) it has sub-quadratic convergence, and (ii) the absence of Hessians does not allow for proper bifurcation analyses. Given that mechanical metamaterials often rely on controlled instabilities, these limitations are serious. Addressing them will reduce the dependency of the solution on the initial guess by perturbing the system towards the correct deformation when a bifurcation point is encountered. Eventually, this enables more accurate and reliable modelling and design of metamaterials. To achieve this goal, a full Newton method, entailing all derivations and definitions of the tangent operators, is provided in detail in this paper. The construction of the macroscopic tangent operator is not straightforward due to specific model assumptions on the decomposition of the underlying displacement field pertinent to the micromorphic framework, involving orthogonality constraints. Analytical expressions for the first and second variation of the total potential energy are given, and the complete algorithm is listed. The developed methodology is demonstrated with two examples in which a competition between local and global buckling exists and where multiple patterning modes emerge. The numerical results indicate that local to global buckling transition can be predicted within a relative error of 6% in terms of the applied strains. The expected pattern combinations are triggered even for the case of multiple patterns.

References listed at the end of the paper:


ABSTRACT: This paper presents an adjoint-based method for solving optimization problems involving pressurized membrane structures subject to external pressure loads. Shape optimization of pressurized membranes is complicated by the fact that, lacking bending stiffness, their three-dimensional shape must be sustained by the internal pressure of the inflation medium. The proposed method treats the membrane structure as an immersed manifold and employs a total Lagrangian kinematic description with an analytical pressure-volume relationship for the inflating medium. To demonstrate the proposed method, this paper considers hydrostatically loaded inflatable barriers and develops an application-specific shape parametrization based on the analytical inhomogeneous solution for the inflated shape of cylindrical membranes. Coupling this shape parametrization approach with the adjoint method for computing the gradients of functionals enables a computationally efficient optimization of pressurized membrane structures. Numerical examples include minimization and minimax problems with inequality and state constraints, which are solved considering both plane strain and general plane stress conditions. The numerical implementation leverages the high-level
mathematical syntax and automatic differentiation features of the finite-element library FEniCS and related library dolfin-adjoint. The overall techniques generalize to a broad range of structural optimization problems involving pressurized membrane and thin shell structures.


ABSTRACT: In this work, porosity-dependent nonlinear large-amplitude oscillation responses of rectangular microplates with and without a central square cutout made of a porous functionally graded material (PFGM) is explored using modified couple stress theory of elasticity (MCSTE). The associated nonlinear size-dependent modified couple stress-based differential motion equations are obtained based on third-order shear deformation plate model (TSDPM). A new power-law function incorporating simultaneously the material gradient and porosity dependency is employed for the extraction of the effective mechanical characteristics of PFGM microplates. Afterwards, the non-uniform rational B-spline (NURBS)-based isogeometric technique is put to use as an efficient discretization method taking the C-super--1 continuity satisfaction into account. It is observed that among various patterns of porosity distribution, the lowest and greatest effects of couple stress size dependency are observed on the nonlinear frequencies of microplates in which the porosity from top and down surfaces to center is increased and decreased, respectively. Also, it was observed that increase of the material property gradient index as well as plate deflection reduces couple stress size effect on the nonlinear oscillations of PFGM microplates. It was shown that there is a specific length to thickness ratio, corresponding to which the modified couple stress-based frequency ratio becomes minimum. This minimum value enhances with the increase of the porosity index of PFGM microplates.


ABSTRACT: This study presents a novel isogeometric Euler–Bernoulli beam formulation for in-plane dynamic analysis of multi-patch beam structures. The kinematic descriptions involve only displacements of the beam axis, which are approximated by non-uniform rational B-spline (NURBS) curves. Translational displacements of the control points are here considered as control variables. The motivation of this work is to propose a penalty-free method to handle in-plane dynamic analysis of multi-patch beam structures. A simple relation between cross-sectional rotations at the ends of the beams and control variables is derived, allowing the incorporation of the end rotations as degrees of freedom. This improved setting can straightforwardly tackle beam structures with many rigid multi-patch connections, a major challenging issue when using existing isogeometric Euler–Bernoulli beam formulations. Additionally, rotational boundary conditions are conveniently prescribed. Numerical examples with complicated beam structures such as circular arches and frames with kinks are considered to show the accuracy and performance of the developed formulation. The computed results are verified with those derived from the conventional finite element method, and the superior convergence properties of the proposed formulation are illustrated. A possible extension of the present approach to spatial beam structures is discussed.


ABSTRACT: This paper introduces, analyzes and validates isogeometric mortar methods for the solution of thick shells problems which are set on a multipatch geometry. A particular attention will be devoted to the introduction of a proper formulation of the coupling conditions, with a particular interest on augmented lagrangian formulations, to the choice and validation of mortar spaces, and to the derivation of adequate integration rules. The relevance of the proposed approach is assessed numerically on various significative examples.
ABSTRACT: In large rotation analysis of shear deformable 3D beams, some features characterize the ideal discretization method: locking-free solution, small number of unknowns, accurate description of curved geometries, no singularity for large rotations, objectivity, additivity and robustness in the iterative solution, path independence and symmetric matrix for conservative loads. This work shows how to achieve all these features using a novel isogeometric weak formulation. Incremental rotation vectors are associated to the control points of quadratic NURBS describing the geometry. The control point vectors are used to define a novel path-independent, objective and singularity-free approximation of the rotation matrix used for the evaluation of the exact strain measure, based on an element-wise corotational system. The inter-element NURBS regularity is preserved also for the rotation. Additivity and symmetry are assured by the vector-like parameterization. Imposing constant spatial forces over each patch results in a locking-free discretization without displacement DOFs within the patch. Boundary conditions can be imposed directly without any ad hoc procedure. Accurate results are obtained using coarse meshes with reduced number of unknowns compared to displacement-based isogeometric analyses and locking-free finite elements.

References listed at the end of the paper:
3 Hodges D., Nonlinear Composite Beam Theory, American Institute of Aeronautics and Astronautics, Reston, Virginia (2006)

Chaemin Lee (1), San Kim (1,2) and Phill-Seung Lee (1)
(1) Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea
(2) Department of Mechanical Convergence Engineering, Gyeongsang National University, 54, Charyong-ro 48beon-gil, Uichang-gu, Changwon-si, Gyeongsangnam-do 51391, Republic of Korea
ABSTRACT: Recently, the strain-smoothed element (SSE) method has been developed for 3-node triangular and 4-node tetrahedral solid elements. The method was also applied for enhancing the membrane performance of a 3-node triangular shell element (MITC3+ element). Using the SSE method, convergence behaviors of the finite elements were significantly improved without additional degrees of freedom. However, the application of the SSE method is limited to constant strain finite elements such as 3-node triangular and 4-node tetrahedral elements. In this paper, the SSE method is applied to a 4-node quadrilateral finite element. Doing so, the piecewise linear shape functions are employed instead of standard bilinear shape functions. The proposed strain-smoothed 4-node quadrilateral element passes all the basic tests, and shows a significantly improved accuracy in various numerical examples.
References listed at the end of the paper:

ABSTRACT: A quadrilateral bi-cubic G1-conforming finite element for the analysis of Kirchoff–Love shell assemblies based on the rational Gregory interpolation is presented. The Gregory interpolation removes the symmetry of the second cross derivative at the corners of the element that allows an independent control of the side rotations of the boundaries of the element. In this way G1-conformity of the deformation can be implicitly obtained for any mesh of quadrilateral elements, also for not G1-continuous parametrizations. The interpolation is defined by means of the kinematics of the boundary ribbons. The ribbon is the differential set generated by the tangents at the boundary of the element. A new set of degrees of freedom is introduced in order to control the deformation of the boundary, and the non-linear map between this new set of degrees of freedom and the control points of the Gregory interpolation is derived. Due to the presence of rational terms, the interpolation is not consistent, so that, in order to recover consistency it is necessary to enforce the vanishing of the discontinuities of the second derivatives with additional constraints. The proposed G1-conforming shell element results accurate and robust as shown by several numerical investigations on benchmark problems.

References listed at the end of the paper:
19 Loop C., Schaefer S., Ni T., Cañaño I., Approximating subdivision surfaces with gregory patches for hardware tessellation, ACM Trans. Graph., 28 (5) (2009), pp. 1-9
20 Longhi L., Interpolating Patches Between Cubic Boundaries: Technical Report UCB/CSD-87-313, EECs Department, University of California, Berkeley (1985)

ABSTRACT: This work extends isogeometric thin shell formulations to incorporate constitutive laws generated by stochastic multiscale analyses. The integration of the constitutive law is performed through the thickness of the shell, in order to account for material heterogeneity. At each thickness integration point, a corresponding representative volume element is assigned, defining the microstructural topology of a composite material comprised of a matrix with arbitrary volumetric inclusions. With the aid of stochastic processes, the impact of material and inclusion variability on the structural response is demonstrated in benchmark and real-scale numerical examples. Spatial material variability is considered in both surface and through thickness coordinates of the shell. As a result, the elimination of geometric error, together with the realistic material descriptions, renders this formulation an ideal candidate for the simulation of shell structures made of composite materials.

References listed at the end of the paper:
7 The NURBS Book (1997), 10.5860/choice.35-0952 Choice Rev. Online
22 Kikis G., Dornisch W., Klinkel S., Isogeometric Reissner–Mindlin shell analysis - employing different control meshes for displacements and rotations, PAMM (2016), 10.1002/pamm.201610093
56 Love A.E.H., On the small free vibrations and deformations of Thin Elastic Shells, Philos. Trans. R. Soc. (1888)
57 Autodesk, T-Spline plug-in for Rhino (2019)
59 MSolve, (n.d.), https://github.com/mgroupntua/
71 TurbosquidFront Bump. (2015)

Computer Methods in Applied Mechanics and Engineering, Vol. 373, Article 113541, 1 January 2021,

More papers published in the journal, Structures (2019 and on):
http://www.sciencedirect.com/science/journal/23520124

https://doi.org/10.1016/j.istruc.2018.11.012

ABSTRACT: The present study develops a finite element model for the lateral torsional buckling analysis of wooden twin beams braced by deck boards subjected to gravity or wind uplift loading. The restraining action of the deck boards is modelled as continuous partial lateral and twist restraints provided at the top of both beams that capture the interaction between both beams. A parametric study is then conducted to examine the effects of beam and deck spans, load type, load height, lateral restraint height and stiffness and number of beam spans on the overall buckling capacity. The results indicate that the restraining effects of deck boards significantly improve the lateral torsional buckling capacity of twin-beam-deck assemblies.

References listed at the end of the paper:
1 American Wood Council, National design specification (NDS) for wood construction. (2015) (Leesburg, VA, USA)
2 Canadian Standard Association (CSA), Engineering design in wood O86-14, (2014) (Mississauga, ON, Canada)
5 Y. Du, M. Mohareb, G. Doudak, Nonsway model for lateral torsional buckling of beams under wind uplift, J Eng Mech, 142 (2016), Article 04016104
9 J.R. Burow, H.B. Manbeck, J.J. Janowiak, Lateral stability considerations for composite wood I-joists, 2005 ASABE Annual Meeting, American Society of Agricultural and Biological Engineers (2005), p. 1
12 R. St-Amour, Lateral torsional buckling of wood I-joint, Department of Civil Engineering, University of Ottawa, Ottawa, ON, Canada (2016) (Master of Applied Science Thesis)
14 Y. Hu, M. Mohareb, G. Doudak, Lateral torsional buckling of wood beams with lateral bracing offset from section midheight, J Eng Mech, 143 (2017), Article 04017134
15 J.J. Zahn, Lateral stability of deep beams with shear-beam support, U.S.D.A. forest service research paper FPL 43 (1965)
16 P.M. Jenkinson, J.J. Zahn, Lateral stability of beam and deck structure, J Struct Div, 98 (1972), pp. 590-609
18 V. Vlasyk, Thin-walled elastic beams, (2nd ed.), Israel Program for Scientific Translations, Jerusalem, Israel (1961)
21 T. Apparao, Problems in structural diaphragm bracing, Cornell University, School of Civil Engineering (1968)
22 G.J. Hancock, N.S. Trahair, Finite element analysis of the lateral buckling of continuously restrained beam-columns, Institution of Engineers (Australia) civ eng trans (1978)
23 N. Trahair, Elastic lateral buckling of continuously restrained beam-columns, The profession of a civil engineer (1979), pp. 61-73
25 C. Albert, J. Dawe, Buckling of continuous steel girders with flange restraint, Can J Civ Eng, 17 (1990), pp. 121-128
27 T. Pekoz, P. Sorouhishian, Behavior of C- and Z-purlins under wind uplift, Sixth International Specialty Conference on Cold-formed Steel Structures, St Louis, MO (1982)
31 Z. Ye, R.J. Kettle, L. Li, B.W. Schafer, Buckling behavior of cold-formed zed-purlins partially restrained by steel sheeting, Thin-Walled Struct, 40 (2002), pp. 853-864
32 X. Chu, R. Kettle, L. Li, Lateral-torsion buckling analysis of partial-laterally restrained thin-walled channel-section beams, J Constr Steel Res, 60 (2004), pp. 1159-1175
33 L. Li, Lateral–torsional buckling of cold-formed zed-purlins partially-laterally restrained by metal sheeting, Thin-Walled Struct, 42 (2004), pp. 995-1011
34 X. Chu, J. Rickard, L. Li, Influence of lateral restraint on lateral-torsional buckling of cold-formed steel purlins, Thin-Walled Struct, 43 (2005), pp. 800-810
37 S.J. Errera, T.V. Apparao, Design of I-shaped beams with diaphragm bracing, J Struct Div, 102 (1976), pp. 769-781
42 T.A. Helwig, J.A. Yura, Shear diaphragm bracing of beams. II: design requirements, J Struct Eng, 134 (2008), pp. 357-363
43 Forest Products Laboratory (FPL), Wood handbook—wood as an engineering material, (2010) (Madison, USA)

ABSTRACT: The objective of this paper is to investigate the behaviors of concrete-filled circular stainless steel tubular (CFCSST) stub columns under axial loading. A fine finite 3D solid element model was established, and the FE results revealed that the increased ultimate bearing capacity of CFCSST stub columns compared with their carbon steel counterparts was mainly due to that the confinement effect of CFCSST stub columns was stronger than that of carbon steel counterparts and the stress contribution of stainless steel was higher than that of carbon steel. The stress nephogram was simplified reasonably in accordance with the limit state of core concrete and a formula was proposed to estimate the ultimate bearing capacity of CFCSST stub columns using superposition method. Finally, the difference of the experimental and predicted results using the proposed formula and the existing codes were illustrated.

References listed at the end of the paper:
1 B. Uy, Stability and ductility of high performance steel sections with concrete infill, J Constr Steel Res, 64 (7–8) (2008), pp. 748-754
2 G. Gedge, Structural uses of stainless steel—buildings and civil engineering, J Constr Steel Res, 64 (11) (2008), pp. 1194-1198
6 L.H. Han, W. Li, R. Bjorhovde, Developments and advanced applications of concrete-filled steel tubular (CFST) structures: members, J Constr Steel Res, 100 (2014), pp. 211-228
7 B. Uy, Z. Tao, L.H. Han, Behaviour of short and slender concrete-filled stainless steel tubular columns, J Constr Steel Res, 67 (3) (2011), pp. 360-378
8 D. Lam, L. Gardner, Structural design of stainless steel concrete filled columns, J Constr Steel Res, 64 (11) (2008), pp. 1275-1282
19 ACI-318-11, Building code requirements for structural concrete and commentary ACI committee 318, American Concrete Institute, Detroit (MI) (2011)

Hui-huan Ma, Shao-zhen Li and Feng Fan (Key Lab of Structures Dynamic Behavior and Control (Harbin Institute of Technology), Ministry of Education, Harbin, 150090, China), “Static performance analysis of
ABSTRACT: For a hyperbolic steel-structure cooling tower, a single-layer reticulated shell system was designed. The static behaviors of the single-layer reticulated shell system were studied under different load combinations. By analyzing the stability of the system, a whole load-displacement curve of the structure was obtained, and a reasonable strengthening scheme was proposed. Taking the grid form and grid size as the optimization parameters, the single-layer reticulated shell system for a steel-structure cooling tower was optimized at heights of 90, 124, and 220 m. The static behaviors of the single-layer reticulated shell system with different parameters, including the quantity of steel, maximum displacement of the nodes, peak stress, and ultimate bearing capacity, were compared. The optimum grid form and grid size of the single-layer reticulated shell system under different heights were obtained.

References listed at the end of the paper:
2 A. Al-Dabbagh, A.K. Gupta, Meridional imperfection in cooling tower, J Struct Div, 105 (1979), pp. 1089-1102
4 W.B. Krätzig, Konstantin Meskouris, Natural draught cooling towers - an increasing need for structural research, Bull Int Assoc Shell Spat Struct, 34 (1993), pp. 37-51
8 M.A. Goudarzi, Proposing a new technique to enhance thermal performance and reduce structural design wind loads for natural draught cooling towers, Energy, 62 (2013), pp. 164-172
9 G. Li, W.B. Cao, Structural analysis and optimization of large cooling tower subjected to wind loads based on the iteration of pressure, Struct Eng Mech, 46 (2013), pp. 735-753
15 L. Kollar, Large reticulated steel cooling towers, Eng Struct, 7 (1985), pp. 263-267
18 F.M. Zheng, Application of ANSYS in cooling tower design, J Jianghan Univ, 33 (2005), pp. 87-90


ABSTRACT: Stainless steel is becoming popular as structural members because of its increased corrosion resistance and durability, compared with carbon steel. In cold-formed steel structures, such as trusses, wall frames and portal frames, the use of face-to-face built-up cold-formed stainless steel channel sections as compression members are becoming increasingly popular. In such an arrangement, intermediate fasteners at discrete points along the length prevent the individual channel sections from buckling independently. Current guidance by the American Iron and Steel Institute (AISI) and the Australian and New Zealand (AS/NZS) standards for built-up sections describes a modified slenderness approach, to take into account the spacing of the screws. Not even a single experimental test or finite element analysis, however, have been reported in the
literature for such face-to-face built-up stainless steel channel sections, to understand the effect of screw spacing. The issue is addressed numerically herein. This paper presents a finite element investigation on the behaviour of face-to-face cold-formed stainless steel built-up channel sections, subjected to axial compression. Three different grades of stainless steel i.e. duplex EN1.4462, ferritic EN1.4003 and austenitic EN1.4404 have been considered. The effect of screw spacing on axial strength of face-to-face built-up stainless steel channel sections was investigated. A comprehensive parametric study was carried out, covering a wide range of slenderness and different cross sectional geometries to assess the performance of the current design guidelines by AISI and AS/NZS. In total, 160 finite element models were analyzed. From the results of the parametric study, it was found that the AISI & AS/NZS are conservative by around 15% for all stainless steel face-to-face built-up columns failed through global buckling. However, the AISI & AS/NZS are un-conservative by around 5% for face-to-face built-up stainless steel columns failed through local buckling.


ABSTRACT: Structures used for temporary works are lightweight so that they are easy to transport, erect and dismantle. Particular care should be taken in their design as local instabilities could arise due to their thin-walled nature. This article presents 12 tests on proprietary soldier beams subjected to two concentrate opposing loads applied simultaneously. The geometry of the proprietary beams feature cold-formed C-shaped sections with web holes connected back to back with internal spacers. In the absence of design rules for application to such members, the experimental results are used in the present investigation to assess the suitability of the provisions for the web crippling design of cold-formed steel members as well as existing design methods from the literature, which account for the effect of perforations in the web. Experimental and predicted resistances are compared and design recommendations are provided.


ABSTRACT: Single angle members are widely used in transmission line towers due to light weight and easy installation. However, angle members may experience complex behaviors such as flexural, flexural-torsional or lateral-torsional buckling due to unsymmetrical section and eccentric loading. The current design practice is generally based on the effective length method, in which semi-empirical formulas should be used to account for the actual end conditions and member initial imperfections. In contrast, advanced beam-column elements or finite shell elements should be used when using second-order direct analysis method without the need of effective length assumption. Direct model of the failure modes (i.e. local and global failure modes) of angle members is still a challenging task. This paper firstly investigates the sensitivity of the flexural-torsional buckling of eccentrically loaded members compared to the assumed flexural buckling mode about the principal minor axis which is implemented in most of available beam-column elements. Moreover, an effective stress-strain relationship representing the typical failure modes and initial imperfections, which has been calibrated by extensive finite element analysis and experimental results, is developed for the direct analysis of steel structures made of angle sections without use of the effective length method. The proposed method is so simple that it can be incorporated into any conventional beam-column elements to implement the direct analysis of angle structures. The examples show that the proposed method is sufficiently accurate and therefore it can be employed in the practical design of angle structures.


ABSTRACT: The objective of this work is to examine the bracing effect of sheathing boards in inhibiting the instability failure modes of cold-formed steel (CFS) studs in the wall panel construction. A development of accurate and robust sheathing braced design concepts for CFS wall panels will eliminate the need for additional lateral steel bracing, thereby leading to efficient use of construction materials. The current design method by the American Iron and Steel Institute lacks in accurately predicting the design strength of the sheathed CFS stud.
Therefore, the current investigation endeavors to fill the gap by carrying out experiments that simulate the behavior of the CFS studs subjected to out-of-plane loading. A total of sixty-seven experiments were carried out with seven different sheathing board types and ten different CFS studs to accomplish the objective. The experiments were carried out using a newly devised test set-up that simulates the worst case failure mode of the sheathing board. The experimental results indicate that the strength, stiffness and failure modes of the sheathing boards vary depending on the following: (i) fiber composition and material properties of the sheathing board; (ii) dimensions of the CFS stud. In addition, the test results also indicated that the stiffness of the sheathing board against the pull-through failure was not influenced by the thickness of the sheathing boards. Based on the inferences (trend of sheathing stiffness and failure modes) from the test results, a new expression is formulated to determine the stiffness of the sheathing board on a function of the tensile modulus of the sheathing board (E) and dimensions of the CFS stud (d/2). The validation study indicates that the new expression is accurate in terms of both statistical and design application.


ABSTRACT: Circular concrete-filled double-skin tubular (CFDST) columns increase considerably the displacement ductility and peak strength of the sandwiched concrete due to the confinement provided by the steel tubes. This study describes the characteristics of short CFDST columns under compression and investigates the influences of the sandwiched concrete thickness, the yield stress of outer tube, tube thickness of the both outer and inner components and sandwiched concrete strength on the structural performance of circular short CFDST columns. To obtain the structural behaviour of circular CFDST columns, a finite element analysis is conducted. In this numerical modelling, the choice of the concrete and steel material properties is essential. Accordingly, different steel and concrete models are adapted from previous researches, and then they are verified by comparing their results with the experimental results. The best material models are presented and used in the parametric study which aims at examining the effects of several factors on the load-displacement relationships of the CFDST columns.


ABSTRACT: Large modern buildings frequently are enclosed by lightweight, panelised, aluminium-framed facades, known as unitised curtain walls. This study shows that, in such wall systems, the established procedures for analysing the stability of structural extrusions ignore two of the three greatest causes of lateral movement in the main member, or mullion. One of these overlooked influences is the force caused by the pressurisation of the mullions' interior cavity, and the other is the moment transferred to the mullion, through structural adhesive, from the wall's face material, which is usually glass. A new, closed-form, algebraic expression is proposed to describe the lateral movement of a unitised mullion's interior flanges, and predictions obtained in this way are compared with results from a finite element model. It is suggested that the novel analytical approach might obviate the need for conventional lateral torsional buckling calculations, which are not only time-consuming to produce, but which are also of questionable accuracy. This simplification of the structural design process will make it easier for facade engineers to design extrusions in which metal is used efficiently, and because the production of aluminium is energy-intensive, material savings achieved in this way will bring both commercial and environmental benefits.


ABSTRACT: External confinement and internal stiffening have been widely adopted for strengthening concrete-filled steel tube (CFST) columns. This paper presents an attempt to study the possibility of combining the external confinement using reinforcing rings and the internal stiffening using reinforcing bars for strengthening CFST columns. In order to investigate the structural performance of the proposed combination method, a total of 18 specimens were tested under axial compression. These specimens were strengthened using three different methods: confinement in the form of external reinforcing rings (ERRs), stiffening in the form of
internal reinforcing bars (IRBs), and a combination of both methods. For all tested specimens, the thickness of steel tube, outer diameter, and tube length were 4.15 mm, 114.3 mm, and 260 mm, respectively. CFST specimens were filled using self-compacting concrete (SCC) of normal compressive strength. The main parameters considered in the test procedure are the spacing between the ERRs, the number of IRBs, and a combination of the ERRs spacing and the number of IRBs. The experimental results show that the proposed combination method is more effective to improve the structural performance of short CFST columns compared to using only ERRs or IRBs. Further improvement is achieved when the spacing between the ERRs decreases and the number of IRBs increases. The proposed combination method increases the compressive load-carrying capacity up to 27.2% and 57.4% compared to ERRs and IRBs, respectively. It deserves noting that the proposed combination method, ERRs, and IRBs improve the compressive load-carrying capacity up to 120.3%, 93.5%, and 40%, respectively, compared to the control specimen. In addition, specimens strengthened by the proposed combination method show an excellent ductility behavior.


ABSTRACT: This paper presents a numerical investigation on the patch loading resistance of slender austenitic stainless steel plate girders. Current design provisions for the resistance to patch loading of stainless steel girders are based on the plastic collapse mechanism observed in experimental and numerical studies conducted for carbon steel girders, disregarding the strain hardening capacities of stainless steel. At present, strength-curves approaches are used within European standards to deal with stability problems in steel plated structural elements. In this regard, three parameters require special attention: the yield load for plastic resistance, the resistance function depending on element slenderness, and the elastic buckling load. In this paper, an experimental study is firstly collected from the literature for comparative analysis. Subsequently, an extensive parametric study is conducted through nonlinear finite element analyses covering a wide range of slender stainless steel I-girder sections. Then, a resistance function is calibrated throughout a statistical evaluation of experimental and numerical results. Finally, the results show significant improvements in the predicted patch loading resistances of slender stainless steel I-girders.


ABSTRACT: The robustness of the equivalent Circular-Hollow-Section (CHS) diameter expressions for the Elliptical-Hollow-Sections (EHSs) under pure axial compression proposed in earlier studies is assessed and found to be conservative and inconsistent with respect to the Eurocode 3 (EC3) CHS cross-section classification criteria. Thus, to promote consistent application of the cross-section slenderness parameter limits and design strength curves specified for CHSs, also to the EHSs, an improved empirical expression for the equivalent CHS diameter is derived in this study using the results of EHS stub column analyses from the literature, based on a novel Equivalent-Resistance-Capacity-Method (ERCM). Additionally, a unified empirical expression based on the Direct-Strength-Method (DSM) approach for predicting the axial compressive capacity is also determined by using an exhaustive data of EHS and CHS stub-column analyses from the literature.


ABSTRACT: Concrete-filled steel tube (CFST) column is one of the most effective forms of composite members in which the steel tube provides both axial strength and confining pressure to improve the compressive capacity and the ductility of the core concrete. This paper presents an evaluation of the structural behavior of CFST short columns strengthened by external and internal continuous spirals. A total of 16 CFST specimens were tested under axial compression. Specimens were stiffened as follows: (1) external continuous spiral (ECS) welded to the exterior surface of the steel tube, (2) internal continuous spiral (ICS) welded to the interior surface of the steel tube, and (3) unwelded internal continuous spiral (UICS) placed longitudinally inside the steel tube. Self-compacting concrete (SCC) was used in the experimental study. The main parameters in this
study are the diameter of spiral bar, the number of spiral turns, and the location of the continuous spiral. From the test results, it was concluded that toughness, elastic strength, and ductility were improved significantly as a result of stiffening the CFST columns by external and internal spirals. ECS, ICS, and UICS improved the compression capacity up to 46.8%, 48.7%, and 47.9%, respectively, as compared with the control specimen. A theoretical model to estimate the ultimate load of stiffened CFST columns was developed and close correlations were found between the model and the experimental results.

Viet-Hung Truong (1), George Papazafeiropoulos (2), Van-Trung Pham (3) and Quang-Viet Vu (3)
(1) Department of Civil Engineering, Thuyloi University, 175 Tay Son, Dong Da, Hanoi, Viet Nam
(2) Dept. of Structural Engineering, National Technical University of Athens, Zografou, Athens 15780, Greece
(3) Faculty of Civil Engineering, Vietnam Maritime University, 484 Lach Tray Street, Le Chan District, Hai Phong City, Viet Nam


ABSTRACT: In the present paper, the effect of multiple longitudinal web stiffeners (up to four) located at their optimum location on the ultimate strength of steel plate girders subjected to predominant shear loading, and combined bending and shear loading is investigated by using nonlinear inelastic analysis. Three dimensional (3D) finite element (FE) models of the steel plate girder are developed and analyzed by using ABAQUS commercial software. The accuracy of the FE models is validated by comparing their results with analogous experimental data. An extensive parametric analysis has been carried out to estimate the influence of specific geometric parameters on the ultimate strength. It has been shown that the shear resistance obtained from AASHTO LRFD equation is conservative since the influence of the longitudinal stiffeners was not considered in computing the shear resistance of the web plate girders under predominant shear loading and combined bending and shear. In addition, it has been demonstrated that the variation of the ultimate strength of the girder is almost monotonic against the various dimensionless geometric parameters, enabling thus the design of girder beams based on interpolation of tabulated data. Finally the results indicate that by adding not more than four stiffeners at the web of a steel plate girder subject either to predominant shear or combined shear and bending loads, an increase in its ultimate strength between 8% and 105% can be achieved.

Stelios Vernardos and Charis Gantes (Institute of Steel Structures, School of Civil Engineering, National Technical University of Athens, 9 Iroon Polytechneiou str., Zografou Campus, 15780 Athens, Greece),


ABSTRACT: Concrete-filled double-skin steel tubular (CFDST) members have been proven through many years of research as a competitive structural concept in comparison with conventional steel tubular members or concrete-filled steel tubular members (CFST), as well as an apt example of efficient composite action between the two materials. In this study, the compressive behavior of stub CFDST members is investigated through a meticulous review of numerous experimental endeavors over a 20-year time span. A summary of these tests and their pertinent results is presented, followed by an exploration of their structural response and predominant failure mechanisms for different cross-section shapes and geometrical factors. The efficiency of the CFDST concept is subsequently quantified by means of a comparison between CFDST members and their components acting individually, in terms of both ultimate strength and energy absorption. An extensive parametric analysis is finally carried out with respect to the influence of various key-factors on axially-compressed CFDST stub members' structural performance.

Husam Alsanat (1,2), Shanmuganathan Gunalan (1), Keerthan Poologanathan (3), Hong Guan (1) and Konstantinos Daniel Tsavdaridis (4)
(1) School of Engineering and Built Environment, Griffith University, Gold Coast Campus, QLD 4222, Australia
(2) School of Engineering, Al-Hussein Bin Talal University, Ma’an, Jordan
(3) Faculty of Engineering and Environment, University of Northumbria, Newcastle, UK
(4) School of Civil Engineering, University of Leeds, Leeds LS2 9JT, UK

ABSTRACT: Aluminium alloys have recently been utilised in the fabrication of thin-walled members using a roll-forming technique to produce purlins, floor joists and other structural bearers. Such members are often subjected to transversely concentrated loads which may possibly cause a critical web crippling failure. Aluminium specifications do not explicitly provide clear design guidelines for roll-formed members subjected to web crippling actions. Therefore, this study was conducted to investigate the mechanism of web crippling for roll-formed aluminium lipped channel (ALC) sections with flanges attached to supports (fastened) under two-flange loading conditions. Based on the experimental works presented in a companion paper, numerical simulations were conducted including an extensive parametric study covering a wide range of ALC geometrical dimensions, bearing lengths, and 5052 aluminium alloy grade with H32, H36 and H38 tempers. The acquired web crippling data were then used to investigate the influence of the flange restraints on the web crippling mechanism of the ALC sections. Furthermore, a detailed assessment of the consistency and reliability of the currently available design rules used in practice was carried out. The predictions of the web crippling design guidelines given in the Australian, American and European specifications were found to be unsafe and unreliable, whereas a good agreement was obtained between the predictions of our recently proposed design guidelines and acquired web crippling results. Further a suitable Direct Strength Method (DSM)-based design approach was developed in this study with associated equations to predict the elastic bucking and plastic loads of fastened ALC sections under two-flange loading conditions.

References listed at the end of the paper:
1 F.M. Mazzolani, Structural applications of aluminium in civil engineering, Struct Eng Intern, 16 (4) (2006), pp. 280-285
4 S. Gunalan, M. Mahendran, Web crippling tests of cold-formed steel channels under two flange load cases, J Const Steel Res, 110 (2015), pp. 1-15
5 S. Gunalan, M. Mahendran, Experimental study of unlipped channel beams subject to web crippling under one flange load cases, Adv Steel Constr, 15 (2) (2019), pp. 165-172
6 L. Sundararajah, M. Mahendran, P. Keerthan, New design rules for lipped channel beams subject to web crippling under two-flange load cases, Thin Walled Struct, 119 (2017), pp. 421-437
7 L. Sundararajah, M. Mahendran, P. Keerthan, Experimental studies of lipped channel beams subject to web crippling under two-flange load cases, J Struct Eng, 142 (9) (2016), p. 04016058
8 L. Sundararajah, M. Mahendran, P. Keerthan, Web crippling studies of SupaCee sections under two flange load cases, Eng Struct, 153 (2017), pp. 582-597
9 P. Keerthan, M. Mahendran, E. Steau, Experimental study of web crippling behaviour of hollow flange channel beams under two flange load cases, Thin Walled Struct, 85 (2014), pp. 207-219
10 A. Uzzaman, J.B.P. Lim, D. Nash, J. Rhodes, B. Young, Cold-formed steel sections with web openings subjected to web crippling under two-flange loading conditions—part I: tests and finite element analysis, Thin Walled Struct, 56 (2012), pp. 38-48
11 A. Uzzaman, J.B.P. Lim, D. Nash, J. Rhodes, B. Young, Web crippling behaviour of cold-formed steel channel sections with offset web holes subjected to interior-two-flange loading, Thin Walled Struct, 50 (1) (2012), pp. 76-86
12 E. Steau, M. Mahendran, P. Keerthan, Web crippling tests of rivet fastened rectangular hollow flange channel beams under two flange load cases, Thin Walled Struct, 95 (2015), pp. 262-275
13 E. Steau, P. Keerthan, M. Mahendran, Web crippling capacities of rivet fastened rectangular hollow flange channel beams under one flange load cases, Steel Constr, 9 (3) (2016), pp. 222-239
17 B. Janarthanan, M. Mahendran, S. Gunalan, Bearing capacity of cold-formed unlipped channels with restrained flanges under EOF and IOF load cases, Steel Constr, 8 (3) (2015), pp. 146-154
Nakisa Haghi (1), Siamak Epackachi (2) and Mohammad Taghi Kazemi (3)

(1) Dept. of Civil Engineering, University of Science and Culture, Tehran, Iran
(2) Dept. of Civil Engineering, Amirkabir University of Technology, Tehran, Iran
(3) Dept. of Civil Engineering, Sharif University of Technology, Tehran, Iran


ABSTRACT: To date, many researchers have developed various types of macro models to simulate the general response of conventional steel plate and reinforced concrete shear walls. Although extensive numerical and experimental studies have been conducted to assess the seismic response of steel-plate concrete composite shear walls, a robust macro-model for simulation of the cyclic response of such systems has not been developed yet. Herein, a fiber-based model is proposed to simulate the nonlinear seismic response of SC walls using PERFORM-3D program. The details of the proposed model, including material properties, element type, and boundary condition, are presented. The proposed model is validated using the available test data of seventeen SC wall specimens with and without boundary elements. Based on the analysis results, this novel approach can capture the global response of SC shear walls including initial stiffness, peak shear strength and its corresponding displacement, stiffness and strength degradation, and pinching behavior accurately. The proposed macro model for SC shear walls can be considered as a reliable tool to extend the engineering application of SC walls in the building industry.

References listed at the end of the paper:


33 A. Vulcano, V.V. Bertero, V. Colotti, Analytical modeling of RC structural walls, Proceedings of 9th World Conference on Earthquake Eng, Tokyo-Kyoto, Japan (1988), pp. 41-46


38 V. Colotti, Shear behavior of RC structural walls, J Struct Eng, 119 (1993), pp. 728-746


41 M. Youssef, A. Ghobarah, Modelling of RC beam-column joints and structural walls, J Earthquake Eng, 5 (2001), pp. 93-111


50 L.M. Massone, Strength prediction of squat structural walls via calibration of a shear flexure interaction model, Eng Struct, 32 (2010), pp. 922-932


58 Y. Ozcelik, P.M. Clayton, Strip model for steel plate shear walls, with beam-connected web plates, Eng Struct (2017), pp. 369-379


63 Y. Bai, X. Lin, B. Mou, Numerical modeling on post-local buckling behavior of circular and square concrete-filled steel tubular beam columns, Int J Steel Struct, 16 (2016), pp. 531-546

64 R.P. Dhakal, K. Maekawa, Modeling for post yield buckling of reinforcement, J Struct Eng (202), pp. 1139-1147


ABSTRACT: This paper presents an analysis on the effect of the initial form-finding models properties on the shape of shells with free edges, and consequently on the structural behaviour concerning force paths and buckling. The stiffness distribution of these initial models determines the membrane forces that equilibrate the applied loadings and, in this way, the obtained shape. With physical models, this question corresponds to the choice of material: latex rubber membrane or orthotropic fabrics. Continuous models with isotropic materials lead to a higher distribution of forces and reduced curvatures, without concentration along the free edges; this is in contrast to what occurs in discrete models without in-plane shear stiffness. In shells with free edges, the effects on the structural behaviour are related to curvatures and even more dependent on the initial model properties. Solutions with higher curvatures have higher concentrations of forces in the free edges. The reduction of curvatures and forces along the free edges of shells with an approximately square plan is favourable; this is in contrast to shells with elongated rectangular or triangular plans. The presented results and discussion aim to contribute to the design of new thin-shell structures.

References listed at the end of the paper:

ABSTRACT: Un-plasticized polyvinyl chloride (uPVC) tubes are increasingly used as stay-in-place formwork and protection for reinforced concrete columns from chemical attacks, peeling of concrete cover and corrosion of steel in a harsh environment. The provision of uPVC lateral confinement to the concrete improves the strength, ductility and energy absorption of the columns. However, since there is no available design guideline for uPVC tube confined concrete columns, the contribution of uPVC confinement to the column resistance has not been considered during the design stage. In this study, the strength reduction factor $\Phi$ provided by ACI 318–14 for a reinforced concrete column with circular tie reinforcement is modified to account for uPVC confinement for application in design. The subset simulation method was applied to assess the effect of uPVC confinement on the reliability of uPVC confined concrete columns. Based on the reliability study, a new strength reduction factor was proposed for uPVC confined reinforced concrete columns. Additionally, the effect of column variables on the reliability index was also investigated. The result shows that the additional uncertainties associated with the uPVC material properties and the peak strength model have an effect on the strength reduction factor. Therefore, the strength reduction factor needs to be reduced to achieve the same reliability level of the unconfined column. However, for the same design load used, the reliability index and strength reduction factor increased from 4.03 to 4.53 and 0.65 to 0.75, respectively as the $2t/D$ ratio increases from 0 to 0.04. Therefore, a strength reduction factor ($\Phi$) of 0.75 can be used instead of 0.65 to design a reinforced concrete column according to ACI 318–14 if the uPVC tube is going to be used as stay-in-place formwork; otherwise, the new proposed model can be used to calculate the strength reduction factor and design a uPVC confined concrete column according to ACI 318–14.

References listed at the end of the paper:

8 K. Wang, B. Young, Fire resistance of concrete-filled high strength steel tubular columns, Thin-Walled Struct., 71 (2013)
9 Jamaluddin N., et al., “Experimental investigation of concrete filled PVC tube columns confined by
13 A.S. Saadoon, Experimental and Theoretical Investigation of PVC-Concrete Composite Columns, University of Basrah (2010)
Axial capacities of GGBFS concrete CFSTs were found to be more than those of control concrete CFSTs. Increase in axial capacity of CFSTs was proportional to the increase in compressive strength of GGBFS concrete mixtures due to the inclusion of GGBFS. Stiffness of GGBFS concrete CFSTs were similar to those of control concrete CFSTs. Dependent compressive strengths of GGBFS concretes were also compared with those predicted by the equation of MC42 Comrel, 2019., A module of the Strurel set of programs for reliability analysis. RCP Consult & Eracons, Munich.

Subhan Ahmad (1), Ajay Kumar (2) and Kamal Kumar (2)
(1) Department of Civil Engineering, Indian Institute of Technology, Roorkee 247667, India
(2) Department of Civil Engineering, Vivekananda College of Technology and Management, Aligarh, India


ABSTRACT: Fifteen circular concrete-filled-steel tubes (CFST) containing ground granulated blast furnace slag (GGBFS) concretes were tested in axial compression. CFST columns were casted with four concrete mixtures having 0, 15, 25 and 35% GGBFS replacement levels and two different length-to-diameter ratio of 2.87 and 4. Compressive strength for concrete mixtures was determined after 28, 56 and 90 days. Time-dependent compressive strengths of GGBFS concretes were also compared with those predicted by the equation of MC-10. Axial capacities of GGBFS concrete CFSTs were found to be more than those of control concrete CFSTs. Increase in axial capacity of CFSTs was proportional to the increase in compressive strength of concrete mixtures due to the inclusion of GGBFS. Stiffness of GGBFS concrete CFSTs were similar to those of control concrete CFSTs. Experimental axial capacities of CFST columns tested were also compared with the provisions of Architectural Institute of Japan (AIJ), ACI 318, Chinese code (DL/T) and EC 4. ACI 318 was found to be most over conservative followed by AIJ for the estimation of axial capacities of GGBFS concrete CFST columns. EC 4 and DL/T provisions provided accurate estimates of the axial capacities of GGBFS.
concrete CFST columns. Furthermore, embodied energy (EE) and cost of CFSTs with different concretes are also compared. EE and cost of CFST was reduced linearly with the increase in GGBFS content in concrete. References listed at the end of the paper:

1. Z. Jokar, A. Mokhtar, Policy making in the cement industry for CO2 mitigation on the pathway of sustainable development-a system dynamics approach, J Cleaner Prod, 201 (2018), pp. 142-155
8. K. Rashid, A. Yazdanbakhsh, M.U. Rehman, Sustainable selection of the concrete incorporating recycled tire aggregate to be used as medium to low strength material, J Cleaner Prod, 224 (2019), pp. 396-441
10. ACI 116R00, Cement and Concrete Terminology, Detroit, Michigan, 2005.
16. S.E. Chidici, D.K. Panesar, Evolution of mechanical properties of concrete containing ground granulated blast furnace slag and effects on the scaling resistance test at 28 days, Cem Concr Compos, 30 (2) (2008), pp. 63-71
27. D.Y. Yoo, J.M. Yang, Effects of stirrup, steel fiber, and beam size on shear behavior of high-strength concrete beams, Cem Concr Compos, 87 (2018), pp. 137-148
ABSTRACT: This paper presents a numerical, experimental, and theoretical study on the behavior of concrete Structures, Vol. 23 (2016), pp. 10.1016/j.istruc.2016.08.004

ABSTRACT: Imperfections in buckling analyses are often assumed to take the form of either initial member imperfections or load eccentricity, but these effects are typically treated separately. In this paper, these two imperfections are treated simultaneously, focusing on the case in which the two effects neutralize each other. A linear analysis is performed to determine the critical ratio of load eccentricity to member imperfection amplitude at which the column switches its direction of buckling. The results are validated through a series of experimental tests leveraging the capability of 3D-printing to incorporate prescribed geometric imperfections.

References listed at the end of the paper:
1 A. Klasson, R. Crocetti, E.F. Hansson. Slender steel columns: how they are affected by imperfections and bracing stiffness, Structures, 8 (2016), pp. 35–43, 10.1016/j.istruc.2016.08.004
9 L.N. Virgin. Tailored buckling constrained by adjacent members. Structures, 16 (2018), pp. 20-26, 10.1016/j.istruc.2018.08.005

Fa-xing Ding (1,2), Wen-jun Wang (1), De-ren Lu (1) and Xue-mei Liu (3)
(1) School of Civil Engineering, Central South University, Changsha, Hunan Province, 410075, PR China
(2) Engineering Technology Research Center for Prefabricated Construction Industrialization of Hunan Province, 410075, PR China
(3) Department of Infrastructure Engineering, The University of Melbourne, Parkville, VIC 3010 Australia


ABSTRACT: This paper presents a numerical, experimental, and theoretical study on the behavior of concrete-filled square double-skin steel tubular (CFDST) stub columns under axial compressive loading. Firstly, three-dimensional solid model of CFDST stub columns was established by ABAQUS finite element software and verified through the existing experimental results. Then a full-scale model was established to investigate the influence of various parameters on ultimate bearing capacity and internal and external compressive stress of concrete. By considering the confinement coefficient, the practical calculation formula for the bearing capacity of CFDST stub columns was proposed. Finally, the experimental research on the mechanical properties of two large hollow ratio CFDST stub columns under axial compression was carried out. And the experimental
research further verified the applicability of the FE model and calculation formula of the CFDST stub column with large hollow ratio under axial compression.

References listed at the end of the paper:

3 W.-B. Yuan, J.-J. Yang, Experimental and numerical studies of short concrete-filled double skin composite tube columns under axially compressive loads, J Constr Steel Res, 80 (2013), pp. 23-31
5 L.-H. Han, H. Huang, X.-L. Zhao, Analytical behavior of concrete-filled double skin tubular (CFDST) beam-columns under cyclic loading, Thin-Walled Struct, 47 (6-7) (2009), pp. 668-680
6 F. Zhou, W. Xu, Cyclic loading tests on concrete-filled double-skin (SHS outer and CHS inner) stainless steel tubular beam-columns, Eng Struct, 127 (2016), pp. 304-318
8 K. Uenaka, K. Kitoh, K. Sonoda, Concrete filled double skin circular stub columns under compression, Steel Const, 48 (1) (2010), pp. 19-24
12 Han Lin-Hai, Tao Zhong, Huang Hong, et al., Concrete-filled double skin (SHS outer and CHS inner) steel tubular beam-columns, Thin-Walled Struct, 42 (9) (2004), pp. 1329-1355
16 Huang Hong, Ch.a. Baojun, Chen Mengcheng, et al., Comparative test study on mechanical behavior of concrete-filled double-skin steel tubular with hollow-centered square section short columns under axial compression, Railway Eng, 10 (2015), pp. 85-89 (in Chinese)
17 R. Grzebieta, Strength and Ductility of Concrete-Filled Double Skin (SHA inner and SHA outer) Tubes, Thin-Walled Struct, 40 (2002), p. 199
20 Ding Fa-xing, Li Zhe, et al., Composite action of octagonal concrete-filled steel tubular stub columns under axial loading, Thin-Walled Struct, 107 (2016), pp. 453-461
22 Fu. Gong Yong-zhi, Ding Fa-xing Lei, et al., Bearing capacity of axially loaded stirrup confined concrete-filled square steel tubular stub columns, J Build Struct (2016)
23 Lu. Ding Fa-xing, Bai Yu De-ren, et al., Comparative study of square stirrup-confined concrete-filled steel tubular stub columns under axial loading, Thin-Walled Struct, 98 (2018), pp. 443-453
26 X.L. Zhao, B. Han, R.H. Grzebieta, Plastic mechanism analysis of concrete-filled double-skin (SHS inner and CHS outer) stub columns, Thin-Walled Struct, 40 (10) (2002), pp. 815-833

ABSTRACT: Ribbed plates are common components in structures, aircrafts, and ships. Owing to safety considerations and proper functioning, it is important to predict the natural frequencies and mode-shapes of such systems efficiently. There are many analytical, numerical, and experimental methods that extract the modal parameters of ribbed plates. However, each present advantages and tradeoffs. The aim of this paper is to implement various modeling and experimental approaches, optimize them, and compare their strengths and weaknesses. Analytical models are based on the assumed-modes method and differ in geometric configuration and trial function selection. Finite element models employ higher-order shear theories. Two experiments are performed to compare theoretical results, and to weigh the benefits of the two common setups. Parallelization and concurrency, mathematical simplifications, and algorithmic improvements are used to optimize the performance of the analytical models so that the benefits of each geometry can be understood. Parallelized programs are then put through algorithmic analysis to estimate local order of growth and study running time. By comparing the performance, accuracy, simplicity, stability, affordability, and parametrization potential of the approaches, vibration scientists and engineers are better able to select methods suitable for their research, application, or design.

References listed at the end of the paper:
4 P. Dumond, N. Baddour, Effects of using scalloped shape braces on the natural frequencies of a brace-soundboard system, Appl Acoust, 73 (2012), pp. 1168-1173, 10.1016/j.apacoust.2012.05.015
Tian-Yi Song (1) and Kai Xiang (2)
(1) College of Architecture and Civil Engineering, Beijing University of Technology, Beijing 100124, China
(2) Tianjin Fire Research Institute of the Ministry of Public Security, Tianjin 300381, China


ABSTRACT: Finite element analysis (FEA) is conducted to investigate the structural behaviour of axially-loaded ultra-high strength concrete (UHSC) filled steel tube circular columns in this paper. A new stress-strain model of UHSC confined by circular steel tube is proposed by recalibrating the existing normal strength concrete constitutive model. The comparison between FEA predictions and test results indicates that the proposed FEA model is able to capture the brittleness characteristic of UHSC in circular CFST columns accurately. Based on the proposed FEA model, the structural performance of axially-loaded UHSC filled steel tube circular columns, including load versus deformation relationship, stress development, confinement effect and preliminary optimized design, are analysed and discussed. Finally, a parametric study is conducted to investigate the influence of key parameters on the load-deformation curve and strength utilization index of axially-loaded UHSC filled steel tube circular column during the entire loading process.

https://doi.org/10.1016/j.istruc.2020.01.015

ABSTRACT: Mechanical and thermal buckling of corrugated-core sandwich plates is investigated in this study. To consider the effect of shear deformations, the first-order shear deformation theory is applied to the finite strip method. The validity of the proposed method is evaluated by comparing the results with those presented by previous research. Various boundary conditions and different loading types, as well as the geometric parameters affecting the buckling loads and critical temperatures are explored and evaluated. To the authors' best knowledge, investigation of the effective geometric parameters, convergence process and different boundary conditions are discussed for the first time using finite strip method.

Olga Mijušković (1), Biljana Šćepanović (1), Ljiljana Žugić (1) and Branislav Ćorić (2)
(1) University of Montenegro, Faculty of Civil Engineering, Džordža Vašingtona bb, 81000 Podgorica, Montenegro
(2) University of Belgrade, Faculty of Civil Engineering, Kralja Aleksandra 73, 11000 Belgrade, Serbia

“Analytical approach to elastic stability problems of plates with different boundary conditions subjected to combined bending, shear and patch loading”, Structures, Vol. 24, pp 335-350, April 2020,
https://doi.org/10.1016/j.istruc.2020.01.016

ABSTRACT: The elastic stability of plates with simply supported edges (SSSS) and with two edges clamped and two simply supported (CSCS) under combination of bending, shear and patch load is investigated. General analytical approach for elastic buckling analysis of plates with different boundary conditions, subjected to any combination of in-plane loads, is presented. Exact solutions for pre-buckling stress distributions and double Fourier series for deflection functions within Ritz energy method guarantees accuracy of results and enabled very complex stability analysis.

Combined in-plane loads action is very common during incremental bridge lunching and different stress conditions can occur in web girders. All analyses conducted so far regarding such problems are related to simply supported plate (SSS). However, web girder is elastically restrained to the certain point depending on flanges rigidity and authors considered interesting to investigate behavior of plate with two opposite edges restrained and other two simply supported (CSCS) under same load conditions as simply supported plate. First part of the paper deals with patch load problem for plates with two different boundary conditions and evaluation of input data for bending-patch load (M-F), shear-patch load (V-F) and bending-shear-patch load...
(M-V-F) interaction curves and surfaces definition. Second part is dedicated to presentation, analysis and comparison of the interaction curves and surfaces for the cases of simply supported plate (SSSS) and plate with two clamped and two simply supported edges (CSCS), in order to obtain realistic bucking load ratios in accordance with boundary conditions.

C.K. Lee (1), M.K.I. Khan (1), Y.X. Zhang (2) and Mohammad M. Rana (1)
(1) School of Engineering and Information Technology, The University of New South Wales, Canberra ACT 2600, Australia
(2) School of Computing, Engineering and Mathematics, Western Sydney University, NSW 2751, Australia
ABSTRACT: This paper presents an experimental investigation on the behaviour of a new form of engineered cementitious composites (ECC) encased concrete-steel composite stub columns. The proposed column section uses ECC encasement as a potential confinement layer to control the premature concrete spalling and explosive brittle failure of concrete encased steel composite columns. In this study, twelve stub columns including two bare steel and ten composite sections were tested under concentric compression. The effects of some key parameters such as material strengths, steel section type and column section configuration on the performance of proposed column sections were investigated in terms of failure behaviour, load deformation response, toughness and ductility. It was found that ECC encasement improved the compressive failure behaviour of encased composite columns and enhanced their ductility and toughness. Strain analysis was performed to trace the strain development and damage patterns of different materials. Finally, a simple equation to estimate ultimate strength of proposed columns was proposed which gave good predictions agreed well with test results.

ABSTRACT: Innovative steel girders with corrugated webs have been recently developed utilizing advances in the fabrication and manufacturing technology. Additionally, horizontal curved web panels in curved steel girders have been incorporated into a variety of bridges and buildings. With several practical advantages and architectural-appearance requirements, the curved corrugated web panel is used. This paper presents a discussion of the buckling behaviour of horizontally curved corrugated webs under shear loading. An alternative approach to estimating the shear strength that combines local and global buckling for the curved corrugated web was presented. The presented formula includes elastic and inelastic domains for local and global buckling. The proposed approach is validated against experimental data. A thoroughly validated finite element model is used to provide additional assurance that the proposed equations are meaningful, and then additional factors affecting the behaviour of I-girders with curved corrugated webs are studied. The results show that the curvature parameter (Z) has a minor effect on the shear strength of the curved corrugated panel, whereas the corrugation angle and web thickness have a considerable effect on the behaviour of horizontally curved corrugated webs.

Rui Bai (1), Wen-Long Gao (2), Si-Wei Liu (2) and Siu-Lai Chan (1)
(1) Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
(2) School of Civil Engineering, Sun Yat-Sen University, Tangjiawan, Zuhai, China
ABSTRACT: Modern structural design requires the nonlinear characteristics within structural behaviors to be considered in analysis. Due to the limited deformation capacity of the conventional cubic Hermite beam-column element, a frame member has to be finely meshed into a number of the beam-column elements for nonlinear analysis, leading to a huge computational expense. Moreover, the tedious modeling process makes the use of advanced analysis approaches, such as the direct analysis method, impossible for complicated structures. In this paper, a fourth-order displacement function and an advanced beam-column element with 16 independent degrees of freedom are proposed for elastic geometrically nonlinear analysis. The element formulation is
developed based on the compatibility conditions at the end and internal nodes. The potential energy function is adopted to derive the element stiffness matrices, and the matrices are presented in the Gauss integral form for easy programming. The verification examples presented in this paper demonstrate the significant deformation capacity of this innovative element. The one-element-per-member modeling method can accurately and effectively capture the structural buckling capacity and post-buckling behaviors. The proposed method can considerably reduce modeling and computational efforts in engineering practices.


ABSTRACT: This paper describes the development of a steel beam with a novel dog-bone shaped cross-section, referred to as the Dinobeam. The Dinobeam is intended for use as a secondary floor beam in high-rise construction, capable of spanning distances greater than 12 m. The cross-section comprises triangular shaped flanges, which are press-braked to an overlapping fit and then continuously welded to a web plate at each flange-to-web junction, i.e. with two welds per flange. The primary advantage of the Dinobeam cross-section is the fact that its closed hollow flanges give the cross-section increased resistance to lateral torsional buckling compared to the typical I-cross section. In this paper, ten experimental concentrated flange loading tests are described that cover typical loading conditions, the tests include Dinobeams both with and without circular web openings. The experimental test results show that the flange-to-web PJP welds have sufficient strength and ductility to resist a tearing failure when subject to bearing. Finite element models were then developed and validated against the experimental results. The validated finite element models were used to conduct an extensive parametric study comprising 108 finite element models, to investigate the effect of thicknesses, bearing length, and hole diameter to web height ratios.

Milad Bahrebar (1), James B.P. Lim (1), George Charles Clifton (1), Tadeh Zirakian (2), Amir Shahmohammadi (1) and Mohammad Hajsadeghi (3)
(1) Department of Civil and Environmental Engineering, The University of Auckland, Auckland, New Zealand
(2) Department of Civil Engineering and Construction Management, California State University, Northridge, CA, USA
(3) School of Engineering Sciences, University of Liverpool, Liverpool L69 3BX, UK

ABSTRACT: Steel Plate Shear Walls (SPSWs) are traditionally designed with vertical infill plates, which are connected to the surrounding frame and can be stiffened or un stiffened. Recently, the application of plates with different geometrical shapes and perforations has attracted the attention in the literature with the aim of understanding the behavior of high-performing SPSW systems. However, detailed and systematic investigations are still required to fully understand the behavior of such relatively new lateral-force-resisting systems, further complicated by the introduction of perforations. This paper addresses this issue, with the structural performance of curve-corrugated SPSWs with centrally-placed opening being the subject of investigation. The research described herein describes 128 nonlinear finite element models of SPSWs, analyzed under cyclic and monotonic loading. The effects associated with web corrugation angle, thickness, and opening size on the buckling, yielding, strength, and stiffness performances, hysteretic behavior, and energy dissipation characteristics of SPSWs are investigated. It is shown that consideration of 90° corrugation angle and larger web-plate thicknesses can be beneficial. However, having a panel perforation layout as a web plate and increasing the perforation size can adversely affect the performance of such systems. Overall, curved-corrugated SPSWs with web perforations are found to be a good structural system, and a desirable performance can be ensured through proper design variables and detailing each component of the system.

Vipulkumar Ishvarbhai Patel (1), Qing Quan Liang (2) and Muhammad N.S. Hadi (3)
(1) School of Engineering and Mathematical Sciences, La Trobe University, Bendigo, VIC 3552, Australia
(2) College of Engineering and Science, Victoria University, PO Box 14428, Melbourne, VIC 8001, Australia
(3) School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia

ABSTRACT: Circular double-skin concrete-filled stainless-steel tubular (DCFSST) columns have the distinguishing feature of high resistance to corrosion so that they can be constructed by either normal concrete or seawater sea-sand based concrete without corrosion. The numerical study of circular short DCFSST columns is very limited. This paper presents the computational modeling and behavior of short DCFSST columns of circular sections loaded concentrically. A computational model is developed for simulating the structural behavior of concentrically loaded short circular DCFSST columns, taking into account the effects of the concrete confinement induced by the double stainless-steel skins and significant strain hardening of stainless steel. The accuracy of the computational modeling technique proposed herein is assessed by means of comparing computations with available experimental data. The verified computational method is utilized to investigate the significance of geometric configurations as well as material strengths on the structural performance of circular DCFSST columns. The applicability of the current design provisions for steel tubular columns filled with concrete to the design of circular DCFSST columns is evaluated by comparisons against experimental and numerical results on DCFSST columns. The comparative study shows that the present computational model and the design formula proposed by Liang predict well the ultimate strengths of short DCFSST columns composed of circular tubes. The codified design approaches in current design codes generally give conservative estimations of the strengths of circular DCFSST stub columns.

Qiyun Qiao (1), Zhaoyuan Yang (1) and Ben Mou (2)
(1) College of Architecture and Civil Engineering, Beijing University of Technology, Beijing 100124, China
(2) School of Civil Engineering, Qingdao University of Technology, Qingdao 266033, China


ABSTRACT: This paper studies the axial compressive behavior of square timber filled steel tube (TFST) stub columns. A total of twelve specimens, including bare timber columns, hollow steel tube columns, and TFST columns, are fabricated and tested. Test variables include the number of confining carbon fiber reinforced plastics (CFRP) layers and the timber condition (with or without knots). The failure modes, load versus deformation relationships, strain characteristics, ultimate strength, ductility, stiffness, and strength-to-weight performance are investigated. The confining effect of CFRP on TFST columns is also analyzed. Test results show that the TFST columns have higher strength and ductility compared with the hollow steel tube columns or the bare timber columns. The presence of knots reduces column strength and ductility. CFRP can increase the axial compressive strength of columns. TFST columns have good strength-to-weight performance, indicating that high strength values can be achieved using light TFST columns.

Khalid Bashir (1), Arif Ahad (2), P. Sachithanantham (2) and Chaidul Haque Chaudhuri (3)
(1) Department of Earthquake Engineering, Indian Institute of Technology Roorkee, Uttrakhand 247667, India
(2) Department of Civil Engineering, Bharath Institute of Higher Education and Research, Chennai, Tamil Nadu-600073, India
(3) Department of Civil Engineering, Indian Institute of Technology Bombay, Maharashtra-400076, India


ABSTRACT: This paper presents the test results of an experimental program to investigate the load-bearing capacity of twenty-seven Glass Fibre Reinforced Polymer GFRP funicular shells under pure compression load. The test parameters include the number of glass fiber layers, the rise of shells and the effect of inclusion of steel mesh as an additional reinforcement to the glass fiber. Comparisons between the experimental test results of various parameters are performed in terms of the ultimate load-carrying capacity. A parametric study was conducted which showed the significant effect of the increasing rise on the load bearing capacity of GFRP shells. In general, the results of this study revealed that the ultimate load-carrying capacity gets increased by nearly 58% by increasing the number of normal glass fiber layers from two to four. Moreover, an increase in the ultimate load-carrying capacity of nearly 15% to 26% was observed with the inclusion of steel mesh as an additional reinforcement to the glass fiber. In the latter case, the deflections were comparatively lesser than the former. The failure loads of all the specimens were found and two equations were proposed to express the relation between rise, span to rise ratio, with ultimate load. It is concluded that the ultimate loads are a function
of the rise of the shell and the number of fiber layers. The addition of steel mesh increases stiffness of shells, there by reduces total deflection.


ABSTRACT: This study presents an experimental and numerical investigation on sandwich type cold formed tubular braces involving different designs with their load bearing members, inner buckling controllers, outer buckling controllers and end stiffeners. A total of 4 tubular brace specimens, using square HSS sections for the buckling controller and load bearing member, were tested under quasi-static cyclic loading conditions. In concert to previous research, a conventional tubular brace and tube in tube system were also used with all details relating to the specimens, including equations used for the designs, presented in full. The performance of the specimens were experimentally tested under quasi static cyclic loading, with all strain distribution patterns subsequently numerically evaluated. The effects, both individual and combined, on the outer buckling controller, inner buckling controller and end stiffeners on the load bearing member were all also carefully examined. The sandwich type tubular brace system showed symmetric and stable cyclic behavior up to a 3% drift ratio, with no global buckling during the cyclic loadings observed. Multiple instances of minor buckling were spread along the load bearing member. This study, to our knowledge, is the first to report such desired damage conditions for buckling controlled tubular braces. The energy dissipation capacity was found to increase almost 6 times the amount of the conventional tubular brace specimen. Contrary to results from previous studies, the usage of an outer buckling controller and end stiffeners provided the only control for global buckling. This type of design, therefore, was not effective in controlling local buckling or in providing significant energy dissipation when compared with conventional tubular braces.

Xin Cheng (1,2), Dexin Duan (1), Asif Ali (1) and Yiyi Chen (2)
(1) College of Civil Engineering, Taiyuan University of Technology, No. 79, Yingze West Street, Wanbailin District, Taiyuan City, Shanxi Province, China
(2) Disaster Reduction in Civil Engineering, Tongji University, No. 1239, Siping Road, Shanghai, China

ABSTRACT: Since earthquakes occur in random directions, the seismic behavior of thin-walled structures about the weak-axis cannot be ignored, thus the corresponding constitutive model is necessarily needed. To achieve sufficient calculation accuracy and efficiency, the constitutive model of thin-walled steel H-sections, based on moment-curvature curves in the sectional level, is proposed in this paper. Firstly, the validated FEA models were utilized to conduct the parametric studies, where the effects of strain hardening rate and loading protocol on the constitutive model were fully discussed. Based on a large number of moment-curvature curves derived from the FEA models results, the undetermined parameters of the constitutive model were identified. The constitutive model provided precise predictions on hysteretic responses of H-sections, with the unfavorable coupling effects of plate interaction and local buckling fully considered. According to the different buckling mechanisms of H-sections based on the experimental and numerical results, the model was divided into two categories, including the post-buckling stage with decreased-reloading-stiffness (DRS) and increased-reloading-stiffness (IRS). Correspondingly, the proposed constitutive model contains one backbone curve and four types of hysteretic rules. Finally, comparisons of the proposed constitutive models with experimental and numerical results are conducted for further adjustments, which shows the model achieved high accuracy in a variety of loading scenarios.


ABSTRACT: A beam-column consisting of linked rigid segments with rotational resistance at the joints rests on an elastic foundation. The buckling problem due to axial compression is formulated for N identical segments. The characteristic equation show the buckling force depends on N and a parameter representing the
relative importance of joint rigidity and foundation resistance. Exact solutions are found for columns up to $N = 5$ segments.


ABSTRACT: With automated prefabrication on the rise and sustainability principles becoming more prevalent in buildings, a novel material efficient stiffened engineered timber wall system has been developed. Lightweight timber framing is limited to only a few stories and although Cross-Laminated Timber (CLT) structures have been recently used in taller wooden buildings, they are material inefficient against buckling due to their basic monolithic design. A novel material efficient prefabricated stiffened engineered timber wall system is proposed as an intermediary solution. This fully prefabricated panelised system was designed and manufactured to typical conditions with the aid of an industry partner. Experimental axial load testing was conducted, with the stiffened engineered timber walls in various structural configurations to robustly understand its performance under various design scenarios. Areas of particular focus were the serviceability load, ultimate capacity, out-of-plane deflection and failure modes. The key findings around these have been presented along with the behavioural and performance response to alternative loading conditions, height of wall and manner of connection between the key components.


ABSTRACT: In this paper, an analytical solution is obtained using a modal expansion method to study the forced vibration response of axially-loaded, multi-cracked Euler-Bernoulli (EBT) and Timoshenko beams, including shear deformation and rotary inertia (TBTSDR), with differing boundary conditions, namely, hinged-hinged, clamped-clamped, clamped-hinged, and clamped-free, subjected to two moving loads travelling with a constant velocity. The effects of crack depth and number of cracks on the dynamic response of axially-loaded, cracked beams are studied. Also, the effects of the two moving loads’ velocity and axial loading on the dynamic responses are studied in detail. The results obtained in this study are reasonable and agree well with analytical results available in the literature.


ABSTRACT: LiteSteel (LSB) beams are made of two rectangular hollow flanges and a slender web. Although the flexural capacity and bending stiffness are enhanced due to hollow flanges, they are vulnerable to the web crippling failure under concentrated loads and reactions due to high web slenderness values. In current steel buildings, cold-formed steel sections with web holes have been used to accommodate service ducts in floor systems. These LiteSteel beams (LSBs) are innovative new sections, hence current web crippling equations cannot be used to predict the web crippling capacities of them. Keerthan et al. (2014, 2016) and Steau et al. (2015) proposed coefficients to the unified web crippling equation which is available in Australian/New Zealand standard (AS/NZS 4600) and North American Specification (AISI S100) for unfastened and fastened supports, respectively for LSB sections without web holes under four load cases based on their experimental studies. However web crippling behaviour of these sections with web holes is still unknown under all four load cases. In past studies, the web holes are classified into two groups such as centred beneath and offset web holes to investigate their effect on the web crippling behaviour. This study investigates web crippling behaviour of LiteSteel beams with centred beneath and offset circular web holes with unfastened supports under End-Two-Flange load case (ETF) using finite element analysis in ANSYS. Accurate validations have been performed for five different web crippling datasets, and the parametric study was conducted using validated FE models. Web crippling equations were proposed for LiteSteel beams with centred beneath and offset web holes and without web holes based on 1067 FE model values.
ABSTRACT: This paper presents the results of twelve experimental tests on the flexural capacity of perforated aluminium circular hollow section (CHS) tubes; four of which were carried out without perforations. Two heat-treated aluminium alloys were used: 6061-T6 and 6063-T5. The tests covered the size and number of perforations. The flexural capacity, failure modes, and the distribution of strains around circular perforations were determined. The experimental results were then compared against the design strengths calculated from the North American Specification (NAS) for cold-formed steel (CFS) sections with perforations, derived from modified Direct Strength Method (DSM) and modified Continuous Strength Method (CSM) for aluminium alloy members with perforations, which were found to be conservative by approximately 23%, 27% and 22%, respectively. When strength reduction factors were applied, and the unified design equations proposed by Zhou and Young were used, the reduction in strength was 6% conservative to the test strengths.


ABSTRACT: A force-based finite element formulation for the buckling analysis of two-layer composite beam structures with partial interaction is presented. The geometrically nonlinear beam elements possess a single flexible shear interface and each layer is modelled by means of Timoshenko’s theory. The formulation relies on a hybrid variational principle of complementary energy only involving force/moment-like variables as fundamental unknown fields. The approximate field variables are selected such that all equilibrium differential equations are satisfied in strong form. The inter-element equilibrium, as well as Neumann boundary conditions are enforced by means of the Lagrangian-multiplier method. The accuracy and effectiveness of the proposed formulation is demonstrated through the analysis of several numerical tests.

Junchang Ci (1), Hong Jia (2), Shicai Chen (1), Weiming Yan (1), Tianyi Song (1) and Kang-Suk Kim (3)
(1) Department of Civil Engineering, Beijing University of Technology, Beijing, China
(2) China Railway Urban Construction Group Co., Ltd., Hunan, China
(3) Korea Institute of Civil Engineering and Building Technology, Gyeonggi 10223, Korea

ABSTRACT: Concrete-filled double steel tubular (CFDST) columns have been proposed in recent years. This paper presents the performance analysis and a new bearing capacity calculation method of circular CFDST stub columns under axial compression. In order to establish accurate finite element (FE) model, various constitutive models for both the concrete infill and steel tubes are analyzed and compared with experimental results in FE analysis, and the suitable constitutive models for sandwich concrete, core concrete and steel tube are proposed in the FE model developed. Based on the validated numerical model, the variation of confining stress between steel tube and concrete is analyzed in detail. In addition, parametric studies are conducted to investigate the effects of concrete strength, external tube thickness, inner tube thickness, diameter ratio of inner tube to external tube and yield strength of steel tube on the axial compressive performance of circular CFDST stub columns. A new simplified formula based on the confining pressure is proposed to evaluate the ultimate bearing capacity of the circular CFDST stub columns. Based on the comparisons with experimental results and numerical simulation results, it is shown that the proposed formulae for the circular CFDST stub columns appear to be satisfactory.
Mohamed Ghannam (1) and Ibrahim M. Metwally (2)
(1) Structural Engineering Department, Faculty of Engineering, Mansoura University, Mansoura, Dakahlia 35516, Egypt
(2) Structural Engineering (Concrete Structures) Housing & Building National Research Center, Concrete Structures Research Institute, Egypt


ABSTRACT: Concrete filled double tube (CFDT) columns are considered effective to be used in heavy loaded structures, such as bridges, subway stations, and skyscrapers owing to the numerous advantages of concrete filled steel tube (CFST) columns. This paper aimed to numerically study the performance of CFDT columns under concentric loads and present innovative strengthening methods for CFDT columns, which yield more load bearing capacity compared to the existing ones. The proposed stiffened CFDT column will meet the requirements for use in heavy loaded structures. Circular steel hollow sections have been used for the inner and outer tubes. Stiffeners with different profiles (rectangle, T and bar stiffeners) have been welded to the outer and inner tube to check their contribution in increasing the load capacity and enhancing the performance of the circular CFDT columns. The behaviour of CFDT columns is investigated numerically by using a verified finite element (FE) model from the ABAQUS program. Verification of the FE model is achieved by comparing the obtained results with previous test results. Several parameters have been investigated using the FE model. The result revealed that using stiffeners in CFDT Column has a significant effect in increasing its load capacity, which can be increased to more than 15% of its original capacity by increasing number of stiffener and decreasing its slenderness. Based on the parametric study design guide line is presented. A new simplified design model is proposed for the prediction of the axial load capacity of stiffened circular CFDT columns.


ABSTRACT: This paper deals with the free vibration study of doubly curved sandwich shell panels having a core of viscoelastic material, constrained by a Functionally Graded Material (FGM) layer. The FGM constraining layer used in this analysis is made up of Metal-Ceramic (Al/ZrO₂) constituents with top surface being the ceramic rich and the bottom surface is rich in metal. Constrained layer damping (CLD) used for the viscoelastic core improves the damping characteristics of the sandwich shell panel. The mechanical properties of the FGM top layer is considered to vary through the thickness direction, following the Power Law distribution. The normal and shear deformations of the viscoelastic core is considered in the analysis and, the variation of the in-plane and transverse displacements of the core is assumed to be linear along the thickness direction. The base layer of the sandwich structure is made up of isotropic elastic material. The modelling is carried out using the First Order Shear Deformation Theory (FOSDT) with the help of Finite Element Analysis (FEA) by considering that, the transverse deformations of the face layers are independent of their in-plane deformations. Parametric analyses have been carried out to investigate the effect of variation of various system parameters such as power law index, aspect ratio, core thickness ratio, constraining layer thickness ratio and core loss factor on the natural frequencies and modal loss factors of the sandwich shell structure.


ABSTRACT: A finite element study was carried out to investigate the effects of stiffened perforation on the torsional capacity of perforated slender lean duplex stainless steel semi-elliptical hollow section members. Four different stiffener arrangements viz. horizontal, vertical, square frame and ring, were considered for single circular perforation on flat element of the member. Effects of their geometric parameters i.e. width, thickness, anchorage length etc. on single circular perforated member torsional capacity were studied. Of the geometric parameters investigated, stiffener thickness was observed to provide considerable stiffening effect on the torsional capacity. For members with perforation on the curve element, horizontal and ring stiffeners were considered. Horizontal and vertical stiffener could only provide partial recovery, even at higher stiffener
thickness. On the other hand, full recovery of torsional capacity was found to achieve with ring and square frame stiffeners with thickness higher than six times the member thickness.


ABSTRACT: On the basis of a wind tunnel test of the structural rigid model, this paper first calculates the target responses (TRs) of the fluctuating wind loads which are used to compute the universal equivalent static wind loads (UESWLs) of a linear complex large-span roof. Via the linear combination of multiple-order structural mode inertial forces (MOSMIFs), the uncompensated UESWL method of a few lower-order frequencies and modes is then presented. This, however, incurred considerable errors. Therefore, according to the response differences between the accurate TRs and the corresponding UESWL-induced responses (UESWL-IRs) by the uncompensated UESWLs, a new compensated UESWL method is proposed by compensating structural frequencies and modes to eliminate or lessen the errors in the uncompensated UESWL method. Finally, the two methods are applied to a linear complex large-span roof. The computations show that the compensated UESWL method has the clear physical meaning, high accuracy and wide applicability, and it owns an application potential for large-span roofs as well as other structures.


ABSTRACT: Circular concrete-filled steel tubular columns (CFST) with an inner bamboo culm, by replacing the internal steel tube of concrete-filled double skin steel tubular (CFDST) columns with a structural bamboo culm, promote the use of natural materials with lower cost and lighter weight. This type of composite column is expected to integrate the advantages of all the three kinds of materials. Twenty-two circular stub columns including 12 CFST with an inner bamboo culm, 3 CFST columns, 4 CFDST columns and 3 hollow CFST columns were tested under axial compression. The test parameters include the bamboo culm thickness, the bamboo culm diameter and the diameter to thickness ratio of the external steel tubes. Test results indicated that the columns with an inner bamboo culm had excellent ductility. Furthermore, the columns with an inner bamboo culm showed strain-hardening behaviour after an initial decline in its axial load-displacement curve, but the inner bamboo culm contributed mildly to the ultimate load. Finally, a unified formula was proposed to predict the load-carrying capacities of all the four types of composite columns.


ABSTRACT: This paper presented an experimental investigation on the Polyvinyl Chloride-Carbon Fiber Reinforced Plastic (PVC-CFRP) Confined Concrete (PVC-CFRP-CC) stub columns under axial compression. A total of two PVC Confined Concrete (PVC-CC) columns and ten PVC-CFRP-CC columns were conducted. The effect of spacing of CFRP strips on mechanical behaviors of PVC-CFRP-CC stub columns was investigated. Meanwhile, the influence on mechanical behaviors was also analyzed in terms of equivalent confining effect coefficient. Test results demonstrated that PVC-CC stub columns failed by the buckling of PVC tube while the PVC-CFRP-CC stub columns were damaged by the tensile fracture of CFRP strips and the cracking of PVC tube. The bearing capacity of PVC-CFRP-CC stub columns increased gradually as the equivalent confining effect coefficient increased while the bearing capacity decreased with the increase of spacing of CFRP strips. With the decrease of spacing of CFRP strips or the improvement of equivalent confining effect coefficient, the confinement of PVC-CFRP tube on core concrete enhanced, the ultimate compressive strain of the PVC tube and the ultimate tensile strain of the CFRP strips increased. Based on a large and up-to-date test data including measured data in this study and data collected from the literatures, a modified model for conveniently predicting the stress–strain relation of PVC-CFRP-CC stub columns was established and verified the test data with good agreement.
ABSTRACT: In China, due to the extensive use of brick as the non-structural walls in the old concrete building, it is hard to exclude the waste brick from the waste concrete in the production of recycled coarse aggregates. This paper investigates the axially loaded recycled aggregate concrete filled steel tubes with the inclusion of crushed bricks as the coarse aggregates, which is called as the recycled brick aggregate concrete filled steel tubes (RBACFSTs). It was found that the compressive resistance only decreased by up to 3.8% when half of the recycled coarse aggregate was substituted by the crushed clay brick (CCB). The structural effects of the CCB replacement are much smaller than the corresponding effects in the material property tests, owing to the confinement effects. The stress states of the steel and the concrete infill were analyzed separately. Model equations to describe the stress–strain responses and the design recommendations for RBACFSTs were proposed.

ABSTRACT: Elastic buckling of stiffened steel plate walls (S-SPWs) under combined compression and shear was studied focusing on the stiffness demand on stiffeners to implement subpanel’s buckling mode. Flat-bars and closed form stiffeners were considered. Threshold stiffness of stiffeners is presented for elastic buckling of subpanels of S-SPWs in pure compression, pure shear and combined compression and shear. The effect of stiffeners’ torsional stiffness has been included. Then the elastic–plastic (E-P) buckling of S-SPWs under combined compression and shear was studied. A criteria was established to identify the E-P shear buckling stress under a prescribed compression stress for S-SPWs with given stiffness of stiffeners. Threshold stiffness of stiffeners was taken on the buckling stress – stiffness curve at the transition point as the E-P buckling shear stress reaches a plateau. The demand of keeping stiffeners straight when stiffeners are compressed simultaneously has been incorporated in such defined threshold stiffness. Equations for threshold stiffness of flat-bars and closed form stiffeners are proposed separately and comparisons with finite element results show good accuracy.

ABSTRACT: The steady-state response of a rectangular plate with four free edges supported at internal points subjected to external force is determined. The general analytical solution is obtained by a hybrid method that decomposes the original structure into four basic rectangular plates with different boundary conditions. A numerical example is presented to show that the high-degree accuracy can be gained with a small effort of calculations using the theoretical solution. Sensitivity studies using the analytical solution were also conducted to investigate the effects of load magnitude, sectional dimension (or area), bending stiffness of rectangular plate, and location of internal point on the support reaction, displacement, bending moment, and shear force of rectangular plate.

ABSTRACT: Lateral torsional buckling (LTB) of I-beams is characterized by simultaneous lateral deflection and twist. In this paper the influence of destabilizing and neutral effects of loadings and the possibility of the occurrence of web distortion, which characterizes the lateral distortional buckling (LDB), is numerically investigated. Recent research has shown divergences between the standard procedures of the American Institute of Steel Construction, Australian Standards and Eurocode with LTB numerical results. In addition, some procedures have recently been proposed for correcting possible deviations between the results of numerical
analysis and standard procedures. In order to investigate this situation, elastic stability and physical and geometrical nonlinear analyzes are performed, using GBTul and ABAQUS softwares, respectively. The numerical model is calibrated considering experimental tests. The beams are simply supported, with fork supports at the ends, and subject to neutral and destabilizing effects of loading. The beams are subject to uniform bending, mid-span concentrated load and uniformly distributed loads. The parametric study is performed by varying the geometric cross section parameters. The results are compared with international standards and analytical procedures. It is concluded that the influence of destabilizing and neutral effects of loadings is responsible for providing non-conservative results when compared to the American Institute of Steel Construction procedure. The occurrence of LDB in hot-holed I sections influences the lateral stability strength of I-beams, but it is not predominant. With the possibility of using the elastic critical moment obtained by the elastic stability analysis, the conservative situation of EC3 is verified. The Australian Standards procedure is in agreement with all the situations analyzed.

ABSTRACT: Concrete-filled steel tube (CFST) has been widely used in civil engineering. Numerous studies have shown that concrete-filled double-skin steel tube (CFDST) columns exhibit satisfactory mechanical properties under various loading conditions. Furthermore, ultra-high performance fiber-reinforced concrete (UHPFRC) has been developed as a prominent representative of new construction materials. This study investigates the residual bearing capacities of 10 concrete-filled steel tube specimens (three CFST columns and seven CFDST columns) after impact loading. The investigated parameters include the steel ratio, the concrete type, the section form, axial load ratio, the impact energy and the presence/absence of impact load. The results demonstrate that, when the inner steel tube thicknesses are identical, increasing the steel ratio from 0.296 to 0.467 (the outer steel tube thickness increases from 5 mm to 8 mm) can effectively improve the residual performance. For the non-impacted specimens, the bearing capacity of the CFDST columns is increased by 47.1% as the concrete type is changed from NSC to UHPFRC. For the impacted specimens, due to the influence of the test setup and other reasons, the concrete type has only a slight influence on the residual performance of CFDST columns; however, it has a substantial influence on the residual performance of the CFST columns. Furthermore, with the concrete type in the CFST columns changing from NSC to UHPFRC, the residual performance of CFST columns can be significantly enhanced.

ABSTRACT: The nonlinear dynamic response of cantilever beams under transverse harmonic excitation is investigated experimentally and numerically. The experimental set up, finite element formulation with accurate representation of curvature/inertia nonlinearities, multi-modal transverse displacement approximation and solution methodology for the periodic solution of the resulting nonlinear equations of motion are described. The experimental and numerical results of nonlinear periodic response are compared and the detailed study is carried out to investigate the effects of approximation of curvature/inertia nonlinearities and transverse displacement on the nature/degree of nonlinearity.

ABSTRACT: Circular hollow section (CHS) specimens are widely employed in long-span space structures, truss structures, and bridge structures; however, only a few experimental and numerical investigations on CHS aluminum alloy beams have been conducted in China. This paper presents a detailed experimental investigation on CHS beams made of 6082-T6 aluminum alloys. The effects of length and section slenderness on the ultimate strength and buckling behaviour were investigated. Seventeen extruded CHS specimens were subjected to four-point bending tests, with the diameter-to-thickness ratio (D/t) ranging from 16.4 to 29.1. The failure modes observed included overall buckling and the coupling of local and overall buckling. The initial geometric
imperfections were measured prior to the bending tests. Subsequently, fine finite-element (FE) models were developed using the nonlinear analysis program ABAQUS and validated against the experimental results. An extensive parametric study involving 600 numerical results was performed to evaluate the effects of $D/t$, the section dimensions, and the slenderness ratio on the mechanical responses and bending strength of the CHS beams. The test results, together with the obtained FE analysis results, were utilised to assess the accuracy of the bending-strength provisions in the current design codes GB 50429 (China), Eurocode 9 (Europe), and AA-2015 (America), as well as optional design approaches, i.e. the direct strength method (DSM) and continuous strength method (CSM). The results indicated that all five design provisions provided conservative predictions of the ultimate moment capacities; the predicted results of DSM and CSM were more accurate than the three design specifications. The reliability levels of the bending-strength provisions were confirmed and compared using statistical parameters from the corresponding specifications.


ABSTRACT: This paper presents an experimental investigation on the mechanical behaviour of the Self-stressing Steel Slag Aggregate Concrete Filled Steel Tubular (SSSACFST) short columns under axial compression. Ten SSSACFST short columns with different diameter-thickness ratios and expansion rates of Steel Slag Aggregate Concrete (SSAC) are designed, and three different axial compression tests are conducted including the load applied to the core SSAC (type-A loading), load applied to the outer steel tube (type-B loading), and load applied to the steel tube and core SSAC simultaneously (type-C loading). The experimental results show that all SSSACFST short columns subjected to axial load exhibit drum-like failures. The Incremental Range of Load Capacity (IRLC) and the ultimate axial and circumferential strains of the specimens will be improved by increasing the expansion rate. The effect of the loading mode on the ultimate bearing capacity is not very evident, while the influence of the loading mode on the strains is remarkable. The ultimate axial and circumference strains of the specimens with type-B loading mode are significantly larger than those of the specimens with type-A loading mode or type-C loading mode. The increase in the diameter-thickness ratio decreases the ultimate bearing capacity and ultimate axial and circumferential strains of the specimens. According to the experimental results, the adaptability of the existing CFST design codes for estimating the strength of SSSACFST short columns is examined. Additionally, a model for predicting the ultimate bearing capacity of SSSACFST short columns with the type-C loading mode is proposed depending on the limit equilibrium theory. On this basis, the calculation methods of the bearing capacity of the SSSACFST short columns under axial compression with the other two loading modes are suggested. The results predicted by the proposed models are in good agreement with the test data.


ABSTRACT: Designing crashworthy components requires a special structural configuration that provides effective crushing deformation to absorb crash impact energy. Recent developments in crash impact energy absorption for crashworthy components include thin wall structures, honeycomb structures, and metallic foam sandwich structures. The honeycomb and metallic foam structures appear to have high specific energy absorption capability. However, both structural configurations have a shortcoming, i.e. honeycomb structures only have the unidirectional capability, while the metallic foam structures have highly irregular (random) three-dimensional cell configuration. The advanced development of additive manufacturing has paved the way for the developments of complicated geometry that will support the development of crashworthy components in the form of lattice structures. The lattice structures provide both three-dimensional and regular structural configurations that are able to absorb crash impact energy efficiently. Therefore, lattice structures have excellent potential to be used for energy management of crash impact structures. Eleven types of lattice configurations were examined to determine the highest specific energy absorption capability, i.e. $kagome$, $tetrahedron$, $pyramid$, $cube$, $truncated-pyramid$, $octahedron$, $rhombicuboctahedron$, $rhombic dodecahedron$, $open-cell$, and $octet$ lattice structures. Numerical analysis and design optimization were performed on a single cell unit of each lattice configuration. It was found that the optimum lattice configuration for crashworthy
components was the octet lattice structure. Further topology optimization of the octet lattice configuration resulted in an optimum solution of the octet structure in the form of a twisted octet lattice structure. The twisted lattice structure with 20% relative density was able to generate the highest specific energy absorption. A case study on an aircraft subfloor surface structures showed that the twisted lattice structure was able to absorb aircraft grounding impact energy efficiently. General buckling failure in the twisted lattice structure can be avoided by using a tapered configuration. This tapered lattice structure has a high potential to provide specific energy absorption of up to 127 kJ/kg. These results show the potential applicability of the lattice structure for aircraft crashworthy components.

ABSTRACT: Plate panels of ships and floating offshore structures are likely subjected to cyclic loads arising from waves at sea. Depending on sea states, e.g., whipping in harsh sea states, the maximum amplitude of the cyclic loads may reach over 70% of ultimate loads. Of concerns is how the cyclic loads will affect the ultimate strength compared to a case of monotonically increasing loads. The aim of this paper is to experimentally investigate the ultimate strength characteristics of a steel stiffened plate structure under cyclic axial-compressive loading. A full-scale collapse testing in association with bottom structures of an as-built 1,900 TEU containership was conducted. It is concluded that the effects of cyclic loading on the ultimate compressive strength of steel stiffened plate structures are small as far as fatigue damages are not suffered due to the small number of load cycles and/or local structural members do not reach the ultimate strength during cyclic axial-compressive loading. Details of the test database are documented, which will be useful to validate computational models for the ultimate strength analysis.

ABSTRACT: Corrugated webs are often utilized in bridge engineering applications due to better shear resistance and improved aesthetics. The stress distribution due to flexure and shear of corrugated girders is different from that of the flat girders. Generally, due to the accordion effect, it is assumed that the web contribution is negligible to the bending moment resistance. Further, the use of slender flanges poses stability problems that require investigation. The current study evaluates the adverse effect of slender flange buckling on the moment of resistance of the corrugated web girders through the stability and strength analysis of the steel I-girders with corrugated webs. Extensive parametric studies on buckling co-efficient and moment capacities are carried out using a validated numerical model to develop a better understanding of the flexural capacities of slender (Class 4) cross-section corrugated girders. Also, various design models proposed over three decades from the literature are compared. Based on numerical results, an empirical equation is presented for the determination of the ultimate moment of resistance of slender flanges for corrugated girders.

ABSTRACT: Numerical study on structural performance of hybrid stainless steel stub columns are provided in this paper by utilizing finite element (FE) software, Abaqus. Two novel stainless steel grades were used viz., Lean duplex stainless steel (LDSS) and Duplex stainless steel (DSS) for hybrid stainless steel stub columns. The current investigation on hybrid stub columns consist of two configurations: (1) Hybrid stainless steel (HSS) stub column adopting DSS on the flanges and LDSS on the web; and (2) Hybrid stainless steel (HSS) stub column using DSS and LDSS on the web and flanges respectively. The numerical results are presented in terms of column capacity (P) and failure modes. As observed from the investigation, both flange thickness (t) and flange width (b) have more influence on the column capacity for HSS stub column as compared to HSS stub column. On the other hand, increase in web thickness (t) is found to provide an enhancement in column capacity for HSS compared to HSS stub column, in contrast to the effect of t and b. In general, EN 1993-1-4 Class 3 limit for internal web is observed to be reliable for all stainless steel stub columns. Based on the FE
results, new DSM formulation for HSS and HSS stub columns was proposed based on modified DSM equation for carbon steel.

ABSTRACT: Stainless steels are highly corrosion resistant, durable, ductile and aesthetically appealing materials. They are classified into the five main categories of austenitic, ferritic, martensitic, duplex and precipitation-hardening material grades. Among such available stainless steel material grades, ferritic materials are the most competitive economically due to its lower nickel content, and so potentially have the widest structural applications. Structural performance of cold-formed ferritic stainless steel channels subject to concentrated transverse loads is described in this paper. The channels are with unfastened flanges and with offset web openings, due to ease in service integration and loaded under one-flange load scenarios. In total, 594 results consisting of 18 experimental and 576 numerical analyses results are presented. For the numerical investigations, the finite element models developed using quasi-static analysis with implicit integration scheme. A complementary parametric investigations are then conducted to ascertain the web bearing strength reduction factor equations in terms of various channel sizes and position of openings in the web. Strength reduction factors recommended in previous research for lipped stainless steel channels are then compared to reduction factors determined from current study. It is found that the suggested reduction factors for such channels are unreliable to use and un-conservative to apply for unlipped ferritic stainless steel channels as much as 17%. From both experimental and numerical results, reliable web bearing strength reduction factors are proposed applicable to channels with offset web openings and fastened flanges loaded subject to one-flange load scenarios.

ABSTRACT: As significant growth of iron production in China in recent decades, plenty of blast furnace slag is generated. Meanwhile, the policies on the natural aggregate exploitation has been getting more restricted as it threatens the environmental conditions. There is an alternative solution to the above issues that furnace slag aggregate concrete is filled in middle between double-skin tubular (DST) columns with external stainless steel tubes. This study conducted a series of tests on furnace slag aggregate concrete filled double-skin tubular (CFDST) stub columns under sustained loading condition. The experimental investigations were conducted on circular specimens with furnace slag aggregate replacement ratio of 100%. The hollow ratio of the specimens ranged from 0.5 to 0.75. A total of 8 specimens were tested to capture the behaviours of the creep, shrinkage, ultimate strength before and after 6 months sustained loading. The results indicated that the shrinkage strain of the sandwiched furnace slag aggregate concrete tended to stabilise after 30 days and the creep developed constantly throughout the 180 days of the test. The furnace slag aggregate CFDST specimens with stainless steel tubes have demonstrated well load carrying capacity and ductility under sustained loading. The existing design methods were evaluated on the applicability on the stainless steel-furnace slag aggregate specimens under sustained loading and reasonable predictions were obtained.

ABSTRACT: Tests and numerical simulation of rectangular recycled aggregate concrete filled steel tube (RACFST) stub columns under concentric compression are carried out. Eighteen specimens, including 12 RACFST specimens and 6 concrete filled steel tube (CFST) specimens as reference, with varied width-to-thickness ratio (\(w/t\)), depth-to-width ratio (\(d/w\)) and recycled coarse aggregate replacement ratio (\(R\)) are tested. The test results show that rectangular RACFST stub column specimens have similar failure pattern as their counterparts. However, the bearing capacity and the composite elastic modulus of RACFST specimens are lower than those of CFST ones while they both decrease with higher \(w/t\). Moreover, the specimens with larger and
ABSTRACT: In this paper, semi-columns, locking FGSs. and results of this paper can provide a reference for structural designs and engineering applications of self-ability have hindered further innovations and applications of such structures. In this paper, the geometric performance of thin-walled T-shaped concrete filled steel tubular (CFST) stub columns. Eight CFST columns with and without stiffener were fabricated and exposed to different elevated temperatures, then tested for axial compressive performance. The complete load-displacement curve of the specimens under axial compression, the failure pattern after test and the failure characteristics of concrete core are also discussed. The finite element analysis is then developed to establish the calculation model of temperature field and axial pressure field of thin-walled T-shaped concrete filled steel tubular stub columns with stiffeners at constant high temperature. The FE model presents a highly agreement with experimental data in term of load-displacement behavior, which enable to further investigate stress distribution and failure mechanism of the columns. In addition, parametric study is conducted showing that temperature, thickness of steel tube, yield strength of steel tube and compressive strength of concrete are the key factors in contributing to axial compressive performance of the CFST stub columns. Finally, to provide reference for practical application of engineering, a simplified calculation formula for ultimate bearing capacity and axial compression stiffness of CFST stub columns were obtained via the regression analysis based on results from the experimental and numerical analysis. The result shows that the relative errors between results calculated from simplified formulae and from FE models are within 10%, which indicates that the proposed formulae are able to provide the theoretical reference for the practical engineering applications.

ABSTRACT: Self-locking foldable grid structures (FGSs) can be converted from a mechanical state to a structural state without the need to impose additional geometric constraints. However, the lack of a systematic understanding of the self-locking mechanism and the absence of a simple method to assess the self-locking capability have hindered further innovations and applications of such structures. In this paper, the geometric incompatibility function of structural units (SUs) was proposed by analyzing the mechanism motion of the two types of scissor-like elements (SLEs), thereby clarifying the self-locking mechanism of FGSs. Then, based on this function, the approximate expression for evaluating the self-locking capability of SUs was derived using the work-energy principle. This evaluation shows that the expression is concise in form and has a good application feasibility in the preliminary design phase. Furthermore, the results obtained by the expression show that the parameters t (thickness) and h (distance between the lower central node and the plane) have a critical influence on the self-locking performance compared to parameter L (side length), and the method of adjusting the h value can be preferentially adopted to control the self-locking capability of the entire structure. The research methods and results of this paper can provide a reference for structural designs and engineering applications of self-locking FGSs.

ABSTRACT: In this paper, semi-analytical solution is developed to predict post-buckling configurations of simply-supported columns consisting of an arbitrary number of segments. Geometric and equilibrium relations of the deformed column are utilized to derive the nonlinear governing equations and the closed-form solution is obtained. Unknown parameters in the proposed solution are determined by using a numerical method. The column is assumed to be an inextensible and the Euler-Bernoulli beam hypotheses are used. The proposed
solution is validated by comparing the results obtained with available data in the literature. Furthermore, by using the proposed solution, the post-buckling behaviour of various columns with geometry or material discontinuities is investigated.


ABSTRACT: Aluminium sections are significantly used as primary load bearing members in the building industry due to its corrosion resistance, ease of fabrication and erection, and high strength-to-weight ratio. Roll-formed aluminium lipped channel beam (LCB) is one of these sections which are typically used as roof purlins, floor joists and rafter. However, LCBs are vulnerable to buckling failures due to the increased web slenderness and low elastic modulus compared to steel. Hence an experimental study was conducted at Griffith University to investigate the shear behaviour of these sections. Finite element models of aluminium LCBs were then developed and validated with test results. A detailed parametric study was also undertaken with different sections, web slenderness, aluminium grades and aspect ratios to obtain the shear strengths and shear buckling characteristics of aluminium LCBs. The ultimate shear capacities of aluminium LCBs obtained from the tests and finite element analyses (FEA) were compared with the current shear design rules of Australian/New Zealand Standard and Eurocode for both aluminium structures and cold-formed structures as well as direct strength method (DSM). The comparison showed that these current shear design rules are not suitable to predict the shear capacities of aluminium LCBs. Hence new design rules were proposed in this study to accurately predict the shear capacities of roll-formed aluminium LCBs. This paper presents the details of the experimental and numerical studies and the development of shear design rules based on Australian/New Zealand Standard, Eurocode and DSM.


ABSTRACT: Artificial Neural Network (ANN) model was developed as a reliable modeling method for simulating and predicting the ultimate moment capacities of castellated steel beams. The training and testing data for neural networks are obtained using Finite Element Analysis (FEA). For this purpose, a series of nonlinear finite element analyses have been carried out to simulate the distortional buckling behavior of castellated steel beams, and the effects of nine independent parameters on the lateral-distortional buckling mode, have been investigated. Moreover, unlike the existing design codes, the ANN model considers the effects of web distortion on the ultimate buckling strength of beams. Then, a new formula based on ANNs has been proposed to predict the ultimate moment capacities of castellated steel beams subjected to lateral-distortional buckling. The attempt was done to evaluate a practical formula considering all parameters which may affect the distortional capacity of castellated steel beams. Then, a sensitivity analysis using Garson’s algorithm has been developed to determine the importance of each input parameter. Finally, a comparison has been made between the proposed formula and the predictions obtained from AS4100, EC3, and AISC codes. It is shown that the proposed formula is more accurate than these design codes.


ABSTRACT: Curved beams are sometimes used in practical framed structures due to good mechanical properties and artistic design. In a framed structure, curved beams may undergo large displacement and experience nonlinear behavior as same as the other straight slender beam-column members. Thus, a geometrically nonlinear curved beam element plays an important role in the analysis of framed structures with curved beams. However, most existing curved beam elements are not accurate enough and still need several or even dozens of elements to accurately describe the behavior of a curved beam with a large subtended angle. To fill this gap, this paper presents a novel geometrically nonlinear curved beam element based on the element-independent co-rotational (EICR) method. The proposed element can simulate a curved beam using only one
single element in the analysis and design of most practical framed structures. Moreover, this element is directly derived in a Cartesian coordinate system and can be directly and conveniently used with straight beam-column elements in nonlinear structural analysis. In this manuscript, the derivation of the proposed geometrically nonlinear curved beam element is detailed and several benchmark problems are proposed to verify its accuracy and efficiency.

ABSTRACT: The structural behaviour and design of hot-rolled steel square and rectangular hollow sections (SHS and RHS) under combined axial compression and bending are studied in the present paper. Finite element (FE) models were developed and validated against existing experimental results on hot-rolled normal strength and high strength steel SHS and RHS under combined loading. Upon validation against the test results, an extensive parametric study was then performed with the aim of expanding the available structural performance data over a wide range of cross-section geometries, cross-section slendernesses, steel grades and loading scenarios. Both the experimentally and numerically obtained data were utilised for an assessment of the accuracy of the current design rules in European and American standards for hot-rolled steel tubular sections under combined loading. The comparisons revealed that the codified capacity predictions are generally somewhat conservative and scattered, due mainly to the neglect of strain hardening in the case of stocky cross-sections and the rather crude treatment of the partial spread of plasticity for Class 3 (semi-compact) cross-sections. The deformation-based continuous strength method (CSM) has been successfully applied to the design of hot-rolled steel cross-sections under isolated loading conditions (i.e. compression or bending), and shown to provide more accurate and consistent ultimate resistance predictions than the existing design provisions. This paper presents the first study to extend the CSM to the design of hot-rolled steel SHS and RHS, made of both normal and high strength steels, under combined loading, underpinned by both experimentally and numerically derived data points. Advantages of the proposed approach include eliminating the discontinuity in the current codified methods, yielding more accurate and consistent resistance predictions and providing knowledge of the level of strain required to reach a given resistance. The reliability of the proposed method is statistically verified in accordance with EN 1990.

ABSTRACT: Steel-concrete composite beams, when requested by negative moment, can fail due to Lateral Distortional Buckling (LDB), local buckling, by a combination of these stability modes or achieve the plastic behavior. LDB is a mode of stability in which the web must distort in order for the compression flange to displace and twist during buckling. Several papers were published in an attempt to clarify the LDB behavior of steel-concrete composite beams. These papers can be divided into two strands of studies. The first that seeks to investigate the elastic behavior of the LDB, in an attempt to determine the elastic critical moment, through bifurcation equilibrium analyzes. And the second strand, which investigates the LDB strength of steel-concrete composite beams, through the development of experimental investigations or by non-linear numerical analyzes. However, there is still no consensus regarding the behavior of LDB in steel-concrete composite beams. Researchers who investigated the elastic behavior of LDB show divergences between the methodologies for determining the elastic critical moment. Furthermore, the publications that are aimed at investigating the LDB strength, show inconsistencies in the standard procedures. Therefore, the main objective of this article is to present a critical review about LDB in steel-concrete composite beams. For this purpose, the main studies that analyzed the elastic and inelastic behavior of LDB are presented, in addition to an overview of the main standard procedures. Finally, the future research directions have been discussed, presenting parameters that still need further investigation.

ABSTRACT: This paper presents a study on the fire performance of steel-reinforced concrete-filled steel tubular (SRCFST) columns with square cross-section. The numerical models of SRCFST members, including a heat transfer analysis model and a structural analysis model, are established by ABAQUS to simulate the fire performance. The numerical models are validated against with the experimental data reported previously in terms of temperature field, axial deformation versus time curves, fire resistance and failure modes, and acceptable agreement can be achieved. Sensitivity analyses on contact thermal resistance and transient thermal strain are performed. It can be found that considering transient thermal strain of concrete and thermal resistance across the interface of concrete and steel tube is more realistic and gives accurate assessment for FE models.

The fire performances of SRCFST columns, including temperature distributions, the axial deformation-time (\(\Delta-t\)) curves, axial force distribution and strain are investigated and compared with common CFST columns. The results show that the fire behaviour of SRCFST columns can be further enhanced owing to the embedded profiled steel. Finally, the influences of various parameters on fire resistance, including fire load ratio, material strength, steel tube ratio, profiled steel ratio and slenderness ratio are examined. It is found that a higher profiled steel ratio is more favourable to fire resistance of SRCFST columns assuming the total steel ratio same, and the fire resistance significantly decreases with the increase of fire load ratio and slenderness ratio.


ABSTRACT: In the current work, the concept of auxetic structures design is introduced into carbon nanotube-reinforced composite (CNTRC) laminate. Larger values of negative Poisson’s ratio (NPR) of CNTRC laminate are obtained by setting the optimal orientation. Meanwhile, a theoretical model is presented for the nonlinear dynamic response of functionally graded (FG) CNTRC beam with NPR. Using Reddy’s higher order shear deformation plate theory with von Karman's strain–displacement relations, the motion equations are obtained A two-perturbation approach and the fourth-order Runge Kutta method are then used to obtain the time-deflection curve of the auxetic FG-CNTRC beam. The effects of factors such as the CNT distribution, thermal field and foundation stiffness on the dynamic characteristic of the auxetic FG-CNTRC beam are studied in details. Numerical results indicate that the thermal–mechanical behavior of FG-CNTRC beams might be significantly improved by determining a proper distribution of CNTs. Furthermore, the results show that the change of temperature and foundation stiffness have a significant effect on the dynamic characteristic of FG-CNTRC laminated beams with NPR.


ABSTRACT: In this paper a novel method for the shape optimization of tapered arches subjected to in-plane gravity (self-weight) and horizontal loading through compressive internal loading is presented. The arch is discretized into beam elements, and axial deformation is assumed to be small. The curved shape of the tapered arch is discretized into a centroidal B-spline curve with beam elements. Constraints are imposed for allowable axial force and bending moment in the arch so that only compressive stress exists in the section. The computational cost for optimization is reduced, and the convergence property is improved by considering the locations of the control points of B-spline curves as design variables. The height of section is also modeled using a B-spline function. A section update algorithm is introduced in the optimization procedure to account for the contact and separation phenomena and to further speed up the computation process. The objective function is chosen to minimize the total strain energy of the arch under self-weight and horizontal loading. Numerical examples are presented that demonstrate the effectiveness of the proposed method. To validate the findings, the properties of the obtained optimal shapes are compared to shapes obtained by a graphic statics approach.


ABSTRACT: The behavior of thin-walled round-ended concrete-filled steel tubular (RECFST) short columns loaded axially is characterized by the local-buckling of the flat steel walls and the concrete confinement exerted
by the round-ended steel walls. A numerical modeling method implementing fiber analysis is presented in this paper for the determination of the behavior of short thin-walled RECFST columns subjected to axial loads. The mathematical simulation method explicitly incorporates the progressive local buckling of the flat steel walls as well as concrete confinement induced by the round-ended tube walls. A new constitutive model is developed by analyzing the available test results for determining the lateral pressures on the concrete confined by the round-ended tube walls. A coefficient of strength degradation is provided to quantify the residual strength of the encased concrete. The independent test results are utilized to assess the accuracy of the computational modeling scheme. Comparative investigations are carried out to evaluate the accuracy of the numerical models of RECFST columns presented by other investigators. The computer modeling program designed is utilized to quantify the structural responses of thin-walled RECFST composite columns subjected to the variations of material and geometric parameters. A design equation is given for designing thin-walled RECFST columns considering local buckling and concrete confinement effects. The applicability of the current design standards for circular and rectangular CFST columns to RECFST columns is assessed by utilizing experimental data. It is found that the current design codes need to be modified to be used to design RECFST thin-walled columns. The proposed computer simulation program and design equation are demonstrated to accurately yield the performance of RECFST columns under axial loading.


ABSTRACT: This paper developed novel steel–concrete–steel sandwich composite walls (SCSSCWs) with enhanced C-channels (SCSSCW-ECs), and studied their compressive behaviours through seven axial compression tests. The studied parameters include layout of C-channels in SCSSCWs, faceplate thickness, strength of concrete core, vertical and horizontal spacing of C-channels. Test results exhibited a three-stage working mechanism for SCSSCW-ECs under compression. Experimental observations also showed that under axial compression SCSSCW-ECs failed in concrete core crushing and local buckling of faceplate. The test results also offer useful information on the mechanism and influences of these studied parameters on axial compressive behaviours of SCSSCW-ECs. The layout of novel ECs in SCSSCW-ECs was finally optimized including layout of C-channels as well as their spacings. This paper also developed theoretical models and modified code equations in AISC, CECS, and Eurocode 4 to estimate ultimate compressive resistance of SCSSCW-ECs. These models have been validated by reported 11 test results. The validations showed that developed theoretical models offered the most accurate predictions on ultimate compressive resistance of SCSSCW-ECs.


ABSTRACT: In the present research, the energy absorption and collapse behaviors of a rigid polyurethane foam-filled sandwich beam with expanded metal sheets as core were studied. Three types of steel lattice core, both unfilled and foam-filled, were subjected to the quasi-static three-point bending test. Force-displacement relationships, collapse modes of the beam, and the impact parameters, including absorbed energy, crushing force efficiency and Specific Energy Absorption (SEA) were discussed. Also, the impact of the direction of the lattice sheets in the core of the sandwich beams, both longitudinal and transverse directions, as well as the effects of the cell geometry on energy absorption, was further evaluated. It was found that the polyurethane foam reinforcement could enhance the energy absorption of the sandwich beam by up to 80%. The appropriate direction of the lattice sheets in the core could increase the energy absorption by 74.6%. The presented sandwich beam with the polyurethane foam reinforced lattice core due to high absorption capacity and lightweight structure could be implemented as an energy absorber in the aerospace, transportation, and elevator industries.

ABSTRACT: Polyethylene terephthalate (PET) fibre-reinforced polymer (FRP) composites are an emerging form of composites based on recycled PET fibres and have a large rupture strain. A novel form of hybrid columns with PET FRP tubes, i.e., square PET FRP-confined concrete encased high-strength steel (HSS) hybrid columns (referred to as PET FRP-confined concrete-steel columns or PFCCSCs), was recently proposed. The compressive behaviour of circular FCCSCs has been investigated, but there is no research on the compressive behaviour of square PFCCSCs (SPFCCSCs). In SPFCCSCs, the inner HSS tube is expected to be effective in decreasing the confinement nonuniformity in FRP-confined square columns and enhancing the ultimate axial strain and compressive strength of the core concrete. Furthermore, the axial strength of the inner HSS tube is expected to be sufficiently utilized because its buckling is delayed due to confinement from the surrounding concrete. In total, fourteen columnar specimens were tested under monotonic or cyclic axial compression, and the effects of key parameters (i.e., the steel tube yield stress and loading patterns) were investigated. The test results demonstrate that the inward and outward buckling of the inner steel tube in SPFCCSCs can be effectively suppressed or delayed by the surrounding concrete, which was well confined by the PET FRP tube. The compressive strength of a hybrid column is approximately 20% higher than the simple summation of the corresponding strengths of an FRP-confined concrete section and an HSS tube section due to the optimal combination of the three components in the hybrid columns. The SPFCCSCs with a PET FRP tube exhibit a monotonically ascending load-strain response with excellent ductility, which is of particular interest for applications in seismic engineering and underground engineering. The loading scheme has a marginal effect on the load-strain envelope response of SPFCCSCs.


ABSTRACT: One of the important forms of smart structure available for various applications in engineering fields is Sandwich beams, for the reason that of variable applications, the capability to withstand at variable loading conditions, significant elastic retaining properties when in comparison to conventional structures. The basic of the present study is to investigate natural frequency ranges for a type of sandwich beam that has been manufactured using natural rubber (NR) that is indigenously available in Tripura, India, in combination to skin material of aluminium alloy 1050 grade. The present article deals with the study of free vibrational characteristics of cantilever sandwich panels (SwPs) with various skin thicknesses. A mathematical approach had been carried out using a standard platform for validating the results obtained from the analytical method. Also, experimentation had been conducted on sample of sandwich panels using Hammer test process and the natural frequencies of the same were obtained. It was found that the results obtained from the analytical method using a standard platform have been in good agreement with the other approach.


ABSTRACT: In the present study, static and free vibration analysis of single walled functionally graded carbon nano-tube (CNTs) reinforced composite plate is carried out in the framework of trigonometric shear deformation theory. Trigonometric shear deformation theory full fills the traction free boundary condition at the top and bottom of the plate due to which it does not require shear correction factor. The Hamilton’s principle is used to derive governing differential equations and the Navier’s solution technique is used to obtain closed-form solution. The analytical approach is used to analyse the effect of the different span thickness ratios, volume fraction of CNTs, and distribution of CNTs on the deflection, stresses, natural frequencies, and corresponding mode shapes of CNTs reinforced composite plate. Four different types of CNTs reinforcement distribution such as, uniformly distribution (UD) and three types of functionally graded (FG) i.e. FG-O, FG-X and FG-V are selected here for the analysis. Here, the efforts are made to achieve the best possible arrangement for the reinforcement distribution that will produce the improved static and free vibration responses for the functionally graded CNTs reinforced composite plate.

Finally, a novel simplified formula was proposed to predict the ultimate bearing capacity of SRCFT stub comprehensively. In addition, the capacity of the energy dissipation for SRCFT composite action among the steel tube, core concrete and steel section was discussed and clarified. A model was established effectively prevent shear cracks in the core concrete from propagating quickly. Furthermore, finite element terms of the axial load of 8 specimens were tested to investigate the compressive performance of SRCFT stub columns in detail, in compressive behavior of SRCFT stub columns through combined experimental and numerical studies. A total of 8 specimens were tested to investigate the compressive performance of SRCFT stub columns in detail, in terms of the axial load-strain curve, ultimate bearing capacity, ductility, strength-weight-ratio and strain ratio. The SRCFT stub columns exhibited better ductility than CFT stub columns. The inserted steel section can effectively prevent shear cracks in the core concrete from propagating quickly. Furthermore, finite element model was established and verified by comparing the experimental and FE results. Then, the complex composite action among the steel tube, core concrete and steel section was discussed and clarified comprehensively. In addition, the capacity of the energy dissipation for SRCFT stub columns was discussed. Finally, a novel simplified formula was proposed to predict the ultimate bearing capacity of SRCFT stub.

**ABSTRACT:** Concrete-filled steel tube (CFT) are widely used as critical members for various types of structures such as bridges, high-rise buildings etc. However, there is a lack of proper models in standards to calculate the capacity of CFT members especially for high strength steel and concrete. This leads to various experiments and simulations conducted and provided in literature and a data-driven is a potential candidate with such plenty of data. The developed model used Artificial Neural Network, ANN, and this model well performed on the test set with R² is up to 0.9899. Consequently, the ANN model is incorporated with a novel optimization algorithm, the Balancing Composite Motion Optimization - BCMO, recently proposed by Le-Duc et al. This new algorithm is compared with other existing algorithms including: Differential Evolution, Dual Annealing and Second-harmonic generation, to observe the differences among these algorithms. The parameter study of the number of individuals and the maximum generations of the BCMO also conducted for further investigations. Finally, taking the advantage of computationally cost saving of the BCMO, the ANN is again conducted with the inputs is the length and the load applied on the short columns and the output is the objective functions. This ANN is a high accuracy model with R² is 0.9984, which aimed to provide the designer a rough prediction of the Objective function, which especially useful when the monetary unit cost of materials used is available.


**ABSTRACT:** The load carrying capacity of cold-formed steel (CFS) beams can be enhanced by employing optimisation techniques. Recent research studies have mainly focused on optimising the bending capacity of the CFS beams for a given amount of material. However, to the best of authors’ knowledge, very limited research has been performed to optimise the CFS beams subject to shear and web crippling actions for a given amount of material. This paper presents the optimisation of CFS lipped channel beams for maximum bending, shear, and web crippling actions combined, leading to a novel conceptual development. The bending, shear and web crippling strengths of the sections were determined based on the provisions in Eurocode 3, while the optimisation process was performed by the means of Particle Swarm Optimisation (PSO) method. Combined theoretical and manufacturing constraints were imposed during the optimisation to ensure the practicality of optimised CFS beams. Non-linear Finite Element (FE) analysis with imperfections was employed to simulate the structural behaviour of optimised CFS lipped channel beams after successful validation against previous experimental results. The results demonstrated that, the optimised CFS sections are more effective (bending, shear, and web crippling actions resulted in 30%, 6%, and 13% of capacity increase, respectively) compared to the conventional CFS sections with same amount of material (weight). The proposed optimisation framework can be used to enhance the structural efficiency of CFS lipped channel beams under combined bending, shear, and web crippling actions.


**ABSTRACT:** Steel-reinforced concrete-filled circular steel tubular (SRCFT) stub columns is a novel type of composite columns, which have a great potential to be used as piers or columns in practical engineering. Hence, it is essential to comprehend the compressive performance of SRCFT stub columns and suitably predict the compressive strength for the engineering design and applications. This paper aims to investigate the compressive behavior of SRCFT stub columns through combined experimental and numerical studies. A total of 8 specimens were tested to investigate the compressive performance of SRCFT stub columns in detail, in terms of the axial load-strain curve, ultimate bearing capacity, ductility, strength-weight-ratio and strain ratio. The SRCFT stub columns exhibited better ductility than CFT stub columns. The inserted steel section can effectively prevent shear cracks in the core concrete from propagating quickly. Furthermore, finite element model was established and verified by comparing the experimental and FE results. Then, the complex composite action among the steel tube, core concrete and steel section was discussed and clarified comprehensively. In addition, the capacity of the energy dissipation for SRCFT stub columns was discussed. Finally, a novel simplified formula was proposed to predict the ultimate bearing capacity of SRCFT stub.
columns. The studies may provide a considerable reference for designing this type of structures in engineering practice.


**ABSTRACT:** The large-deflection analysis of a tapered beam-column under transverse loadings and restrained axially is presented. The proposed method is based on the Differential Transform Method (DTM) but with improved efficiency. This is achieved by separately analyzing and incorporating the differential transform of the trigonometric functions $\sin(\theta)$ and $\cos(\theta)$ with $[\text{math}]$ being the solution to the problem making possible to work with series of order $m = 20$ without incurring into excessive computational effort and calculation time. The transformed equations convert the governing integro-differential equation of the problem into a polynomial equation with the coefficients found by recurrence with its solution much easier to determine. The accuracy of the improved DTM depends on the order $m$ of the series becoming the “exact” solution to the differential integral equation as $m$ tends to infinity. The minimum value of $m$ required in the expansion depends on the applied loads on the beam-column, its support conditions and geometry. Two classic beam-columns are analyzed herein using the proposed method: 1) a simple-supported beam-column partially restrained axially subject to a uniformly distributed transverse load; and 2) a tapered cantilever beam-column subject to a concentrated transverse load at the free end. The obtained results are compared with those reported by other researchers with excellent agreement showing the validity and simplicity of the proposed method and its corresponding equations.


**ABSTRACT:** This research is aimed to develop an efficient and high-performance four-node *iso*-parametric beam element, which is composed of Functionally Graded Material (FGM). In addition, different patterns of material distribution will be considered through the height of element. On the other hand, beam’s imperfection, presented here with porosity, is taken into account by using the rule of mixture. In order to alleviate the shear locking, Mixed Interpolation of Tensorial Components (MITC) is utilized by using tying points. Strain interpolation at some tying points reduces the order of strain functions. Therefore, three Gauss points can be employed for numerical integration instead of four Gauss points. Furthermore, the geometrically nonlinear effects are incorporated by using Green-Lagrange strains. Since the material properties are considered to be thermal-independent, they remain constant during the analysis. Finally, some benchmark problems are solved to illustrate the correctness of formulation and accuracy of the proposed element. Several parameters, including porosity percentage, FGM patterns and corresponding power indices, are investigated in the other examples. It is observed that the proposed element is more accurate for linear and nonlinear analyses of the thin beam with large deformations and rotations, even by using fewer numbers of elements compared to other developed elements. On the other hand, both axial and transverse displacements decrease when the value of the exponent of sigmoid pattern increases. On the contrary, the exponent of power pattern has a different effect on the axial displacement.


**ABSTRACT:** Estimating the buckling resistance of stiffened plates with detailed numerical models can provide high fidelity results, but for the preliminary design phase of aircraft structures this is impractical, since numerous iterations or sensitivity analyses are required. Analytical solutions become preferable for this design phase. To this end, an approximate closed-form solution is developed to estimate the critical skin local buckling load of stiffened plates with omega stringers with antisymmetric cross-ply and angle-ply lamination. This is obtained using an innovative energy-based homogenization method that yields to an equivalent bending stiffness matrix. The research further examines the influence of two key parameters to the analytical estimation of the buckling load of the fore mentioned partially anisotropic skin. The first parameter concerns the selection of the appropriate boundary conditions that must be assumed for the skin-stringer junction. The mathematical
model considers the part of the skin between two consecutive omega stringers. The rest of the stiffened plate is replaced by equivalent transverse and rotational springs, which act as elastic edge supports. The elastic restraints are determined with two distinctive approaches considering the bending and torsional stiffness of the omega stringers. As a second parameter two different deflection functions (trigonometric and polynomial) are considered for the Rayleigh-Ritz method. Aim is to determine the appropriate combination of elastic restraint stiffness and deflection function that yield to more accurate buckling results for the cases of antisymmetric cross-ply and angle-ply skin laminations. Finally, the obtained analytical results are evaluated by comparing them with the respective numerical. The comparison showed that a satisfactory correlation can be achieved, for a certain combination of boundary conditions and deflection functions. Discussion and conclusions regarding the accuracy, discrepancies and limitations of the derived buckling solution are highlighted.

Structures, Vol. 28, pp 1196-1209, December 2020,


ABSTRACT: A novel family of smooth-shell structures is introduced as mechanical metamaterials of exceptional specific energy absorption capacity. The proposed shell structures respect all symmetries of the face-centered cubic crystal. To obtain a smooth curvature shell structure, the exact shape of the shell mid-plane is determined through the minimization of a bending-energy based measure of the overall curvature. Among the members of this new family, the mechanical properties of a Triply Periodic Minimal Surface (TPMS) -like architecture and an elastically-isotropic derivate are investigated in detail. The TPMS-like structure showed important anisotropy in both its small and large strain responses, with loading-direction dependent differences in stiffness of more than 100%. The mechanical properties of the elastically-isotropic shell-lattice turned out to be close to the mean value for all directions of loading for the TPMS-like structures. For relative densities ranging from 1% to 50%, the shell-lattices always exhibited a higher mechanical performance than truss-lattices of equal density. For relative densities greater than 20%, the mechanical response of the shell-lattices is more stable than that of truss-lattices which makes them particularly suitable as higher order structures in hierarchical metamaterial design. The computational results are partially confirmed through compression experiments on additively-manufactured stainless steel specimens. A direct comparison of the stress–strain curve of additively-manufactured stainless steel 316 L with that of sheets made from the same alloy revealed an increase in yield strength of about 30% related to the selective laser melting process.


ABSTRACT: Voltage controlled dielectric membranes exhibit two fundamental types of instability, strongly affecting their performances: the occurrence of wrinkling, which is due to membranal compressive stresses, and the onset of pull-in, a catastrophic thinning localisation that precludes electrical breakdown. In this manuscript we provide a unifying energetic description of both instabilities for large, out-of-plane and inhomogeneous deformations. By using the ideas of relaxation and regularisation of the energy, originally proposed by Pipkin (1986) and Hilgers and Pipkin (1992) for purely elastic membranes, we show that the onset and development of wrinkling can be effectively described by the relaxed electroelastic energy. For axially symmetric membranes and neo-Hookean materials, we show that pull-in corresponds to failure of the strong ellipticity condition of the regularised electroelastic energy, thus extending to out-of-plane deformations the validity of a previous estimate for planar systems (Zurlo et al., 2017). In agreement with ubiquitous experimental evidence, we also show that wrinkled states are always stable below the pull-in voltage. Our theoretical findings are assessed by the
comparison with experiments on out-of-plane, voltage-actuated annular membranes, showing good agreement both in terms of description of wrinkled states, and for the prediction of the pull-in instability.

References listed at the end of the paper:


ABSTRACT: As one typical representative of van der Waals structures, multilayered graphene sheets (MLGSs) have attracted much attention in recent years due to their unusual properties and new phenomena. Due to the ultralow interlayer interaction, these materials may easily encounter mechanical failure and subsequently the malfunction of devices. It becomes essential to clarify failure modes and the beneath mechanism. Through an inverse blister test, bending induced failure (local buckling) of MLGSs is observed experimentally. Theoretical modeling and molecular dynamics simulations are then conducted to investigate the bending behavior of MLGSs without any edge constrain. We demonstrate three failure modes, including interlayer shearing, rippling and kink buckling/delamination. Compared with previous studies, we find the occurrence of failure is length and thickness dependent. Short sheets prefer to continuous interlayer shearing, long and thin/thick sheets prefer to snap-through sliding, while long and medium-thick sheets prefer to kink buckling. We propose failure criteria and draw a phase diagram to predict the failure modes. Furthermore, we analytically deduce the bending stiffness of MLGSs before the failure which is also found to be length dependent that below a critical length (≈9.7 nm), it decreases dramatically. Our results not only shed new light for understanding the bending behavior of MLGS, but also extend to other heterostructures, paving the way for potential implications of 2-dimensional materials.

References listed at the end of the paper:
1 F. Ahmadpoor, P. Sharma, Flexoelectricity in two-dimensional crystalline and biological membranes, Nanoscale, 7 (2015), pp. 16555-16570
In this work, the electromechanical wrinkling of a highly stretched substrate-free dielectric elastic membrane is theoretically and experimentally studied. Considering the hyperelasticity, anisotropy of the bending stiffness, and electromechanical coupled deformation of the dielectric elastic membrane, a general theoretical model for the wrinkling of a pre-stretched substrate-free membrane is developed. The theoretical model analytically predicts the critical voltage and wavelength of the membrane at the onset of its buckling, which agrees well with the experimental and simulation results. In the post buckling stage, based on Föppl-von Karman stain, the buckling amplitude is analytically derived and coincides with the experiments and
simulations as well. The effects of pre-stretching ratio, membrane geometry, electrode thickness, and material property on the critical wrinkle voltage, wrinkle wavelength and electrical breakdown are discussed systematically, based on which a full deformation diagram of the substrate-free membrane under voltage is given. Compared to previous works that interpreted membrane wrinkling simply by the direction change of principle stress (from positive to negative), this work takes a significant step forward to develop theoretical models that can analytically and quantitatively predict the wrinkle wavelength, post-buckling amplitude, and critical wrinkling voltage of the substrate-free membrane. The results herein shed useful insights for the regulation and control of membrane wrinkling which holds potential applications in intelligent structures and devices.

References listed at the end of the paper:
28 Y. Liu, J. Genzer, M.D. Dickey, "2D or not 2D": Shape-programming polymer sheets, Prog. Polym. Sci., 52 (2016), pp. 79–106
ABSTRACT: Motivated by observations of snap-through phenomena in buckled elastic strips subject to clamping and lateral end translations, we experimentally explore the multi-stability and bifurcations of thin bands of various widths and compare these results with numerical continuation of a perfectly anisotropic Kirchhoff rod. Our choice of boundary conditions is not easily satisfied by the anisotropic structures, forcing a cooperation between bending and twisting deformations. We find that, despite clear physical differences between rods and strips, a naive Kirchhoff model works surprisingly well as an organizing framework for the experimental observations. In the context of this model, we observe that anisotropy creates new states and alters the connectivity between existing states. Our results are a preliminary look at relatively unstudied boundary conditions for rods and strips that may arise in a variety of engineering applications, and may guide the avoidance of jump phenomena in such settings. We also briefly comment on the limitations of current strip models.

References listed at the end of the paper:

45 Dias, M.A., personal communication.
63 Such toys are known under various names, including princess wands and spinsations. For videos, see www.hippie-sticks.com.


ABSTRACT: Tensegrity structures are special architectures made by floating compressed struts kept together by a continuous system of tensioned cables. Their existence in a mechanically stable form is decided by the possibility of finding geometrical configurations such that pre-stressed tendons and bars can ensure self-equilibrium of the forces transmitted through the elastic network, the overall stiffness of which finally depends on both the rigidity of the compressed elements and the cables’ pre-stress. The multiplicity of shapes that tensegrity structures can assume and their intrinsic capability to be deployable and assembled, so storing (and releasing) elastic energy, have motivated their success as paradigm –pioneeringly proposed three decades ago by the intuition of Donald E. Ingber– to explain some underlying mechanisms regulating dynamics of living cells. The interlaced structure of the cell cytoskeleton, constituted by actin microfilaments, intermediate filaments and microtubules which continuously change their spatial organization and pre-stresses through polymerization/depolymerization processes, seems in fact to steer migration, adhesion and cell division by obeying the tensegrity construct. Even though rough calculations lead to estimate discrepancies of less than one order of magnitude when comparing axial stiffness of actin filaments (cables) and microtubules (struts) and recent works have shown bent microtubules among stretched filaments, no one has yet tried to remove the standard hypothesis of rigid struts in tensegrity structures when used to idealize the cell cytoskeleton mechanical response. With reference to the 30-element tensegrity cell paradigm, we thus introduce both compressibility and bendability of the struts and accordingly rewrite the theory to simultaneously take into
account geometrical non-linearity (i.e. large deformations) and hyper-elasticity of both tendons and bars, so abandoning the classical linear stress-strain constitutive assumptions. By relaxing the hypothesis of rigidity of the struts, we demonstrate that some quantitative confirmations and many related extreme and somehow counter-intuitive mechanical behaviors actually exploited by cells for storing/releasing energy, resisting to applied loads and deforming by modulating their overall elasticity and shape through pre-stress changes and instability-guided configurational switching, can be all theoretically found. It is felt that the proposed new soft-strut tensegrity model could pave the way for a wider use of engineering models in cell mechanobiology and in designing bio-inspired materials and soft robots.


ABSTRACT: We present results from physical and numerical experiments on the rigidity of hemispherical gridshells under point load indentation. By systematically exploring the relevant parameters of the system, we provide a scaling law for the rigidity of elastic gridshells in terms of the dimension of the structure and the number of rods it contains, as well as the geometric and material properties of the individual rods. Our approach combines a set of precision desktop-scale experiments and discrete elastic rod simulations, which are found to be in excellent quantitative agreement. Our proposed empirical relation for the rigidity also points to the underlying nonlocal nature of the mechanical response of gridshells, in contrast to the local response of isotropic continuum shells. We further assess this nonlocality by quantifying the resulting radial displacement field as well as inspecting the effect of the location of the indentation point on the rigidity.


ABSTRACT: Wrinkles commonly occur in uniaxially stretched rectangular hyperelastic membranes with clamped-clamped boundaries, and can vanish upon excess stretching. Here we develop a modeling and resolution framework to solve this complex instability problem with highly geometric and material nonlinearities. We extend the nonlinear Föppl-von Kármán thin plate model to finite membrane strain regime for various compressible and incompressible hyperelastic materials. Under plane stress condition, 2D hyperelastic constitutive models can be systematically deduced based on general 3D strain energy potentials, e.g., Saint-Venant Kirchhoff, neo-Hookean, Mooney-Rivlin, Gent model and Gent-Gent model. Moreover, we establish a novel and efficient numerical resolution framework combining a path-following continuation technique by Asymptotic Numerical Method (ANM) and a discretization by a spectral method. The main advantages of this framework include the generality for both compressible and incompressible materials, ease of programming, high precision and efficient continuation predictor. Based on the proposed approach, effect of different incompressible constitutive models on the post-buckling response is investigated, which shows that restabilization points and wrinkling amplitudes are quantitatively influenced. However, for compressible materials, Poisson’s ratio plays a critical role in the wrinkling and restabilization behavior. We find that smaller Poisson’s ratio makes later onset of wrinkling, lower amplitude and earlier disappearance of wrinkles. Besides, severe strain-stiffening phenomena are explored by accounting for phenomenological models such as Gent model and Gent-Gent model. Efficiency and accuracy of the proposed modeling and resolution framework were examined by comparing with some benchmarks.


ABSTRACT: Interaction between two straight-sided buckles propagating in opposite directions has been investigated by atomic force microscopy. Below a critical separation distance, it is observed that the two buckles are attracted towards each other once their fronts have crossed. A mechanical analysis using finite element simulations has shown that the buckle interaction is strongly influenced by the substrate elasticity. The deviation of the two buckles from their initial straight propagation is discussed at the light of mode mixity mappings extracted from finite elements simulations along the crack path of the two interacting buckles.
Finally, a phase diagram depending on both the separation distance and the film/substrate elastic mismatch is proposed, in good agreement with the experimental results.


ABSTRACT: An experimental study is conducted on localized bulging of inflated latex rubber tubes of a range of wall thicknesses and tube lengths, guided by newly emerged analytical results. In the case when the tube has one free closed end that may or may not be subjected to a dead weight, the initiation pressure for localized bulging is determined by a bifurcation condition, and the propagation pressure is determined by Maxwell’s equal-area rule. It is shown that after bulge initiation the pressure will decrease monotonically towards, but will never reach, the propagation pressure, and it is when the pressure is sufficiently close to this propagation pressure that rapid propagation of the bulge in the axial direction takes place. It is found that the experimentally observed initiation pressure is around 15% below the theoretical prediction, which is consistent with the fact that bulging initiation is a sub-critical phenomenon and is therefore sensitive to imperfections. The experimentally observed propagation pressure is always very close to the theoretical prediction, which confirms the insensitivity of this pressure to imperfections and demonstrates the predictive power of the material model fitted from our own experiments on equibiaxial stretching. In the other case when the tube is first stretched and then fixed at both ends, bulge initiation takes place in the same manner as in the previous case, but the propagation pressure is no longer determined by Maxwell’s equal-area rule. After bulge initiation the pressure will first decrease to a minimum and then rises slowly, and it is on the latter ascending path that the bulge starts to propagate rapidly in the axial direction. A semi-analytical method is proposed for the determination of the minimum pressure. Numerical simulations with the use of the software Abaqus are also conducted to verify the theoretical predictions.


ABSTRACT: We study the dynamics of snap-through when viscoelastic effects are present. To gain analytical insight we analyse a modified form of the Mises truss, a single-degree-of-freedom structure, which features an ‘inverted’ shape that snaps to a ‘natural’ shape. Motivated by the anomalously slow snap-through exhibited by spherical elastic caps, we consider a thought experiment in which the truss is first indented to an inverted state and allowed to relax while a specified displacement is maintained; the constraint of an imposed displacement is then removed. Focussing on the dynamics for the limit in which the timescale of viscous relaxation is much larger than the characteristic elastic timescale, we show that two types of snap-through are possible: the truss either immediately snaps back over the elastic timescale or it displays ‘pseudo-bistability’, in which it undergoes a slow creeping motion before rapidly accelerating. In particular, we demonstrate that accurately determining when pseudo-bistability occurs requires the consideration of inertial effects immediately after the indentation force is removed. Our analysis also explains many basic features of pseudo-bistability that have been observed previously in experiments and numerical simulations; for example, we show that pseudo-bistability occurs in a narrow parameter range at the bifurcation between bistability and monostability, so that the dynamics is naturally susceptible to critical slowing down. We then study an analogous thought experiment performed on a continuous arch, showing that the qualitative features of the snap-through dynamics are well captured by the truss model. In addition, we analyse experimental and numerical data of viscoelastic snap-through times reported previously in the literature. Combining these approaches suggests that our conclusions may also extend to more complex viscoelastic structures used in morphing applications.


ABSTRACT: Under a variety of external stimuli, hydrogels can undergo coupled solid deformation and fluid diffusion and exhibit large volume changes. The numerical analysis of this process can be complicated by numerical instabilities when using mixed formulations due to the violation of the inf-sup condition. In addition,
the large deformations produce complex instability patterns causing singularities in the underlying set of equations. For these reasons, the experimentally observed complex patterns remain elusive and poorly understood. Furthermore, a stability criterion suitable to detect critical conditions and predict post-instability patterns is lacking for hydrogel simulations. Here we investigate the stability criterion for coupled problems with a saddle point nature and propose a generic framework to study diffusion-driven swelling-induced instabilities of hydrogels. Adopting a numerically stable subdivision-based mixed isogeometric analysis, we show that the proposed framework for stability analysis accurately captures instability points during the transient swelling of hydrogels. The influence of geometrical and material parameters on the critical conditions are also presented in stability diagrams for two useful problems involving the buckling of hydrogel rods and the wrinkling on the surface of hydrogel bilayers. The results show that the short-time response of hydrogels immersed in water are highly unstable. We believe that this generic scheme provides a theoretical and computational foundation to study the morphogenesis in nature, and it also paves the way to create functional materials and design novel hydrogel devices through stability diagrams.


ABSTRACT: Like all other materials, biological soft tissues are subject to general laws of physics, including those governing mechanical equilibrium and stability. In addition, however, these tissues are able to respond actively to changes in their mechanical and chemical environment. There is, therefore, a pressing need to understand such processes theoretically. In this paper, we present a new rate-based constrained mixture formulation suitable for studying mechanobiological equilibrium and stability of soft tissues exposed to transient or sustained changes in material composition or applied loading. These concepts are illustrated for canonical problems in arterial mechanics, which distinguish possible stable versus unstable mechanobiological responses. Such analyses promise to yield insight into biological processes that govern both health and disease progression.


ABSTRACT: Many forms of stretchable electronic systems incorporate planar, filamentary serpentine structures to realize high levels of stretchability in ways that allow the use of high performance of inorganic functional materials. Recent advances in mechanics-guided, deterministic three-dimensional (3D) assembly provide routes to transform these traditional, two-dimensional (2D) serpentine layouts into 3D architectures, with significantly improved mechanics and potential for applications in energy harvesters, pressure sensors, soft robotics, biomedical devices and other classes of technologies. One challenge is that, by comparison to other geometries, the relatively low bending stiffnesses of the serpentine structures create difficulties in overcoming the interfacial adhesion energy to allow delamination from the underlying elastomeric substrate, as an essential aspect of the assembly process. An additional complication is that many of the functional materials widely used in stretchable electronics have a low strain threshold for failure such that damage can occur during buckling-induced assembly. Therefore, a clear understanding of the mechanics of buckled serpentine structures is essential to their design, fabrication and application. Through theoretical modeling and finite element analysis, we present models for the phase diagram of buckled states and the maximum strain in the globally-buckled serpentine structures. The analysis yield formulae in concise and explicit forms, clearly showing the effect of geometry/material parameters and the prestrain. The results can be used in designing buckled serpentine structures to ensure their compatibility with the mechanics-guided, deterministic 3D assembly and facilitate their applications in stretchable electronics.

ABSTRACT: We propose a 3D-printed graded lattice made of hollow elliptical cylinders (HECs) as a new way to design impact mitigation systems. We observe asymmetric dynamics in the graded HEC chains with increasing and decreasing stiffness. Specifically, the increasing stiffness chain shows an acceleration of the propagating waves, while the decreasing stiffness chain shows the opposite. From the standpoint of impact mitigation, the decreasing stiffness chain combined with the strain-softening behavior of HECs results in an order-of-magnitude improvement in force attenuation compared to the increasing stiffness chain. We extend this finding to the graded 2D arrays and demonstrate a similar trend of wave transmission efficiency contrast between the increasing and decreasing stiffness lattices. The 3D-printed HEC lattices shown in this study can lead to the development of a new type of impact mitigating and shock absorbing structures.


ABSTRACT: The stretchability of metal materials is often limited by the onset and development of necking instability. For instance, necking of lithium metal often occurs at low strains and thus hinders its practical applications in stretchable lithium batteries. Substrate/metal bilayers are emerging as a promising solution to the stringent stretchability requirement of metal electrodes and current collectors in flexible and stretchable batteries. So far, a comprehensive understanding of the bifurcation instability of substrate-supported metal layers under arbitrary biaxial in-plane tensile loading still remains elusive. Most existing theoretical and numerical studies of the bifurcation instability of substrate-supported metal layers assume either plane strain condition or single-necking mode (i.e., a single diffusive neck occurs). However, in conducted experiments, substrate/metal bilayers are subjected to uniaxial tensile loading and formation of multiple necks is observed during the tests. This paper presents an all-wavelength bifurcation analysis to understand the deformation instability of substrate/metal bilayers under arbitrary biaxial tensile loadings, from equi-biaxial tension, to plane-strain tension, and to uniaxial tension. Two representative bilayer structures are investigated, namely, a metal layer supported by a plastic substrate and a metal layer supported by an elastomer substrate. The analysis predicts three bifurcation modes of substrate/metal bilayers, including single-necking mode, multiple-necking mode, and surface mode. The results quantitatively demonstrate the bifurcation retardation effect of the supporting substrate: the stiffer/thicker is the substrate, the higher is the bifurcation limit. More importantly, it is further shown that there exists a theoretical upper bound of the bifurcation limit of a substrate/metal bilayer structure, which has not been reported before. Understandings from the present study may shed light on the optimal design of substrate/metal bilayer structures with enhanced deformability under complex biaxial loading conditions.


ABSTRACT: Centimetres-long carbon nanotube (CNT) bundles with tensile strength over 80 GPa have been fabricated and tested recently [Nat. Nanotechnol. 13, 589–595 (2018)], but it is still a tremendous challenge to predict their nonlinear mechanical behaviors by full-atom molecular dynamics (MD) due to the huge computational cost, particularly for carbon nanotube networks. We completely established here the explicit expressions of the chirality-dependent higher-order nonlinear coarse-grained stretching and bending potentials based on the full-atom Reactive Empirical Bond-Order interatomic potential of second generation (REBO potential). In particular, the coarse-grained non-bonded potentials are improved by using the 18–24 Lennard-Jones potential. By comparison with available experimental results and full-atom MD simulations as well as our analytical results, the present nonlinear coarse-grained potentials have high accuracy. The obtained nonlinear coarse-grained potentials can be used to efficiently characterize the nonlinear mechanical behaviors and understand the failure mechanism of the CNT bundles and networks with 2~5 orders of magnitude reduction in computing time, which should be of great help for designing and assembling CNT-based flexible microdevices.

ABSTRACT: Subjected to compressive stresses, soft polymers with stiffness gradients can display various buckling patterns. These compressive stresses can have different origins, like mechanical forces, temperature changes, or, for hydrogel materials, osmotic swelling. Here, we focus on the influence of the transient nature of osmotic swelling on the initiation of buckling in confined layered hydrogel structures. A constitutive model for transient hydrogel swelling is outlined and implemented as a user-subroutine for the commercial finite element software Abaqus. The finite element procedure is benchmarked against linear perturbation analysis results for equilibrium swelling showing excellent correspondence. Based on the finite element results we conclude that the initiation of buckling in a two-layered hydrogel structure is highly affected by transient swelling effects, with instability emerging at lower swelling ratios and later in time with a lower diffusion coefficient. In addition, for hard-on-soft systems the wavelength of the buckling pattern is found to decrease as the diffusivity of the material is reduced for gels with a relatively low stiffness gradient between the substrate and the upper film. This study highlights the difference between equilibrium and transient swelling when it comes to the onset of instability in hydrogels, which is believed to be of importance as a fundamental aspect of swelling as well as providing input to guiding principles in the design of specific hydrogel systems.


ABSTRACT: The buckling and the post buckling of a simple model involving both large deformations and elastic-plasticity are studied. Plasticity is described by the classical incremental constitutive law involving in particular non regularized transition between plastic loading and elastic unloading. The kinematics is chosen in order to take into account any rotation, however large, without having to resort to approximations or asymptotic expansions. The work focusses essentially on the specificity of the coupling between these two types of nonlinearity. At small strains the global behavior is correctly given by Hutchinson’s simple model involving the same elastic-plastic constitutive law and linearized deformations. But at very large strains, the response notably differs from that of Hutchinson’s model. Indeed plasticity seems to have no effect and the behavior is that of a system involving the same nonlinear deformations but with a constant modulus. From the point of view of bifurcation analysis this result is qualitatively interesting due to the fact that the elastic-plastic constitutive law can be regarded as a strong, or non-smooth, nonlinearity, whereas large deformations is a smooth, we could say weaker, non linearity, so that the result contradicts the intuition that the strongest non linearity should be associated with the strongest bifurcation effect. The analysis is carried out using two different geometrical nonlinearities.

(No appropriate papers through October 2019)


ABSTRACT: In this paper, a gradient theory for large deformation analysis of elastic membranes is developed. Thin membranes are modelled as material surfaces, and the formulation starts with an internal energy density function, which is assumed to be dependent upon the first as well as the second spatial derivatives of deformation field. Governing equilibrium equations and boundary conditions are derived in a variational framework. General forms of constitutive equations for the developed model are discussed. In particular, constitutive laws incorporating two material length-scale parameters and suitable for isotropic as well as anisotropic materials are introduced. Since the strong form of the governing differential equations is highly nonlinear, a finite element formulation for numerical solution of initially flat gradient-elastic membranes is developed. As an application of the introduced theory, wrinkling phenomenon in a thin elastic membrane under uniaxial stretching is studied. Numerical simulations show that by proper selection of the material length-scale
parameters in the proposed constitutive law, the theory is capable of capturing the detailed wrinkling patterns in stretched membranes. Notably, the maximum wrinkling amplitude obtained by the present formulation has good agreement to the experimental data reported in the literature. Applicability of the developed formulation to predict the deformation of anisotropic materials is also investigated. In particular, it is also shown that the formulation is able to successfully capture the buckling of pantographic lattice as well as wrinkling of engineering fabrics.

Steven Wehmeyer (1), Frank W. Zok (2), Christopher Eberl (3,4), Peter Gumbsch (3,5), Noy Cohen (6), Robert M. McMeeking (6) and Matthew R. Begley (1,2)
(1) Department of Mechanical Engineering, University of California, Santa Barbara, United States
(2) Materials Department, University of California, Santa Barbara, United States
(3) Fraunhofer Institute for Mechanics of Materials IWM, Freiburg, Germany
(4) University of Freiburg, Freiburg, Germany
(5) Institute for Applied Materials IAM, Karlsruhe Institute of Technology KIT, Karlsruhe, Germany
(6) Department of Mechanical Engineering & Materials Department, University of California, Santa Barbara, United States

ABSTRACT: This paper presents analytical and reduced-order numerical solutions describing the non-linear response of slender, elastic struts (or plates) inclined relative to the loading direction. The solutions provide a highly efficient framework to predict post-buckling behaviors in cellular structures, including: stability regimes, peak strains during and after buckling, the work dissipated via cyclic loading, the impact of biaxial loading, and the role of geometric imperfections in the struts. Regime maps are presented that illustrate configurations that lead to snap-through, permanent deformation after unloading, strut failure, and enhanced hysteresis during cyclic loading. The maps illustrate that reversible snap-through events only occur within a very specific range of relative density (e.g., about 0.25 – 0.4 for rhombic lattices). A highly efficient non-linear single degree-of-freedom dynamics model is derived from the statics solution, and is shown to be in excellent agreement with fully explicit, non-linear, dynamic finite element simulations for inclined struts. This simplified dynamics model is used to quantify the relationships between quasi-static responses, loading frequencies and energy dissipation during cycling loading. A key finding is that effective damping during cyclic loading is dramatically increased by non-linear behavior, even when the corresponding quasi-static result exhibits zero hysteresis. The implications for structured foams and the design of lightweight structural dampers is briefly discussed.

ABSTRACT: This work studies experimentally and numerically the post-bifurcation response of a magneto rheological elastomer (MRE) film bonded to a soft non-magnetic (passive) substrate. The film-substrate system is subjected to a combination of an axial mechanical pre-compression and a transverse magnetic field. The non-trivial interaction of the two fields leads to a decrease of the critical magnetic field with applied pre-compression, while the observed wrinkling patterns evolve into crinkles, a bifurcation mode that is defined by the accompanied curvature localization and strong shearing of the side faces of the wrinkled geometry. Using a magneto-elastic variational formulation in a two-dimensional finite element numerical setting, we find that the crinkling is an intrinsic feature of magnetoelasticity and its presence is directly associated with the repulsive magnetic forces of the neighboring wrinkled-crinkled faces. As a result, the presence of the magnetic field prohibits the formation of creases and folds. In an effort to obtain a good quantitative agreement between the numerical and the experimental results, we also introduce an approximate way to model the friction of the lateral film-substrate faces. This analysis reveals the strong effects of friction upon the magneto-mechanical wrinkling modes.

Ting Wang (1), Yifan Yang (1), Chenbo Fu (1), Fei Liu (1), Kui Wang (2) and Fan Xu (1)

(1) Institute of Mechanics and Computational Engineering, Department of Aeronautics and Astronautics, Fudan University, 220 Handan Road, Shanghai 200433, PR China
(2) School of Traffic and Transportation Engineering, Central South University, Changsha 410075, PR China


ABSTRACT: Transverse wrinkles usually occur in a uniaxially tensile elastic membrane and will be smoothed upon excess stretching. This instability-restabilization response (isola-center bifurcation) can originate from the nonlinear competition between stretching energy and bending energy. Here, we find a crucial factor, the curvature, which can control effectively and precisely the wrinkling and smoothing regimes. When the sheet is bent, the regime of wrinkling amplitude versus membrane elongation is narrowed, with local wrinkling instability coupled with global bending. There exists a critical curvature, where no wrinkles appear when the value is beyond this threshold. The curvature effects on wrinkling-smoothing behavior have been quantitatively explored by our theories, computations and experiments. The models developed in this work can describe large in-plane strains of soft shells to effectively capture this transition behavior, which build on general differential geometry and thus can be extended to arbitrarily curved surfaces. Our findings may shed light on designs of wrinkle-tunable membrane surfaces and structures.

References listed at the end of the paper:
11 N. Friedl, F.G. Rammerstorfer, F.D. Fischer, Buckling of stretched strips, Comput. Struct., 78 (2000), pp. 185-190
17 N. Jacques, M. Potier-Ferry, On mode localisation in tensile plate buckling, C.R. Mec., 333 (2005), pp. 804-809

Flexible carbon nanosprings and wavy nanofibers can be used in micro and nanoelectromechanical system devices, deployable structures, flexible displays, energy storage, catalysis, and nanocomposites and a multitude of other uses. A novel method to produce wavy and helical carbon nanofibers (CNFs) is presented here. The CNFs with controlled geometry were fabricated via pyrolysis of electrospun polyacrylonitrile (PAN) nanofibers as the precursor. The waviness/helicity of nanofibers was achieved by subjecting the precursor nanofibers to constraint buckling inside a thermally shrinking matrix. The much higher tendency of the matrix to shrink, compared to PAN nanofibers, was achieved by controlling the microstructure and crystallinity of the precursors. The formation of the wavy/helical geometry was explained quantitatively via mechanic models, by minimizing the total mechanical energy stored in the PAN-matrix system during the matrix shrinkage. Despite its simplicity in considering elastic deformations only, the model provided reasonably quantitative matching with the experiments. Compared to existing methods in generating wavy/helical
nanofibers, such as chemical vapor deposition growth methods, our method provides a more controllable geometry which is suitable for large scale production of aligned buckled CNFs.

References listed at the end of the paper:


4 J. Bicerano, Prediction of Polymer Properties (Plastics Engineering), Marcel Dekker (2002), p. 746


15 L. Del Castillo, et al., Flexible electronic assemblies for space applications, presented at the 2010 IEEE Aerospace Conference (2010), http://dx.doi.org/10.1109/aero.2010.5446717


ABSTRACT: Advanced composite materials enable the development of lightweight and stiff deployable structures that have significant potential for the space sector. In particular, a morphing cylindrical lattice can deploy from a small cylinder to one that is substantially thinner and longer and is particularly suited for deploying solar arrays or antennae. The morphing behaviour of the lattice stems from the nonlinear strain energy state obtained from prestressing strips of orthotropic material. Current analytical models used to describe the behaviour of morphing lattices only consider bending strains in the strain energy formulation. This paper extends state-of-the-art modelling techniques by including both transverse curvature and membrane strains, associated with non-zero Gaussian curvature, in the strain energy formulation. Transverse curvatures in tandem with longitudinal curvatures lead to the development of membrane strains, giving a complex interplay between membrane and bending strain energies and their combined effect on morphing properties of the lattice providing a rich tailorable nonlinear response. The analytical model developed is compared against finite element modelling and the first experimental results reported for such multi-stable composite helical lattices, showing good agreement over a range of designs.

Fei Jia (1) and Martine Ben Amar (2)
(1) Department of Astronautical Science and Mechanics, Harbin Institute of Technology (HIT), No. 92 West Dazhi Street, Harbin 150001, China
(2) Laboratoire de Physique de l’Ecole normale supérieure, ENS, Université PSL, CNRS, Sorbonne Université, 24 rue Lhomond, Paris 75005, France


ABSTRACT: We revisit the classical theory of indentation for very soft materials. Many experiments consist in extracting the stiffness of a membrane from the cubic answer of the force versus indentation depth. However, this law is restricted to a perfect membrane under a sharp point loading. In biophysical experiments, where this technique recovers some success at low scales thanks to AFM, the thin samples are highly deformable, hyper-elastic, pre-stretched and often attached to a substrate which cannot be neglected. In addition microscopic tiny pores may exist or may be created by the indenter. This diversity requires specific studies with the correct elasticity: here we choose the neo-Hookean elastic model at large membrane deformations. We show that, the weak loading regime is extremely sensitive to any physical properties of the thin layer but also of the indenter geometry. In addition, when a hole exists, at finite forcing or finite indentation depth, we discover a topological bifurcation with abrupt dynamical jump variation of typical quantities such as the hole size. This bifurcation is similar to the famous catenoid instabilities which are also due to a topological bifurcation, when the two rings of support are pulled apart. This bifurcation is robust in the sense that it always exists whatever the physical properties of the sample.

Yan Zhao (1), Hanlin Zhu (1), Chao Jiang (1), Yanping Cao (2) and Xi-Qiao Feng (2)
(1) State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, College of Mechanical and Vehicle Engineering, Hunan University, Changsha 410082, PR China
(2) Institute of Biomechanics and Medical Engineering, AML, Department of Engineering Mechanics, Tsinghua University, Beijing 100084, PR China

ABSTRACT: We investigate the effects of surface curvature on the wrinkling pattern evolution in soft materials. Theoretical analysis and the Fourier spectral method are combined to understand the occurrence of surface wrinkling and pattern transitions. We reveal that surface curvature and its anisotropy play a key role in wrinkling pattern transitions, for example, from the sinusoidal to the hexagonal mode. Based on the nonlinear equilibrium equations, a Fourier spectral method is developed to track the surface wrinkling pattern evolution in a curved bilayer system. This method is validated by comparison between the simulation results and relevant experiments. The simulations show that a hexagonal phase may evolve into either a bistable or labyrinth phase, depending on the curvature anisotropy, the excess stress, a dimensionless curvature parameter, and the curvature gradient. This work can not only help understand the pattern formation in some natural systems, but the methods presented here can also find a broad range of technical applications, for example, design of anticounterfeiting systems with high-security levels using labyrinth patterns on curved surfaces.

Yang Ye (1), Yang Liu (1) and Yibin Fu (2)
(1) Department of Mechanics, Tianjin University, Tianjin 300072, China
(2) School of Computing and Mathematics, Keele University, Staffordshire ST5 5BG, UK


ABSTRACT: A weakly nonlinear analysis is conducted for localized bulging of an inflated hyperelastic cylindrical tube of arbitrary wall thickness. Analytical expressions are obtained for the coefficients in the amplitude equation despite the fact that the primary deformation is inhomogeneous and the incremental governing equations have variable coefficients. It is shown that for each value of wall thickness a localized bulging solution does indeed bifurcate sub-critically from the primary solution for almost all values of fixed axial force or fixed axial stretch for which the bifurcation condition is satisfied, as reported in all previous experimental studies, but there also exist extreme cases of fixed axial stretch for which localized bulging gives way to localized necking. Validation is carried out by comparing with results obtained under the membrane assumption and with fully numerical simulations based on Abaqus. It is shown that even for thin-walled tubes the membrane approximation becomes poorer and poorer as the tube is subjected to increasingly larger and larger axial stretch or force prior to inflation.

Yipin Su (1,2), Bin Wu (3), Weiqiu Chen (1) and Michel Destrade (2,1)
(1) Department of Engineering Mechanics, Zhejiang University, Hangzhou 310027, PR China
(2) School of Mathematics, Statistics and Applied Mathematics, NUI Galway, University Road, Galway, Ireland
(3) Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Torino 10129, Italy


ABSTRACT: We propose theoretical and numerical analyses of smart bending deformation of a dielectric-elastic bilayer in response to a voltage, based on the nonlinear theory of electro-elasticity and the associated linearized incremental field theory. We reveal that the mechanism allowing the bending angle of the bilayer can be tuned by adjusting the applied voltage. Furthermore, we investigate how much the bilayer can be bent before it loses its stability by buckling when one of its faces is under too much compression. We find that the physical properties of the two layers must be selected to be of the same order of magnitude to obtain a consequent bending without encountering buckling. If required, the wrinkles can be designed to appear on either the inner or the outer bent surface of the buckled bilayer. We validate the results through comparison with those of the classical elastic problem.

J. Furer (1) and P. Ponte Castañeda (1,2)
(1) Graduate Group in Applied Mathematics and Computational Sciences, University of Pennsylvania, Philadelphia, PA, 19104-6315, USA
(2) Department of Mechanical Engineering and Applied Mechanics, University of Pennsylvania, Philadelphia, PA, 19104-6315, USA

ABSTRACT: This paper deals with the stability and post-bifurcation response of reinforced hyperelastic composites under general loading conditions. It has long been known that these types of materials can undergo both microscopic and macroscopic instabilities. In the latter case, when the instability does not result in material failure, the behavior of the composite after the onset of the instability is less well understood. Recent work (Avazmohammadi and Ponte Castañeda, 2016) indicates that it is possible for the “principal” solution, i.e. the solution before the onset of any instability, to bifurcate into a lower energy solution via the formation of domains. These domains form on a scale much larger than that of the heterogeneity, but still smaller than that of the macroscopic specimen. This work is concerned with such domain formation in neo-Hookean laminates under general three-dimensional loading. In order to obtain the post-bifurcation behavior, the quasiconvexification or relaxation of the principal solution is computed explicitly. In addition, it is shown that the macroscopic instabilities are triggered not by the loss of strong ellipticity, but rather by the loss of global rank-1 convexity of the principal solution, which, in general, happens first. The calculation also reveals that the relaxation requires, in general, a rank-2 “laminate-within-a-laminate” microstructure and allows for multiple “perfectly soft” modes of deformation.


ABSTRACT: Under compression deformation in low-density foams localizes into narrow bands of crushed cells. Crushing spreads at nearly constant stress with crushed and relatively undeformed material coexisting. The material returns to homogeneous deformation with increasing stress when the crushing has spread over the whole specimen. This paper presents a first attempt at representing the inhomogeneous behavior exhibited by open-cell aluminum alloy foams with relative density of 8%. A plasticity model is presented with a compressible yield function calibrated to a set of multiaxial foam crushing tests coupled with a non-associated flow rule. An essential component of the modeling effort is the introduction of a softening branch to the material stress-strain response. A cubical finite element model with an irregular mesh of solid elements is used to simulate a set of numerical crushing tests on micromechanically accurate foam models performed in a true triaxial apparatus in Yang and Kyriakides (2019). Small geometric imperfections are used to trigger localized deformation in the form of planar bands of high strain normal to the loading directions of compression. The bands broaden with the stresses tracing plateaus that mimic the random foam test results. The predicted mean stress–change in volume responses perform equally well up to a volume reduction of about 50%. At higher compressions, the stresses exhibit the gradual increase characteristic of foams in the densification regime. These parts of the stress–displacement trajectories, and mean stress–change in volume responses under-predict to some degree those recorded in the random foams. The material hardening in the densification regime appears to be deformation-dependent causing this difference.

Basile Audoly (1) and John W. Hutchinson (2)
(1) Laboratoire de mécanique des solides, CNRS, Institut Polytechnique de Paris, France
(2) School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA

ABSTRACT: This paper addresses localization of the deformation due to buckling that occurs immediately following the onset of bifurcation in the axisymmetric buckling of a perfect spherical elastic shell subject to external pressure. The localization process is so abrupt that the buckling mode of the classical eigenvalue analysis, which undulates over the entire shell, becomes modified immediately after bifurcation transitioning to an isolated dimple surrounded by an unbuckled expanse of the shell. The paper begins by revisiting earlier attempts to analyze the initial post-buckling behavior of the spherical shell, illustrating their severely limited range of validity. The unsuccessful attempts are followed by an approximate Rayleigh-Ritz solution which captures the essence of the localization process. The approximate solution reveals the pathway that begins at bifurcation from the classical mode shape to the localized dimple buckle. The second part of the paper presents an exact asymptotic expansion of the initial post-buckling behavior which accounts for localization and which further exposes the analytic details of the abruptness of the transition.

ABSTRACT: We propose a general method for deriving one-dimensional models for nonlinear structures. It captures the contribution to the strain energy arising not only from the macroscopic elastic strain as in classical structural models, but also from the strain gradient. As an illustration, we derive one-dimensional strain-gradient models for a hyper-elastic cylinder that necks, an axisymmetric membrane that produces bulges, and a two-dimensional block of elastic material subject to bending and stretching. The method offers three key advantages. First, it is nonlinear and accounts for large deformations of the cross-section, which makes it well suited for the analysis of localization in slender structures. Second, it does not require any a priori assumption on the form of the elastic solution in the cross-section, i.e., it is Ansatz-free. Thirdly, it produces one-dimensional models that are asymptotically exact when the macroscopic strain varies on a much larger length scale than the cross-section diameter.


ABSTRACT: The adhesive behavior of biological attachment structures such as spider web anchorages is usually studied using single or multiple peeling models involving “tapes”, i.e. one-dimensional contacts elements. This is an oversimplification for many practical problems, since the actual delamination process requires the modeling of complex two-dimensional adhesive elements. To achieve this, we develop a theoretical-numerical approach to simulate the detachment of an elastic membrane of finite size from a substrate, using a 3D cohesive law. The model is validated using existing analytical results for simple geometries, and then applied in a series of parametric studies. Results show how the pull-off force can be tuned or optimized by varying different geometrical or mechanical parameters in various loading scenarios. The length of the detachment boundary, known as the peeling line, emerges as the key factor to maximize adhesion. The approach presented here can allow a better understanding of the mechanical behavior of biological adhesives with complex geometries or with material anisotropies, highlighting the interaction between the stress distributions at the interface and in the membrane itself.


ABSTRACT: Multi-stable structures can provide desired reconfigurability and require relatively simple actuation. This paper considers general bar and plate structures connected by frictionless hinges that are to be made locally stable in a set of chosen target configurations by attaching extensional and rotational, linear-elastic springs to the structure. The unstressed lengths and angles of the springs, as well as their stiffnesses, are the unknown design parameters to be determined. A set of equilibrium and stability conditions to be satisfied in each of the target configurations of the structure are derived. Solutions of these equations provide specific values of the spring properties that correspond to local energy minima in all of the target configurations. The formulation is fully general and is applicable to structures of any complexity. A simple example is used to illustrate the design process for a bi-stable origami structure and a physical prototype is also presented.

ABSTRACT: A ridge-spring is a thin-walled bent strip with flat side panels. It may be folded elastically along its length, to create a localised hinge region of mostly uniform cylindrical curvature and bending moment, which do not vary with the fold angle of hinge. A simple analysis shows a common grouping in closed-form expressions; $\alpha^{4/3} \cdot (b/t)^{1/3}$, where $\alpha$ is the pitch angle of the ridge line, $b$ is the strip width and $t$ its thickness. More accurate calculations of the hinge curvature and moment confirm the robustness of simpler expressions, which are compared to data obtained from finite element simulations. It is shown that, for many initial geometries, theoretical predictions of curvature and moment are typically within 10% of the computational results—which project the same dimensional performance. We also compare a ridge-spring to a more familiar tape-spring of equal cross-sectional proportions. For moderate pitch angles and relatively small thicknesses, it is shown that a ridge-spring has a higher folded hinge curvature and bending moment, comparatively, which may prove attractive for certain applications.

Gayatri K. Cuddalorepatta (1), Wim M. van Rees (1,2), Li Han (3), Daniel Pantuso (2), L. Mahadevan (1) Joost J. Vlassak (1)

(1) School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA
(2) Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
(3) Technology Manufacturing Group, Intel Corporation, Portland, OR USA


ABSTRACT: The Poisson’s ratio and residual strain of ultra-thin films (<100 nm) are characterized using the phenomenon of transverse wrinkling in stretched bridges. The test methodology utilizes residual stress driven structures and easy to replicate clean-room fabrication and metrology techniques that can be seamlessly incorporated into a thin-film production assembly line. Freestanding rectangular ultra-thin film bridges are fabricated using dimensions that generate repeatable transverse wrinkling patterns. Numerical modeling based on the non-linear Koiter plate and shell energy formulation is conducted to correlate the Poisson’s ratio and residual strain to the measured wrinkling deformation. Poisson’s ratio affects the peak amplitudes without significantly changing the wavelength of the wrinkles. By contrast, the strain affects both the wavelength and amplitude. The proof of concept is demonstrated using 65 nm thick copper films. A Poisson’s ratio of $0.34 \pm 0.05$ and a tensile residual strain of $6.8 \pm 0.8$ are measured. The measured residual strain is in good agreement with the residual strain of $7.1 \pm 0.2$ measured using alternate residual stress-driven test structures of the same films.

G. Carta (1), D.J. Colquitt (2), A.B. Movchan (2), N.V. Movchan (2) and I.S. Jones (1)

(1) Liverpool John Moores University, Mechanical Engineering and Materials Research Centre, Liverpool, L3 3AF, UK
(2) University of Liverpool, Department of Mathematical Sciences, Liverpool, L69 7ZL, UK


ABSTRACT: A new class of elastic waveforms, referred to as “chiral flexural waves”, is introduced for a multi-structure, which encompasses an elastic plate connected to a system of elastic flexural rods with gyroscopic spinners. The junction conditions describing the connection between the plate and the thin flexural rod require logarithmic asymptotics. The directional preference of the system is governed by the motion of gyroscopic spinners. For doubly-periodic chiral multi-structures studied here, parabolic modes associated with strong dynamic anisotropy of Bloch–Floquet waves are identified. Closed form analytical findings are accompanied by numerical simulations, which identify one-way flexural waves propagating along a straight interface in a flexural chiral system, without requiring the presence of Dirac cones on the dispersion surfaces.
ABSTRACT: A framework is introduced for benchmarking periodic microstructures in terms of their ability to maintain their stiffness under large deformations, accounting in a unified manner both for buckling and softening due to geometric and material nonlinearities. The proposed framework is applied to three classical 2D lattice microstructures at different volume fractions as well as to an optimized hierarchical microstructure from the literature. The high slenderness of the structure members, often assumed in analyses, is demonstrated not to be valid at volume fractions of 10% and above, with the infinitesimal volume fraction solutions underestimating the actual buckling resistance considerably. The performed analyses provide useful and quantitative insight regarding the compressive load carrying capacity of materials with a moderately dense periodic microstructure, in a rather universal and practical form.

Zhaohe Dai (1), Daniel A. Sanchez (2), Christopher J. Brennan (3,4) and Nanshu Lu (1,2,4)  
(1) Center for Mechanics of Solids, Structures and Materials, Department of Aerospace Engineering and Engineering Mechanics, The University of Texas at Austin, Austin, Texas 78712, USA  
(2) Texas Materials Institute, The University of Texas at Austin, Austin, Texas 78712, USA  
(3) Microelectronics Research Center, The University of Texas at Austin, Austin, Texas, 78758, USA  
(4) Department of Electrical and Computer Engineering, The University of Texas at Austin, Austin, Texas, 78701, USA  
ABSTRACT: Microscale tents, formed when transferring two-dimensional (2D) materials over nanoparticles or nanopillars, or when indenting a suspended 2D material drumhead with an atomic force microscope (AFM) tip, emerge to be a useful structure for the strain engineering of 2D materials. In the periphery of the tents, where the 2D materials are supported by the substrate, radial buckle delamination can often be observed, yet the formation mechanism and the profile characteristics remain unclear. Here, we suggest that the tent-induced buckles result from the 2D material-substrate interface sliding radially inward, and their profiles and extent are controlled by the interface adhesion and friction. We experimentally characterized that the crest curvature of the buckles is proportional to a characteristic length that compares the elastic bending energy of the 2D material with its adhesion energy to the substrate. We then obtain theoretical predictions for the extent of those buckles by exact closed-form solutions to Föppl–von Kármán (FvK) equations under both near-threshold and far-from-threshold conditions. Our results are highly analytical, provide a direct means to estimate the interfacial shear and adhesive properties of the 2D material-substrate system based on simple topological characterizations of buckles. Our theoretical understandings also establish a fundamental base for the rational design of 2D material tents.

Fan Xu (1), Shichen Zhao (1), Conghua Lu (2) and Michel Potier-Ferry (3)  
(1) Institute of Mechanics and Computational Engineering, Department of Aeronautics and Astronautics, Fudan University, 220 Handan Road, Shanghai 200433, P.R. China  
(2) School of Materials Science and Engineering, Tianjin University, Tianjin 300072, P.R. China  
(3) Université de Lorraine, CNRS, Arts et Métiers ParisTech, LEM3, Metz F-57000, France  
ABSTRACT: Curvature-induced symmetry-breaking pattern formation and transition are widely observed in curved film/substrate systems across different length scales such as embryogenesis, heterogeneous microparticles, dehydrated fruits, growing tumors and planetary surfaces. Here, we find, both experimentally and theoretically, that morphological pattern selection of core-shell spheres, upon shrinkage of core or expansion of surface layer, is primarily determined by a single dimensionless parameter $C$ which characterizes the stiffness ratio of core/shell and geometric curvature of the system. When the core remains relatively soft ($C < 1.3$), the core-shell sphere usually experiences subcritical buckling behavior with local dimples at the critical threshold. With a stiffer substrate ($1.3 < C < 15$), the system morphs into periodic buckyball patterns. With the continuous...
increase of the core stiffness ($C > 15$), symmetry-breaking disordered patterns involving polygon and labyrinth modes appear to be energetically favorable. With extremely large $C \sim 1000$, the core-shell sphere approximates to a planar film/substrate system and thus checkerboard patterns with grain boundaries are observed. Moreover, we find that the transition from subcritical to supercritical bifurcations can be quantitatively characterized by this parameter. Pattern selection based on this single key factor remarkably agrees with our experimental observations on oxidized polydimethylsiloxane (PDMS) microspheres in the entire validity range. Our results not only provide fundamental understanding of pattern selection in spherical film/substrate systems, but also pave a promising way to facilitate the design of morphology-related functional surfaces by quantitatively harnessing such curvature-modulus co-determined pattern formation.

Tianshu Liu (1), Zezhou Liu (1), Anand Jagota (2,3) and Chung-Yuen Hui (1)
(1) Field of Theoretical and Applied Mechanics, Cornell University, Ithaca, NY 14853, USA
(2) Department of Bioengineering, Lehigh University, 111 Research Drive, Bethlehem, PA 18015, USA
(3) Department of Chemical & Biomolecular Engineering, Lehigh University, 111 Research Drive, Bethlehem, PA 18015, USA


ABSTRACT: We study wetting of an elastic membrane whose surface can resist stretch by surface stress. Through energy minimization, we obtain the general equilibrium equations and a configurational energy balance equation at the contact line, i.e., the Young equation, modified for an elastic membrane. We use a 3D large deformation formulation with general elastic constitutive behavior for the membrane and its surfaces. Our results allow for non-flat reference membrane shape, non-uniform and anisotropic tension and dependence of surface stress on surface strain – the generalized Shuttleworth effects. We use two examples to demonstrate the application of our theory: plane strain and axisymmetric wetting of an initially flat elastic membrane. A large deformation solution for an axisymmetric droplet on a deformable membrane is obtained numerically. We show that when surface elastic moduli for solid–vapor and solid–liquid interfaces are different, continuity of membrane strain, a key assumption used in many previous studies, no longer holds at the contact line.


ABSTRACT: Non-conservative loads of the follower type are usually believed to be the source of dynamic instabilities such as flutter and divergence. It is shown that these instabilities (including Hopf bifurcation, flutter, divergence, and destabilizing effects connected to dissipation phenomena) can be obtained in structural systems loaded by conservative forces, as a consequence of the application of non-holonomic constraints. These constraints may be realized through a 'perfect skate' (or a non-sliding wheel), or, more in general, through the slipless contact between two circular rigid cylinders, one of which is free of rotating about its axis. The motion of the structure produced by these dynamic instabilities may reach a limit cycle, a feature that can be exploited for soft robotics applications, especially for the realization of limbless locomotion.


ABSTRACT: We present a study on the pressure buckling of thin, elastic spherical shells containing a thickness defect. Methodologically, we combine precision model experiments, finite element simulations, and a reduced axisymmetric shell model. We observe qualitatively different buckling behavior by varying the geometry of the defect: either one buckling event or two events comprising local buckling at the defect and global buckling of the entire shell. We systematically analyze the loading path for the imperfect shell under prescribed pressure or volume change and identify three buckling regimes. We then explore a wide parameter space to study the dependence of the buckling regimes on the defect geometry, thus obtaining a phase diagram with quantitative relationships between critical buckling pressures and defect geometry. We find that the global buckling
becomes insensitive to the defect beyond a critical value of its amplitude, and we demonstrate that the buckling regimes are governed by the three geometric parameters of the defect, namely its width, amplitude and the width of the transition region across the edge of the defect.


ABSTRACT: Elastic thin shells are well-known for their highly unstable post-buckling, a response that exhausts their pressure bearing capacity and leads to catastrophic collapse. This paper examines elastic thin shells with a large axisymmetric imperfection that can escape the classical bifurcation of perfect spherical shells. We employ a shell theory formulation with exact expressions of the middle surface strains, curvature changes, and live pressure along with validating experiments and numerical simulations. The results show that a large axisymmetric imperfection in the form of a circular arc can induce snap-through buckling followed by a stable post-buckling that offers increasing resistance to pressure over a large change in volume. In addition, a sensitivity analysis on the role of defect geometry and shell radius to thickness ratio reveals the emergence of four buckling modes. For small imperfections, bifurcation buckling (mode 1) is dominant and resembles the typical dimple-like mode of perfect spherical shells. For larger imperfections, the shell attains the maximum pressure at the snap-through buckling where strain localization appears either within the imperfection (mode 2) or just below (mode 3). In the fourth mode, snap-through buckling precedes the attainment of the maximum pressure following a post-buckling path characterized by a large change of volume that makes the shell harder and stronger. These findings show that harnessing defect geometry and shell radius to thickness ratio can be effective in programming the post-buckling characteristics and transition between buckling modes, thus offering potential routes for the design of soft metamaterials with application to soft robotics and other sectors.


ABSTRACT: Inflation of an elastomer balloon is one of the most classical and important problems in the field of nonlinear elasticity. Many intriguing phenomena associated with the inflation of elastomer balloons such as snap-through instability and bulge propagation have been often observed and intensively studied. In this article, we report a new phenomenon during the inflation of a cylindrical balloon made from nematic elastomer. We found in the experiment that with a small increment of inflating pressure, the balloon contracts significantly along its axial direction while expands in its radial direction. With further increase of the pressure, the balloon expands mainly in the radial direction while maintains its length almost unchanged. Finally, the balloon expands both in the radial and axial directions abruptly with a tiny increase of inflating pressure, often leading to rupture of the balloon. The inflation behavior of the nematic balloon can be changed when it is subjected to an additional axial load. To quantitatively understand the experiments, we adopt a quasi-convex free energy function of nematic elastomer to derive the relationship between the inflating pressure and its deformation state. We have shown that the anomalous inflation of the nematic balloon is closely associated with the soft elasticity of the nematic elastomer. Our theoretical predictions agree with experimental measurements well with only two material parameters separately determined by uniaxial tension test of nematic elastomer.


ABSTRACT: Rigidly and flat-foldable quadrilateral mesh origami is the class of quadrilateral mesh crease patterns with one fundamental property: the patterns can be folded from flat to fully-folded flat by a continuous one-parameter family of piecewise affine deformations that do not stretch or bend the mesh-panels. In this work, we explicitly characterize the designs and deformations of all possible rigidly and flat-foldable quadrilateral mesh origami. Our key idea is a rigidity theorem (Theorem 3.1) that characterizes compatible crease patterns surrounding a single panel and enables us to march from panel to panel to compute the pattern and its corresponding deformations explicitly. The marching procedure is computationally efficient. So we use it to formulate the inverse problem: to design a crease pattern to achieve a targeted shape along the path of its
rigidly and flat-foldable motion. The initial results on the inverse problem are promising and suggest a broadly useful engineering design strategy for shape-morphing with origami.


ABSTRACT: The mechanics of cellular honeycombs—part of the rapidly growing field of architected materials—in addition to its importance for engineering applications has a great theoretical interest due to the complex bifurcation mechanisms leading to failure in these nonlinear structures of high initial symmetry. Of particular interest to this work are the deformation patterns and their stability of finitely strained circular cell honeycomb. Given the high degree of symmetry of these structures, the introduction of numerical imperfections is inadequate for the study of their behavior past the onset of first bifurcation. Thus, we further develop and explain a group-theoretic approach to investigate their deformation patterns, a consistent and general methodology that systematically finds bifurcated equilibrium orbits and their stability. We consider two different geometric arrangements, hexagonal and square, biaxial compression along loading paths, either aligned or at an angle with respect to the axes of orthotropy, and different constitutive laws for the cell walls which can undergo arbitrarily large rotations, as required by the finite macroscopic strains applied. We find that the first bifurcation in biaxially loaded hexagonal honeycombs of infinite extent always corresponds to a local mode, which is then followed to find the deformation pattern and its stability. Depending on load path orientation, these first bifurcations can be simple, double or even triple. All bifurcated orbits found are unstable and have a maximum load close to their point of emergence. In contrast, the corresponding instability in square honeycombs always corresponds to a global mode and hence the deformation pattern will depend on specimen size and boundary conditions.


ABSTRACT: Many plastics show necking and drawing behavior in tension, sometimes called “cold drawing”. In contrast, elastomers stretch homogeneously in tension. We examine the tensile behavior of rubber–plastic laminate composites using 3D finite element simulations and an analytical model. A rate-independent constitutive behavior was adopted in which the modulus at small-strain, strain hardening at large strain, and yield stress (only for the plastic) can all be varied independently. For sufficiently small rubber/plastic thickness ratio, layered composites show necking and drawing wherein a tensile bar coexists in two strain states, one with a large stretch (necked region) and the other with a modest stretch (unnecked region). With increasing rubber/plastic thickness ratio, the two strain states approach each other in a manner resembling a second order phase transition culminating in a critical point. Above this critical rubber/plastic thickness ratio, the layered composites stretch homogeneously. An analytical model based on adding the First Piola–Kirchoff stresses of the rubber and plastic layers, along with a modification for inelastic deformation, is shown to capture most of the results of 3D simulations accurately. We comment on the practical relevance of these results to toughening relatively brittle plastics, and more specifically, the critical importance of strain hardening of the rubber.


ABSTRACT: An experimental and analytical investigation is conducted to study the underwater interaction of implosion pressure pulses with large plates. Two plates with stiffnesses significantly apart are investigated experimentally in a large-diameter pressure vessel for their Fluid-Structure Interaction (FSI) phenomena during proximal implosions of thin metallic shells. High-speed photography, in conjunction with 3D Digital Image Correlation (DIC) measurements, is employed to obtain full-field displacements of the plates. Local dynamic pressure histories are also simultaneously recorded to investigate the incident, reflected and transmitted fluid pressures across the plates during dynamic loading. The lesser stiffness plate showed higher deflection, allowed a weaker reflected pressure pulse and allowed a stronger transmitted pressure pulse as compared to the higher
stiffness plate. The peak deflections of the plates occurred during the underpressure phase of the implosion event. Four analytical modeling iterations with increasing complexities starting from Taylor's FSI model are considered to assess the response of water backed plates to dynamic pressure pulse loadings. Each iteration is analyzed individually in an experimental context to understand its role as a building block in a final analytical model. The final model developed is based on the classical plate-bending equation and fluid velocity corrected for ‘afterflow’ effects and performed better than Taylor's original model in predicting pressure-time history of the plates’ reflected pressure and transmitted pressure. The plates’ mid-point deflection profiles are also better predicted using this model. Furthermore, the model showed that the response of a plate during a dynamic implosion pressure pulse interaction is weakly dependent on its bending stiffness. Instead, it is observed that for a large plate, its areal mass density is the dominant factor in determining the reflected pressure, the transmitted pressure and the plate mid-point deflection profiles.

ABSTRACT: We examine the problem of an elastic film bonded to an elastic substrate and subjected to compressive stress (induced by growth of the film or lateral compression of the whole system). Following the linear analysis previously carried out to determine the critical growth/compression ratio required to induce wrinkling in the film, we carry out a weakly-nonlinear analysis to derive an amplitude equation that describes the evolution of the wrinkling amplitude beyond the bifurcation point. We carry out a comprehensive numerical bifurcation analysis of the problem using the finite element method and show excellent agreements between the weakly-nonlinear analysis and the numerical experiments. We are also able to solve directly for the bifurcation point in our discretized system and characterize the effect of implementation details such as the aspect ratio of the computational domain on the observed bifurcation point. Finally, we explore solutions of the amplitude equation in the case that the wrinkling amplitude is allowed to vary over long spatial and/or temporal scales.

ABSTRACT: We study jump instability phenomena due to external disturbances to an axially loaded beam resting on a nonlinear foundation that provides both lateral and axial resistance. The lateral resistance is of destiffening-restiffening type known to lead to complex localisation phenomena governed by a Maxwell critical load that marks a phase transition to a periodic buckling pattern. For the benefit of having a concrete and realistic example we consider the case of a partially embedded trenched subsea pipeline under thermal loading but our results hold qualitatively for a wide class of problems with non-monotonic lateral resistance. In the absence of axial resistance the pipeline is effectively under a dead compressive load and experiences shock-sensitivity for loads immediately past the Maxwell load, i.e., extreme sensitivity to perturbations as may for instance be caused by irregular fluid flow inside the pipe or landslides. Nonzero axial resistance leads to a coupling of axial and lateral deformation under thermal loading. We define a ‘Maxwell temperature’ beyond which the straight pipeline may snap into a localised buckling mode. Under increasing axial resistance this Maxwell temperature is pushed to higher (safer) values. Shock sensitivity gradually diminishes and becomes less chaotic: jumps become more predictable. We compute minimum energy barriers for escape from pre-buckled to post-buckled states, which, depending on the magnitude of the axial resistance, may be induced by either symmetric, or anti-symmetric or non-symmetric perturbations.

ABSTRACT: Mylar balloons are popular in funfairs or birthday parties. Their conception is very simple: two pieces of flat thin sheets are cut and sealed together along their edges to form a flat envelope. Inflation tends to deform this envelope in order to maximize its inner volume. However, although thin sheets are easy to bend and hardly resist compressive loads, they barely stretch, which imposes non-trivial geometrical constraints. Such
thin sheets are generally described under the framework of “tension field theory” where their stiffness is considered as infinite under stretching and vanishes under compression or bending. In this study, we focus on the shape after inflation of flat, curved templates of constant width. Counter-intuitively, the curvatures of the paths tend to increase upon inflation, which leads to out of plane buckling of non-confined closed structures. After determining the optimal cross section of axisymmetric annuli, we predict the change in local curvature induced in open paths. We finally describe the location of wrinkled and smooth areas observed in inflated structures that correspond to compression and tension, respectively.


ABSTRACT: Understanding the feature-rich buckling-dominated behavior of thin elastic ribbons is ripe with opportunities for fundamental studies exploring the nexus between geometry and mechanics, and for conceiving of engineering applications that exploit geometric nonlinearity as a functioning principle. Predictive mechanical models play an instrumental role to this end. As a direct consequence of their physical appearance, ribbons are usually modeled either as one-dimensional rods having wide cross sections, or as narrow two-dimensional plates/shells. These models employ drastically different kinematic assumptions, which in turn play a decisive role in their predictive capabilities. Here, we critically examine three modeling approaches for elastic ribbons using detailed measurements of their complex three-dimensional deformations realized in quasistatic experiments with annulus-shaped ribbons. We find that simple and practically realizable ribbon deformations contradict assumptions underlying strain-displacement relationships in nonlinear rod and von Kármán plate models. These observations do not point at shortcomings of the theories themselves, but highlight fallacies in their application to modeling ribbon-like structures that are capable of undergoing large displacements and rotations. We identify and validate, seemingly for the first time, the 1-director Cosserat plate theory as a model for elastic ribbons over a useful range of loading conditions. In the process, we demonstrate annular ribbons to be prototypical systems for studying the mechanics of elastic ribbons. Annular ribbons exhibit a tunable degree of geometric nonlinearity in response to simple displacement and rotation boundary conditions—a feature that we exploit here for highlighting the consequences of kinematic assumptions underlying different ribbon models. We additionally provide experimental evidence for the existence of multiple stable equilibria, bifurcation phenomena correlated with the number of zero crossings in the mean curvature, and localization of energy, thus making annular ribbons interesting mechanical systems to study in their own right.


ABSTRACT: Two-phase piecewise homogeneous plane deformations are examined in respect of a neo-Hookean matrix material reinforced with embedded aligned fibres characterized by a single stiffness parameter. The deformations are interpreted in terms of fibre kinking and fibre splitting. Previous work has shown that such a transversely isotropic material can lose ellipticity if the reinforcing stiffness is sufficiently large and the fibre direction is sufficiently compressed. In particular, it was shown that the associated failure modes are characterised by the emergence of weak surfaces of discontinuity that are normal to the fibre direction (the onset of fibre kinking) or parallel to the fibre direction (the onset of fibre splitting). Here, the analysis of strong surfaces of discontinuity, developing from weak ones, is studied. The considered model can give rise to piecewise smooth plane deformations separated by a plane stationary surface of discontinuity, interpreted as either kinking or splitting. Attention is restricted to (plane) deformations in which, on one side of the surface of discontinuity, the load axis is aligned with the fibre axis. Then the fibre stretch on this side of the discontinuity is a natural load parameter. The ellipticity status of the two-phase piecewise homogeneous plane deformations is shown to span all four possible ellipticity/non-ellipticity permutations. If both deformation states are elliptic, then a suitable intermediate deformation is shown to be non-elliptic. Moreover, it is shown that the mechanism is dissipative, and maximally dissipative quasi-static failure motion is examined in respect of both kinking and splitting. It follows that, firstly, surfaces of discontinuity perpendicular to the fibre direction, associated with fibre kinking, are nucleated followed by surfaces of discontinuity parallel to the fibre direction, associated with fibre splitting. With respect to kinking, such maximally dissipative kinks nucleate only in compression as weak
surfaces of discontinuity, with the subsequent motion converting non-elliptic deformation to elliptic deformation.

ABSTRACT: The hydraulic circular and elliptical bulge tests have been widely used in extracting mechanical properties of sheet materials. Theoretical analysis of bulge tests usually requires the kinematic relationships between the apex strains, radii of curvatures and dome heights to be established. Most of the available analytical solutions are derived on a case-by-case basis and are often limited to circular bulge tests of isotropic materials, and thus cannot be applied to materials with more complicated constitutive behaviors or non-circular bulge tests. Based on the variable-separable assumption and proportional kinematic conditions at the apex, this study develops a set of power-law relationships between the apex strains, radii of curvatures and dome heights that hold for both circular and elliptical bulge tests, irrespective of material properties. Numerical simulations of a set of circular and elliptical bulge tests with different material models are performed and the scaling laws between the apex strains, radii of curvatures and dome heights are verified. An extensive set of experimental results of circular and elliptical bulge tests from the literature are compared with the theoretical predictions and the power-law kinematic relationships are again validated. This general and unified theory contributes to the fundamental understanding of the intrinsic kinematic constraints in circular and elliptical bulge tests and is expected to facilitate the application of bulge tests to a broader class of sheet materials.

ABSTRACT: This paper presents an investigation on the formation of adiabatic shear bands in metallic sheets subjected to dynamic shear-compression loading under plane-stress conditions. For that purpose, we have developed a theoretical model based on perturbation analysis, and have performed finite element calculations. The material behavior has been modeled with von Mises plasticity, and the evolution of the yield stress has been considered dependent on plastic strain, plastic strain rate, and temperature. The theoretical model extends the linear stability analysis for simple-shear formulated by Molinari (1997) to shear-compression loading. The numerical simulations have been performed in ABAQUS/Explicit (2016) using a unit-cell model based on the work of Rodríguez-Martínez et al. (2015) in which the shear band formation is favored introducing geometric and material imperfections. Moreover, we have developed a calibration procedure for the stability analysis that enables to make qualitative and quantitative comparisons with the finite element calculations. Both stability analysis predictions and finite element results display the same overall trends, and show that any small negative triaxiality has a profound stabilizing effect on the material behavior delaying, or even preventing, the formation of a shear band. This key outcome has been substantiated for a wide range of strain rates and for materials with different strain hardening coefficients, strain rate sensitivities, and thermal softening behaviors.

ABSTRACT: The material characterization of ultra-thin solid sheets, including two-dimensional materials like graphene, is often performed through indentation tests on a flake suspended over a hole in a substrate. While this ‘suspended indentation’ is a convenient means of measuring properties such as the stretching (two-dimensional) modulus of such materials, experiments on ostensibly similar systems have reported very different material properties. In this paper, we present a modelling study of this indentation process assuming elastic behaviour. In particular, we investigate the possibility that the reported differences may arise from different geometrical parameters and/or non-Hookean deformations, which lead to the system exploring nonlinearities with geometrical or material origins.

ABSTRACT: Microlattice structures possess properties imparted by the architected microstructure of their constituents (unit cells) and micro/nanofeatures rather than their bulk material properties. Post-processing techniques have revealed intriguing length scale effects, encompassing enhanced behavior or shape morphing of various structures. Although monolithic structures consisting of single unit cells have been successfully fabricated by advanced additive manufacturing techniques, such as multiphoton lithography, innovations towards the tactical architecture of localized failure and design-inherent controllable collapse have been fairly limited. Using as a point of reference the octet truss structure, we designed substitutional unit cells and slip-plane defect-like features inspired by crystalline materials. Through finite element analysis, we investigated how the directional effective stiffness of a material can be augmented and altered in predetermined orientations. Fabricating these structures by multiphoton laser lithography and testing them by in situ scanning electron microscopy-nanoindentation we discovered a remarkable enhancement of the structural integrity, stiffness, and strain energy density, emulating the corollaries of hardening bulk materials. In addition, we observed that these structures demonstrate localized plastic deformation and collapse, distinguishing their mechanical behavior from the conventional layer-by-layer collapse reported in previous studies. The nanofeatures detected in fractographies obtained by helium ion microscopy provided further insight into the collapse mechanisms of the structures. The present design methodology of strategically placed structural features yields architected microstructures with microlattice geometries that can be used to enhance and control the mechanical performance of metamaterial structures.


ABSTRACT: The lungs are among the most deformable body organs, a mechanical feature that is key to the vital process of breathing. Current micromechanical constitutive models of the lung parenchyma construct the tissue response function either as strain-driven or pressure-driven. However, the lung parenchyma resembles an open-cell foam material consisting of a solid phase and a fluid phase that closely interact with each other. In this work, we introduce a novel finite-deformation micromechanical poroelastic model of the lung parenchyma. Using a two-scale homogenization framework for poroelasticity, we construct the effective coarse-scale response of the tissue by solving a poroelastic fine-scale problem. To this end, we develop a non-linear structural model based on a tetrakaidecahedron (TKD) unit cell that only depends on four microstructural parameters. We validate the TKD model showing that it predicts the effective response of representative volume elements (RVE) constructed from micro-computed-tomography images of the lung under several combinations of deformation and alveolar pressure. Further, we show that the estimation of the effective stress using the TKD model delivers a speed-up in computation time of more than 284,000 × when compared to RVE simulations, at the same time that it delivers higher numerical stability. In addition, we demonstrate through a sensitivity analysis that the model response predominantly depends on the alveolar-wall elasticity and initial tissue porosity, which are parameter values that are inherently connected to measurable microstructural features of the lung tissue. The present TKD model opens the door to large-scale poroelastic simulations of the lung by providing a predictive yet efficient constitutive model of the lung parenchyma. Codes are available for download at https://github.com/dehurtado/PoroelasticTKDModel.


ABSTRACT: Bacteria usually grow in populations to survive in various environments. A yet unsolved issue is how mechanical forces at the cellular level regulate the morphogenesis of bacterial population. In this paper, we combine experiments and theoretical analysis to investigate the growth of bacterial chains constituted by rod-shaped Bacillus subtilis. Our experiments show that due to cellular proliferation-induced compressive forces, one-dimensional bacterial chains can buckle into a morphology similar to toppling dominoes. A rod–spring model which considers both cell–cell connection and cell–substrate interaction is established to study the
buckling behaviors of bacterial chains. The critical features at the growth-induced instability of bacterial chains are determined by the energetic competition associated with elastic strain energy and cell–substrate bonding energy. An active rod method is further presented to simulate the bacterial growth dynamics from a single bacterium to a chain structure and, subsequently, to a two-dimensional biofilm, where Johnson–Kendall–Roberts theory is adopted to account for intercellular contact forces. This work suggests a novel mechanism of instability in the self-organization and expansion of bacterial biofilms.


ABSTRACT: We combine discrete differential geometry (DDG)-based models and desktop experiments to study supercritical pitchfork bifurcation of a pre-compressed elastic plate under lateral end translation, with a focus on its width effect. Based on the ratio among length, width, and thickness, the elastic structures in our study fall into three different structural categories: rods, ribbons, and plates. In order to numerically simulate the mechanical response of these structures, we employ two DDG-based numerical frameworks — Discrete Anisotropic Rods method and Discrete Elastic Plates method. Even though the multi-stability and bifurcation of a narrow strip can be precisely captured by a naive one dimensional rod model, it fails to match with experiments as the ribbon increases in width. A two dimensional approach using a plate model, on the other hand, accurately predicts the geometrically nonlinear deformations and the supercritical pitchfork points for plate even when the width is as large as half of the length. Exploiting the efficiency and robustness of the simulator, we perform a systematic parameter sweep on plate size and lateral displacement to build a phase diagram of different configurations of the elastic plates. We find that the deformed configuration of the nearly developable strips can be described, up to a very good approximation, using the bending and twisting of the centerline. This indicates that a one dimensional energy model for the simulation of nearly developable strips can potentially be developed in the future. The results can serve as a benchmark for future numerical investigations into modeling of ribbons. Our study can also provide guidelines on the choice of the appropriate structural model – rod vs. ribbon vs. plate – in simulation of thin elastic structures.


ABSTRACT: A lattice (or ‘grillage’) of elastic Rayleigh rods (possessing a distributed mass density, together with rotational inertia) organized in a parallelepiped geometry can be axially loaded up to an arbitrary amount without distortion and then be subjected to incremental time-harmonic dynamic motion. At certain threshold levels of axial load, the grillage manifests instabilities and displays non-trivial axial and flexural incremental vibrations. Including every possible structural geometry and for an arbitrary amount of axial stretching, Floquet–Bloch wave asymptotics is used to homogenize the in-plane mechanical response, so to obtain an equivalent prestressed elastic solid subject to incremental time-harmonic vibration, which includes, as a particular case, the incremental quasi-static response. The equivalent elastic solid is obtained from its acoustic tensor, directly derived from homogenization and shown to be independent of the rods’ rotational inertia. Loss of strong ellipticity in the equivalent continuum coincides with macro-bifurcation in the lattice, while micro-bifurcation remains undetected in the continuum and corresponds to a vibration of vanishing frequency of the lowest dispersion branch of the lattice, occurring at finite wavelength. Dynamic homogenization reveals the structure of the acoustic branches close to ellipticity loss and the analysis of forced vibrations (both in physical space and Fourier space) shows low-frequency wave localizations. A perturbative approach based on dynamic Green’s function is applied to both the lattice and its equivalent continuum. This shows that only macro-instability corresponds to localization of incremental strain, while micro-instabilities occur in modes which spread throughout the whole lattice with an ‘explosive’ character. In particular, extremely localized mechanical responses are found both in the lattice and in the solid, with the advantage that the former can be easily realized, for instance via 3D printing. In this way, features such as shear band inclination, or the emergence of a single shear band, or competition between micro and macro instabilities become all designable features. The comparison between the mechanics of the lattice and its equivalent solid shows that the homogenization technique allows an almost perfect representation, except when micro-bifurcation is the first manifestation of
instability. Therefore, the presented results pave the way for the design of architected cellular materials to be used in applications where extreme deformations are involved.


ABSTRACT: In this paper, an accurate solution for the in-plane vibration analysis of rotating circular panels with general edge restraints is established by solving the governing equations and boundary conditions, simultaneously. Two coupled in-plane displacement fields are constructed as Fourier series with smoothed supplementary polynomials to remove the relevant differential discontinuities associated with the original radial component at inner and/or outer edges. Any type of boundary conditions can be easily achieved by setting the boundary restraining stiffness accordingly. System characteristic matrix is obtained through the comparison of all expanded Fourier series coefficients. Numerical examples are then presented to validate the correctness and reliability of the proposed solution by comparing them with those solved from other approaches. Based on the model established, significant influence of elastic boundary condition on the in-plane modal characteristics of rotating annular panel is investigated and addressed. This work represents the first time that analytical solution for the in-plane vibration of rotating circular panel with general boundary conditions is derived, and can also shed some new light on the understanding of complex dynamic behavior of such structural system.


ABSTRACT: Modal shifting and jumping in thermally buckled plates has been investigated previously using computational models; however, relatively few experimental explorations have been reported. In this study, the modal shifts and jumps in a simple rectangular plate or panel were investigated using digital image correlation to obtain detailed mode shapes. One face of the planar panel, which was 219 × 146 mm, was speckled and viewed with a stereoscopic digital image correlation system using pulsed-laser illumination and with a laser vibrometer at a single point. The other face was heated using a set of 1 kW quartz lamps to produce a non-uniform temperature distribution which progressively increased from room temperature to around 760 K. An infra-red camera recorded the time-varying temperature distribution on the panel while it was excited with an electrodynamic shaker. A waterfall plot, or time-frequency spectrogram, showing natural frequencies as a function of time was generated, which highlighted the shifting response of the panel with temperature. The heating sequence was repeated and the panel excited at the natural frequencies identified in the waterfall plot, which permitted the corresponding mode shapes to be measured. These data showed that mode shifting and jumping was present with asymmetric heating, but not with spatially uniform heating, and was associated with thermally-induced buckling.

References listed at the end of the paper:
4 D.J. Mead, Vibration and buckling of flat-free plates under non-uniform in-plane thermal stresses, J. Sound Vib., 260 (2003), pp. 141-165
ABSTRACT: Thermally loaded panels from a primarily experimental perspective, with an additional focus on nonlinear (essentially buckling) behavior in thermally loaded panels.

The suppression of expansion in thin clamped panels subjected to elevated thermal loading often results in buckling. However, a number of possible post-buckled equilibrium configurations typically exist, and which shape ensues depends on a number of factors including the role of symmetry, boundary conditions, aspect ratio, and the effect of small geometric imperfections associated with the initial shape. It is possible to force the panel to go between different buckled shapes, given a sufficiently large perturbation. Sometimes the panel will spontaneously jump, or snap, when the temperature is gradually increased or decreased (mode jumping). The extent to which these features occur when the thermal loading is applied locally is also investigated. This paper describes some interesting nonlinear (essentially buckling) behavior in thermally loaded panels from a primarily experimental perspective, with an additional focus on non-uniform heating. The full force of stereo 3D digital image correlation and forward-looking infrared cameras are exploited to provide a relatively complete picture of this behavior.


ABSTRACT: Thermally-buckled composite panels of high-speed aircraft may experience dynamic snap-through due to aerodynamic loading, which can accelerate damage growth. Therefore, understanding post-buckled dynamic responses can be an important step in developing reliable simulation tools to predict consequent damage growth. To address this issue, this work experimentally and numerically investigates...
nonlinear dynamics and snap-through boundaries of post-buckled laminated composite plates under various harmonic loading scenarios. Full-field and single-point sensing methods are used to explore the spatio-temporally complex behavior and parameter sensitivity of post-buckled plates. Based on the full-field data of the specimen's static buckled shape, a numerical model was generated using an in-house finite element code, which was written in MATLAB based on the classical laminated plate theory along with nonconforming (semi-C-continuity) cubic Hermite elements and Rayleigh damping. The simulation results including numerical snap-through boundaries showed an excellent agreement with the experimental observations, thereby providing robust validation of the model. The experimental and numerical data obtained through this work provide a benchmark for the development of an efficient dynamic model for simulation of damage growth in composite structures subjected to high-frequency dynamic loading.


ABSTRACT: Porous materials are effective for the isolation of sound with medium to high frequencies, while periodic structures are promising for low to medium frequencies. In the present work, we study the sound insulation of a periodically rib-stiffened double-panel with porous lining to reveal the effect of combining the two characters above. The theoretical development of the periodic composite structure, which is based on the space harmonic series and Biot theory, is included. The system equations are subsequently solved numerically by employing a precondition method with a truncation procedure. This theoretical and numerical framework is validated with results from both theoretical and finite element methods. The parameter study indicates that the presence of ribs can lower the overall sound insulation, although a direct transfer path is absent. Despite the unexpected model results, the method proposed here, which combines poroelastic modeling and periodic structures semi-analytically, can be promising in broadband sound modulation.


ABSTRACT: In this work we present a novel semi-analytical model of the vibrational dynamics of a multi-layered tapered prismatic cantilever. The derivation of the model is based on a perturbation expansion of the tapered cantilever's partial differential equations using Euler-Bernoulli beam theory as a starting point. The proposed semi-analytical solution of the model enables a 101-sample modal analysis to run more than \( \times 250 \) faster when using 20 perturbation components than a computationally efficient commercial FEM solution that uses 101 shell-type finite elements along the beam length and 6 elements along the beam width. In this case, the primary mode prediction error on resonance frequency is below 0.1\% for 20 perturbation components and below 10\% for 4 components.


ABSTRACT: The paper presents experimental and theoretical studies of wave phenomena accompanying transient edge waves (EW) excitation by a piezoelectric transducer attached at the edge of an elastic plate. Theoretical investigations are conducted on the basis of the three-dimensional elastodynamic theory. The boundary value problem describing non-stationary wave motion is solved with the use of integral transforms and the modal expansion technique. The asymptotic analysis with the wavenumber considered as a small or large parameter is applied to the three-dimensional problem. In the first case (long-wave vibrations) the approximate formulae for the fundamental EW's pole and corresponding residue are derived. These relations take into account the influence of the transverse shear load arising because of coupling between long-wave integral and Saint-Venant's boundary layer. In the second case (short-wave vibrations) an infinite series of poles corresponding to higher order EW is revealed. Results of numerical investigations of EW dispersion properties and waveforms are presented and used for an analysis of experimental data acquired with the use of Laser Doppler vibrometry. It is shown that the contribution of EW is predominant in the wave-field excited by the load under consideration. A good agreement between theoretical predictions and measurements is demonstrated.
For the calculation of transient wave-field three different models of actuator-plate interaction are developed: in the low-frequency range the interaction is considered as a static one, while the lower and higher eigenfrequencies of the actuator are taken into account in the medium- and high-frequency ranges respectively. For the low-frequency range, an explicit analytical formula is derived for calculation of EW contribution into the transient wave-field. In the high-frequency range, the excitation of the first higher order EW is predicted by the numerical solution and observed experimentally.


ABSTRACT: In this work, passive constrained-layer damping with periodically embedded acoustic black holes (ABHs) on a viscoelastic layer is used to reduce vibrations and noise. The ABH is a tapered profile described by a power-law relation which is embedded in the host structure. The tapered profile allows progressive decrease of the velocity of propagating waves, which enables highly efficient vibration attenuation in the high-frequency range (kilohertz). This research proposes an efficient modeling technique that combines ABHs with a sandwich plate to enhance the low-frequency (hertz) vibration reduction. The loss factor of the sandwich plate with embedded ABHs is numerically evaluated via a modal strain energy method. The results suggest that the proposed approach enables highly efficient vibration dissipation performance in the low-frequency range.


ABSTRACT: It is well known that rotating beams are stretched due to centrifugal forces. Accordingly, it can be speculated that the stretching effect for rotating curved beams leads to changes of the curvature. But this speculation has been not verified and reported in existing literatures. In this paper, a dynamic model of curved beams is derived by using the Absolute Nodal Coordinate Formulation based on radial point interpolation method (ANCF/RPIM), and the transient analysis of curved beams rotating at the steady state angular speed are especially performed by using the ANCF/RPIM. The results show that the curvature of curved beams is reduced due to centrifugal forces. These configuration changes have an important influence on frequency characteristics. Thus, modal analysis should take account of the configuration changes by using steady states which can be obtained in a manner of static analysis. The “static external force” for steady states is a non-zero centrifugal force, while centrifugal forces are identically equal to zero in the original ANCF. To this end, this paper uses a floating frame to describe overall rotations of beams, and defines the nodal coordinates located on the floating frame to describe configurations of beam. Based on this description, new ANCF dynamic equations can be easily obtained by using coordinate transformation of the original ANCF dynamic equations, in which the centrifugal forces are not equal to zero. The results show that the configurations in steady and transient states are very close, and transient states are almost located in both sides of the steady state. Therefore, steady states can be regarded approximately as equilibrium positions of vibrational curved beams. By using steady states, the new ANCF dynamic equations can be linearized to determine frequencies of curved beams. Finally, the effects of curvature changes on the frequencies of curved beams, especially “dynamic softening” effect, are investigated, and the reason that these effects are caused in curved beams is explained in detail.


ABSTRACT: Conventional sound barriers are constrained by fixed geometry which results in many limitations. In this research, origami, the paper folding technique, is exploited as a platform to design deployable and reconfigurable sound barriers, as well as to actively tailor the attenuation performance. As a proof of concept, a three-dimensional barrier structure is constructed based upon Miura-ori unit cells, whose shape can be significantly altered via folding with a single degree of freedom. Folding also generates periodic corrugations on the origami sheets, which can be exploited as backing cavities to form resonant sound absorbers with a micro-perforated membrane. The absorption performance of the constructed absorber and the insertion loss of
the origami barrier are investigated using both numerical and experimental tools. The proposed origami barrier involves two fundamental mechanisms: sound reflection and absorption, and the origami offers unique tunability to enrich both mechanisms owing to the folding-induced geometric evolutions. Specifically, the sound reflection effect can be effectively tuned via changing the acoustic shadow zone and the diffracted sound paths by folding, and the sound absorption effect can also be regulated by altering the depth/shape of the backing cavities during folding. Overall, the results of this research offer fundamental insights into how folding would affect the acoustic performance and open up new opportunities for designing innovative origami-inspired acoustic devices.


ABSTRACT: Linear thermal-acoustic responses of a composite panel in a progressive wave tube are studied based on wavenumber-frequency analysis in both pre- and post-buckling ranges. The coupled finite element method/boundary element method (FEM/BEM) is developed to study the modal behavior of the panel under thermal environment. The effects of temperature-dependent material property, thermal stresses and initial deflection on the modal behavior are investigated. Wavenumber-frequency analysis is performed to predict the thermal-acoustic responses of the thermally loaded panel under the excitation of a travelling pressure wave. Both unstiffened and stiffened panel have been investigated. As temperature rose, modal frequencies decrease to the minimum values in sequence due to the softening effect of thermal stresses, and then turn to increase mainly due to the stiffening effect of initial deflection, which provides additional stiffness to prevent the minimal modal frequencies drop to zero. Wavenumber-frequency analysis is able to offer a physical explanation of interaction between the excitation and the dynamic behavior of the panel, especially in terms of a filtering effect in the wavenumber domain. The dynamic characteristics of the unstiffened and the stiffened panel under combined thermal and travelling pressure wave excitations are different. Finally, an experiment is carried out to partially validate wavenumber-frequency analysis under ambient temperature in a progressive wave tube. It is demonstrated that the proposed method is of reasonable accuracy for the test article. However, it is limited to predicting linear responses and will over predict the thermal-acoustic responses in a conservative way.


ABSTRACT: A dynamic model to study the coupled longitudinal and transverse vibrations of a submarine elastic propeller-shaft-hull system is developed using the FRF-based substructuring method (FBSM). The total system is firstly modeled as two substructures: the elastic propeller-shaft subsystem and the hull shell. For the former substructure, the elastic propeller is modeled by using harmonic blade array elements and the shafts are assumed to be Timoshenko beams, while the latter one is modeled using traditional finite element method. After that, the two substructures are synthesized using FBSM. The modes, the natural frequencies and the coupled longitudinal and transverse vibration characteristics of the propeller-shaft subsystem, the hull shell, and the total system are analyzed. An experiment studying the dynamic characteristics of a large-scale submarine experimental setup is processed and compared with the numerical results, which shows great consistency. Finally, a further discussion is carried out focused on how the bearing stiffness affects the coupled vibration characteristics of the total system.


ABSTRACT: The viola caipira is a folk guitar widely used in traditional and modern Brazilian music. It consists, in general, of 10 metallic strings arranged in five pairs, tuned in unison or octave, with the thinnest
string located in the middle. An experimental study of the viola caipira pluck by means of a high speed camera reveals some specificities of the instrument. It is found that the instrument is characterized by a double pluck excitation since the two strings of a given pair are plucked successively and rapidly. Collisions between strings arranged in the same pair are identified. A hybrid model, based on a modal approach, is carried out for sound synthesis purposes. It includes 10 strings with non-planar motions coupled with the body and collisions between strings. A finite difference scheme is used to compute the coupling forces at each time-step, which permits a set of sound simulations. The effects of string/string collisions on the viola caipira sounds are identified and discussed. It is found that the model reproduces the main vibroacoustic features of the viola caipira, among which the sympathetic string resonances and the string/string collisions observed in the video analysis.


ABSTRACT: Structures in demanding environments where high-temperatures and high-frequency vibratory loads are combined often experience fatigue which shortens their lifecycle. A limited amount of experimental data is available on the mechanical behaviour of plates under such thermo-acoustic loading. In this work, on Hastelloy-X plates, non-contact techniques were used to simultaneously acquire full-field temperature and out-of-plane displacement data for a thin plate. The plate was heated using halogen quartz lamps arranged in two different configurations and mechanically loaded using a commercially-available shaker. The centre of the plate was mounted to the shaker through a stinger with a commercially-available shaker. The centre of the plate was heated using halogen quartz lamps arranged in two different configurations and mechanically loaded using a commercially-available shaker. The centre of the plate was mounted to the shaker through a stinger with a randomly varying signal from 0 to 800 Hz. Modal shapes were studied by exciting the plate to its first eleven resonant frequencies and acquiring displacement data using a PL-DIC (Pulse Laser Digital Image Correlation) method. Infrared imaging was used to acquire temperature maps across the specimen. A finite element model was developed to include temperature-dependent material properties in the prediction of the plate's resonant frequencies and mode shapes. For the first time, experimental results showed the resonant response of the plate to strongly depend on the temperature distribution across the structure, correlating well with past predictive work in the literature. This was supported by the results from the finite element model, which were validated against experimental data and found to yield reliable predictions.


ABSTRACT: To investigate the nonlinear vibration behavior of bolted joined cylindrical-cylindrical shell, a macroslip model was considered into the radial connection at the interface between the shell segments. Based on Sanders’ shell theory and the connection condition, the vibration differential equation of the structure was established. The mono-harmonic method was used to linearize the connection model and incremental harmonic balance method was used to obtain the results of the dynamic response. First, to test the accuracy of the present method, the frequency analysis was done and the results were compared with those by ANSYS and a good agreement was shown. Then, the convergence of the method was discussed. And finally, the effects of the preload of bolts, excitation amplitude, frictional coefficient and connection stiffness on the forced response were studied. The soft nonlinearity of the response curves was easily obtained under some conditions. The results show the resonance frequency and amplitude are sensitive to the preload of bolts, excitation amplitude, frictional coefficient and connection stiffness. The results reveal the dynamic characteristics of bolted joined cylindrical-cylindrical shell and would be of signification for shell structure design and vibration control.

ABSTRACT: The use of nonlinear, dynamic methods for the simulation of aerospace structures has increased dramatically in recent years [1]; however, very little relevant experimental data exists to properly guide these developments. An experimental campaign was initiated by the AFRL Structural Sciences Center (SSC) for three reasons: (1) to observe and measure the effect of turbulence, shock boundary-layer interactions (SBLI) and heated flow on an aircraft-like panel; (2) to explore severe structural events (dynamic instabilities and material failure); and (3) to refine full-field and non-contacting experimental measurement techniques necessary to characterize the flow environment and structural response. All of the objectives were achieved. The panel response to turbulent, heated flow and sensitivity to panel back-pressure modulation was studied, with large-deformation limit cycle behavior leading to panel failure, observed and measured. For the first time, the 3D Digital Image Correlation (DIC) technique was also used to record the panel behavior while filming through the flow and SBLI environment. Finally, fast reacting pressure sensitive paint (PSP) was used, concurrently with 3D DIC, to record the dynamic pressure across the panel surface.


ABSTRACT: With structural health monitoring techniques based on measuring transverse vibrations of beam-like components it can be difficult to provide transverse excitation, while longitudinal excitation can be easier. We experimentally investigate how transverse vibrations in a beam can be excited by a longitudinal hammer impact. We carry out a comparative study on the measured transverse natural frequencies and frequency response coherence for different input and output locations and directions. It is shown that transverse vibrations are excited regardless of the impact locations and directions. Theoretical explanation to this counter-intuitive phenomenon is provided in terms of various imperfections associated with beams and impacts.


ABSTRACT: Controlling and guiding elastic waves in solids is more complicated compared with electromagnetic and acoustic waves; design and fabrication of an elastic wave cloak with non-singular, homogeneous, and isotropic material parameters is a challenging task. Recent studies in the literature that focus on manipulating flexural waves in elastic thin plates mainly use a linear transformation with a linear radial-dependent mapping function, which has drawbacks of being narrowly banded or even having negative cloaking efficiency that results from singular material parameters on the internal boundary of the cloak. This paper presents a theory of nonlinear transformation-based flexural waves and derives the nonlinear ray-tracing equation for flexural waves. A broadband cylindrical cloak for flexural waves in an elastic thin plate is realized based on a nonlinear transformation, whose materials can be simplified as layered non-singular, homogeneous, and isotropic materials using an effective medium theory. Some advantages and improvements of the invisibility nonlinear-transformation cloak are analyzed by comparison with the linear-transformation cloak. The invisibility capability of the nonlinear-transformation cloak can be tuned by adjusting an impact parameter that is shown to have influence on flexural wave energy emitting into the region inside the cloak. Numerical simulations show that the nonlinear-transformation cloak is more effective for guiding flexural waves that propagate in the region outside the cloak than the linear-transformation cloak in a broad frequency range. They also show that the nonlinear-transformation cloak can accurately control ray tracing of different types of flexural waves under disturbances outside the cloak. The methodology developed here can be used to construct nonlinear-transformation cloaks for other types of waves.

ABSTRACT: A modified mode-superposition method (MMSM) was presented in this paper to solve the free vibration problem of the “unconstrained” beams that the conventional mode-superposition method (CMSM) cannot easily tackle. For convenience, a beam without any attachments is called the “bare” beam, and the beam carrying any concentrated elements (CEs) is called the “loaded” beam, in this paper. Furthermore, the mode-superposition method (MSM) with only the “elastic” modes of the bare beam considered is called the CMSM, and the MSM with both the “elastic” and the “rigid-body” modes considered is called the MMSM. From the existing literature, one finds that the CMSM is one of the effective approaches for the free vibration analysis of a “constrained” bare beam (such as the C-C, P-P, or C-F beam) carrying various CEs, where “C, P and F” denote the abbreviations of “clamped, pinned and free”, respectively. However, the CMSM is not available for that of an “unconstrained” bare beam (such as the F-F beam) carrying various CEs. For this reason, this paper presented a MMSM to solve the title problem so that one can easily obtain the natural frequencies and mode shapes for both the “rigid-body” motions and the “elastic” vibrations of the F-F loaded Timoshenko beam. The main difference between a “constrained” bare beam and an “unconstrained” one is that the free vibration responses of latter consist of the “rigid-body” motions and those of the former do not, so that the coupling effect between the “rigid-body” motions and the “elastic” vibrations” of the F-F loaded beam are not considered by using the CMSM. To confirm the correctness of the presented theory and the developed computer program for this paper, all numerical results obtained from the MMSM are compared with those obtained from the finite element method (FEM) and good agreement is achieved. Numerical examples reveal that the CMSM can provide neither any information regarding the “rigid-body” motions nor the accurate natural frequencies and mode shapes for the “elastic” vibrations of a F-F loaded beam, and all the above-mentioned drawbacks of the CMSM have been improved by the presented MMSM.

ABSTRACT: This paper develops an inverse method to simultaneously estimate complex Young’s and shear moduli of a rectangular-shaped solid material. This new method exploits a relatively simple experiment and is designed for a frequency range of approximately 1 kHz–10 kHz. A fully elastic spatial domain model of a plate is derived and corresponding experimental measurements are collected. An error function is defined using the residual between the model displacements and the measured displacements, which allows a metric for a search over a space where the complex model values of Young’s and shear moduli are allowed to vary. When this error function is minimized, the parameters used to create the model are considered the best estimate possible. An experiment is included to illustrate the estimation process, and it is shown that the real parts of both moduli compare favorably to previously available measurements. Finally, the model is compared to the experimental measurements to illustrate its accuracy when it is formulated using the material property estimates obtained using this method.

ABSTRACT: Vibrational broadband energy harvesting has been the most focused application of bistable composite plates paired with piezoelectric materials due to their wide array of nonlinear responses at low frequencies. Various cross-well behaviors between the two potential wells allow large amplitudes and broadband characteristics favorable for generating ample power even away from resonance. With most past works being experimental, there are limitations in the available literature for validated model predictions of the electromechanical response resulting from cross-well dynamics under harmonic excitation. This paper presents the formulation, implementation, and experimental validation of the nonlinear analytical model for the rectangular piezoelectrically generated bistable laminate with a fixed center consisting of Macro Fiber Composites (MFC) in a cross-ply layup. The full range of nonlinear responses observed in tests are predicted by the simulated electromechanical equations of motion such as intermittency, limit cycle, chaotic, and subharmonic oscillations. These responses and the corresponding voltage and power outputs are investigated for
a range of excitation parameters using both time and frequency domain analysis, and they show good agreement with experimental results.


ABSTRACT: A theory of flexible shallow nano-shells is developed based on the modified couple stress theory in higher approximation. The shell material is considered as isotropic, elastic and both von Kármán and Kirchhoff-Love hypotheses are taken into account. Variational Hamilton's principle yields differential equations of motion of both shallow size-dependent nano-shells with rectangular planforms and axially symmetric nano-shells with circular planforms. The derived PDEs are reduced to the Cauchy problem by using the FDM (finite difference method), and then solved by the Runge-Kutta-type methods. Convergence of the numerical results is analysed with respect to the number of the shell radius partitions and time step. The Fourier power spectra, various wavelets-type spectra, phase and modal portraits, as well as signs of the LEs (Lyapunov exponents) are investigated. All results associated with the analysis of LEs are validated based on the case studies of non-linear dynamics. Two kinds of boundary conditions are employed: movable and fixed clamping along the shell edge. It is shown that the size-dependent parameter essentially influences shell vibrations (in particular, the chaotic vibrations become periodic).


ABSTRACT: In this paper, a new solution approach based on Lagrange multipliers is developed to investigate the free vibrations of rectangular composite plates equipped with piezoelectric layers such as Macro Fiber Composites (MFCs). The piezo-composite plate has general stacking sequences and is subjected to the elastic edge restraints. Using the first-order shear deformation theory (FSDT) and Hamilton’s principle, the boundary conditions of the problem are deduced. To solve the problem, the generalized displacements and electric potentials are expanded using the Legendre polynomial series as the base functions. Afterward, the strain and kinetic energies of the problem are achieved. Then, all the boundary conditions have been added to the energy expression by means of Lagrange multipliers to form the functional. This functional is extremised to give the natural frequencies and mode shapes of the problem through the generalized eigenvalue problem. Capability and credibility of the proposed approach are confirmed by comparing the results with those achieved by the experimental, finite element method (FEM) and 3D elasticity. The method finally is used to investigate the effects of MFCs orientations on the vibrational behavior of the smart plates.


ABSTRACT: An efficient and explicit topology optimization approach is initially proposed for eigenfrequencies of a rotating thin plate in this study. First of all, an accurate dynamic model of the rotating thin plate is established via the thin plate elements of the absolute nodal coordinate formulation (ANCF). When performing the modal characteristic analysis of the rotating thin plate at a prescribed angular velocity, the linear perturbation analysis is employed, during which the coupling between the membrane and bending deformations is considered. The coupling term makes the dynamic model established in the study more accurate than conventional models, especially in the case of large deformations. Then, the moving morphable components (MCC) are used to describe the topology of the plate. In the frame of MCC-based topology optimization, explicit geometrical parameters, positions, and orientations of the components are taken as the design variables so that the total number of the design variables can be greatly reduced. For the topology optimization, the sensitivities of a simple eigenfrequency and multiply repeated eigenfrequencies with respect to a design variable
are analytically derived. During the optimization, in order to remove the localized modes in the low-density areas, the mass and stiffness matrices of the thin plate elements of ANCF are carefully penalized. Finally, four numerical examples are presented to validate the proposed topology optimization approach and to demonstrate its effectiveness for two objectives, i.e., maximizing either the first eigenfrequency or the gap between two consecutive eigenfrequencies of a rotating thin plate.


ABSTRACT: In this paper we proposed a hierarchical structure with tetrad elliptical patterns in perforated plates. It is discovered that the introduction of structural hierarchy can enhance wave energy localization and introduce additional band gaps in 3d plates, in which elastic wave cannot propagate. However, if the hierarchical level increases further, extra vibration modes will be introduced, which may lead to the narrowing or vanishing of the band gaps. Parametric studies have been carried out to illustrate the possibility of tuning band gaps with geometric variation, and the results also demonstrate that the effect of structural hierarchy is not only limited to one specific geometric configuration. In this study, the finite element analysis and band diagram analysis are used for investigation. Moreover, experimental tests have been conducted for level-1 and level-2 perforated plates for comparison, and excellent agreement between numerical analysis and experimental tests has been achieved, which also shows the feasibility of applying this strategy in structural design and other vibration mitigation applications.


ABSTRACT: Stability investigations of general non-conservative parametrically excited systems with asynchronous excitation are presented. Focusing on the global stability effects outside of the traditional resonance areas, systems with two degrees of freedom are considered featuring displacement- and/or velocity-proportional parametric excitation with variable phase relations. In particular, facing the lack of studies on this subject, special attention is paid to time-periodic systems containing gyroscopic and circulatory terms. Through the application of the semi-analytical method of normal forms, general conditions for the appearance of possible global effects are derived. Apart from the “total instability” – presently the only known global effect – new stabilizing and destabilizing effects affecting the stability over the whole range of excitation frequencies are discovered. The derived conditions show, that such global effects are expected to be rather common in complex mechanical system, especially those, featuring circulatory terms. The qualitative analytical results are also confirmed by numerical stability analysis based on Floquet theory. As a mechanical example a minimal model of a squealing disk brake is examined. It is shown that this complex model is indeed subject to parametric excitation leading to global stability effects. These findings may contribute to a better understanding of the squealing phenomenon. Further, the newly obtained knowledge may as well be utilized for extended vibration suppression in mechanical systems in the context of parametric anti-resonance.


ABSTRACT: Experiments were conducted in a tow tank on the steady current-induced vibration of the smaller flexible cylinder (aspect ratio \( L/d = 61 \) and mass ratio \( m = 1.38 \)) in a piggyback configuration with the main pipe half-buried in the seabed. The effect of the gap-to-diameter ratio (\( G/d \)) based on the smaller cylinder diameter is studied for five different configurations from 1.0 to 4.0 and \( \infty \) (open flow) at different reduced velocities (\( U_r \)) from 2 to 10 based on the 1st modal natural frequency. An underwater optical measurement system was used in the current experiment to acquire both cross-flow (CF) and in-line (IL) vibration with a both spatially and temporally dense format. The results show that the existence of the half-buried larger cylinder will increase the
mean drag coefficient for the smaller flexible cylinder and induce a positive mean lift coefficient pushing it away from the larger cylinder. For the smallest gap-to-diameter ratio of $Gd = 1.0$ when the interaction is the strongest, experiments show that the root mean square (RMS) of the CF vibration will increase due to the appearance of the stronger higher harmonic motion compared to the open flow case. The results of the inversely calculated vortex forces reveal that the 3rd harmonic fluid force in the CF direction is even stronger than the 1st harmonic fluid force for $Gd = 1.0$. In addition, it is found that there is a strong correlation between the positive lift coefficient in phase with velocity ($C_L$) and the counter-clockwise trajectory between the CF and the IL vibrations of the smaller flexible cylinder, even with the existence of the large half-buried main pipeline.


ABSTRACT: Two laminated composite shells, one with a conventional straight fiber laminate denoted the classical laminated shell and the second one with a variable angle tow reinforced composite, had been excited and their natural frequencies and mode shapes had been measured and monitored as a function of the axial compression load. Then, the in-situ buckling loads of the two tested specimens were predicted using the Vibration Correlation Technique (VCT) and compared with actual experimental buckling loads and Finite Element buckling predictions, yielding matching, consistent and repeatable results. It was shown that the VCT predicts the actual in-situ buckling loads of laminated composite thin walled cylindrical shells with a high accuracy, yielding 96% and 98.6% of the experimental buckling load, for the classical and variable angle tow composite shells, respectively. These results, although based on only two specimens, join the relatively small data base published in the literature, proving the nondestructive nature of the VCT approach, making it an adequate method for application on thin-walled structures, like shells. In addition, some testing recommendations are presented, to effectively enable the successful application of the VCT for in-situ buckling prediction of the buckling sensitive structures, like composite cylindrical shells.


ABSTRACT: A full nonlinear model is developed for the dynamics of a hanging tubular cantilever that is simultaneously subjected to internal and external axial flows. These two flows are dependent on each other and are in opposite directions. Also, the external flow is confined over the whole length of the cantilever. A nonlinear equation of motion for the cantilever is obtained via Hamilton’s principle to third-order accuracy. The virtual work due to the fluid-related forces acting on the cantilever is derived, to the same accuracy, considering the non-conservative forces associated with the internal flow as well as the inviscid, viscous and hydrostatic forces related to the external one. In addition, a vortex-lift mechanism due to the external flow is considered, and the associated steady hydrodynamic forces are derived and added to the expression of the virtual work. The equation of motion is then discretized and solved using the pseudo-arclength continuation method and a direct time-integration technique. The dynamical behaviour obtained is compared to the one predicted by another linear theoretical model, from the literature, for the same system parameters. The two models are in good qualitative and quantitative agreement with each other in terms of the type of instability, namely flutter, that occurs with increasing flow velocity and its onset. However, the proposed model can also predict quantitative facets of the dynamical behaviour beyond the onset of instability, such as limit-cycle amplitude and frequency. Moreover, the influences of various system parameters are investigated theoretically, namely the degree of confinement of the external flow, gravity, mass ratio, drag coefficient, and the thickness of the tubular cantilever.

S. Kumar and K. Renji (First author is from: Structures group, ISRO Satellite Centre, Bangalore, 560017, India), “Estimation of strains in composite honeycomb sandwich panels subjected to low frequency diffused
ABSTRACT: Acceleration responses of panels subjected to diffused acoustic field are often determined using a coupled Finite Element - Boundary Element Method. In many such models the structure is represented by its natural modes and the acceleration responses can be determined. But for the verification of the structure for its survivability, its strain responses are essential to be determined. In practice such coupled models do not have the information on the structural details and hence it is not possible to determine the strains in the structure. A methodology to estimate the strains in the low frequency modes of the structure based on the acceleration responses is developed in this work. An expression relating the spectral density of strain to the spectral density of the acceleration is derived. A composite honeycomb sandwich panel is subjected to diffuse acoustic field in a reverberation chamber and accelerations, strains are measured. The strains are estimated using the methodology developed in this work and it is seen that the strains determined using this technique are very much in agreement with the measured strains. Thus, the present work enables determination of strains in the panel even when the structure is represented by its free vibration characteristics and its physical properties are not known.

Geng Peng, Youming Xiong, Liming Liu, Yun Gao, Menghao Wang and Zheng Zhang (State Key Laboratory of Oil and Gas Reservoir Geology and Exploration, Southwest Petroleum University, Chengdu, 610500, China), “3-D non-linear dynamics of inclined pipe conveying fluid, supported at both ends”, Journal of Sound and Vibration, Vol. 449, pp 405-426, 9 June 2019, https://doi.org/10.1016/j.jsv.2019.02.040

ABSTRACT: In this paper, the three-dimensional (3-D) non-linear dynamics of inclined supported pipes conveying fluid with motion constraints are investigated. The motion constraints are modeled by an array of four and an array of two cubic non-linear springs. The spring forces are incorporated into the equations of motion via the method of virtual work. The equations of motion, obtained from Hamilton's principle, are discretized into 18 coupled non-linear ordinary differential equations using Galerkin's method, and solved numerically via Houbolts's method and Newton-Raphson iterative technique. Bifurcation diagram and oscillation trajectories are plotted to show the characteristics of some typical motions. The effect of system parameters, such as the inclination angel and spring stiffness, on the system dynamics is investigated.

S.D. Akbarov and E.B. Bagirov (First author is from: Department of Mechanical Engineering, Faculty of Mechanical Engineering, Yildiz Technical University, Yildiz Campus, 34349, Besiktas, Istanbul, Turkey), “Axisymmetric longitudinal wave dispersion in a bi-layered circular cylinder with inhomogeneous initial stresses”, Journal of Sound and Vibration, Vol. 450, pp 1-27, 23 June 2019, https://doi.org/10.1016/j.jsv.2019.03.003

ABSTRACT: The paper studies the axisymmetric longitudinal wave propagation in a bi-layered hollow cylinder with inhomogeneous initial stresses by utilizing the 3D linearized theory of elastic waves in initially stressed bodies. It is assumed that the initial stresses in the cylinder are caused by the internal and external hydrostatic pressures. Assuming that the materials of the layers of the cylinder are sufficiently stiff, these initial stresses are determined within the scope of the classical linear theory of elasticity. The discrete analytical method is employed for the solution to the corresponding 3D linearized equations of motion. The dispersion equation is obtained which is solved numerically for various values of the problem parameters. As a result of this solution, the dispersion curves are constructed and, according to these curves, the character of the influence of the inhomogeneous initial stresses on the dispersion curves obtained for the lowest first and second modes is established. Analysis of the results shows that the inhomogeneous initial stresses not only quantitatively but also qualitatively act on the character of the dispersion curves.


ABSTRACT: The equation of motion for thin rectangular plate was formulated in its correct form about 200 years ago. Exact solution, for some cases, and high accuracy solution for few more cases, have been obtained along the years since. For several other cases, high accuracy solutions were composed of separate solutions for symmetric and anti-symmetric cases. In this work a new high accuracy solution, that covers all the possible combinations is presented. It is obtained by using carefully chosen series that solve the partial differential
equations of motion, for all possible combinations of edge conditions. Examples of the new solutions are given and compared with approximate solutions for these cases.


ABSTRACT: This paper provides a contribution to the understanding of both the vibroacoustical behavior and the influence of passive constrained layer damping (PCLD) applications on the sound radiation of a grid-stiffened panel. A test specimen is manufactured and an experimental set-up with a synthetic turbulent boundary layer excitation is developed. In addition, a numerical model is created and updated with the results of an experimental modal analysis. Further, the acoustic effect of PCLD applied to the ribs and to the skin fields of the grid panel is assessed by measurement of the radiated sound power. It is shown that the ribs are suitable for an efficient application of PCLD. Generally, additional damping of the grid panel is achieved with PCLD for frequencies above 300 Hz. By partially covering the ribs with PCLD, a reduction of the radiated sound power of up to 2 dB in third-octave bands is achieved. In case of a total coverage of the grid panel, a reduction of up to 4 dB in third-octave bands is attained.


ABSTRACT: This paper attempts in analysing the transient dynamic response behaviour of multi layered hybrid composite plates by a modified higher order refined zigzag theory (HRZT). An improved C0 continuous model is developed based on the refined higher order zigzag theories (HRZT) with warping effect for multilayered plates using eight noded isoparametric quadratic plate bending element to get the stress distribution across the thickness under dynamic load in a realistic manner. The continuity condition of transverse shear stresses is ensured with the help of 3D equilibrium equation at the interfaces of two adjacent layers along with the shear stress free condition at the outermost faces of a laminate. A computer code is developed with the help of MATLAB software package. The hybrid laminate is modeled by placing carbon fibres in the outermost layers and glass fibres in the rest and thus the flexural behaviour is improved. The experimental study on the transient dynamic response of hybrid laminates is also performed. Transient dynamic response obtained from the finite element based numerical model is verified by comparing the time history data obtained numerically and experimentally. The interlaminar stresses are also extracted and recorded under dynamic loading condition. The displacement and the stress components of laminated plates under static load are also computed in the present study and the results are compared with the theoretical outcome obtained in the relevant literature for validation of the present FE formulation. An exhaustive study on glass and hybrid fibre reinforced laminates is carried out to investigate the effectiveness of the hybrid laminate in terms of the response data of laminates with mono fibre as well as multiple (hybrid) fibres.


ABSTRACT: Membrane- and plate-type acoustic metamaterials are thin membranes or plates consisting of periodic unit cells with small added masses. It has been shown in numerous studies, that these metamaterials exhibit tunable anti-resonances with transmission loss values much higher than the corresponding mass-law. However, in most studies it is assumed that the unit cell edges (or grid) of the metamaterial are fixed. This idealised boundary condition is not applicable to real world applications in noise control. Therefore, the acoustic performance of these metamaterials under more realistic circumstances, where the grid structure cannot be perfectly rigid, can be expected to be different. In this contribution, the vibro-acoustic behavior of membrane- and plate-type acoustic metamaterials with a non-rigid grid is investigated. For this purpose, an efficient analytical model is developed to predict the eigenmodes and sound transmission loss of such metamaterials. In this model, elastic unit cell edges are modelled using a grid of Euler-Bernoulli beams and the sound transmission loss can be calculated for oblique incidence. A comparison to FEM simulations shows that the proposed model yields the same results but with a considerably reduced computational effort. The analytical model is then used to discuss the vibro-acoustic properties of the metamaterial, with particular focus on the influence of the mass and stiffness of the grid beams. It is shown that even when a non-rigid grid and diffuse
incident sound fields are considered, the transmission loss of the metamaterial exhibits anti-resonances with remarkably high noise reduction values. These anti-resonances can be tuned by choosing appropriate values of the grid parameters. Furthermore, the formation of band gaps in the propagation of bending waves is discussed by investigating the dispersion curves of the metamaterial. The results in this contribution show that membrane- and plate-type acoustic metamaterials can still efficiently reduce low-frequency noise, even when the unit cell edges are not assumed to be fixed. This important finding and the proposed analytical modal can support the utilization of these metamaterials in practical noise control applications.


ABSTRACT: Vibration of pipes and cylindrical shells leading to noise and damage is an important engineering problem in plant systems and air conditioners, among others. To attenuate such vibration, a viscoelastic material is attached to pipes as a damping material. To predict the vibration reduction effect in detail, three-dimensional finite-element analysis is usually conducted considering the characteristics of the viscoelastic material, but such analysis requires considerable computation time. To overcome this problem, this study proposes added mass and added damping to address the effects of vibration of the damping material on the vibration of a pipe. By this method, one-dimensional analysis can be performed. To assess the validity of the proposed method, numerical results for the vibration of a pipe fitted with silicone obtained using the proposed method are compared with measurements from a hammering test and numerical results from three-dimensional analysis. The computational results obtained using the proposed method agree very well with the measurements and the three-dimensional numerical results. Furthermore, it is found that the vibration of the pipe is attenuated by not only the damping of the viscoelastic material but also the effect of dynamic behavior similar to that of a dynamic absorber.


ABSTRACT: Active control of swept smart aircraft wings in an incompressible flow are examined. The wing structure is modeled as a composite thin-walled beam featuring fiber-reinforced host structure and piezo-composite actuators. The nonclassical effects, such as twist-bending elastic coupling, warping inhibition, transverse shear and rotatory inertia are incorporated. The unsteady incompressible aerodynamics are derived based on the concept of indicial functions, applicable to arbitrary small motion in the time domain. The influence of directionality property both of the host structure and piezo-actuators on improving aeroelastic performance are specifically investigated. The potential for active aeroelastic control via the actuation couplings due to the anisotropic piezoelectric properties is highlighted. A number of conclusions are outlined at the end.


ABSTRACT: This paper investigates a metamaterial solution for efficient vibration attenuation and acoustic radiation reduction of an aluminum pipe. To this end, using unit cell predictions, locally resonant structures are designed to have a pronounced flexural resonance frequency at the vicinity of a dominant vibration mode of the pipe. A direct approach of the Bloch-Floquet theorem is adopted to provide the dispersion relation representing wave motion in an infinite metamaterial pipe. Using these wave dispersion relations, the frequency range of the stopband zone created by the metamaterial solution is predicted. The dynamic behavior of the finite counterpart is predicted using the Finite Element Method (FEM). The resonant structures are produced from polymethyl methacrylate (PMMA) panels and are added to the host structure. In order to properly characterize both the vibrational behavior of the metamaterial pipe and the acoustic radiation from its wall, impact tests using roving hammer technique is performed on the pipe and both accelerations and acoustic pressures are measured at different locations. The experimental results show a pronounced stopband zone created by the addition of a few rows of resonant structures. Moreover, comparisons between the measurements and numerical predictions show a good agreement.

ABSTRACT: A new high-order model for in-plane vibrations of rotating rings is developed in this paper. The inner surface of the ring is connected to an immovable axis through an elastic foundation (distributed springs), whereas the outer surface is traction free. The developed model enables the dynamic analysis of the rings on stiff elastic foundation that rotate with a high speed. The traction force at the inner surface of such rings is so high that it influences significantly the through-thickness stress distribution. This boundary effect cannot be captured by the classical low order theories while the model proposed in this paper can account for this effect. Nonlinear equations of motion are first derived, considering the geometrical nonlinearity of the system while assuming the linear elastic behaviour of the ring material. The formulation accounts for the stress caused by rotation and the significant normal and tangential traction forces at the inner surface of the ring. The displacement fields are assumed to be polynomials of the through-thickness coordinate in both the radial and circumferential directions. The derivation is generic and can yield ring theories of different order, i.e. of the Timoshenko-type and beyond, with proper consideration of both the internal state of the body and the boundary effects at the surfaces. Two types of critical speeds are investigated, namely the one at which the free vibrations become unstable and the one at which the forced vibration of a rotating ring subjected to a constant stationary point load experiences resonance. A comparison is presented of the predictions of the developed model to those of the lower order theories. It is shown that even for thin rings on elastic foundation, high order corrections, beyond the ones of the Timoshenko theory, need to be considered for an accurate estimation of the critical speeds of rotating rings. The new high-order model is superior to the existing ring models in predicting dynamic behaviour of either stationary or rotating rings. Without loss of generality, the model is applicable to both plane strain and plane stress configurations.


ABSTRACT: A layerwise finite element formulation based on B-spline function is used to study dynamic instability of damped laminated composite plates with embedded delaminations in this article. The out-of-plane variation of in-plane displacement components are interpolated by Linear Lagrange interpolation function and the in-plane variation of in-plane and out-of-plane displacement fields are interpolated by B-spline functions. Delamination between layers of composite plate is modeled by jump discontinuities in displacement fields using Heaviside functions. In the delaminated region, virtual springs are added to prevent interpenetration of lower and upper sublaminates. The local buckling of thinner sublamine is observed when delamination is placed near the top/bottom interface. The dynamic instability regions are computed by Bolotin’s method. The effects of delamination lengths and its position on the natural frequencies, mode shapes, buckling loads and dynamic instability regions of the composite plates with various boundary conditions are examined. Both uniform and non-uniform periodic edge loading in the form of concentrated and partial edge loading are considered. Furthermore, the effect of damping on the dynamic instability regions of composite plate is studied. From the linear and nonlinear responses in the stable and unstable regions, various characteristics such as beats, its dependence on forcing frequency and damping are observed.


ABSTRACT: This work presents a methodology to obtain physically-sound models of composite structure laminates using a combination of modal analysis, numerical modelling and parameter updating, avoiding the common uncertainties on the constructions of similar numerical models. Moreover this model establishes the baseline (pristine situation) of the dynamic behaviour of the set of composite plates. Therefore it could be applied for condition assessment or quality manufacturing control of existing structures through a non-destructive Structural Health Monitoring (SHM), and hence it could help to detect degradation or defects of the composite components. The driven data of the methodology were the modal frequencies and shapes of composite plates. To obtain these values an extensive experimental campaign of modal analysis has been performed on a set of carbon/epoxy laminates. A multiple input single output technique has been applied, using
a roving hammer exciting the plates at evenly distributed Degrees of Freedom (DoF), and a mono-axial accelerometer attached to a single DoF reference point. The use of a high dense grid of points has allowed to identify a number of natural frequencies greater than usual in similar works, as well as improving the smoothness of the mode shape. Modal characteristics numerically obtained from a Finite Element Method (FEM) model based on manufacturer reference data were compared with experimental results. This baseline model was updated through a gradient based optimization algorithm. Before the process of model updating, a sensitivity analysis has been performed to identify the driven uncertain parameters using a Montecarlo approach. This technique reduces the number of parameters to be optimized to a small set increasing the efficiency of the methodology. As a result of the whole process, a physically more accurate model is obtained on which discrepancies with the corresponding experimentally measured modal parameters are drastically reduced. Analysis of the consistency of the adjusted numerical parameters has been done with alternative experimental tests (Quasi Static Loading (QSL) and Ultrasonic inspection).


ABSTRACT: In this paper, a nonlinear Timoshenko model of the coupled vibration of a pipe conveying fluid is established to distinguish it from the Euler-Bernoulli coupled model and the Timoshenko model of the transverse vibration in terms of application scope and accuracy. The generalized Hamilton’s principle is utilized to derive the coupled Timoshenko model. The coupled Timoshenko model can be degenerated into three other models, namely the integro-partial differential Timoshenko transverse model, the partial differential Timoshenko transverse model, and the Euler-Bernoulli coupled model. The finite difference method (FDM) is developed to calculate the time history of the free vibration of the pipe. Based on the time history, the nonlinear frequency is obtained by using the discrete Fourier transform method (DFT). Furthermore, the amplitude-frequency curves of the forced vibration of the viscoelastic pipe are studied. The necessity for the Timoshenko coupled pipe model is shown by comparing with the other three models. Through extremely time-consuming calculations, comparisons show that these nonlinear models agree well at a low flow velocity and slight vibration. However, when the flow velocity or the initial displacement amplitude is large, the relative error of the nonlinear frequencies of the free vibration may exceed 30%. Moreover, the results indicate that the nonlinear coefficient has great influence on the nonlinear frequency when the flow velocity or the initial amplitude is large. Interestingly, the shear coefficient has a significant impact on the nonlinear frequency when the initial amplitude is small. In general, this paper shows that a large flow velocity, a large vibration amplitude or a shorter pipe length makes the coupled Timoshenko theory more necessary for modeling pipes conveying fluid.


ABSTRACT: The effects of a dynamic terminal moment on the stability characteristics of a cantilever beam, not studied heretofore, are investigated using both theory and experiments. The terminal moment is assumed to be proportional to the slope or curvature of the beam measured at some point along its length. The moment is non-conservative when it is curvature-dependent as well as when it is slope-dependent provided the measurement is not taken from the free end of the beam. Irrespective of whether the moment is slope-dependent or curvature-dependent, the beam loses stability through divergence when the constant of proportionality is positive, and through flutter when the constant of proportionality is negative. For the case where the terminal moment is proportional to the negative slope or negative curvature, multiple stability transitions can occur and higher modes of flutter instability are induced as the point of measurement shifts from the fixed end to the free end of the beam. These conclusions are drawn through analytical and numerical investigations of stability. In the experimental component of work, the terminal moment is designed to be curvature-dependent for ease of measurement. Flutter oscillations are observed at or slightly beyond the point of instability and the frequency and mode shape of the oscillations are found to match reasonably well with those predicted analytically.


ABSTRACT: This paper deals with optimization of the sizing, location and orientation of the piezo-fiber reinforced composite (PFRC) actuators and active vibration control of the smart composite plates using particle-swarm optimized self-tuning fuzzy logic controller. The optimization criteria for optimal sizing, location and orientation of the PFRC actuators is based on the Gramian controllability matrix and the optimization process is performed by involving the limitation of the plates masses increase. Optimal configurations of five PFRC actuators for active vibration control of the first six modes of cantilever symmetric (90°/0°/90°/0°), antisymmetric cross-ply (90°/0°/90°/0°/90°/90°/0°) and antisymmetric angle-ply (45°/-45°/45°/-45°/45°/-45°) composite plates are found using the particle swarm optimization. The detailed analysis of influences of the PFRC layer orientation and position (top or bottom side of composite plates), as well as bending-extension coupling of antisymmetric laminates on controllabilities is also performed. The experimental study is performed in order to validate this behavior on controllabilities of antisymmetric laminates. The particle swarm-optimized self-tuning fuzzy logic controller (FLC) adapted for the multiple-input multiple-output (MIMO) control is implemented for active vibration suppression of the plates. The membership functions as well as output matrices are optimized using the particle swarm optimization. The Mamdani and the zero-order Takagi–Sugeno–Kang fuzzy inference methods are employed and their performances are examined and compared. In order to represent the efficiency of the proposed controller, results obtained using the proposed particle swarm optimized self-tuning FLC are compared with the corresponding results in the case of the linear quadratic regulator (LQR) optimal control strategy.


ABSTRACT: The concept of total-internal-reflection elastic metasurface (TIR-MS) was recently proposed [1] and employed within flexible planar waveguides in order to create highly subwavelength sound-hard barriers impenetrable to low frequency elastic waves. The underlying physical mechanism relies on the design of engineered interfaces exhibiting extreme phase gradients such that any incoming wave at, approximately, any incidence will experience total-internal-reflection conditions. At the design frequency, the metasurface exhibits a large phase gradient such that, in accordance with the generalized Snell’s law, the first critical angle is virtually always exceeded. It is worth noting that in practical realizations, the actual total reflection performance might vary depending on the angle of incidence. This dependence is due to the discrete implementation of the metasurface which results in diffraction effects. This paper presents the results of an experimental study that explores the vibration isolation performance of TIR-MS when applied to structures made of complex combinations of different elastic waveguides (e.g. bolted assemblies of beams, plates, and shells). Such system can be seen as a prototypical structure emulating mechanical assemblies of practical interest for many engineering applications. Experimental results confirm that, when the TIR-MS is embedded in the host waveguide, significant vibration isolation capabilities are achieved under quasi-omnidirectional incidence and highly subwavelength excitation conditions (i.e. the ratio of the operating wavelength to the width of the TIR-MS is approximately 5.25). These experimental results suggest new interesting directions to achieve vibration isolation and mechanical energy filtering for practical engineering systems.


ABSTRACT: The paper describes a methodology for computing the sound transmission loss of any flat, curved and cylindrical, homogeneous and periodic structure, under any type of acoustic and/or aerodynamic load. An approximate excitation model is introduced to reproduce uncorrelated and spatially-correlated loads using a wavenumber integration of surface waves. Then, a wave finite element formulation is developed and interfaced with the excitation models in order to cover industrially-relevant case studies. Analytical, numerical and experimental transmission losses are presented for validation purposes. Finite size effects are also taken into account using a spatial windowing and a cylindrical analogy, for curved structures. Different periodic-cell designs are also compared and investigated under turbulent boundary layer and diffuse acoustic field excitations.

ABSTRACT: This paper presents a numerical method for analyzing the nonlinear structural and acoustic responses of a coupled stiffened composite laminated cylindrical shell and piecewise isolation system immersed in an infinite acoustic fluid. The cylindrical shell is reinforced by a series of circumferential rings and longitudinal stringers, which may be few or many in number, non-uniform or uniform in size, and arbitrarily distributed in space. The isolation system in the shell contains motion-limiting stops, and the restoring forces of the isolators are assumed as bi-linear functions of the isolator deformations. A modified variational approach for the shell combined with a discrete element method for the rings and the stringers is employed to establish the nonlinear dynamics model of the structural system. The exterior acoustic fluid is computed by a time-domain Kirchhoff boundary integral formulation. The structural and acoustic models are coupled together by considering the compatibility conditions on their interface. The validity of the present method for predicting the structural and acoustic responses of the coupled shell and isolator system is confirmed. The contribution of the grouped circumferential wave modes of the shell to the vibration and radiated sound of the coupled structural system is examined. The effects of the excitation frequency of the external load, as well as the stiffness ratio and the gap of the suspension springs in each isolator on the structural and acoustic responses of the coupled system are discussed.


ABSTRACT: This paper is concerned with the problem of free vibration of an Euler-Bernoulli beam supported with an arbitrary number of translational springs of different constant stiffnesses. The natural frequencies and mode shapes are calculated by means of the Green's function method. Seven different boundary conditions are considered at both ends of the beam: fixed, pinned, sliding, free, translational spring, rotational spring and combined translational-rotational spring. Each boundary condition on one end is combined with all other boundary conditions on the other, yielding a total of 49 possible cases. It has been shown in this paper that a Green's function for any set of boundary conditions can be represented as a linear combination of function coefficients calculated for homogeneous boundary conditions, and also a new form of the general solution is formulated using this principle. Green's functions are calculated and tabulated for each of the 49 possible cases, which in essence closes the question of analytical solutions for this particular kind of problem using Green's functions. The tabulated solutions were used as the starting point in the derivation of the general formulae and to provide a new insight into the underlying mathematical structure of the solutions formulated with Green's functions. This can be of practical interest to the end user who wishes to implement them in computer code. The validity of the obtained solutions is demonstrated with examples, whose solutions are compared to the results in the published literature and to the results obtained with FEM.
ABSTRACT: This research points out the positive results of structural deformations and follower forces exerted on a sandwich composite plate. This phenomenon that is named “flutter” is a dynamic instability and defines the ductility of the structure in fluid flow. Herein, the effective elastic properties of the reinforced composite by carbon nanotubes are acquired by the rule of mixture. Pasternak foundation has developed normal and shear modulus. The upper and lower layers of the sandwich are selected from the smart magnetostrictive sheets. A feedback control system pursues the magnetization effects of Terfenol-D films on the flutter vibration characteristics of sandwich plate. Five coupled equations of motion are derived using Hamilton's principle. These equations are solved by differential quadrature methods. Results of this study detected the critical values of follower forces corresponding to the start of flutter and divergence instabilities considering the effect of thickness ratios of the sandwich plate and velocity feedback gain, volume fraction of fibers and temperature gradient. The results of this research are used in the diagnosis of new structures used in aerospace, military and facilities industries.

ABSTRACT: The High Resolution Wavevector Analysis (HRWA) is presented and its application illustrated. Extending the High Resolution Wavenumber Analysis method [1] to 2D signals, it allows the wide-band and local characterization of the linear elastic behavior of anisotropic plates. The method belongs to the family of experimental wavenumber-based characterization methods and uses the high resolution signal processing algorithm ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques) and the ESTER criterion (ESTimation of ERror) to overcome some of the limitation of Fourier-based methods. Three experimental applications on composite plate specimens are presented. First (i), from the out-of-plane velocity field of a sandwich plate with a foam core, different wave types (bending, shear and compression) are extracted. The results are compared with numerical predictions. Second (ii), individual layer contributions are separated on a honeycomb sandwich plate by means of the observation of the dependence of the extracted complex wavevectors as a function of wave propagation direction and frequency. Third (iii), a local wavenumber extraction is performed on a 4-layer carbon-epoxy plate made of fiber patches with spatially varying orientations. The local specific bending stiffness of the plate is identified from the extracted wavevectors and compared with theoretical results.

ABSTRACT: This study investigates the linear free vibration and elastic buckling behaviors of functionally graded (FG) multilayer graphene platelet (GPL)-reinforced composite beams containing a single edge crack and resting on a Pasternak-type elastic foundation. GPLs are randomly oriented, and their concentration varies layer-wisely through the beam thickness. A modified Halpin-Tsai model is employed to estimate Young’s modulus of the GPL-reinforced composite (GPLRC). The first-order shear deformation beam theory is applied in structural modeling. The bending stiffness of the cracked section is assumed to be equivalent to that of a massless rotational spring, which is related to the stress intensity factor (SIF) at the crack tip. SIFs of the cracked FG multilayer GPLRC beams are calculated by the finite element method. The differential quadrature method is used to discretize the equations of motion of the cracked beams. A parametric study is performed after a validation study for the present approach to illustrate the effects of crack location, crack length, boundary condition, GPL weight fraction, GPL distribution pattern, GPL size and geometry, and foundation stiffnesses on the fundamental frequencies and critical buckling loads.
ABSTRACT: This paper presents a general electromechanical model for predicting the dynamics of thin or moderately thick plates with surface-integrated piezo-patches. Using spectral Tchebychev (ST) technique, the boundary value problem governing the electroelastic dynamics of the two dimensional (2D) plate and piezo-patch structure is developed with Mindlin plate theory assumptions. Mass and stiffness contributions of piezo-patch(es) as well as two-way electromechanical coupling behavior are incorporated in the model for both modal analysis and frequency response calculations. To validate the accuracy of the developed solution technique, the modal analysis results are compared against the existing Rayleigh-Ritz solution from the literature as well as the finite-element simulation results for various piezo-patch sizes on thin and moderately thick host plates; and it is shown that the maximum difference in the predicted natural frequencies between the ST and FE results are below 1%. The electromechanical frequency response functions (FRFs) including the vibration response and electrical output of the system under a transverse point force excitation are obtained using the ST model and the results are shown to match perfectly with the finite element (FE) simulations. Additionally, comparisons of the electromechanical FRFs calculated based on Rayleigh-Ritz method from the literature versus the developed framework is presented to highlight that the exclusion of shear deformation terms in the former model leads to an inaccurate estimation of electroelastic behavior for the case of thicker plates with integrated piezo-patches. Finally, the investigated case studies demonstrate that the computational efficiency of the developed method is significantly higher than that of FE simulations.

ABSTRACT: A novel dynamic stiffness formulation which includes the effects of shear deformation and rotatory inertia is proposed to carry out the free vibration analysis of thick rectangular orthotropic plates i.e. the formulation is based on an extension of the Mindlin theory to orthotropic plates in a dynamic stiffness context. The modified trigonometric basis is used to construct the general solution for the free vibration problem of the plate in series form, permitting the derivation of an infinite system of linear algebraic equations which connect the Fourier coefficients of the kinematic boundary conditions of its four edges. The boundary conditions are essentially the deflections and angles of rotations constituting the displacement vector and shear forces and bending moments constituting the force vector. The force-displacement relationship is then obtained by relating the two vectors via the dynamic stiffness matrix. Essentially the ensuing infinite system forms the fundamental basis of the paper, which defines the dynamic stiffness matrix for an orthotropic Mindlin plate in an exact sense. Numerical results are obtained by using the Wittrick-Williams algorithm as solution technique. The theory is first validated using published results and then further illustrated by a series of numerical examples. The paper concludes with significant conclusions.


ABSTRACT: Tire vibration includes not only radial vibration, but also lateral vibration. The lateral vibration always plays an important role to vehicle Noise, Vibration and Harshness (NVH), especially high-order lateral bending vibration. In this paper, a new theoretical three-dimensional ring based model and related new displacement function were both developed for tire radial and lateral vibrations, especially for tire high-order bending vibration. The proposed model considers the detailed features of the 3D ring such as the ring thickness, the shear strain in lateral-tangential plane and lateral normal strain, tangential and lateral pre-stress induced by inflation. The new displacement function in Dual Flourier series was developed for the tire model, which can in particular describe the belt bending vibrations in transverse direction. Either of the proposed model and displacement function is indispensable to compute high-order modes of the belt. The proposed model was
verified with the conducted physical experiments. The proposed model costs less than 5s to compute the natural frequencies of tire. The results show that the tire vibration modes from 300Hz to 500Hz could be predicted quite well as well as that below 300Hz. The model is an efficient and effective tool to investigate the dynamic characteristics of tire.


ABSTRACT: The emergence of phononic crystals paves a new way for manipulating elastic waves in structures for their particular bandgap properties. In this paper, the two-dimensional soft porous periodic structures that can be filled with hard inclusions are considered. Both numerical simulations and experiments are conducted to study the effects of inclusions on the buckling modes, post-buckling deformations, and band structures in soft porous periodic structures. It is found that either the number or the arrangement (i.e. filling pattern) of the inclusions has a great influence on the bandgap characteristics. Meanwhile, the material damping affects the wave propagation in soft phononic crystals significantly in the high frequency range. Compared with the unfilled soft porous structure, the sensitivity of the post-buckling deformation to the initial geometrical imperfections can be significantly reduced for the structure filled with inclusions. This means the post-buckling deformation could develop robustly. Further numerical study indicates that the bandgaps can be tuned in a versatile and reversible way when the structure undergoes a large deformation. A more fruitful manner to tune the bandgaps therefore can be achieved by changing the filling pattern of inclusions along with dramatically deforming the structure. The work provides a useful reference for the design of tunable phononic switches and acoustic filters.


ABSTRACT: In this experimental work a scanning laser Doppler vibrometer is used to measure mode shapes and natural frequencies of beam bending vibrations above the critical frequency predicted by Timoshenko theory. Above the critical frequency the mode shapes are intricate, so to quantitative compare theoretical and experimental mode shapes, the modal assurance criterion (MAC) is applied. This reveals that the order of the modes is not as theory predicts, and that other plane modes can easily be misinterpreted as bending modes. This can lead to an incorrect comparison of natural frequencies. With the MAC tool it is found that the correlation between theoretical mode shapes and measured mode shapes is very high; It can be concluded that supercritical Timoshenko-predicted mode shapes agrees well with the experimentally observed modes, and the supercritical natural frequencies deviate from Timoshenko theory within five percent. Comparisons are made to other studies, and against a numerical 3D model.


ABSTRACT: This paper presents a theoretical analysis of sound transmission through a sandwich structure in the presence of external mean flow. The structure is comprised of two panels connected by two-layered pyramidal cores and filled with fibrous material. The fibrous absorptive material in the core is characterized by an equivalent fluid model. The interaction between the structure and the surrounding fluid is taken into account by imposing a velocity continuity condition at the interfaces. The inclined beams in the core exert forces and moments on the panels. The space-harmonic approach and virtual work principle are applied to derive the governing equations. A validation is carried out by comparison with finite element simulations and existing experimental measurement. Numerical calculations are used subsequently to explore the influence of the material, mean flow and structure geometry. The results demonstrate that the absorptive material influences the sound transmission loss (STL) at low frequencies and that the effectiveness is affected by the geometry of the structure.
ABSTRACT: This paper investigates sound radiation by an inflated dielectric elastomer membrane. The constitutive equations of the coupled electromechanical system are derived from general mechanical equilibrium equations, from Maxwell's equations, and from thermodynamic considerations. A finite deformation model featuring a hyperelastic constitutive law is written for the case of a thin membrane. The static finite deformation obtained when the membrane is inflated and when a voltage is applied is computed. The linear dynamics around this equilibrium are studied on the modal basis: the mode shapes and eigenfrequencies are computed, as well as the modal forces created by the voltage applied to the electrodes. The radiated acoustic pressure is estimated using a modified Rayleigh integral to take into account curvature effects. All numerical calculations are validated against measurements. The model is shown to be able to predict the linear vibrations, as well as the radiated pressure. The effect of the volume of the cavity on which the membrane is inflated is taken into account in the model. This model can therefore be used to optimize the design of dielectric loudspeakers, in terms of spectral balance for example.


ABSTRACT: This paper investigates sound radiation by an inflated dielectric elastomer membrane. The constitutive equations of the coupled electromechanical system are derived from general mechanical equilibrium equations, from Maxwell's equations, and from thermodynamic considerations. A finite deformation model featuring a hyperelastic constitutive law is written for the case of a thin membrane. The static finite deformation obtained when the membrane is inflated and when a voltage is applied is computed. The linear dynamics around this equilibrium are studied on the modal basis: the mode shapes and eigenfrequencies are computed, as well as the modal forces created by the voltage applied to the electrodes. The radiated acoustic pressure is estimated using a modified Rayleigh integral to take into account curvature effects. All numerical calculations are validated against measurements. The model is shown to be able to predict the linear vibrations, as well as the radiated pressure. The effect of the volume of the cavity on which the membrane is inflated is taken into account in the model. This model can therefore be used to optimize the design of dielectric loudspeakers, in terms of spectral balance for example.


ABSTRACT: The main objective of this study is to determine the effects of two-phase cross-flow and nonlinear clearance constraint on the dynamic characteristics of steam generator tube bundles. The equation of motion of a cantilevered tube with nonlinear clearance constraint is established utilizing quasi-static fluid force of two-phase flow. The analytical model, after Galerkin discretization and Runge-Kutta algorithm numerical solution, exhibits several interesting behaviors of bifurcations and chaotic motions with increasing two-phase flow velocities after fluidelastic instability occurs. Numerical solutions show that, the bifurcation velocities of Hopf, pitchfork, period-doubling are delayed and the amplitudes of tube vibration at the corresponding bifurcation points become larger with increasing void fraction of two-phase. Moreover, the clearance size, constraint stiffness and asymmetry of clearance support have remarkable effects on nonlinear dynamic behavior. Larger clearance size, constraint stiffness and asymmetry lead to more complex nonlinear behavior, including distorted break along bifurcation track, inverse bifurcation and wider range of chaotic motions, so that some typical bifurcation points become indiscernible.


ABSTRACT: This paper investigates the potential use of an equivalent cylindrical shell model to analyze the vibration of a ring truss structure for a large deployable circular mesh antenna clamped along one generatrix. The simplified method, which reduces the three-dimensional cell structure into a two-dimensional “flattened” cell structure of the ring truss, is presented. According to the drum-like structure of the antenna, the equivalent cylindrical shell model of the ring truss structure is established. Using the flattened cell structure, the equivalent membrane stiffness and bending stiffness are derived by using the equivalent process and the homogenization method. The differential governing equation of motion for the equivalent cylindrical shell clamped along one generatrix is established based on the Donnell thin shell theory. The theoretical results are verified by numerical simulations. The natural frequencies of the equivalent cylindrical shell are calculated with the non-normal boundary condition clamped along one generatrix. The natural frequencies are compared to ones obtained using a full-scale model by using the finite element method (FEM). The mode shapes of the equivalent cylindrical shell agree well with the ones of the ring truss structure for the full-scale finite element.

Yang Liu (1), Jiyuan Han (1), Zengyuan Xue (2), Ye Zhang (3) and Qiang Yang (4)
(1) School of Mechanical Engineering and Automation, Northeastern University, Shenyang, 110004, China
(2) Shanghai Automobile Gear Works, Shanghai, 200000, China
(3) Guodian Science and Technology Research Institute(Shenyang), Shenyang, 110004, China
(4) Department of Mechanical & Aerospace Engineering, University of Dayton, Dayton, OH, 45469, USA

ABSTRACT: Structural vibrations and radiation noise are common problems in the blade–shafting–shell coupled system. To research this problem, a coupled system consisting of a five-leaf blade, shaft, bearing, and shell was established using a dynamic equilibrium equation. To describe the dynamic behaviour, a blade excitation force model consisting of transverse and vertical excitation forces generated by the blade was established using a quasi-steady method. It was found that the transverse excitation force resulted in more complex frequency components than the vertical excitation force. The frequency components of the blade frequency doubling (2.5f) and the blade frequency (5f) in the spectrogram were mainly produced by the transverse excitation force (where f is the rotational frequency of the shafting). In addition, in the acoustic analysis section of this paper, a finite element model of the coupled system was established. Blade excitation forces were applied to the model, and the vibrational response data of the coupling model's nodes were obtained. Using the acoustic boundary element method, the coupled system’s acoustic response was calculated from the surface node vibration velocity data of the coupling model. The effects of the transverse and vertical excitation forces on the acoustic radiation of the coupled system were considered. Finally, dynamic and acoustic experiments of the blade–shafting–shell coupled system were conducted. The results verified the accuracy of the simulation model.


ABSTRACT: For vibroacoustic analysis, honeycomb-cored panels are often modelled as homogenised solid plates, which involves various assumptions and approximations. In this paper, a wave and finite element (WFE) based modelling strategy is proposed to predict sound transmission through honeycomb-cored panels. In this method, a three-dimensional periodic cell of the structure is modelled using a conventional finite element (FE) method. Due to the complexity of the core geometry, the FE model can contain a large number of internal nodes. Guyan reduction is used to reduce the model size. The in-vacuo wavenumbers are found, and from them the group velocities and modal densities determined. Wave propagation in the fluids surrounding the structure is modelled analytically. The acoustic loading is modelled using equivalent external nodal forces. The relatively small-sized mass and stiffness matrices are then post-processed using periodicity theory and equilibrium conditions. An accurate homogenised model is developed for calculating the structural response to acoustic excitation. Excitation of the structure by oblique plane waves and a diffuse sound field are both considered. Various numerical examples are presented to illustrate this model. The homogenised model developed in this paper is general and accurate, and can model sound transmission through honeycomb-cored panels of any configurations.

Zhicheng Yang (1,3), Airong Liu (1), Jie Yang (2), Jiyang Fu (1) and Bin Yang (3)
(1) Guangzhou University-Tamkang University Joint Research Centre for Engineering Structure Disaster Prevention and Control, Guangzhou University, Guangzhou, 510006, China
(2) School of Engineering, RMIT University, PO Box 71, Bundoora, VIC, 3083, Australia
(3) Guangzhou Municipal Engineering Group Ltd., Guangzhou, 510060, China


ABSTRACT: This paper presents dynamic buckling analysis for a functionally graded graphene nanoplatelets reinforced composite (FG-GPLRC) arch subjected to a step central point load at its center. The arch is composed of multiple composite layers reinforced with graphene nanoplatelets (GPLs) which are evenly distributed in each layer while the GPL weight fraction changes from layer to layer along the thickness direction. The effective materials properties are predicted by Halpin-Tsai micromechanics model for each GPLRC layer. Analytical solutions for symmetric limit point dynamic buckling load and anti-symmetric bifurcation dynamic buckling load for fixed and pinned FG-GPLRC arches are obtained by using energy-based methods. The critical geometric parameters governing the dynamic buckling mode switching behavior are also identified and discussed. It is found that the dynamic stability of the arch can be considerably improved by
adding a small amount of GPLs as reinforcing nanofillers, and both symmetric limit point dynamic buckling and anti-symmetric bifurcation dynamic buckling can happen to pinned FG-GPLRC arch while the fixed FG-GPLRC arch can buckle in a symmetric mode only. The influences of GPLs distribution, concentration, dimension of GPL as well as the arch geometrical parameters on the dynamic buckling behavior of FG-GPLRC arches are comprehensively investigated through parametric studies.

Yunbo Yuan (1), Hongliang Li (2), Donghua Wang (1), Chen Liu (2), Yibin Guo (1) Wanyou Li (1)
(1) College of Power and Energy Engineering, Harbin Engineering University, Harbin, 150001, China
(2) College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin, 150001, China

“An exact analytical solution for free in-plane vibration of sector plates with simply supported radial edges”,
Journal of Sound and Vibration, Vol. 466, Article 115024, 3 February 2020,
https://doi.org/10.1016/j.jsv.2019.115024

ABSTRACT: In this paper, an exact analytical solution is proposed to investigate the free in-plane vibration of sector plates. The highly complex and coupled differential equations of in-plane vibration motion are decoupled by invoking Helmholtz decomposition. The method of separation of variables is used to solve the resulting uncoupled Helmholtz equations. Applying the boundary conditions at both radial edges, the compatible eigenvalue problems for sector plates are obtained. Then, applying the boundary conditions at inner and outer circumferential edges, the corresponding characteristic equations can be solved to obtain the natural frequencies and the associated mode shapes. The results from the proposed method agree very well with the results from the available literature and the FEM. Significant influence of the boundary conditions and the geometric parameters on the free in-plane vibration characteristics of sector plates is investigated and addressed. The superficial frequency veering “aberration” between neighboring modes is discussed and found in fact to be an eigenvalue crossing phenomenon. It is proved that for a sector plate, only with simply supported radial edges, there exists an exact analytical solution. The proposed exact analytical solution can provide not only the detailed characteristics of the free in-plane vibration of sector plates but also the benchmark for further study.

Laurent Maxit (1), Oriol Guasch (2), Valentin Meyer (3) and Mahmoud Karimi (4)
(1) Univ Lyon, INSA–Lyon, Laboratoire Vibrations-Acoustique (LVA), 25 bis, av. Jean Capelle, F-69621, Villeurbanne Cedex, France
(2) GTM - Grup de recerca en Tecnologies Mèdia, La Salle, Universitat Ramon Llull, C/ Quatre Camins 30, 08022, Barcelona, Catalonia, Spain
(3) Naval Group Research, 199 Avenue Pierre-Gilles de Gennes, 83190, Ollioules, France
(4) Centre for Audio, Acoustics and Vibration, University of Technology Sydney, Sydney, Australia


ABSTRACT: This work proposes a semi-analytical method to model the vibroacoustic behavior of submerged cylindrical shells periodically stiffened by axisymmetric frames and excited by a homogeneous and fully developed turbulent boundary layer (TBL). The process requires the computation of the TBL wall-pressure cross spectral density function and the sensitivity functions for stiffened cylindrical shells. The former is deduced from an existent TBL model and the latter are derived from a wavenumber-point reciprocity principle and a spectral formulation of the problem. The stiffeners’ dynamic behavior is introduced in the formulation through circumferential admittances that are computed by a standard finite element code using shell elements. Four degrees of freedom are taken into account for the coupling between the shell and the stiffeners: three translation directions and one tangential rotation. To investigate the effect of the stiffeners on the radiated noise, two case studies are considered. The first one examines a fluid-loaded cylindrical shell with regularly spaced simple supports. The influence of Bloch-Floquet waves and the support spacing on the noise radiation are highlighted. The second case study inspects the fluid-loaded cylindrical shell with two different periodic ring stiffeners, namely stiffeners with T-shaped and I-shaped cross-sections. Their influence on the vibroacoustics of the shell is thoroughly analyzed.

Qing Li and Deqing Yang (State Key Laboratory of Ocean Engineering, Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai, 200240, China), “Vibro-acoustic performance
ABSTRACT: An exciting paradigm in the ongoing development of materials is the development of auxetic mechanical metamaterials, which can be flexibly designed to exhibit a unique range of physical and mechanical properties. Inspired by nonuniform or nonhomogeneous metamaterials and structures, annular cellular structures composed of auxetic metamaterials with graded negative Poisson's ratios (NPRs) are studied, and the considered models are divided into two types of configurations: models with graded decreasing NPRs and models with graded increasing NPRs along the radial direction. The spectral element method (SEM) is applied to accurately predict the structural dynamic responses with a limited number of elements and the system scale for arbitrary frequencies. The static stiffness and vibro-acoustic performance of the proposed structures are investigated and compared. The computational results show that the bending stiffness, vibrating mode shapes and deformations, and sound transmission loss (STL) of the considered cellular structures are strongly affected by the arbitrarily patterned graded auxetic metamaterials. Within the studied STL frequency range from 1 to 1500 Hz, optimal designs of the conventional and graded configurations for the maximum STL are obtained for specified tonal and frequency band cases under cylindrical incident sound waves. The results show that the graded configurations have more potential than the conventional ones for optimal acoustic performance and that compared with the graded decreasing NPR models, the graded increasing NPR models exhibit STL increases of 6.73 dB, 1.22 dB, and 2.06 dB for the studied cases. Both the STL and optimal design results indicate the advantages of the graded increasing NPR models for use in acoustic attenuation applications. Thus, graded auxetic metamaterials offer a great opportunity for achieving unusual vibro-acoustic performance and extending the route to obtain an optimized set of physical properties for cellular metamaterials and structures.


ABSTRACT: A nonlinear fluid-elastic continuum model for the dynamics of a slender cantilevered plate subjected to axial flow directed from the free end to the clamped end, also known as the inverted flag problem, is proposed. The extension of elongated body theory to large-amplitude rotations of the plate mid-plane along with Bollay's nonlinear wing theory is employed in order to express the fluid-related forces acting on the plate, while retaining all time-dependent terms in both modelling and numerical simulations; the unsteady fluid forces due to vortex shedding are not included. Euler-Bernoulli beam theory with exact kinematics and inextensibility is employed to derive the nonlinear partial integro-differential equation governing the dynamics of the plate. Discretization in space is carried out via a conventional Galerkin scheme using the linear mode-shapes of a cantilevered beam in vacuum. The pseudo-arclength continuation technique is adapted to construct bifurcation diagrams in terms of the flow velocity, in order to gain insight into the stability and post-critical behaviour of the system. Integration in time is conducted using Gear's backward differentiation formula. The sensitivity of the nonlinear response of the system to different parameters such as the aspect ratio, mass ratio, initial inclination of the flag, and viscous drag coefficient is investigated through extensive numerical simulations. It is shown that for flags of small aspect ratio the undeflected static equilibrium is stable prior to a subcritical pitchfork bifurcation. For flags of sufficiently large aspect ratio, however, the first instability encountered is a supercritical Hopf bifurcation giving rise to flapping motion around the undeflected static equilibrium; increasing the flow velocity further, the flag then displays flapping motions around deflected static equilibria, which later lead to fully-deflected static states at even higher flow velocities. The results exposed in this study help understand the dynamics of the inverted-flag problem in the limit of inviscid flow theory.

Mitao Song (1), Yuhao Gong (1), Jie Yang (2), Weidong Zhu (3) and Sritawat Kitipornchai (4)
(1) Faculty of Civil Engineering and Mechanics, Jiangsu University, Zhenjiang, Jiangsu, 212013, PR China
(2) School of Engineering, RMIT University, PO Box 71, Bundoora, VIC, 3083, Australia
(3) Department of Mechanical Engineering, University of Maryland, Baltimore County, Baltimore, MD, 21250, USA
(4) School of Civil Engineering, The University of Queensland, St Lucia, Brisbane, QLD, 4072, Australia

ABSTRACT: The present paper studies the nonlinear free vibration of edge-cracked graphene nanoplatelet (GPL)-reinforced composite laminated beams resting on a two-parameter elastic foundation in thermal environments. GPL nanofillers are assumed to be randomly oriented and are functionally graded distributed in a layer-wise pattern along the beam thickness. The temperature field considered is assumed to be a uniformly distributed in the domain of the beam. Effective material properties of the GPL-reinforced nanocomposite (GPLRC) are estimated by micromechanical models. Stress intensity factors are calculated based on the finite element methods. In the framework of the first order shear deformation beam theory, the equations of motion of cracked GPLRC beams are established including the von Kármán-type geometric nonlinearity. The bending stiffness of the cracked section is evaluated by the massless rotational spring model. The differential quadrature method is used to calculate the linear and nonlinear natural frequencies of the cracked beams. Numerical results illustrate the effects of GPL distribution pattern and concentration, GPL geometry and size, crack length, foundation stiffnesses and temperature variation on the linear and nonlinear free vibration characteristics of the cracked GPLRC beams.


ABSTRACT: Aiming to better understand how the presence of both structural and aerodynamic nonlinearities affect the aeroelastic behavior of laminated composite panels in transonic flow, we employ fluid-structure coupling algorithm with a midpoint serial staggered procedure to solve nonlinear aeroelastic responses. In this algorithm, the Euler equations are solved by a flux splitting scheme to obtain unsteady aerodynamic pressure in case of shock movement; a finite element co-rotational formulation, as well as stress-strain relations in the laminate coordinate system, is applied to model geometric nonlinear composite structure; the algorithm is validated by aeroelastic response analysis of a flat panel in the transonic and supersonic regime. Then six different thin laminated composite panels, which have two different layer orientations, cross-ply [0°/90°/0°/90°/0°] and angle-ply [45°/-45°/45°/-45°/45°], as well as three different sizes of curvature, H/h = 5 and H/h = 10, are numerically simulated at Mach 1.01. The results, comprising the static divergence, flutter onset, amplitude, and spectra of the post-flutter responses are determined. They illustrate that with different layer orientation and curvature, the aeroelastic response of the composite panel presents entirely different forms. Especially, due to the development of the multiple-shock structure in the transonic regime, oscillations with very low-frequency are observed for the curved composite panels with ply [45°/-45°/45°/-45°/45°], which have not as yet been found in the work of previous researchers.

Yuanzhao Chen (1,2), Xian Guo (2), Dingguo Zhang (2) and Liang Li (2)
(1) Institute of Mechanical and Transportation Engineering, Guangxi University of Science and Technology, Liuzhou, 545006, China
(2) School of Sciences, Nanjing University of Science and Technology, Nanjing, 210094, China

ABSTRACT: A novel meshless radial point interpolation method (RPIM) for thin plates in the frame of the absolute nodal coordinate formulation (ANCF) is proposed to overcome the limitations of the finite element method (FEM). Finite elements, such as the reduced-order triangle element base on Specht's function (RTE/SF) and the reduced-order rectangle element (RRE), are often used to discretize thin plates in the frame of the ANCF. But these elements may lead to discontinuity of strains (curvatures) and element distortions especially when flexible bodies produce large deformations. Furthermore, the RTE/SF has poor accuracy and low convergence rate while the RRE is not suitable for discretization of the plate with an arbitrary shape. To overcome above limitations, field nodes inside the support domain are used to construct the shape functions of the RPIM without using finite elements. Thus, the points of interest, such as gauss integral points, are generally located in the center of the support domain, in which support domains of different points have more overlapped
parts (common nodes). On the other hand, the number of interpolated nodes in the RPIM case is more than that in the FEM case for the same point of interest. These characteristics ensure that the shape function of the RPIM can describe displacement fields of ANCF with the higher order continuity and overcome the limitations of the FEM. Finally, the RPIM in the frame of the ANCF and its advantages are validated by several numerical examples.

Seyyed M. Hasheminejad (1), M.M. Mohammadi (2) and Ali Jamalpoor (1)
(1) Acoustics Research Laboratory, Center of Excellence in Experimental Solid Mechanics and Dynamics, School of Mechanical Engineering, Iran University of Science and Technology, Narmak, Tehran, 16846-13114, Iran
(2) Fuel Cell Technology Research Laboratory, Malek Ashtar University of Technology, Tehran, 158751774, Iran
ABSTRACT: Partly filled rectangular containers are widely used for liquid transportation and storage in many industrial and civil applications. Undesirable liquid sloshing in these structures can highly degrade their reliable and safe operations. This paper presents a rigorous 3D hydro-elasto-dynamic analysis for suppression of transient liquid sloshing in a rigid-walled rectangular parallelepiped container that is equipped with a smart piezo-sandwich free-floating rectangular panel. The problem formulation is based on the linear water wave theory, the thin piezo-sandwich floating plate model, the pertinent structure/liquid compatibility condition, and the active damping control strategy. The controller gain parameters are systematically tuned using a standard MOPSO algorithm with conflicting objective functions. The key hydro-electro-elastic response parameters are calculated and discussed for three different external excitations, namely, a bidirectional seismic event, an oblique planar base acceleration, and a distributed impulsive floating roof excitation. Effectiveness of proposed active floating panel control configuration in remarkable suppression of the main hydro-elastic parameters is established, essentially regardless of liquid depth and loading configuration. Limiting cases are considered and validity of model is demonstrated against available data as well as by comparison with the results of a general finite element package.

ABSTRACT: In this paper, highly accurate closed-form solutions for the free in-plane vibration of rectangular isotropic plates with arbitrary homogeneous boundary conditions are achieved by an iterative separation-of-variable method, and all solutions are presented in an elegant explicit form. For plates with at least a pair of opposite edges simply supported, the present solutions are the exact solutions. For other homogeneous boundary conditions, the accurate closed-form solutions agree well with the results of the fine finite element method. This work shows that the iterative separation-of-variables method is a powerful method to find the closed-form eigensolutions of partial differential equations. The present solutions can be taken as the benchmarks for the validation of numerical methods, a guide in parametric design of structure and the basis of constructing new numerical methods.

Jaesoon Jung (1), Cheol-Ho Jeong (1) and Jakob Søndergaard Jensen (2)
(1) Department of Electrical Engineering, Technical University of Denmark, 2800, Kgs. Lyngby, Denmark
(2) Department of Mechanical Engineering, Technical University of Denmark, 2800, Kgs. Lyngby, Denmark
ABSTRACT: As an alternative to conventional loudspeakers, panel loudspeakers have been investigated. However, it is challenging to avoid structural modes in a panel loudspeaker, which results in an uneven frequency spectrum and highly directional sound radiation. Here, we present a technique to eliminate modes in a frequency range of interest based on a band gap (BG) structure that forbids the propagation of waves. In order to open a BG between 300 and 500 Hz, a thin aluminum plate with periodic resonators is considered. Using
finite element (FE) simulations, vibro-acoustic responses of the BG structure are analyzed, leading to more spectrally smooth and spatially uniform sound radiation. Experimental results agree well with the numerical predictions, displaying a smoother frequency spectrum and smaller variation of sound pressure at six different measurement orientations in an anechoic chamber. For this specific case, the overall SPL is amplified by 5.5 dB and the standard deviation is reduced by 5.7 dB at frequencies ranging from 300 Hz to 500 Hz.


ABSTRACT: The present work focuses on the nonlinear forced vibrations of a supported pipe conveying fluid under an axial base excitation, devoting to exploring the effects of internal flow velocity and axial base excitation on the nonlinear dynamical behaviors of the pipe. Based on Hamilton's principle, the nonlinear coupled governing equations of the pipe system are introduced and discretized into a set of coupled ordinary differential equations by the aid of a Galerkin method. The resulting equations are then solved by a fourth-order Runge-Kutta integration algorithm. Numerical results indicate that the excitation amplitude and internal flow velocity have a combined effect on the dynamic responses of the pipe. When the internal flow velocity is below the critical value for buckling instability, an axial base excitation with small, moderate or large amplitude can only induce oscillations of the pipe in the axial direction, while an axial excitation with very large amplitude, interestingly, could induce the oscillations of the pipe in both axial and transverse directions. When the internal flow velocity is beyond the critical value for buckling instability, however, an axial base excitation with small amplitude can make the pipe oscillate around a positive or a negative static/dynamic equilibrium position in a wide range of excitation frequencies. In addition, a strong axial base excitation with large amplitude can make the pipe conveying a supercritical fluid oscillate around both positive and negative equilibrium positions for relatively large excitation frequencies. Indeed, various dynamical behaviors including periodic, multi-periodic, quasi-periodic and chaotic oscillations can be observed in many cases.

Joachim Golliard (1,2), Yves Aurégan (2) and Thomas Humbert (2)
(1) Centre de Transfert de Technologie du Mans (CTTM), 20 Rue Thalès de Milet, 72000, Le Mans, France
(2) Laboratoire d’Acoustique de l’Université du Mans (LAUM), Avenue Olivier Messiaen, 72085, Le Mans Cedex 9, France


ABSTRACT: Acoustic propagation in corrugated pipes offers interesting features in presence of a mean flow, which are investigated experimentally in this paper. The scattering matrix of the corrugated section is measured with and without a mean flow. The analysis of the results is based on the extraction of the wavenumbers of propagation within the corrugated pipe. Without flow, a small decrease of the speed of sound and a slight increase of the attenuation are observed. In presence of mean flow, oscillations against the frequency of both the real part and the imaginary part of the wavenumber occur. For sufficiently large flow velocities, the oscillation caused by the sound-flow interaction is such that the acoustic waves are amplified by the flow. The Strouhal number for maximum gain shows a small dependency on the Reynolds number, and converges to values of 0.4–0.5 depending on the presence of rounded or sharp upstream edges of the cavities. Non-linear effects begin to appear for an acoustic amplitude such that the acoustic velocity is about 1% of the flow velocity.

Zi Huang (1), Chaoping Zang (1), Genbei Zhang (1) and Michael I. Friswell (2)
(1) College of Energy and Power Engineering, Nanjing University of Aeronautics and Astronautics, Jiangsu Province Key Laboratory of Aerospace Power System, Nanjing, 210016, China
(2) College of Engineering, Swansea University, Bay Campus, Swansea, SA1 8EN, UK


ABSTRACT: A modeling error location method based on modal strain energy is presented in this paper. Errors in the design model with shell elements are located by an error indicator which is based on changes between the equivalent modal strain energy and the modal strain energy of the design model. The equivalent modal strain
energy is defined as a quadratic form using the stiffness matrix of the design model and the mode shape of the reference coming from the sophisticated and high fidelity finite-element model, called the supermodel, or the full-field measurement. The major obstacle to obtain the equivalent modal strain energy is how to match the mode shapes of a solid element and those of a shell element since each node of the solid element contains only three translation degrees of freedom (dofs) while each node of the shell element has six dofs, including three translation and three rotation components. In order to solve this problem, a mode shape transformation method from the solid element to the shell element is proposed using the shape functions or linear approximation. Using this approach, the errors in the design model can be determined and the updating parameters can be selected so that the updated model has physical meaning and can represent the dynamic characteristics of the real structure. The simulation of a simple plate is used initially to illustrate the effectiveness of the proposed method. Then, a rotor test rig casing is taken as an example for further investigation. A comparison of the updating parameters selected by the proposed method and the traditional sensitivity analysis technique is then undertaken. It is verified that the updating parameters selected based on error location have physical sense and represent the true errors in the design model through the updating results. The advantage of this technique is that only detailed mode shapes from the reference is required. The approach shows potential for further industrial engineering applications.


ABSTRACT: This paper examines the propagation of elastic waves of large amplitudes in two-dimensional square lattices that include an alternating pattern of linear springs and nonlinear bistable springs. Because of the presence of bistable springs, these lattices have multiple stable configurations. In this paper, a theoretical model that takes into account the non-linearity of the bistable springs while neglecting geometric nonlinearities is used to study non-linear wave propagation in these lattices. Results from numerical simulations demonstrate that, for a lattice that is initially in a deformed stable equilibrium configuration, stimuli of large amplitudes are able to cause a reconfiguration of the lattice to a configuration of lower potential energy. Even for initial stable configurations that exhibit omnidirectional or directional bandgaps for infinitesimal wave propagation, waves of large amplitudes can propagate in the lattice due to its reconfiguration; however, due to the nonlinearity of bistable springs, the transmitted response tends to have multiple spectral peaks or be broadband for narrow-band stimuli of large amplitude. Simulations are used to study how the reconfiguration of the lattice depends on the amplitude and duration of the stimulus, on damping, and on the energy barrier between the two stable equilibria of the bistable springs. These numerical results suggest that these multistable lattices can serve as reconfigurable wave guides for which the amplitude of the stimulus offers opportunities for enhanced tunability.

Chaofeng Li (1), Zixuan Zhang (1), Qingyu Yang (2) and Peiyong Li (1)
(1) School of Mechanical Engineering and Automation, Northeastern University, 110819, Shenyang, China
(2) SAIC Volkswagen Automotive Co., Ltd., 200000, Shanghai, China

ABSTRACT: A in-depth experimental investigation of the nonlinear vibration of a thin-walled cylindrical shell with points-supported condition is presented in this paper. Firstly the point-supported thin-walled cylindrical shell structure is designed, in which bolts are used to restrain the cylindrical shell, and the nonlinear response test system for the cylindrical shell is built. Then, the error analysis of each degree of freedom during system alignment is given. The sensitivity indexes are used to guide the system alignment, and the Response Surface Method is used to identify the stiffness of the bolt. The comparisons of natural characteristics of points supported shell by experiment are conducted with the results by theory. Finally, the effects of supported stiffness and number of point on the nonlinear response of the points-supported thin-walled cylindrical shell are investigated.

Guiyun Xia (1,2), Wenya Shu (2) and Ilinca Stanciulescu (2)
(1) School of Civil Engineering, Changsha University of Science and Technology, Changsha, 410114, China

ABSTRACT: In this work, a comparative study is performed between the slope inertia-based Timoshenko (SIBT) beam and other classical beam theories. We prove that the SIBT beam comprehensively incorporates physical effects of shear deformation, rotary inertia, and shear inertia. The transcendental equations of frequency are derived from the initial parameter solutions, and then used to demonstrate that the frequency spectrum of the SIBT beam theory has only one branch. A finite element implementation of the SIBT beam is developed and verified using closed-form solutions. We find that the SIBT and Love theories predict the same mode shape but different frequencies. Comparisons of frequency spectra obtained from different beam theories also suggest that the shear deformation influences the frequency more than the rotary inertia and that the SIBT beam theory predicts lower frequency values due to its complete consideration of shear deformation, rotary inertia and shear inertia. Parametric studies demonstrate that boundary conditions influence lower order frequencies predicted by the SIBT beam theory significantly, but only marginally influence the high order frequencies; they also show that the frequency spectrum of the SIBT beam theory has an upper bound.

Dana B. Giacobbi (1,3), Christian Semler (2,3) and Michael P. Païdoussis (3)
(1) Conseilier Organisationnel et Stratégique, Montreal, QC, Canada
(2) Maya Heat Transfer Technologies Ltd, Westmount, QC, H3Z 1T3, Canada
(3) Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street West, Montreal, QC, H3A 0C3, Canada


ABSTRACT: The dynamics of a flexible slender pipe conveying fluid the density of which varies along the pipe-length is investigated in this paper analytically and numerically. Apart from its academic interest, this problem has application to the pipes used in mining methane crystals from the bottom of the ocean, and to more mundane situations involving piping conveying a gas at high speed or piping in a temperature environment varying along its length. Some CFD results are presented first, and then a linear analytical model is developed using a Hamiltonian approach. Pipes with clamped ends and cantilevered pipes are considered. The former lose stability by static divergence (buckling) and the latter by flutter, as for a constant-density fluid. The most important findings are two: (i) the density at the discharging end of the pipe influences stability most crucially; (ii) for cantilevered pipes, the magnitude of density variation strongly influences the mode and critical flow velocity of flutter.

Georg A. Mensah (1,2), Alessandro Orchini (2) and Jonas P. Moeck (3)
(1) CAPS Laboratory, Department of Mechanical and Process Engineering, ETH Zürich, Switzerland
(2) Institute of Fluid Dynamics and Technical Acoustics, TU Berlin, Germany
(3) Department of Energy and Process Engineering, NTNU, Trondheim, Norway


ABSTRACT: In this work, a comparative study is performed between the slope inertia-based Timoshenko (SIBT) beam and other classical beam theories. We prove that the SIBT beam comprehensively incorporates physical effects of shear deformation, rotary inertia, and shear inertia. The transcendental equations of frequency are derived from the initial parameter solutions, and then used to demonstrate that the frequency spectrum of the SIBT beam theory has only one branch. A finite element implementation of the SIBT beam is developed and verified using closed-form solutions. We find that the SIBT and Love theories predict the same mode shape but different frequencies. Comparisons of frequency spectra obtained from different beam theories also suggest that the shear deformation influences the frequency more than the rotary inertia and that the SIBT beam theory predicts lower frequency values due to its complete consideration of shear deformation, rotary inertia and shear inertia. Parametric studies demonstrate that boundary conditions influence lower order frequencies predicted by the SIBT beam theory significantly, but only marginally influence the high order frequencies; they also show that the frequency spectrum of the SIBT beam theory has an upper bound.

ABSTRACT: The paper is mainly concerned with the analytical approach of the behaviour of a two-dimensional miniaturized MEMS transducer, namely a rectangular or square clamped plate loaded by a fluid-gap (squeeze film), surrounded by a small cavity (reservoir), and excited by an incident acoustic field (assume to be uniform on the plate). Until now, the problem has not been analytically solved owing to the geometry of the device in conjunction with the nature of the diaphragm (elastic plate) and its boundary conditions (zero deflection and zero normal slope along all edges); namely analytical eigenfunctions do not exist for the clamped plate. On the other hand, the analytical approach classically used to express the acoustic field in the fluid-gap relies on a modal expansion which does not match correctly with both the displacement field of the diaphragm and the boundary conditions at the entrance of the reservoir. Then, two particular questions arise: how to derive analytically the modal behaviour of the loaded clamped plate, and what analytical approach for the acoustic field in the fluid gap is convenient to describe its coupling with the displacement field of the plate? The aim of the paper is both to provide basically an exact analytical approach and to handle a numerical implementation (FEM) against which the analytical results are tested.


ABSTRACT: This paper investigates the influence of the boundary conditions on the stop band effect in finite locally resonant metamaterial beams. In a first step, a Timoshenko beam with tuned vibration absorbers is used to describe a metamaterial beam. The influence of different boundary conditions for beams with different lengths as well as of tuned vibration absorbers with different amounts of added mass or different tuned frequencies is assessed numerically. It is found that edge modes are present inside the stop band frequency region predicted by the unit cell analysis and these edge modes reduce the level of vibration attenuation achieved. Three solutions are analysed to reduce the effect of the edge modes: (i) varying the tuned frequency, (ii) the number or (iii) the positions of the individual tuned vibration absorbers added to the host structure. In a second step, the results of the numerical investigation are experimentally validated: the experimental results are in good agreement with the numerical results.


ABSTRACT: Impact identification is a major concern in structural health monitoring. It consists in localizing the impact point and in reconstructing the applied load history from indirect measurements. However, it is well-known that this double inverse problem is ill-posed. In this paper, a single-sensor approach for quickly localizing a Dirac-like impact and for estimating its intensity from vibration measurements is proposed. It is proved that the relative proportions of specific modal ponderations are a signature of impact location. Rules are
provided to select the appropriate vibration modes in the analysis and to position the sensor. The identification process is robust if the vibration modes kept in the analysis are weakly damped and if their natural frequencies are well separated. Experiments are conducted on a metallic plate to validate this single-sensor approach on a 2D structure. The success rate for localizing impacted cells is 100% when appropriate method parameters are selected.

R. Cornaggia (1), E. Darrigrand (2), L. Le Marrec (2) and F. Mahé (2)
(1) Aix Marseille Univ, CNRS, Centrale Marseille, LMA UMR 7031, Marseille, France
(2) Université de Rennes, CNRS, IRMAR - UMR 6625, F-35000, Rennes, France


ABSTRACT: This work presents a new enriched finite element method dedicated to the vibrations of axially inhomogeneous Timoshenko beams. This method relies on the “half-hat” partition of unity and on an enrichment by solutions of the Timoshenko system corresponding to simple beams with a homogeneous or an exponentially-varying geometry. Moreover, the efficiency of the enrichment is considerably increased by introducing a new formulation based on a local rescaling of the Timoshenko problem, that accounts for the inhomogeneity of the beam. Validations using analytical solutions and comparisons with the classical high-order polynomial FEM, conducted for several inhomogeneous beams, show the efficiency of this approach in the time-harmonic domain. In particular low error levels are obtained over ranges of frequencies varying from a factor of one to thirty using fixed coarse meshes. Possible extensions to the research of natural frequencies of beams and to simulations of transient wave propagation are highlighted.

Fabien Marchetti (1), Kerem Ege (1), Quentin Leclère (1) and N.B. Roozen (2)
(1) Univ Lyon, INSA-Lyon, Laboratoire Vibrations Acoustique, LVA, F-69621, Villeurbanne, France
(2) KU Leuven, Laboratory of Acoustics, Department of Physics and Astronomy, Celestijnenlaan 200D, B-3001, Heverlee, Belgium


ABSTRACT: This paper presents the modelling and the dynamic characterisation of laminated composite plates and sandwich structures in terms of stiffness and damping. The developments used in this paper are based on the analytical multilayer model of Guyader and Lesueur (JSV, 1978). The model considers linear shear, membrane and bending effects in each layer. The characteristics of the structure are determined by means of an equivalent thin plate methodology. The first main novelty of this paper consists in adapting this methodology for laminated plates (orthotropic multilayers with arbitrary orthotropic angle per layer). An experimental validation of this adaptation is presented for a laminated composite plate. Concerning the modelling of the structural loss factor, a space domain definition based on the spatial attenuation of a plane wave is compared to an energetic method and an equivalent definition based on the thin plate theory. The results show that the equivalent definition overestimates the loss factor in high frequencies since the thin plate theory only considers the flexural behaviour of the structure. On the contrary, the space domain definition (which give similar results as compared to the energetic one for lightly damped structures) considers the frequency dependent variation of the dynamic behaviour of the structure by means of the ratio between the group and phase velocities. The latter approach is considered to be more correct. The second main novelty of this article is on the experimental validation of this space domain definition. The structural loss factors of two sandwich structures are identified from measurements using modal, energetic and spatial methods. The results using the space domain definition are in very good agreement with the analytical predictions and the estimations of the modal and energetic methods for both plates for a large frequency band (up to 20 kHz), demonstrating the validity of the approach developed in this paper.

Satoshi Ishikawa (1), Katsunori Tanaka (2), Daiki Yano (3) and Shinya Kijimoto (1)
(1) Department of Mechanical Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, Japan
(2) Technology & Intelligence Integration, IHI Corporation, 1 Shin-nakahara-cho, Isogo-ku, Yokohama, Japan
ABSTRACT: Contactless ultrasound energy transfer from a piezoelectric cylinder or disk subjected to forced vibrations to a piezoelectric receiver offers the capability of safely transferring energy to sensors and devices, which is of great interest in different applications. Physical processes supporting ultrasonic energy transfer include piezoelectric-generated vibrations at a transmitting element, piezoelectric transduction of elastic vibrations at a receiving element, acoustic wave propagation, and acoustic-structure interactions at the surfaces of the transmitting and receiving elements. Considering these processes, we present an experimentally-validated multi-physics model that fills a knowledge gap in terms of accurately representing the fluid-loaded response of piezoelectric disks, usually used in ultrasonic energy transfer as a cylindrical transmitting source-cylindrical absorber and a Houde damper, respectively.

Xiyue An (1,2), Hualin Fan (1,2) and Chuanzeng Zhang (3)
(1) Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing, 210016, China
(2) College of Mechanics and Materials, Hohai University, Nanjing, 210098, China
(3) Department of Civil Engineering, University of Siegen, D-57068, Siegen, Germany


ABSTRACT: In this work, a new type of planar square lattice structures for the attenuation of elastic wave propagation is proposed and designed. To obtain a high vibration attenuation in low frequency ranges, the internal resonance mechanism of the acoustic metamaterials (AMs) is introduced into the continuous square lattice system with a cross-type core consisting of two segments with a radius jump discontinuity in each unit-cell. The wave propagation and vibration bandgap properties of the AM-based lattice structures are studied by using a spectral element method (SEM) which can provide accurate dynamic characteristics of a lattice structure due to its analytical spectral element matrix. The band structures calculated show that the phononic bandgaps induced by the local resonance and destructive interference co-exist in the considered systems. The effects of the structural and material parameters on the bandgaps are investigated in detail by the frequency response analysis of a spectral element model subjected to a dynamic excitation. Finally, in order to obtain lower and wider frequency bandgaps, the mechanism to optimize the unit-cell of the AM-based lattice structures is illustrated and a composite lattice model is suggested.

Vamsi C. Meesala (1) , Saad Ragab (1) , Muhammad R. Hajj (2) and Shima Shahab (1,3)
(1) Department of Biomedical Engineering and Mechanics, Virginia Tech, Blacksburg, VA, 24060, USA
(2) Department of Civil, Environmental and Ocean Engineering, Davidson Laboratory, Stevens Institute of Technology, NJ, 07030, USA
(3) Department of Mechanical Engineering, Virginia Tech, Blacksburg, VA, 24060, USA

ABSTRACT: Broadband stochastic excitations from environment such as seismic activities, sea waves, wind gusts, and tremors can lead to the terrible damages of tall structures and buildings which usually have a low vibration damping. Tuned liquid dampers (TLD) have been considered for around thirty years although the AMD is more efficient and stable in a specific range of feedback coefficient, the proposed ATLD is reliable in a wider range of control parameters.

Stanislaw Wrona (1), Marek Pawelczyk (1) and Xiaojun Qiu (2)
(1) Silesian University of Technology, Department of Measurements and Control Systems, Gliwice, Poland
(2) University of Technology Sydney, Centre for Audio, Acoustics and Vibration, Sydney, Australia

ABSTRACT: A new method is proposed for precise shaping of the acoustic radiation of a vibrating plate. The potential applications of this method are: to optimize acoustic radiation of a plate employed as a sound source; and to enhance transmission loss of a plate used as a noise barrier, both in passive or active control solutions. The proposed method is based on mounting several additional ribs and masses (passive elements) to the plate surface at locations determined by an optimization process. This optimization involves a model of the vibroacoustic system, a cost function representing the objective under consideration, and an optimization algorithm. The method is described, and results of both numerical simulation and experimental validation are presented. Analysis of results shows that the transmission loss introduced by a passive noise barrier can be enhanced by more than 7 dB in frequency bands of interest. Furthermore, these enhancements can be combined with optimized arrangements of actuators and sensors, resulting in a hybrid passive-active noise control system.


ABSTRACT: Broadband stochastic excitations from environment such as seismic activities, sea waves, wind gusts, and tremors can lead to the terrible damages of tall structures and buildings which usually have a low amount of vibration damping. Tuned liquid dampers (TLD) have been considered for around thirty years regarding their ability for passive suppression and absorb the vibration energy in such structures. In this paper, the fluid-structure interaction of a two-dimensional rectangular tank with elastic side walls and foundation is investigated by the smoothed particle hydrodynamics (SPH) method. First, the implementation of SPH for the frequency analysis of a rectangular container with flexible boundaries, partially filled with liquid, is described. The governing equations of the sloshing of an inviscid liquid in a two-dimensional Cartesian coordinate system coupled with the thin plate vibration on sides are linearized and solved by the SPH method. The sloshing and bulging modes of the system are derived and discussed in this paper. The results of the frequency spectrum of the sloshing tank coupled with the spring-damper system are analyzed and compared with the mechanical equivalent system. Results are validated by analytical benchmark and show the applicability as well as the simplicity of the SPH method for analytical vibration analysis of a fluid-structure coupled system. Then various control method including: Active mass damping (AMD) control designed based on proportional feedback control, the tuned liquid damper (TLD) control based on the analytical model, and a hybrid method of active tuned liquid damper (ATLD) are modeled and compared in a one-story structure. Results demonstrated that although the AMD is more efficient and stable in a specific range of feedback coefficient, the proposed ATLD is reliable in a wider range of control parameters.

Tao Wang (1), Jincheng He (1), Shuo Hou (2), Xi Deng (2), Chen Xi (2) and Huan He (1)
(1) Institute of Vibration Engineering Research, Nanjing University of Aeronautics and Astronautics, Nanjing, 210016, China
ABSTRACT: In numerous engineering structures with local nonlinearities, the nonlinear effects are usually localized and most parts of the structures behave linearly. Considering this, a reduced-order modelling technique for generally damped systems with localized nonlinearities is proposed. Firstly, the linear parts with non-proportional damping of the system is separated to form one component, which can be formulated in state space and transformed into the modal coordinates using its linear vibration complex modes. The residual flexibility matrix, which can be formulated by using a set of equivalent higher-order complex modes, has been developed to improve the accuracy by capturing the effects of the neglected higher-order complex modes. Secondly, the rest regions of the system form another component behaving nonlinearly, which is kept in its original form to adopt the entire set of nonlinear terms. Next, the second-order differential synthesis equation can be obtained by using compatibility conditions at the junctions. In order to calculate dynamic response of the system, the aforementioned synthesis equation needs to transform into the first-order differential equation because of the singularity of the equivalent mass matrix. Finally, two numerical examples are given to illustrate the effectiveness and the efficiency of the presented method.


ABSTRACT: This paper presents a consistent corotational formulation for the geometric nonlinear dynamic analysis of 2D sliding beams. Compared with the works of previously published papers, the same cubic shape functions are used to derive the elastic force vector and the inertia force vector. Consequently, the consistency of the element is ensured. The shape functions are used to describe the local displacements to establish an element-independent framework. Moreover, all kinds of standard elements can be embedded within this framework. Therefore, the presented method is more versatile than previous approaches. To consider the shear deformation, the sliding beam (a system of changing mass) is discretized using a fixed number of variable-domain interdependent interpolation elements (IIE). In addition, the nonlinear axial strain and the rotary inertia are also considered in this paper. The nonlinear motion equations are derived by using the extended Hamilton’s principle and solved by combining the Newton-Raphson method and the Hilber-Hughes-Taylor (HHT) method. Furthermore, the closed-form expressions of the iterative tangent matrix and the residual force vector are obtained. Three classic examples are given to verify the high accuracy and efficiency of this formulation by comparing the results with those of commercial software and published papers. The simulation results also show that the shear deformation and the rotary inertia cannot be neglected for the large-rotation and high-frequency problem.

Bin Zhen (1,4), Jian Xu (2,3) and Jianqiao Sun (4)
(1) School of Environment and Architecture, University of Shanghai for Science and Technology, Shanghai, 200093, PR China
(2) Shanghai Institute of Intelligent Science and Technology, Tongji University, Shanghai, 200092, PR China
(3) School of Aerospace Engineering and Applied Mechanics, Tongji University, Shanghai, 200092, PR China
(4) Department of Mechanical Engineering, School of Engineering, University of California, Merced, CA, 95343, USA


ABSTRACT: The paper deals with the steady state responses of an infinite Euler-Bernoulli beam resting on a nonlinear foundation under a harmonic moving load. Greatly different from previous works, the nonlinear partial differential governing equation of the beam motion is converted to two nonlinear Volterra integral equations by using the Fourier transform, residues Theorem and the convolution theorem. The Volterra integral equations have four different expressions depending on the damping coefficient of the foundation, the linear
part of the foundation stiffness and the frequency of the moving load. The modified Adomian decomposition method in conjunction with a simple iterative formula derived from the integral equation theorems are applied to obtain analytical solutions for the steady state responses of the beam. The closed form solutions presented in this paper do not contain complicated infinite integrals, which are better to show the influence of the nonlinear part of foundation stiffness. The parametric study shows that the nonlinear part of foundation stiffness affects not only qualitative but also quantitative analysis results of the infinite Euler-Bernoulli beam under a harmonic moving load.


ABSTRACT: This study investigates the amplitude dependent damping behaviour of the fundamental mode for composite tubes under dynamic excitations. For this purpose, a closed form solution of damping ratio is derived for a cantilever tube subjected to harmonic base excitation while accounting for stress fields, material properties and cross-sectional configurations of the member. Shake table experiments are performed on square, hexagonal and circular woven carbon fibre-reinforced polymer (CFRP) tubes of length 1 m. To measure the responses along the tube length, accelerometers are used. In addition, table motions are also recorded. Based on these measurements, damping ratios are obtained from the experiments for varying levels of excitation. It is found from the experiments that the damping ratio increases with the increase in excitation amplitude. Among the tubes considered, damping ratio is noted to be higher for the square tube in comparison to the circular tube. This is due to the presence of more material near the edges (which is particularly beneficial as stresses are higher at the edges than the neutral axis) for the square tube in comparison to the circular tube. It is also found that the damping ratios obtained from the proposed expression are in well agreement with the experimentally measured values with a maximum deviation of about 10%.


ABSTRACT: Damping of coupled bending-torsion beam vibrations is realized by local actuators, operating axially on an end cross-section of a fully three-dimensional structure by a collective positive position feedback control with a spatial filter that specifically targets the out-of-plane warping component of the coupled response. To reduce the computational effort, a beam element model is introduced, in which a single control bimoment is supplemented by a fictitious stiffness that accounts for the inability of the local actuators to fully restrain warping. This fictitious stiffness is conveniently calibrated by frequency matching in the limit of infinite control gain and it enables accurate estimation of both complex roots and the stability limit from beam element analysis. It is demonstrated by a numerical example that substantial modal damping is attained by positive position feedback of the torsional warping component from the fully coupled response.

Miguel Ángel Muñoz (1) and Manuel Colera (2)
(1) Departamento de Ingeniería Aeroespacial y Mecánica de Fluidos, Escuela Técnica Superior de Ingeniería, Universidad de Sevilla, Av. de los Descubrimientos s/n, 41092, Sevilla, Spain
(2) Departamento de Ingeniería Energética, E.T.S.I.I., Universidad Politécnica de Madrid., C/ José Gutiérrez Abascal 2, 28006, Madrid, Spain

ABSTRACT: In this work we carry out a numerical study of the influence of the upstream Mach number on the flutter of a three-dimensional, cantilevered, flexible plate subject to a subsonic, inviscid, open flow. We have assumed a linear elastic model for the plate and that the fluid flow is governed by the linearized potential theory. The fluid equations are solved by means of a doublet point method to obtain the generalized aerodynamic forces as a function of the plate displacements. Then, these generalized forces are coupled to the equation of motion of the plate, which is discretized with a spectral Galerkin method, and an eigenvalue
analysis is performed to find the flutter point. The obtained results are in good agreement with those of related theoretical and experimental studies found in the literature.

Cédric Maury (1) and Teresa Bravo (2)
(1) Aix Marseille Univ, CNRS, Centrale Marseille, Laboratoire de Mécanique et d'Acoustique (LMA), 38 rue Frédéric Joliot-Curie, 13013, Marseille, France
(2) Instituto de Tecnologías Físicas y de la Información (ITEFI), Consejo Superior de Investigaciones Científicas (CSIC), Serrano 144, 28006, Madrid, Spain


ABSTRACT: The current work presents theoretical and experimental studies that investigate sound propagation through micro-capillary plates (MCP) under a general plane wave excitation and in the no-flow case. MCPs are characterized by micrometric channels radius with Knudsen number greater than 0.001 so that a slip-flow model has been derived for their viscous transfer impedance. It is found that the slip-flow model should be used instead of the continuum model to predict the transfer impedance of MCPs with channels radii lower than 2 μm as well as their absorption coefficient under near-grazing incident excitations. Otherwise, both approaches provide similar results, as confirmed by comparison with finite element simulations. Due to their high porosity, MCPs provide minute reactance and constant resistance that can be tailored to achieve target absorption over a broad frequency range. Plane wave impedance tube experiments have shown that a near-optimal MCP termination can provide a low frequency flat absorption spectrum that stays above 0.7 up to a Helmholtz number of 1.84. Measurements on rigidly-backed MCPs have led to ultra-wideband absorption with a half-bandwidth spanning up to 12 octaves around the absorber Helmholtz resonance. Expressions have been derived to find the optimal channels radius that maximize the MCPs dissipation under general incidence angle and assuming anechoic or rigid backing. The sensitivity of the MCPs optimal transfer resistance to their load impedance has been examined. It provides a design chart to find the MCP optimal parameters that achieve specific broadband absorption value under general incidence and practical load conditions.


ABSTRACT: A paradigm to generate harmonic circumferential travelling waves on a thin circular plate is proposed. The plate is considered to be connected to three circumferentially placed point actuators that excite the plate transversely with appropriate phasing. Uniform angular distribution of the actuators is observed to lead to wave locking at certain frequencies. The idea of angular detuning in the placement of the actuators is introduced to prevent wave locking. It is found that a simple kinematic phasing, which can generate travelling waves with uniformly distributed actuators, cannot be used in the case of non-uniformly placed actuators. An algorithm to calculate the phase detuning is proposed for a perturbed angular configuration of actuators for a smooth generation of travelling waves near any modal frequency. The mathematical model and the wave generation paradigm is validated using a finite element model developed in ANSYS. The results presented herein is expected to be helpful in studying the mechanics of wave-based transport of granular materials interacting with such surface travelling waves.

Jianing Yang (1), Georg Jacobs (1), Achim Kramer (1), Pascal Drichel (1) and Chenxi Liu (2,1)
(1) MSE – Institute for Machine Elements and Systems Engineering, RWTH Aachen University, Schinkelstraße 10, 52062, Aachen, Germany
(2) School of Mechanical Engineering, Jiangsu University, 301 Xuefu Road, Zhenjiang City, Jiangsu Province, PR China


ABSTRACT: The paper investigates the in-plane vibration property of static and rotating tires with the proposed tire model. The tire model is based on the linear ring model, and a mathematical approach is proposed
to handle the tire contact problem. With this improvement, the tire model allows for directly calculating the eigenmodes of a loaded tire by solving its eigenvalue problem. A group of simulations is carried out using this improved ring model. For a static (not rotating) tire, the eigenfrequency and corresponding mode shape are investigated under both unloaded and loaded conditions. For a rotating tire, the effect of rotational speed on the eigenfrequencies of unloaded and loaded tires are modeled, and the results are observed using co-rotating and non-rotating reference frames. The main original contribution of this work is an evaluation of the quantitative relationship between unloaded and loaded conditions using modal assurance criterion (MAC) or improved modal assurance criterion (IMAC) analyses on both static and rotating tires. For a static tire, the eigenmodes can be classified into rigid ring modes and flexible ring modes, according to their mode shape and MAC evaluation results. For a rotating tire, the eigenfrequency and mode shape could vary with increasing rotational speed and behave differently in non-rotating and co-rotating reference frames. In a non-rotating frame, the IMAC value percentages for a loaded tire vary with increasing rotational speed, especially in the frequency veering ranges. In a co-rotating frame, the IMAC value variations for loaded modes are weaker than those seen in a non-rotating frame.

Alice Cicirello (1,2), Brian R. Mace (3), Michael J. Kingan (3) and Yi Yang (3)
(1) Department of Engineering Science, Oxford University, Parks Road, Oxford, OX1 3PJ, UK
(2) Faculty of Civil Engineering and Geoscience, Delft University of Technology, Stevinweg 1, Delft, 2628CN, Netherlands
(3) Acoustics Research Centre, Department of Mechanical Engineering, University of Auckland, Private Bag, Auckland, New Zealand


ABSTRACT: The first and second order sensitivity analysis of the eigenvalue problem of generalised, non-symmetric matrices using perturbation theory is developed. These results are then applied to sensitivity analysis of wave propagation in structures modelled using the wave and finite element (WFE) method. Three formulations of the WFE eigenvalue problem are considered: the transfer matrix method, the projection method and Zhong's method. The sensitivities with respect to system parameters of wavenumbers and wave mode shapes are derived. Expressions for the group velocity are presented. Numerical results for a thin beam, a foam core panel and a cross-laminated timber panel are used to demonstrate the proposed approach. It is shown that sensitivities can be calculated at negligible computational cost.


ABSTRACT: This paper presents a nonlinear distributed-parameter model for harvesting energy from galloping oscillation. The stepped beam structure is beneficial to increase the stress and strain of the piezoelectric elements, thereby enhancing the power generation. The finite element analysis is used to verify the feasibility and effectiveness of the developed harvester. A nonlinear distributed-parameter model for the piezoelectric energy harvester with a stepped beam is developed. The instantaneous fluid force in the transverse direction is analyzed. Based on Euler-Bernoulli beam theory, a distributed-parameter model for undamped free vibration is derived, which can be used for the modal analysis. The electromechanical coupling model is established by using the piezoelectric effect theory. The forced vibration subjected to the galloping excitation load is analyzed by using the mode superposition method. The state vector and the fourth order Runge-Kutta algorithm are used to seek the numerical solution. The effects of the electrical load resistance, length, width and thickness of the piezoelectric beam, exposure area and mass of the bluff body on the output power are investigated. In order to find the optimal design of the energy harvester, optimization design is performed based on the established theoretical model. The particle swarm optimization algorithm is employed to search the optimal solution in multidimensional space. Finally, experimental work was carried out, the electrical output characteristics of the energy harvester prototypes were measured. The simulation results are validated with the experimental data. It is demonstrated that the optimal configuration of the energy harvester can improve the output power from galloping phenomenon effectively.

ABSTRACT: In this paper, the dynamic behavior of Horizontally Curved Beams (HCBs) resting on an elastic foundation and subjected to a moving mass is investigated. The governing coupled non-linear differential equations of equilibrium are derived, where Coriolis acceleration, centrifugal force and rotary inertia are incorporated in the problem formulation. In the proposed analytical solution, by employing the transition matrix technique, the governing differential equations of motion are subsequently transformed into a new system of linear ordinary differential equations which can be solved using standard numerical procedures. The accuracy as well as the robustness of the solution is ascertained through a comparative study with the solutions previously reported in the literature. Extensive parametric study is then carried out in order to demonstrate the efficiency of the proposed semi-analytical approach. The design Dynamic Amplification Factor (DAF) spectra have been established in terms of influential parameters including radius and subtended angle of the curved beam, mass of the moving object and the number of dynamic modes. The significance of considering the inertial effect of the moving mass is also highlighted in the dynamic response of HCBs, especially in severely curved elements subjected to the excitation of a heavy mass traversing at high speeds. Moreover, the effect of higher dynamic modes in the response has been scrutinized. Thereafter, based on the multiple nonlinear regression analysis, simplified parametric expressions have been proposed for the calculation of DAFs, which can be used in practical and analytical applications. The paper is followed by the reformulation of the problem in order to examine the contribution of axial force on the out-of-plane responses of HCBs. The last two sections are devoted to the study of the influence of additional torsional stiffness due to fasteners as well as foundation vertical damping on the DAF spectra. The results of this study suggest that the effect of additional inertial terms is crucial in a wide range of design parameters. Therefore, in comparison to the unsafe results originated from the moving force method, moving mass approach is a better and a more reliable representative of the real-world dynamic response of HCBs. As a general conclusion, with an increasing curvature of the HCB, the DAFs also increase. In a similar manner, the DAFs intensify due to an increase in the mass and velocity of the moving object. Moreover, it is shown that consideration of the axial force can attenuate the values of DAFs to a degree which mainly depends on the magnitude of the tensile force experienced by the HCB. The results also reveal that the inclusion of the foundation vertical damping leads to a reduction in the DAF spectra, which is shown to be more significant for sharply curved beams subjected to a high-speed heavy mass. However, by adopting the additional torsional stiffness, slightly smaller DAFs would be derived for all cases considered in this study.

Qi Qin, Meiping Sheng, Mingqiu Wang, Chen Wang and Yuanan He (School of Marine Science and Technology, Northwestern Polytechnical University, 127 Youyixilu, 710072, Xi’an, China), “Sound radiation from plates with elastic boundary conditions embedded in an infinite perforated rigid baffle”, Journal of Sound and Vibration, Vol. 479, Article 115361, 4 August 2020, https://doi.org/10.1016/j.jsv.2020.115361

ABSTRACT: Sound radiation from plates with elastic boundary conditions embedded in an infinite perforated rigid baffle (PRB) is analyzed in this paper. Based on the wavenumber domain approach and the solution for transverse vibration of plates with general elastic boundary conditions, the sound power and the radiation efficiency of the plates embedded in the PRB (named ‘PRB-ed plate’ in the following) are derived theoretically. By comparing with the results of sound radiation from baffled and unbaffled plates, it can be found that the PRB-ed plates behave like the dipole source radiation in the fundamental mode region as the perforation in PRB introduces communication of the sound field, while not sufficient to reach the lowest radiation efficiency as unbaffled cases. The parametric analysis of boundary conditions shows that the PRB-ed fully free plate has the lowest radiation efficiency below the critical frequency. For the cases of plates with constraints, the greater the constraints are, the lower the radiation efficiency is in the fundamental mode region, and this order will become totally opposite in the short-circuiting region. Further, the effects of PRB parameters on sound radiation from PRB-ed plates are compared. With the decrease of the PRB thickness and the hole diameter, or the increase of the PRB perforation ratio, the sound power radiated from PRB-ed plates is decreased below the critical frequency. This research could possibly provide ideas on the design of noise control for plate-like structures.
ABSTRACT: The vibroacoustic response of a simply supported panel excited by turbulent flow is analytically and numerically investigated. In the analytical model, the radiated sound power is described in terms of the cross spectrum density of the wall pressure field and sensitivity functions for the acoustic pressure and fluid particle velocity. For the numerical model, a hybrid approach based on the finite element method is described in which the cross spectrum of the wall pressure field is represented by a set of uncorrelated wall plane waves. Realisations of the wall pressure field are used as deterministic input loads to the panel. The structural and acoustic responses of the panel subject to turbulent boundary layer excitation are then obtained from an ensemble average of the different realisations. Analytical and numerical results are compared with experimental data measured in an anechoic wind tunnel, showing good agreement. The effect of adding stiffeners on the vibroacoustic response of the panel is also examined using the proposed numerical approach.

Briscoe Kerferd (1), Daniel Eggler (1), Mahmoud Karimi (2) and Nicole Kessissoglou (1)
(1) School of Mechanical and Manufacturing Engineering, The University of New South Wales, Sydney, 2052, Australia
(2) Centre for Audio, Acoustics and Vibration, University of Technology Sydney, Sydney, Australia


ABSTRACT: The vibro-acoustic response of a two-dimensional cylindrical shell in low Mach number flow is herein derived. The analytical model takes into account the structural elasticity and coupling of the shell vibration with its interior and exterior acoustic fields in the presence of a moving fluid. The cylindrical shell is modelled using Donnell-Mushtari theory. Taylor transformations are employed to transfer the convected wave equation into the ordinary wave equation which was then solved using scattering theory. Three excitation cases corresponding to a plane wave, an external monopole source and a radial point force applied directly to the shell are considered. Shell circumferential resonances and interior acoustic resonances are identified. Two active control strategies are then applied to acoustically cloak the cylindrical shell at its acoustic and structural resonances. The first control approach employs acoustic control sources in the exterior fluid domain. In the second approach, control forces are applied to directly excite the elastic shell, whereby the structural response is actively modified to manipulate the scattered and radiated acoustic fields arising from plane wave excitation of the shell. Results show that the second approach is superior in terms of both reduced control effort and cloaking of the global exterior domain. For both control approaches, the performance of the active cloak is shown to deteriorate if the convected flow field is not accounted for in the control process.

References listed at the end of the paper:

14 M. Rajabi, A. Mojaded, Active acoustic cloaking spherical shells, Acta Acust. united Am., 104 (2018), pp. 5-12
30 M. Amabili, R. Garziera, Vibrations of circular cylindrical shells with nonuniform constraints, elastic bed and added mass. Part II: shells containing or immersed in axial flow, J. Fluid Struct., 16 (2002), pp. 31-51
43 N. Han, S. Feng, X. Qiu, Active control of one-dimension impulsive reflection based on a prediction method, J. Acoust. Soc. Am., 127 (2010), pp. 1193-1196

Zheng-Yang Li (1), Tian-Xue Ma (1), Yan-Zheng Wang (1), Feng-Ming Li (2) and Chuanzeng Zhang (1)
(1) Department of Civil Engineering, University of Siegen, D-57076, Siegen, Germany
made of an incompressible material can be computed by setting Poisson’s ratio linearly elastic problems obtained with the commercial FE software, Abaqus. Furthermore, results for those in the traditional finite element method (FEM) to find converged lowest 100 frequencies and the corresponding mode shapes. No shear correction factor is employed in the TSNDT. The presently computed results agree well with those from either analytical or numerical solutions of the corresponding 3-dimensional linearly elastic problems obtained with the commercial FE software, Abaqus. Furthermore, results for plates made of an incompressible material can be computed by setting Poisson’s ratio $= 0.49$.


ABSTRACT: Topology optimization has the ability to control the eigenfrequencies of a structure and is therefore possible to remove the internal resonances. In this study, topology optimization is studied for removing internal resonances of a rotating rectangular thin plate. First of all, an accurate dynamic model is established for the rotating thin plate by considering the Coriolis force. The thin plate element of the absolute nodal coordinate formulation (ANCF) is used to discretize the rotating thin plate and establish the dynamic equation. When the dynamic equation is transformed from the absolute frame to the rotating frame for modal analysis, the Coriolis force term shows up and is analytically derived. Then, an explicit and efficient topology optimization method, i.e., the method of moving morphable components (MMC) is employed to optimize the rotating thin plate. In order to remove the internal resonances, the detuning parameters are defined so that removing the internal resonances is equivalent to maximizing the minimum absolute detuning parameter. The corresponding max-min optimization problem can be dealt with via a bound formulation. Finally, three numerical examples are presented to validate the dynamic model and the topology optimization methodology. Two objectives are considered for optimization, i.e., removing the internal resonances of the rotating thin plate at different specific angular speeds and removing the most common 1:1 or 1:2 internal resonances of the rotating thin plate during a certain range of angular speeds.

Berk Alanbay (1), Rakesh K. Kapania (1) and Romesh C. Batra (2)
(1) Department of Aerospace and Ocean Engineering, USA
(2) Department of Biomedical Engineering and Mechanics Virginia Polytechnic Institute and State University, Blacksburg, VA, 24061, USA


ABSTRACT: This paper finds up to lowest 100 free vibration frequencies of isotropic and linearly elastic plates with thickness to side length ratio varying from 0.001 to 0.5 by using the Ritz method, a third-order shear and normal deformable plate theory (TSNDT), and weighted Jacobi polynomials as admissible functions that are mutually orthogonal and exactly satisfy essential boundary conditions. The numerical method is stable even for 18-degree polynomials as basis functions. It is shown that this approach requires fewer degrees of freedom than those in the traditional finite element method (FEM) to find converged lowest 100 frequencies and the corresponding mode shapes. No shear correction factor is employed in the TSNDT. The presently computed results agree well with those from either analytical or numerical solutions of the corresponding 3-dimensional linearly elastic problems obtained with the commercial FE software, Abaqus. Furthermore, results for plates made of an incompressible material can be computed by setting Poisson’s ratio $= 0.49$. 
ABSTRACT: Steering flexural waves in thin plates benefits several applications, including vibration energy harvesting and micro-electro-mechanical systems (MEMS). This study proposes a technique using metasurfaces based on U-shaped phononic beams to realize the flexural wave control. This technique demonstrates the use of metasurfaces made of the same material as that of the host plates wherein the flexural waves are to be controlled, which significantly facilitates the fabrication of metasurfaces. The total height $H$ of the U-shaped beams is selected to change the effective bending stiffness and consequently tune the effective phase velocity of flexural waves in the U-shaped phononic beams. Numerical simulations verify that the effective phase velocity of flexural waves in the U-shaped phononic beams is highly dependent on $H$. A macro-model is proposed to estimate the effective phase velocities. The phase shift and transmittance of flexural waves transmitted via U-shaped phononic beams with different values of $H$ are calculated. A full 2 phase shift can be obtained by a change in $H$ within an appropriate range while maintaining the transmittance at a relatively high level. As illustration examples, two subwavelength metasurfaces (refraction and focusing) for flexural waves in thin plates are designed, 3D-printed using VeroPureWhite, and tested. All experimental measurements support our proposed technique for the manipulation of flexural waves in thin elastic plates by metasurfaces.

ABSTRACT: A semi-analytical method is proposed to estimate the vibroacoustic properties of a fluid-loaded thin plate, which is assumed to have an infinite extent and is stiffened by periodically spaced structures in orthogonal directions. By applying the finite element method, the interaction force between the plate and each periodic structure is approximated by a finite number of equivalent nodal forces, which are subsequently represented as functions of the corresponding nodal displacements of the plate. With the space harmonic method and Poisson's summation formula, the acoustic equation of the periodically stiffened plate, stimulated by convected harmonic pressure, is then derived and expressed as a periodic set of nodal displacements. In particular, an efficient method is presented for the vibration response of rib-stiffened plates, which significantly simplifies the solution process. The vibroacoustic properties of different types of periodically stiffened plates under convected harmonic pressures are examined by means of numerical examples. The results demonstrate that, owing to the attachment of the periodic structures to the plate, the sound radiation from the plate system under convected harmonic pressures can be suppressed at low frequencies. The present method can be applied for estimating the vibroacoustic properties of various periodically stiffened plates, which may also contribute to structural design for vibration or sound radiation reduction.

ABSTRACT: In this paper, the nonlinear vibration of a Mindlin plate with a side crack is investigated considering an in-plane preload. Special corner functions are incorporated into the admissible functions of displacements to describe the singularity in stress at the crack tip as well the discontinuities in displacements and rotations across the crack. Based on the Mindlin plate theory and von Kármán's nonlinear plate theory, the potential and kinetic energies of the cracked loaded plated are constructed. The Ritz method with the special admissible functions is employed to determine the initial in-plane stress resultants. The natural frequencies and modes of the plate with or without in-plane preload are also determined through the Ritz method. The nonlinear dynamical equations of the plate are derived using the Hamilton's principle, and are discretized into second-order ordinary differential equations through the Galerkin's method with the three lowest order modes obtained by the Ritz method in free vibration. These equations are transformed into of first-order ordinary differential equations and are solved via the Runge-Kutta algorithm. The nonlinear dynamical response of the plate with various parameters of crack and in-plane preload under transverse harmonic excitation is presented through time history of responses, phase portraits and bifurcation diagrams in conjunction with the maximum Lyapunov
ABSTRACT: The dynamic instability of a thin-walled carbon-fibre reinforced composite cylindrical shell is studied. The analysis is performed with the Finite Element code, ABAQUS, estimating the dynamic buckling load using the Budiansky–Roth criterion. The influence of the following factors on the dynamic behaviour of the shell is analysed: the shape of pulse loading, the initial geometric imperfection and the pulse duration. It is found that for short load duration, the structure resistance to pulse loading in the form of dynamic buckling load is significantly higher compared to the static buckling load. As load duration increases, the magnitude of the Dynamic Load Factor (DLF), defined as the ratio between the dynamic and static buckling loads, decreases significantly, reaching a value of DLF<1 in the vicinity of the natural frequency of the shell. The results of the numerical analyses indicate a slight increase of the DLF with the increase of the initial geometric imperfection of the shell. The present study highlights the increased sensitivity to the shape of the pulse loading. For triangular and double-triangular pulse shapes, for short load duration, the dynamic buckling load is almost 14 times higher than the static buckling load. Simultaneously, when a trapezoidal pulse shape is applied, the dynamic buckling load is four times greater than the static one.


ABSTRACT: The vibro-acoustic behavior of a semi-submerged finite cylindrical shell is studied theoretically and experimentally. An analytical form of the vibro-acoustic coupling equation is developed using the wavenumber transformation and separation of variables for the sound pressure and the mode expansion for the shell's motion. The far-field radiation sound pressure is derived by utilizing the stationary-phase approximation. The radial velocity, radiated sound power, and sound pressure directivities (including the circumferential and axial directivities) from analytical models are compared with numerical and experimental results to verify the method. The assumption that the shell is terminated by semi-infinite rigid baffles is the main reason for the deviations between the analytical and experimental results. Below the ring frequency, acoustic radiation from a semi-submerged finite cylindrical shell occurs primarily because the air–liquid demarcation points on the shell surface act as radiation sources. Therefore, the circumferential and axial directivity patterns of a semi-submerged finite cylindrical shell can be approximated as a superposition of two in-phase dipoles formed by the air–liquid demarcation points and as a superposition of two in-phase dipole line sources, respectively. Simple formulas are derived to predict the circumferential and axial directivity patterns. This is a new and simplified approach for predicting the directivity patterns of a semi-submerged finite cylindrical shell. The vibro-acoustic behavior of a semi-submerged finite cylindrical shell differs from that of a submerged shell, especially the circumferential directivity pattern due to the reflection from the free surface.


ABSTRACT: Due to their unique electromechanical coupling properties, soft electro-active (SEA) resonators are actively tunable, extremely suitable, and practically important for designing the next-generation acoustic and vibration treatment devices. In this paper, we investigate the electrostatically tunable axisymmetric vibrations of SEA tubes with different geometric sizes. We consider both axisymmetric torsional and longitudinal vibrations for an incompressible SEA cylindrical tube under inhomogeneous biasing fields induced

Fangzhou Zhu (1), Bin Wu (2), Michel Destrade (2,1) and Weiqiu Chen (1,3)
(1) Department of Engineering Mechanics, Zhejiang University, Hangzhou, 310027, PR China
(2) School of Mathematics, Statistics and Applied Mathematics, National University of Ireland Galway, University Road, Galway, Ireland
(3) Soft Matter Research Center, Zhejiang University, Hangzhou, 310027, PR China

ABSTRACT: Due to their unique electromechanical coupling properties, soft electro-active (SEA) resonators are actively tunable, extremely suitable, and practically important for designing the next-generation acoustic and vibration treatment devices. In this paper, we investigate the electrostatically tunable axisymmetric vibrations of SEA tubes with different geometric sizes. We consider both axisymmetric torsional and longitudinal vibrations for an incompressible SEA cylindrical tube under inhomogeneous biasing fields induced
by radial electric voltage and axial pre-stretch. We then employ the state-space method, which combines the state-space formalism in cylindrical coordinates with the approximate laminate technique, to derive the frequency equations for two separate classes of axisymmetric vibration of the tube subjected to appropriate boundary conditions. We perform numerical calculations to validate the convergence and accuracy of the state-space method and to illustrate that the axisymmetric vibration characteristics of SEA tubes may be tuned significantly by adjusting the electromechanical biasing fields as well as altering the tube geometry. The reported results provide a solid guidance for the proper design of tunable resonant devices composed of SEA tubes.

References listed at the end of the paper:
11 E. Bortot, G. Shmu, Tuning sound with soft dielectrics, Smart Mater. Struct., 26 (4) (2017), Article 045028

ABSTRACT: Wave based method is a numerical technique to predict steady-state vibration and solve vibroacoustic problems. It is a deterministic approach that is acknowledged to be more efficient than the element based methods in the mid-frequency range. The wave based method for plates with prescribed boundary conditions has been proposed and verified for the ideal constraint cases such as clamped, free and simply supported. To deal with different kind of or more realistic boundary conditions, this paper proposes a modified wave based method. The method is aimed at analyzing the flexural vibration of thin plates with general elastically restrained edges, and it can also consider the damping effect associated with the edge restraint. A number of numerical validation examples are shown, where the plate edges are uniform, non-uniform or partially supported. Within the examples, the responses of the plate under different edge conditions are compared, including elastic supports with different translational and rotational stiffness and damping parameters, rigid supports like clamped and simply supported, and free edges. For all the considered cases, the proposed method is proved to be effective, though the convergence performance is influenced by the boundary conditions. More wave functions may be required for simply supported, non-uniform or partially supported cases.


ABSTRACT: Dynamic response of beams on elastic foundations is of great theoretical significance in the field of engineering. Galerkin truncation method is the most commonly used powerful method to study the vibration of these structures. The number of truncation terms affects the convergence of the analysis and determines the accuracy of the dynamic responses. However, there is still no basis for how to choose the appropriate number of truncation terms. In this paper, two effective schemes based on the natural frequency of the corresponding linear conservative system are proposed to determine the convergent terms of the Galerkin truncation. Since determining the natural frequencies of the corresponding linear conservative system are much easier, the convergence determination method is convenient for application. Based on the dynamic response of the sandwich beam on nonlinear foundations under a moving load, the feasibility of the two schemes for determining the convergent term is confirmed. Moreover, the effects of system parameters on the two schemes are presented. In short, this paper provides two simple and easy schemes for selecting the Galerkin truncation terms in the research of the dynamic response of elastic structures resting on elastic foundations.


ABSTRACT: Severe vibrations and sound production can occur in dry gas flow through corrugated pipes. The addition of very small amounts of liquid to the dry gas flow potentially mitigates these flow-induced vibrations (FIVs) and noise. The different mechanisms behind this whistling mitigation are studied in this work, where acoustic measurements are combined with flow visualization and droplet sizing. Different corrugation geometries are studied. It is shown that noise mitigation mainly occurs through a geometric alteration of the cavity mouth, resulting in a reduced acoustic source strength. Additional acoustic damping as a consequence of the presence of droplets has a very limited contribution to the mitigation of FIVs. A non-axisymmetric filling of the cavities of a corrugated pipe with liquid is more effective in reducing the acoustic output, compared to an axisymmetric filling. The liquid viscosity has a minor effect on the achieved noise mitigation. To predict the acoustic source strength for a particular cavity geometry a numerical method is developed, based on URANS simulations combined with Howe's energy corollary. An energy balance method is applied to obtain the acoustic source strength from experiments. The whistling frequencies are accurately predicted with the simulations, but the acoustic source strength is over-predicted by a factor 2. Trends in the source strength obtained from simulations, however, closely resemble the experimentally obtained results. The developed
method provides an intuitive understanding of sound production by vortical flow structures and shows potential for the prediction of self-sustained oscillations in corrugated pipes.


ABSTRACT: This paper presents a new method to compute the sound radiation emanating from a thin plate structure due to complex inputs that include normal force and in-plane bending moments. A set of new formulas for the sound radiation of baffled and unbaffled plates are derived by substituting the moment components of the plates with the equivalent couples using finite difference analysis. This approach allows to calculate sound power purely by the input location and amplitude of each component. Thus, it enables faster, more accurate calculations than the existing methods such as the average radiation efficiency analysis and the radiation mode analysis. Based on these calculations, the vibroacoustic characteristics of a simply supported rectangular plate are analyzed. The computational results are in good agreement with the finite element analysis results. It is suggested to keep the grid spacing less than 2.5% of the shortest dimension of the target structure to accurately calculate the moment mobility. Accurate sound power can also be obtained by downsampling the grid to satisfy within the frequency band of interest. Furthermore, a sound reduction method is proposed by analyzing each structural mode's contribution to the sound radiation. Using the proposed methodology, sound power at a specific frequency or multi-frequency range can be reduced or amplified by changing the location and angle of the complex inputs.


ABSTRACT: This paper focuses on the derivation of an analytical model of the aeroelastic dynamics of an elastically mounted flexible wing. The equations of motion obtained serve to help understand the behaviour of the aeroelastic wind tunnel setup in question, which consists of a rectangular wing with a uniform NACA 0012 airfoil profile, whose base is free to rotate rigidly about a longitudinal axis. Of particular interest are the structural geometric nonlinearities primarily introduced by the coupling between the rigid body pitch degree-of-freedom and the continuous system. A coupled system of partial differential equations (PDEs) coupled with an ordinary differential equation (ODE) describing axial-bending-bending-torsion-pitch motion is derived using Hamilton's principle. A finite dimensional approximation of the system of coupled differential equations is obtained using the Galerkin method, leading to a system of coupled nonlinear ODEs. Subsequently, these nonlinear ODEs are solved numerically using Houbolt's method. The results that are obtained are verified by comparison with the results obtained by direct integration of the equations of motion using a finite difference scheme. Adopting a linear unsteady aerodynamic model, it is observed that the system undergoes coalescence flutter due to coupling between the rigid body pitch rotation dominated mode and the first flapwise bending dominated mode. The behaviour of the limit cycle oscillations is primarily influenced by the structural geometric nonlinear terms in the coupled system of PDEs and ODE.


ABSTRACT: Vibration analysis of nominally axisymmetric plate structures with either imperfections or geometric asymmetries due to practical motivations is of interest in designing and developing some mechanical structures. Semi-analytical methods to model such structures suffer from either choosing inappropriate admissible functions or both plausible convergence issues and additional computations owing to employing the addition theorem of Bessel functions. Therefore, the present study aims at developing a new mathematical method to analyze the vibrational behavior of circular plates with geometric asymmetries. The suggested approach makes use of the separation of variables to determine general solutions of the partial differential equation of the plate transverse displacement while defining multiple polar coordinate systems each of which
ABSTRACT: It is well known that irregularities of periodic structures will significantly affect the vibration characteristics of structures and may cause the mode localization. When the mode localization occurs, in certain modes, the vibration amplitudes of some sub-structures will be much smaller than those of others and this can be used to suppress the vibration of desired parts in the structure. In this investigation, the affecting factors for the mode localization of two-span beams are studied. Influences of the disorder in the length of sub-spans on the mode localization are analyzed, and the frequency veering and mode exchange phenomena are observed. The variation pattern of the frequency loci and the corresponding mode shapes following the change of the disorder degree is revealed. In addition, it is found that the disorders of material properties and geometrical sizes can also induce the mode localization of structures, and furthermore, they will affect the frequency veering by changing the positions of the veering points. Therefore, in this paper, an axially functionally graded design method is proposed to adjust the configuration of mode localization for the structures. It is also found that the boundary conditions have a significant effect on mode localization and frequency veering. According to these, one can suppress the vibration of a certain span of the beam and enlarge the length of the controlled part.


ABSTRACT: In this work, we show that perfectly localised modal vibrations can be obtained in continuous linear elastic structures, provided that, in addition to the regular boundary and continuity/jump conditions, extra (admissibility) conditions are met. They are derived with the aid of: (i) new parameters and/or DOFs of auxiliary systems, and/or (ii) admissible relationships amongst the original structural parameters. In both cases, however, the solution resorts to a fine-tuning problem. To illustrate the main ideas, we discuss three examples: two simply-supported beams with cantilever extensions and attached lumped oscillators, and a “tuning-fork-like” structure. Finally, to show that there are also systems in which fine-tuning is not possible, we discuss the case of two lumped oscillators attached to the free end of a cantilever beam.


ABSTRACT: An infinite system of one-dimensional differential equations is derived from the two-dimensional theory of elasticity by expanding the displacement field in a series of trigonometrical functions together with a linear term. Since the trigonometrical functions are pure thickness-vibration modes of infinite plates or beams with the top and bottom surfaces being free, the differential equations and the corresponding boundary conditions serve as the basis of an accurate beam theory for vibration analysis, named Lee's beam theory (LBT). Naturally, a high-order set of the infinite system should be quite useful in the analysis of beams at high frequencies. With the objective of vibration analysis of beams, this paper focuses on the first-order approximation, which leads to a first-order shear deformation beam theory for flexural vibrations (LBT1st). The differential equations in LBT1st are equivalent to those in Timoshenko's beam theory (TBT). The most important difference between LBT1st and TBT is the different field displacements. For the assessment of the accuracy of LBT1st, the numerical results of frequencies of free vibrations, frequency spectra and mode shapes of beams with classical boundary conditions are obtained and compared with those by TBT and plane stress problem of elasticity. Considering the plane stress problem as a reference, LBT1st is slightly more accurate in describing the field shapes of beams than TBT. Therefore, LBT1st, as well as LBT, is an addition to the existing beam theories with improved accuracy for the vibration analysis of beams and their combinations.

ABSTRACT: This paper proposes a unified semi-analytical method for the free in-plane and out-of-plane vibrations of arbitrarily shaped plates with clamped edges. The method is derived using boundary conformal mapping (BCM). The BCM is first proposed here to overcome the mathematical difficulty in describing the clamped boundary conditions of complex or/and irregular shaped plates. Elliptical, rectangular and horseshoe plates with clamped edges are studied to demonstrate the proposed method. After that, another two groups of arbitrarily shaped plates including three polygonal plates and three curve-edged plates are studied. The efficiency of the proposed method is checked through a convergence study. Results from the proposed method agree well with the available results in the literature and with finite element results. All the case studies demonstrate that the proposed method is versatile and gives good accuracy for both the in-plane and out-of-plane vibrations of arbitrarily shaped plates with clamped edges. New results from the proposed method can serve as benchmarks for further study on the vibration of plates, especially of irregular shaped plates.


ABSTRACT: Slender beams present interesting dynamic characteristics when they are curved according to a given shape. When the beam is curved according to one of its mode shapes, the natural frequency associated to that mode tends to increase significantly without affecting the other natural frequencies. It has also been noticed that such effect can only occur if the axial displacements of the beam are constrained. The question is why such phenomenon occur? What is the physics behind these effects? This work tackles these questions by the analytical analysis of the in-plane vibrations of the beam curved in different mode shapes.


ABSTRACT: The perforated components are widely used in the intake and exhaust mufflers. The coupling between instable shear layer and acoustic fluctuation has a significant influence on the acoustic impedance of perforated components. To obtain practical and precise acoustic impedance of perforated plates in the presence of grazing flow, the three-dimensional (3D) time-domain computational fluid dynamics (CFD) approach was employed in the present study, and the extraction method of acoustic impedance was presented. The predicted non-dimensional acoustic impedance of the rectangular slot is consistent with the previous published measurement, which validates the accuracy of the present approach. Characterization of the turbulent boundary layer of flat-plate flow was studied and the relation between the convection velocity of vorticity and mean grazing flow velocity was provided. Numerical evaluations were carried out for different mean grazing flow Mach number $M_\infty$ (0.05–0.20), thickness to diameter ratio of orifice $t/d$ (0.2–0.5), porosity $\phi$ (4.51%–24.93%), and Reynolds number $Re$ resulted from the orifice diameter $d$ (2 mm–6 mm), and their effects on the non-dimensional acoustic impedance of circular orifice were investigated in detail. The acoustic impedance formulae are obtained using the piecewise numerical fitting method based on the parameter analyses. As an application of engineering computation, the transmission loss of straight-perforated tube mufflers was predicted by using the present acoustic impedance model and the empirical impedance model of Lee and Ih via finite element computations. Comparison of the predicted and measured transmission loss (TL) results demonstrates that the present model yields highly accurate prediction.

ABSTRACT: The possibility of shifting sound energy from lower to higher frequency bands is investigated. The system configuration considered is a segmented structure having non-linear stiffness characteristics. It is proposed here that such a frequency-shifting mechanism could complement metamaterial concepts for mass-efficient sound barriers. The acoustical behavior of the material system was studied through a representative two-dimensional model consisting of a segmented plate with a contact interface. Multiple harmonic peaks were observed in response to a purely single frequency excitation, and the strength of the response was found to depend on the degree of non-linearity introduced. The lower and closer an excitation frequency was to the characteristic resonance frequencies of the base system, the stronger was the predicted higher harmonic response. The broadband sound transmission loss of these systems has also been calculated and the low frequency sound transmission loss was found to increase as the level of the broadband incident sound field increased. The present findings support the feasibility of designing material systems that transfer energy from lower frequency bands, where a sound barrier is less efficient, to higher bands where energy is more readily dissipated.


ABSTRACT: Parametric resonances of pipes caused by pulsating fluids have received much attention. However, the main concern is the pulsation of subcritical flow. Moreover, it is usually based on the Euler-Bernoulli pipe model. This paper focuses on revealing the characteristics of parametric resonances of the Timoshenko pipe with pulsation of supercritical high-speed fluids. Supercritical flow causes the linear instability of the pipe. The coupled partial differential equations with varying parameters are derived for governing the vibration of the pipe around the non-trivial static equilibrium configuration. A direct multi-scale method is developed to analytically obtain parametric resonance responses from coupled partial differential equations with varying parameters. For the first time, the nonlinear parametric response of the Timoshenko pipe is verified by using the finite difference method (FDM). Some interesting phenomena are demonstrated. For example, unlike parametric resonance at subcritical speeds, the steady-state response of velocity pulsation excitations at supercritical speeds is not monotonic with changes in some physical parameters. For another example, when pulsation occurs at supercritical speeds, the smaller steady-state response and the instability region can be obtained through the Timoshenko pipe model. In addition, the relationship between the instability threshold of the velocity pulsation amplitude and the slenderness ratio is non-monotonic, suggesting that the Euler-Bernoulli pipe model may simplify some vibration characteristics. Due to these different phenomena, the necessity of studying the velocity pulsation in the supercritical high-speed range and the necessity of the Timoshenko model are demonstrated.


ABSTRACT: Sound transmission through a double-walled cylindrical shell with porous cores and the inner shell micro-perforated is studied analytically in this paper. The Donnell's thin shell theory is used to govern shell motions and the Biot's theory is applied to describe sound propagation in the porous layer. Boundary condition at the perforated shell is presented by the mean particle velocity model. When excited by an oblique plane wave with external mean flow, transmission losses through typical configurations are numerically computed. Results show that perforating the inner shell of different sandwich configurations would produce improvement of transmission loss below the ring frequency. In further analysis regarding the perforated configuration with two airgaps in annular space, it retains superiority against the corresponding non-perforated one in the low frequency range despite alteration of the incidence angle, the azimuthal angle or the external flow. In parametrical studies, increase of either the aperture diameter or the perforation ratio is validated to enhance low-frequency sound insulation of this configuration through the imaginary part of the impedance constant.

ABSTRACT: This paper proposes exact dynamic stiffness formulations for membranes and their assemblies under any arbitrary classical boundary conditions. First, by taking exact solutions in one direction satisfying all possible opposite edge supports, we can derive exact general solutions of the Helmholtz equation for membrane vibration. Then, generic force and displacement boundary conditions in the other direction are expressed in terms of the general solutions. Finally, the dynamic stiffness matrices of rectangular membrane elements are formulated, which can be assembled directly and allows applications of arbitrary boundary conditions. As an accurate and efficient modal solution technique, the Wittrick-Williams (WW) algorithm is applied onto the global dynamic stiffness matrix of the final structure. The most important issue of the WW algorithm, Jo count, has been resolved with the analytical expressions derived for all possible cases. The proposed dynamic stiffness method (DSM) is then applied to several examples including individual membranes and their assemblies. High accuracy and exactness of the proposed method within the whole frequency range is demonstrated by comparison with the finite element method. Besides, interesting findings have been observed on repeated eigenvalues with distinct mode shapes corresponding to certain aspect ratio and tension ratio, where physical and mathematical understanding has been provided.


ABSTRACT: The introduction of intermediate support can significantly alter the stability characteristics of an elastic structure subjected to non-conservative loading; this follows from investigations carried out almost three decades ago. A majority of these investigations however assume the non-conservative loading to have the form of a follower force. A new type of non-conservative loading in the form of a dynamic moment was recently introduced in the literature using both theory and experiments and it behooves us to investigate the effect of intermediate support on structures with such type of loading. The dynamic moment is proportional to the curvature of a point on the structure; critical stability is therefore investigated in the two-parameter space defined by the locations of the intermediate support and the point of curvature measurement. For a cantilever beam with terminal dynamic moment, the investigations reveal a rich set of instability transitions not observed heretofore; these include multiple stability transitions between divergence and flutter and between different modes of flutter, transitions occurring with and without jumps in the critical load, orderly and random flutter-to-flutter transitions, and multiple instability transitions involving jumps in the critical load. The jump in the critical load is also observed for the cantilever beam with follower force; this jump, which was reported to be absent in earlier work, results from the veering phenomenon.


ABSTRACT: Owing to their unique wave retarding features, Acoustic Black Hole (ABH) structures with standard power-law thickness profiles have been extensively explored for various structural vibration and sound radiation control applications. In order to achieve even better ABH effects for a given minimum thickness that can be achieved or accepted in practice, this paper reports an alternative ABH thickness profile in a plate through an optimization procedure by using the fast and elitist nondominated sorting genetic algorithm II in conjunction with a 2D semi-analytical Daubechies wavelet model. The new thickness profile features a different geometry from the standard ones in that the position of the imposed minimum thickness is off-set from the ABH indentation center, thus forming a flexible ring-shaped area and creating bi-directional ABH effects, which is conducive to energy focusing and dissipation. Numerical results show that a plate embedded with the optimized ABH indentation exhibits better ABH effects than its standard ABH counterpart, as evidenced by an increase in the total system damping as well as an impairment of other vibration and sound radiation metrics. Mode shape analyses of the optimized ABH plate show that the observed damping increase is mainly attributed to these local (nbar, 1) and (nbar, 2) modes, as a result of the flexible ring-shaped area that is formed inside the
optimized ABH indentation. Finally, the optimized ABH plate is shown to entail reductions in both the vibration response of the plate and its sound radiation into a free acoustic medium.


ABSTRACT: In this paper, the dynamic stiffness method has been applied in the free vibration analysis of open circular cylindrical shells based on Flügge thin shell theory. The dynamic stiffness matrix for a completely free open cylindrical shell element has been derived and coded in MATLAB to compute the natural frequencies and mode shapes. The results of the numerical study have been compared with the results from the finite element analysis, as well as with the results from the literature. After a detailed convergence study, considering the number of terms in the proposed solution, applied boundary conditions and geometry, limitations and recommendations for application of the proposed method have been given.


ABSTRACT: This paper presents an electromechanical model for predicting the dynamics of curved panels with multiple surface-integrated piezo-patches. The boundary value problem governing the electro-elastic dynamic behavior of a (doubly-) curved panel and piezo-patch structure is derived following the first order shear deformation (FSDT) theory. Spectral Tchebychev approach is used to numerically solve the system dynamics and obtain voltage and mechanical frequency response functions (FRFs). Mass and stiffness contributions of piezo-patch(es) as well as two-way electromechanical coupling behavior are incorporated in the model for both modal analysis and frequency response calculations. To validate the accuracy of the developed solution technique, the results for various cases including a single patch and multiple patches on a straight/curved host panel are compared to those obtained from finite-element (FE) analyses. It is shown that the maximum difference in the predicted natural frequencies between the ST and FE results is below 1%, and the harmonic analyses’ results obtained using the presented solution technique excellently match the FE results. Furthermore, the effect of multiple piezoelectric patches to achieve higher voltage values in the application of energy harvesting is investigated when the mode jumping phenomenon occurs due to the increasing curvature.


ABSTRACT: This paper presents a theoretical study on the modelling and active control of bending waves propagating in an orthotropic rectangular panel. The main objectives are to clarify the characteristics of the wave dynamics of an orthotropic rectangular panel and to propose the feedforward control of wave propagation based on a transfer matrix method. As a result of the numerical investigation of the wave dynamics, it is found that there are two types of cut-on frequency in the orthotropic rectangular panel, and the type of bending waves are categorised into progressive, evanescent, and amplitude-varying progressive waves. Next, after the reflected wave absorbing control (RWAC) and the transmitted wave eliminating control (TWEC) laws are derived, numerical simulations on an active wave control system are performed. It is clarified that if the number of control forces is same as that of target mode groups, the RWAC enables the inactivation of vibration modes, and the TWEC enables the vibration-free state in the orthotropic rectangular panel. Moreover, it is concluded that if the number of control forces is lower than that of target mode group, the optimal position of the control force is around the nodal line of the non-targeted mode group which is closer to the disturbance force.

ABSTRACT: The aim of this research is to model various types of viscoelastic supports and to investigate their effects on the fluid-structure interaction (FSI) during the water hammer in straight pipeline systems. Three performance mechanisms of viscoelastic supports are considered. The first is the viscoelastic supports with axial deformation, the second is viscoelastic supports with shear deformation and the third is the viscoelastic supports with both sliding and shear deformation mechanisms. The Poisson and junction coupling were taken into account as the main interacting mechanisms. The viscoelastic behavior of the pipe-wall and the supports was described by the generalized Kelvin-Voigt mechanical model. By providing boundary conditions for the different types of viscoelastic supports modeling at the valve location and along the pipe, the governing equations were solved using the full MOC method in the time domain. The results demonstrated that the use of viscoelastic supports with axial and shear deformation mechanisms are effective in the damping of the pressure head vibrations and reducing the displacement of the pipe-wall caused by FSI. The viscoelastic supports with the shear deformation mechanism exhibited better performance compared to those with the axial deformation mechanism. The results also showed that the behavior of viscoelastic supports with both sliding and shear mechanisms depended on the amount of frictional force in the supports. Using plates with an appropriate friction coefficient for the sliding viscoelastic supports caused a significant reduction in the amount of pressure head and displacement of the pipe-wall as well as considerable pressure head fluctuations damping compared to the performance of two other mechanisms of viscoelastic supports in a similar situation, especially in the elastic pipe.


ABSTRACT: Advanced automotive audio applications are more and more demanding with respect to the visual impact of loudspeakers while still requiring more and more channels for high quality spatial sound rendering. The use of arbitrary plate-like structures driven by electromagnetic actuators or by piezoelectric elements appears as a promising solution to tackle both issues. However, to meet spatial rendering audio constraints (i.e. to be as close as possible to omnidirectional piston-like sources), the generated bending waves must be focused at a given position and to a certain extent within the host plate which can be of arbitrary shape, material, and thickness. Theoretically, this means being able to invert the spatio-temporal wave propagation operator for the generated bending waves to fit a given target shape. There are several methods (modal control, time-reversal, and propagating waves operator inversion) that allow to focus bending waves in a media. However, there is scarce work on their adaption and performances assessment in the context of audio applications. These methods depend differently on the available knowledge of wave propagation in the plate (theoretical, partial spatial or full spatial knowledge) and are here investigated to perform this task. Their performances are assessed with respect to several aspects: geometrical complexity, thickness, and material damping of the host structure, number and type of actuators, position and extent of the focusing area. The various methods are presented in a unified theoretical framework and they are compared by means of two key performance indexes (focus localization error and spatial contrast). An experimental validation on a relevant industrial case is also carried out and learning through a digital twin instead of time consuming experimental data investigated. This work falls within the framework of research which tries to bridge the gap between laboratory research and industrial deployment of this kind of technologies.


ABSTRACT: This paper presents analytical and experimental investigations on the in-plane nonlinear dynamic buckling of an elastic fixed shallow arch subjected to a central impact load generated by a free-falling object. The analytical method for determining the critical weight and impact velocity of the falling object for dynamic buckling is developed based on the principle of conservation of energy in association with the nonlinear equilibrium path of the arch. The experimental investigation is carried out using a test frame designed by authors and the finite element analysis is also conducted. Comparisons with the experimental and finite element results show that the analytical method can accurately detect dynamic buckling of arches under impact action. It is found that the required weight of the falling object for dynamic buckling is much related to the velocity
impacting on the crown of the arch, and decreases with an increase of the impact velocity. It is also found that the weight of the falling object for dynamic buckling is always smaller than the corresponding static buckling load of the arch, indicating that the dynamic buckling of an arch under an impact load is more critical than its static counterpart.

ABSTRACT: When a primary actuator excites the centre point of a rectangular panel speaker, the reflected bending waves at the edges of the plate are superposed with the incident wave and other reflected waves, and this results in a strong modal behaviour. Accordingly, the radiated sound spectrum possesses strong amplitude fluctuations, which results in a poor sound quality. This paper considers via simulations a rectangular panel speaker excited at its centre by a primary actuator and controlled by an edge-located array of control actuators to suppress the multi-modal behaviour of the panel. The basic concept is to eliminate the bending wave reflection from the panel boundary using the control actuator array; thus, only a freely travelling cylindrical wave generated by the main actuator remains. The input gain of the control actuators is obtained via the solution of the inverse problem derived using the transfer matrix between the actuator input and the velocity response on the plate. To ensure the economical use of the input energy required by the control actuators while maintaining the desired acoustic performance, regularisation is employed when solving the inverse problem. By assuming the linearity between the input voltage and the generated force of the actuator, the input efficiency of the control actuators is compared. The control performance is investigated by using a 2-mm thick aluminium panel with an area of $0.7 \times 0.4$ m$. The controlled result shows that the driving-point mobility of the primary actuator approaches that of the infinite plate, which means that the boundary, now the connection line of the control actuators, is converted into an anechoic one. Elimination of the modal effect yields the smoothed spectrum of the radiated sound without severe peaks and troughs.

ABSTRACT: The nonlinear interaction of a dual-frequency Lamb wave with a breathing edge-crack leads to the generation of frequency sidebands in the response spectrum; a phenomenon referred to as the nonlinear frequency mixing. These sidebands appear at algebraic combinations of the two central interrogation frequencies and can serve as a reliable precursor to the existence of an incipient damage. In this paper, an iterative use of the wavelet spectral finite element method is presented for analyzing the phenomenon of nonlinear frequency mixing in a beam with a transverse edge-crack. The beam is modeled using the Timoshenko hypothesis while the local flexibility caused by the crack is modeled by introducing two springs corresponding to the bending and shear deformations, respectively. The intermittent contact between the two crack surfaces is simulated by switching between a defect-free beam configuration and the one containing an open-crack. The underlying steps involved in deriving the element level equations for healthy and damage spectral finite elements, together with an iterative procedure to solve the resulting set of nonlinear equations, are presented in detail. Using this numerical framework, it is exosited that relative strengths of the frequency sidebands are influenced strongly by the temporal overlap that the two constituent wave envelopes have when they propagate through the breathing crack. A modulation parameter is defined for quantifying this dependency. For a simultaneous passage (100% temporal overlap), the modulation parameter attains its maxima, while it reduces to zero when the two constituent waves propagate separately through the breathing crack with zero temporal overlap. Premised on this rationale, an operationally viable damage localization strategy, based on tuning the temporal overlap between the two constituent wave envelopes and further monitoring the modulation parameter, is proposed. The efficacy of the proposed strategy is demonstrated by considering an illustrative numerical example. The present investigation can be of potential use in the analyses concerning nonlinear wave-damage interactions and their effective use in localizing a damage.
ABSTRACT: This paper presents a novel time-domain method for non-stationary random vibration analysis of linear structures. Specifically, using the well-known spectral representation method, the stochastic excitation process is first decomposed into a set of trigonometric basis functions (TBFs) modulated by a series of orthogonal basis random variables (BRVs). Next, each TBF is used as a deterministic excitation input for the structural model, and the induced structural responses are derived analytically using the modal superposition method. After superposition of each TBF-induced deterministic responses, an explicit closed-form expression between the structural stochastic responses and the BRVs is derived, based on which the response statistics of structures at any time instant can be evaluated easily. Furthermore, the accuracy of the solution is independent of the time step used. Finally, several numerical examples in civil engineering, including a Euler beam under stochastic moving load and a shear frame structure subjected to uniformly modulated or fully non-stationary seismic motions, are studied to illustrate the performance of the proposed method. The obtained structural response statistics are compared with the solutions obtained by the Monte Carlo and evolutionary spectral methods. The results verified the high accuracy and efficiency of the proposed method.

ABSTRACT: Dynamical instability characteristics of sandwich truncated conical shell are investigated. The three-layered shell is composed of advanced grid stiffened core and laminated composite skins. The core maybe made of three different fiber paths. The conical shell with simply-supported ends is subjected to two different types of time-dependent axial compressions. The equations of motion and compatibility are derived by considering Kirchhoff-Love assumptions and von Karman relations. The solution procedure is divided to two steps. First, the terms consisting of spatial derivatives are eliminated by applying a stress function and following the Galerkin method. Second, the terms with temporal derivatives are solved with Runge-Kutta method. A new condition of Budiansky-Roth criterion is offered for detection of dynamic buckling load. The effects of different fiber paths and lay-up configurations are investigated.

ABSTRACT: The vibration and sound properties of a type of metamaterial sandwich panels are investigated in this paper. The metamaterial sandwich panels consisting of a host sandwich panel and periodically attached resonant units are designed. Both the panels with and without damping are considered. Via the comparison of metamaterial and bare panels, the effects of the periodic design on wave propagation, vibration, sound radiation and sound transmission properties are analysed and compared numerically. The reduction on the vibration and sound is studied. The numerical results indicate that the vibration, sound radiation and sound transmission are significantly reduced over a wide frequency range. The reduction is obviously larger than that obtained only by increasing the mass. In addition, the experiment specimens of bare and metamaterial sandwich panels are designed. The vibration and sound properties of them are tested and compared. According to the experimental results, the reduction is also observed in a wide frequency range. The simulation results and corresponding analysis are verified. Further, the effects of structural parameters of sandwich panels on the reduction of vibration and sound properties from periodic design are investigated. Several typical cases are analysed concretely. The reasons for the reduction and other effects on the vibration and sound properties from periodic design are analysed. For the panels with various parameter settings, a nice reduction of vibration and sound is generated also form periodic design; on the other hand, the reduction characteristics are changed.
ABSTRACT: Post-buckled beams have been the basic elements of many mechanical devices used for energy harvesting, low-frequency vibration isolation, etc. This paper focuses on the theoretical analysis of nonlinear bending and forced vibration of the post-buckled sandwich beams with graphene reinforced composites (GRC) face sheets. It is assumed that the graphene nanoplatelets are directional in the beam's length and piecewise functionally graded (FG) along with the thickness. Also, the initial imperfection is supposed to possess the same shape as the first-order vibration mode and the material properties are temperature dependent. Based on a modified higher-order shear deformation zig-zag theory, the governing equations considering the thermal effects are derived. To obtain the closed form solutions of the strongly nonlinear system, a combination of the two-step perturbation with the modified Lindstedt-Poincaré method is proposed. The accuracy of the results based on the current models and computation methods is validated. Subsequently, the imperfection sensitivity of bending and principal resonance characteristics under different axial compressions is also discussed. Numerical results reveal the static and dynamic snap-through behaviors and provide the optimal graphene reinforcement type of sandwich beams under different core-to-face sheet thickness ratios.

ABSTRACT: Similitude laws in vibro-acoustics are potentially interesting to extrapolate measurements performed on small structures to the response of larger structures. This paper examines similitude laws for the vibroacoustic response of flat orthotropic flexural rectangular panels radiating sound in a semi-infinite light fluid medium. The scaling parameters considered are the panel size and thickness, its material properties (mass density, elastic moduli) and the properties of the acoustic medium (mass density, sound speed). It is shown that, while no general similarity laws exist for the near-field acoustic radiation, such laws exist for the case of far-field acoustic radiation. Acoustic directivity measurements performed on various isotropic panels confirm the vibroacoustic scaling laws derived theoretically.

ABSTRACT: In this study, a first attempt is made to develop an up-to-date symplectic superposition method for some new analytic free vibration solutions of side-cracked rectangular thin plates that were not obtained by conventional semi-inverse methods. In contrast with the classical Lagrangian system and Euclidean space, the present method is implemented within the Hamiltonian-system framework and symplectic space. The solution procedure involves expressing the problems in the Hamiltonian system and dividing a side-cracked plate into several sub-plates that are analytically solved by the symplectic superposition method, where the imposed quantities are determined by the plate boundary conditions, free edge conditions along the crack, and interfacial continuity conditions between the sub-plates. In the analytic solution of a sub-plate, specifically, the symplectic eigenvalue problems are formulated, followed by the symplectic eigen expansion. The integration of the solutions of the sub-plates yields the final solution of a side-cracked plate. The rigorous mathematical techniques, without predetermined of solution forms, qualify the present method as an unusual approach for exploring more analytic solutions. Comprehensive natural frequency and mode shape solutions of the side-cracked plates under three representative boundary conditions are provided and well validated by other methods. The new analytic solutions obtained may serve as benchmarks for other potential solution methods.

ABSTRACT: The aim of this paper is to propose a methodology for identifying the pressure field applied on a laminated composite plate from its measured vibration response. The general framework of this study is the Corrected Force Analysis Technique (CFAT), which was previously used on isotropic plates. This method estimates the spatial derivatives of the equation of motion with a finite difference scheme and corrects the bias.
error generated by this approximation. The paper presents an extension of this technique to deal with laminated panels. In a first instance, the finite difference scheme has been expanded to allow the identification of the 5 spatial derivatives that compose the equation of motion of such structures. The correction, considered in the wavenumber domain, has also been adapted and is now calculated numerically. In a second instance, the effect of measurement noise has been treated with the implementation of a regularisation technique based on the adaptation of the size of the scheme as function of the frequency. Numerical simulations and contact-less measurements have been conducted on different carbon fibers composite plates. Results are presented in terms of identified pressure fields and input force magnitude.


ABSTRACT: The system considered consists of a hanging cantilevered pipe, surrounded at its upper part by a concentric rigid cylindrical tube, mounted in a tank full of water. Water enters the pipe at its upper and is discharged into the tank at its free end. This generates an upwards flow in the annulus between the pipe and the rigid tube, exiting the system at its upper end. The reverse flow configuration is also considered in which water enters the tank via the annulus and is aspirated by the pipe, exiting at its upper, clamped end. The free end of the discharging pipe could be plain or fitted with an end-piece which allows straight-through axial flow or forces the fluid to exit/enter radially. The system under study may be considered to be a highly idealized version of the operation of salt-mined caverns used for storage and subsequent retrieval of liquid and gaseous hydrocarbons. The problem is studied analytically, and the derivation of the pertinent linear equations of motion of the pipe is outlined. Extensive experiments conducted in a bench-top apparatus are also presented and compared with theoretical predictions. Experimental results and theoretical predictions show flutter for the pipe discharging fluid axially. Annular flow proves to have a strong destabilizing effect on the discharging pipe. The theoretical model predicts stability for the discharging pipe with radial exit flow and this is demonstrated experimentally for light-weight end-pieces. In the reverse flow configuration, flutter is observed in the experiments, while the theory predicts static divergence for low flow velocities and flutter for higher flow velocities.


ABSTRACT: In engineering applications, fluid-conveying pipes usually have geometric imperfections or initially curved configurations. Unlike the initially curved pipe supported at both ends, a slightly curved cantilevered pipe is capable of displaying some interesting behavior because it is a nonconservative system of fluid-structure interactions. In the present study, nonlinear static and dynamic behaviors of cantilevered pipes conveying fluid are explored, with four different initial shapes being considered. To this end, the strongly nonlinear governing equation is derived by employing the extended Lagrange equations written for dynamical systems containing non-material volumes. The static (steady) equilibrium configurations, stability, and nonlinear dynamics of the slightly curved cantilevered pipes are obtained with the aid of absolute nodal coordinate formulation (ANCF). Based on extensive numerical calculations, some interesting and sometimes unexpected results are displayed. The first unexpected feature in this dynamical system is that the flow-induced static deformation of the pipe can be extremely large even if the initial geometric imperfection of the pipe is quite small. The second unexpected result is that the critical flow velocity for flutter instability of the slightly curved pipe conveying fluid may be either lower or higher than that of a straight pipe, mainly depending on the static equilibrium configuration when the critical flow velocity is just reached. Moreover, it is demonstrated that the slightly curved pipe oscillates about the static equilibrium position instead of the initially curved centerline, and the preferred form of post-instability behavior is periodic motion within a wide range of system parameters considered.


ABSTRACT: A new methodology is presented in this work to identify the viscoelastic boundary conditions and dynamical response of Euler-Bernoulli beams under a moving load. A new expression for the transmissibility
function of the beam output responses with unknown viscoelastic boundary conditions with Voigt and more generalized four-element models is derived. The proposed identification method uses modal shapes with a pattern search optimization scheme. Finite element simulation was used to demonstrate the validity of the proposed method. The acceleration response from different locations on the beam was utilized in the identification of the boundary conditions considering six optimization cases. The proposed method provided solutions of the boundaries that can satisfy the requirements of the natural frequencies and damping ratios simultaneously. The effects of the number of selected measurement locations, participant modes, and measurement noise on the accuracy of the resulting boundary parameters were investigated. The results showed that the use of three complex modes and eight measurement points provided an accurate estimation of the modal parameters and reduced the relative error effectively in the resulting eight unknown boundary coefficients, under noise-free and corrupted acceleration signals with 5% noise conditions.


ABSTRACT: On the basis of the smeared stiffener theory, the evolution of nonlinear axisymmetric longitudinal waves in a nonlinear elastic cylindrical shell reinforced by internal stringers is investigated. A non-classical nonlinear physical law is adopted for the shell material, which is characterized by a fractional degree of strain intensity. An analysis of the influence of an external elastic medium on a nonlinear wave process is carried out on the basis of the Winkler and shear-lag model. Using the asymptotic method of multiscale expansions, the Schamel-Ostrovsky quasi-hyperbolic equation for the component of longitudinal displacement was first derived. The Painlevé analysis of the equation showed the impossibility of exact solitary-wave solutions. The dispersion relation is analyzed, the maximum value of the phase velocity of infinitesimal disturbances is determined, above which stationary nonlinear waves can propagate. Based on the finite-difference approach and the Petviashvili method, a numerical simulation of the derived equation is carried out, profiles of stably propagating wave packets and solitary waves are constructed. A special dispersionless case, impossible for an unstiffened shell, has been identified, in which there are exact compactons, peakons and periodic solutions.


ABSTRACT: The symplectic wave-based method is extended to the free and forced vibration analysis of thin orthotropic circular cylindrical shells with arbitrary boundary conditions. The key of this extension is to derive the characteristic equation for thin orthotropic circular cylindrical shells so that the symplectic eigenproblem which gives wave modes can be formed. According to the phase coincidence condition which determines the relationship between the wave modal shape and natural modal shape, the present method gives an analytical procedure for free vibration analysis. And steady state forced responses under arbitrary boundary conditions are obtained by using the wave propagation analysis based on the symplectic system. Compared with the existing methods for vibration analysis of thin orthotropic circular cylindrical shell, the present method shows better accuracy and convergence, especially for high-frequency vibrations, which is illustrated by the results shown in numerical examples.


ABSTRACT: This work focuses on the free and forced vibrations of sandwich beams and plates hosting an arbitrary number of damping cores. A fractional derivatives Zener-type model is adopted for representing the frequency-dependent viscoelastic behaviour, along with conventional series developments. The structural models are formulated within an established variable kinematics approach, which enables to investigate the role of specific assumptions and to identify the most accurate model at a least number of degrees of freedom. Approximate solutions are found by a computationally efficient Ritz method that allows to take into account any type of boundary conditions. Modal loss factors and damped eigenfrequencies are obtained from a complex eigenvalue problem, for which a modal strain energy approach or a complex eigensolution can be employed.
Frequency responses can be computed by a direct approach or by elementary modal projection algorithms. Results are reported for conventional and innovative sandwich configurations. Different modelling and solution strategies are compared and the role of transverse normal deformation of the mechanically weak viscoelastic plies is particularly emphasised.

ABSTRACT: A novel dynamic model of a rotating variable-thickness pre-twisted blade with elastic constraints is established by using the shallow shell theory. The effects of Coriolis and centrifugal force due to the rotational motion are considered in the formulation. Based on the Lagrange equation, the natural frequencies and modes of a rotating pre-twisted blade are obtained by using orthogonal polynomials as admissible functions. The convergence analysis is studied, and the accuracy of the proposed model is verified by comparing it with the literature results and ANSYS data. A comprehensive parameter investigation of the effects of thickness-taper ratio, pre-twist angle, rotational speed, and connection stiffness on blades' modal characteristics is conducted. The results show that the phenomena of frequency locus veering, crossing, and coincidence. Furthermore, mode shape exchanging occurs with parameter changes.

ABSTRACT: As an extension of the previous work on membranes by Kim and Lee (2020), an exact frequency-domain spectral element model is proposed for the transverse vibrations of a rectangular Kirchhoff plate, based on the following procedure. First, in the frequency-domain, the general solution of a finite rectangular plate element is derived in the spectral form in the spatial domain, after removing all the trigonometric terms that vanish at the four boundary edges. Second, as an important theoretical improvement, the boundary functions that represent the boundary conditions at the four boundary edges are also expressed in the spectral forms in the spatial domain. Next, by using the projection method based on the orthogonality of trigonometric functions, the spatial-domain spectral coefficients of the general solution are related to those of the boundary functions. Finally, from the force-displacement relationships, the spectral element matrix (or dynamic stiffness matrix) is formulated for a finite rectangular plate element. As both the general solution and boundary functions are expressed in the spectral forms in both the temporal and spatial domains, a fast Fourier transform (FFT) algorithm can be applied to efficiently simulate the vibration responses and waves in a plate. The accuracy and computational efficiency of the proposed SEM are evaluated by comparison with the exact theory, modal analysis method, and the commercial finite-element-analysis software ANSYS.

ABSTRACT: Lightweight, low-frequency, broadband and highly efficient vibration reduction is widely desired in various devices. Nonlinear acoustic metamaterial (NAM) is a new type of metamaterial that may possess these vibration reduction features. However, the laws governing the manipulation of the NAM vibration response and its optimized design have not been addressed. This paper numerically and experimentally studies the manipulation laws and optimized design of the NAM beam reported in [Nature Comm., 8: 1288(2017)]. The strongly nonlinear metacell consists of three bridging-coupled resonators: A Duffing oscillator, a flexural resonator and a vibro-impact resonator. Both time-domain and frequency-domain finite element models are established to calculate the vibrations of the beam. We systematically study the influences of the amplitude, nonlinear stiffness coefficients, resonance frequencies, mass and beam thickness on the bandwidth and efficiency of its vibration reduction properties. Moreover, based on these laws, we present an optimized lightweight NAM beam to realize the low-frequency, broadband and highly efficient vibration reduction with the greatly reduced attached mass. Finally, different NAM samples are fabricated to verify the efficient reduction effect. This work could support the study, creation and application of NAMs in the future.
ABSTRACT: Several vibro-acoustic models for either single wall or multi-layer constructions are based on classical plate and first order shear deformation theories. The equivalent or condensed plate models employ the thin plate model to extract the dynamic mechanical properties of the multi-layer system considering only flexural and shear motions for the structure under investigation. Since these plate models do not account for the compressional or symmetric motion of the structure, both thin and thick plate theories encounter limitations for mid to high frequency predictions depending on the structures considered. In this work, analytical expressions for the frequency limit of thin and thick plate theories are derived for an elastic layer of isotropic material from the analyses of wavenumbers and admittances. Additionally, refined expressions for coincidence and critical frequencies are presented. Validation of these frequency limits are made by comparing the transmission loss (TL) obtained from both plate theories with the TL computed through the theory of elasticity for a range of thin/thick and soft/stiff materials.


ABSTRACT: This paper is concerned with the prediction of the vibro-acoustic behavior of rib-stiffened panels treated with multiple layers of porous materials. The acoustically treated rib-stiffened panels are assumed to be uniform and infinitely long in one direction (the longitudinal direction) but the cross-section can have an arbitrary and often complicated shape. Although the two-and-half dimensional structural finite element method (2.5D FEM) and the two-and-half dimensional acoustic boundary element method (2.5D BEM) may be combined to perform the vibro-acoustic prediction, the presence of the multiple layers of acoustic treatment often makes the prediction time-consuming. More efficient methods are required for such structures and the aim of this paper is to propose such a method. The rib-stiffened panel and the fluid domain containing the incident and reflected sound waves are modelled using 2.5D FEM-BEM while the acoustic treatment layer and the fluid domain containing the transmitted sound waves are dealt with, approximately, using the transfer matrix method (TMM). The coupling of TMM and 2.5D FEM-BEM is formulated in detail. Since the acoustically treated panel is assumed to be flat and baffled, the 2.5D BEM is based on the Rayleigh integral in the wavenumber domain. Meanwhile, the TMM is based on a two-dimensional Fourier transform which implies that the porous layers also extend to cover the baffle; the validity of this assumption is explored. The accuracy and efficiency of the method is compared with a full 2.5D FE-BE method for a homogeneous plate with attached layers of absorbent material. It is shown that the method proposed in this paper can reduce calculation time by about a factor of three compared with the full 2.5D FE-BE method. The proposed method is then applied to study the sound transmission loss (STL) of a typical rib-stiffened panel from a train carriage which is
acoustically treated with different porous material layers, demonstrating that the design of the acoustic treatment can have a significant effect on the STL of the panel.


ABSTRACT: Whereas the spatial coherence of wall pressure and vibratory fields induced by turbulent boundary layers (TBLs) on flat plates have been studied at extent, their equivalents for cylindrical structures still need further investigation. To that end, this work develops a semi-analytical model which is valid for infinite cylindrical shells filled with a heavy fluid and excited by an internal TBL. The cylindrical shell can be also coupled to two ring stiffeners that account for the flanges generally used to connect a pipe to other portions of a circuit. The cross-spectrum density (CSD) function of the shell radial accelerations is estimated from the system circumferential sensitivity functions and the CSD of the wall pressure field induced by the TBL. The spatial coherence of the pipe vibration field is therefore analysed for a pipe with and without flanges. This is of critical importance for applications such as non-intrusive techniques for detecting acoustic sources inside pipes, like beamforming using arrays of accelerometers. If the pipe conveys a flow, the beamforming efficiency can strongly deteriorate because of the background noise induced by the TBL, which pollutes the coherence signal between sensors. The effects that the spatial coherence could have on the beamforming results of a line of point sensors (accelerometers) and a ring of wire sensors (piezoelectric coiled wires) are also investigated in this paper.

Journal of Sound and Vibration, Vol. 493, Article 115841, 17 February 2021,
continuity conditions along the contact boundary of the plate's subdomains. In order to obtain an indication of the accuracy of the developed mathematical model and the proposed technique, some cases available in the literature have been considered. Original results are presented for solution of representative symmetric multilayered plates showing the effects of the line hinge parameters on the natural frequencies and mode shapes.

References listed at the end of the paper:
8 M. Huang, X.Q. Ma, T. Sakiyama, H. Matsuda, C. Morita, Natural vibration study on rectangular plates with a line hinge and various boundary conditions, J. Sound Vib., 322 (2009), pp. 227-240
9 P.V. Hull, G.R. Buchanan, Vibration of moderately thick square orthotropic stepped thickness plates, Appl. Acoust., 64 (2003), pp. 753-763
18 P. Malekzadeh, S.A. Shahpari, Free vibration analysis of variable thickness thin and moderately thick plates with elastically restrained edges by DQM, Thin-Walled Struct., 43 (2005), pp. 1037-1050
23 M.V. Quintana, L.G. Nallim, A variational approach to free vibration analysis of shear deformable polygonal plates with variable thickness, Appl. Acoust., 71 (2010), pp. 393-401

ABSTRACT: Exact solutions for forced vibration of completely free orthotropic rectangular nanoplates resting on viscoelastic foundations are obtained by an analytical Hamiltonian-based method. Eringen's nonlocal theory is employed to take into account the small size effect. In the present method, a Hamiltonian system for the vibration of the orthotropic rectangular nanoplate is established by introducing a new total unknown vector. The vibration analysis is reduced to an eigenproblem in the symplectic space. Closed-form solutions of the completely free nanoplate are derived by using the solution of a guided supported nanoplate and a superposition of boundararies. Numerical examples including comparison studies are presented to illustrate the efficiency and accuracy of the proposed method. A detailed parametric study and some new results are provided also.

References listed at the end of the paper:
7 M.S. Atanasov, D. Karlicic, P. Kozic, Forced transverse vibrations of an elastically connected nonlocal orthotropic double-nanoplate system subjected to an in-plane magnetic field, Acta Mech., 228 (2017), pp. 2165-2185
20 SH. Hashemi, H. Mehrabani, A. Ahmadi-Savadkoohi, Forced vibration of nanoplate on viscoelastic substrate with consideration of structural damping: an analytical solution, Compos. Struct., 133 (2015), pp. 8-15
38 C.C. Liu, Z.B. Chen, Dynamic analysis of finite periodic nanoplate structures with various boundaries, Phys. E, 60 (2014), pp. 139-146
46 S. Poursaeemaei, E. Ghavanloo, S.A. Fazelzadeh, Vibration analysis of viscoelastic orthotropic nanoplates resting on viscoelastic medium, Compos. Struct., 96 (2013), pp. 405-410

ABSTRACT: Levy's analytical solution approach is extended for analysis of rectangular strain gradient elastic plates under static loading for the first time with different boundary conditions at the edges using the method of superposition. The governing equation of equilibrium and the corresponding classical/non-classical boundary conditions for strain gradient flexural Kirchhoff plate under static loading are considered. Numerical examples on static bending of Kirchhoff nanoplates involving five different combinations of simply supported, clamped and free edge boundary conditions are presented. The effect of negative strain gradient terms is of hardening nature thus resulting in decrease in the deflection. Plates with geometry comparable to the microstructural length scale show significant size effect and this size dependency diminishes with the increase in the plate size. References listed at the end of the paper:

20 M. Di Paola, G. Failla, M. Zingales, Physically-based approach to the mechanics of strong non-local linear elasticity theory, J. Elasticity, 97 (2) (2009), pp. 103-130
ABSTRACT: The buckling (eigenvalue) problem of biaxially compressed laminated plates and shallow cylindrical panels having two symmetric piezoelectrical (PZT) patches on the top and the bottom of laminates is considered. The analysis is carried out with the use of the classical laminate theory and of the first order shear deformation theory. The variable thickness of structures (the local positions of PZT patches) is described by piecewise constant step functions in one direction or in both directions due. Three different methods of the solution of the linear eigenvalue problem are proposed: the exact analytical solution, the approximate solution based on the definition of the Rayleigh quotient and the numerical 3D finite element analysis. For the approximate Donnell's theory of shallow panels two variational formulations of the eigenvalue problem are
derived in the form of the Hu-Washizu functional (the Airy stress functions and transverse normal displacements) and in the form of the Legendre functional (displacements). The influence of geometric parameters of composite panels and PZT patches, piezoelectric effect, external electric voltage and laminate configurations (symmetric angle-ply and cross-ply laminates) on buckling characteristics are discussed in detail. The analysis demonstrates evidently that the use of the local piezopatches should be considered as the buckling problem for structures with the non-uniform thickness distribution. The appropriate use of the local PZT patches should be always combined with the appropriate choice of the best (optimal) laminate configuration. The formulation system developed is suitable to other shell theories and to account for the analysis of thermal effects or the imperfection sensitivity.

References listed at the end of the paper:
1 H. Abramovich, A new insight on vibrations and buckling of a cantilevered beam under a constant piezoelectric actuation, Compos. Struct., 93 (2011), pp. 1054-1057
8 K. Chandrashekkara, K. Bhatia, Active buckling control of smart composite plates—finite element analysis, Smart Mater. Struct., 2 (1993), pp. 31-39
16 P. Kędziora, Optimal design of composite structures with piezo electric layers, Kraków, (2013) (in Polish)
26 A. Muc, Peculiarities in the material design of buckling resistance for tensioned laminated composite panels with elliptical cutouts, Materials, 11 (6) (2018)
ABSTRACT: In the present study, based on the higher-order shear deformation plate theory, the unified numerical formulation is developed in variational framework to investigate the thermal buckling of different shapes of functionally graded carbon nanotube reinforced composite plates. Since the thermal environment has considerable effects on the material properties of carbon nanotubes (CNTs), the temperature-dependent (TD) thermo-mechanical material properties are taken into account. In order to present the governing equations, the quadratic form of the energy functional of the plate structure is derived and its discretized counterparts are presented employing the variational differential quadrature (VDQ) approach. The discretized equations of motion are finally obtained based on Hamilton's principle. In order to convenient application of differential quadrature numerical operators in irregular physical domain, the mapping procedure is considered in accordance to the conventional finite element formulation. Some comparison and convergence studies are performed to show validity and efficiency of the proposed approach. A wide range of numerical results are also reported to analyze the thermal buckling behavior of different shaped FG-CNTRC plates.

References listed at the end of the paper:

16 M. Mirzaei, Y. Kiani, Thermal buckling of temperature dependent FG-CNT reinforced composite plates, Meccanica (2016), pp. 1-17
23 H.S. Shen, Nonlinear bending of functionally graded carbon nanotube-reinforced composite plates in thermal environments, Compos. Struct., 91 (2009), pp. 9-19
33 D.G. Zhang, H.M. Zhou, Mechanical and thermal post-buckling analysis of FGM rectangular plates with various supported boundaries resting on nonlinear elastic foundations, Thin-Walled Struct., 89 (2015), pp. 142-151

ABSTRACT: This research deals with a study of the free vibration of fiber metal laminate thin circular cylindrical shell reinforced by single walled carbon nanotubes with different boundary conditions. The representative volume element is consisting of four phases: fiber, carbon nanotubes (CNTs), polymer matrix and metal. Initially, the CNTs have been added to the matrix and then the fiber phase has been reinforced by them. Finally, the adhesive fiber prepreg has been combined with the thin metal layers. The generated cylindrical shell can be named CNT/fiber/polymer/metal laminate (CNTFPML) cylindrical shell. In this study, Love's first approximation shell theory has been used to obtain the strain-displacement relations and also, beam modal function model has been utilized to satisfy the governing equations of motion. The effects of mass fraction of CNTs, volume fraction of fiber and metal, axial and circumferential modal numbers, and different distributions of CNTs subjected to different boundary conditions on the vibration of the shell have been considered. In addition, the influences of different lay-ups and different material properties of fiber have been investigated.

References listed at the end of the paper:


ABSTRACT: The size-dependent geometrically nonlinear free and forced vibration behaviors of nanoscale beams are studied in this article using a numerical approach. The size effects are captured using Mindlin's second strain gradient theory (SSGT) in which the second-order and third-order derivatives of displacement components are taken into account in the strain energy density. The basic relations are first derived using the Timoshenko beam theory and SSGT. Then, the variational differential quadrature (VDQ) method is adopted to solve the obtained governing equations in the context of variational formulation. Comprehensive numerical results are given to investigate the influences thickness-to-lattice parameter ratio on the nonlinear free and forced vibrations of nanobeams under different types of end conditions. Also, comparisons are made between the predictions of SSGT and the first strain gradient theory as well as the classical elasticity theory.

References listed at the end of the paper:
5 B. Akgöz, Ö. Civalek, Bending analysis of FG microbeams resting on Winkler elastic foundation via strain gradient elasticity, Compos. Struct., 134 (2015), pp. 294-301
ABSTRACT: Dynamic analysis and design of light-weight structures subject to different types of applied forces is of considerable practical interest in engineering applications. Porous structures are a novel class of weight-efficient engineering materials with optimized mechanical properties and improved structural performance. Porous materials with functionally graded porosity are achieved by tailoring the size and density of the internal pores in one or more directions that leads the desired mechanical properties. In this paper, the dynamic response of poroelastic pipes made of a closed–cell porous material with functionally graded porosity subjected to influences induced by fluid flow is investigated. Three different porosity distributions through the pipe thickness are introduced. The finite element formulation of dynamic equations of pipeline conveying fluid are presented based on Timoshenko theory by considering the fluid–structure interaction and the effect of shear deformation. The complex modal analysis is employed to estimate the natural frequencies of a clamped-clamped pipe with different velocities. Finally, the effects of fluid velocity on the dynamic response of a poroelastic pipe are studied.

References listed at the end of the paper:

5 Z. Belabed, M.S.A. Houari, A. Tounsi, S. Mahmoud, O.A. Bég, An efficient and simple higher order shear and normal deformation theory for functionally graded material (FGM) plates, Compos. B Eng., 60 (2014), pp. 274-283
8 D. Chen, J. Yang, S. Kitipornchai, Elastic buckling and static bending of shear deformable functionally graded porous beam, Compos. Struct., 133 (2015), pp. 54-61
16 M. Heshmati, F. Daneshmand, A study on the vibrational properties of weight-efficient plates made of material with functionally graded porosity, Compos. Struct., 200 (2018), pp. 229-238
27 K. Magnucki, M. Malinowski, J. Kasprzak, Bending and buckling of a rectangular porous plate, Steel Compos. Struct., 6 (2006), pp. 319-333
30 M. A. Mekanik, M. Paidoussis, Unsteady pressure in the annular flow between two concentric cylinders, one of which is oscillating: experiment and theory, J. Fluid Struct., 23 (2007), pp. 1029-1046
38 M.T. Piovannini, R. Sampao, Vibrations of axially moving flexible beams made of functionally graded materials, Thin-Walled Struct., 46 (2008), pp. 112-121
45 M. Simsek, Non-linear vibration analysis of a functionally graded Timoshenko beam under action of a moving harmonic load, Compos. Struct., 92 (2010), pp. 2532-2546
48 A. Zare, M. Eghtesad, F. Daneshmand, Numerical investigation and dynamic behavior of pipes conveying fluid based on isogeometric analysis, Ocean Eng., 140 (2017), pp. 388-400

ABSTRACT: The paper concerns flexural buckling and initial post-buckling of axially compressed columns made of aluminium alloy described by the Ramberg-Osgood relationship. The non-linear differential equation of the problem is derived using the stationary total energy principle and the assumptions of classical beam theory within a finite range. The approximate analytical solution of the equation leading to the buckling loads and initial post-buckling equilibrium path is determined by means of the perturbation approach. Numerical examples dealing with simply supported and clamped I-columns are presented, the effect of the material non-linearity on the critical loads and initial post-buckling behaviour in comparison to linear one is discussed too. The analytical results are compared with the FEM solutions to present a good agreement.

References listed at the end of the paper:
2 S. Ádány, B. Schafer, Generalized constrained finite strip method for thin-walled members with arbitrary cross-section: primary modes, Thin-Walled Struct., 84 (2014), pp. 150-169
3 S. Ádány, B. Schafer, Generalized constrained finite strip method for thin-walled members with arbitrary cross-section: secondary modes, orthogonality, examples, Thin-Walled Struct., 84 (2014), pp. 123-133
5 C. Basaglia, D. Camotim, R. Goncalves, A. Biscaya, GBT-based assessment of the buckling behavior of cold-formed steel purlins restrained by sheeting, Thin-Walled Struct., 72 (2013), pp. 217-229
6 O. Basquin, Thin Section and the Strength of Steel Columns in Test, Tech. Rep, Dept. Commerce, Bureau of Standards USA (1924)
14 G. Hancock, C. Pham, Buckling analysis of thin-walled sections under localised loading using the semi-analytical finite strip method, Thin-Walled Struct., 86 (2015), pp. 35-46
18 J.V. Kumar, S.A. Jayachandran, Experimental investigation and evaluation of Direct Strength Method on beam-column behavior of uprights, Thin-Walled Struct., 102 (2016), pp. 165-179
19 GBTUL 2.0 Buckling and Vibration Analysis of Thin-walled Members (2013) [online] www.civil.ist.utl.pt/ght
21 Z. Li, B. Schafer. CFSM Elastic Buckling Analysis of Thin-walled Members with General End Boundary Conditions [online, cited http://www.ce.jhu.edu/bschaefer/cfsm/]
22 Z. Li, J. Abreu, J. Leng, B. Schafer, Review: constrained finite strip method developments and applications in cold-formed steel design, Thin-Walled Struct., 81 (2014), pp. 2-18
25 V. Nguyen, C. Pham, B. Cartwright, M. English, Design of new cold rolled purlins by experimental testing and Direct Strength Method, Thin-Walled Struct., 118 (2017), pp. 105-112
29 W. Ramberg, W. Osgood, Description of Stress-strain Curves by Tree Parameters, Tech. Rep, National Advisory Committee for Aeronautics (1943)
33 M. Rendall, G. Hancock, K. Rasmussen, The generalised constrained finite strip method for thin-walled members in shear, Thin-Walled Struct., 117 (2017), pp. 294-302
37 A. Sarawit. CUTWP global buckling analysis of thin-walled members [online, cite http://www.ce.jhu.edu/~bschafer/cutwp/]
38 N. Silvestre, Generalised beam theory to analyse the buckling behaviour of circular cylindrical shells and tubes, Thin-Walled Struct., 45 (2007), pp. 185-198


ABSTRACT: The circular cylindrical shells have been widely used in modern engineering structures, especially in the aerospace industry such as the oil pipeline, the missile, spacecraft hull, storage tanks. In recent years, functionally graded carbon nanotube composites (FG-CNTRCs) have emerged, as a promising type of composites. Due to the increasing demands for high structures performance, this research paper proposes a closed-form solution to investigate the nonlinear buckling behavior of the FG-CNTRC cylindrical shells subjected to compressive load. The small initial imperfections of the FG-CNTRC cylindrical shells are also considered through analytical modeling. Effective properties of materials of the shells reinforced by single-walled carbon nanotubes (SWCNTs) are estimated through a micro-mechanical model based on the extended rule of mixtures. The Donnell shell theory and von-Karman nonlinear kinematics are used for nonlinear equilibrium equations. The novelty of this work is to exploit an exact solution via Galerkin procedure and term of the Airy stress function in order to reveal the impacts of the imperfection parameter, different types of CNTs distribution, the volume fraction of CNTs on nonlinear behavior and compressive equilibrium paths of FG-CNTRC cylindrical shells.

References listed at the end of the paper:
21 P. Malekzadeh, M. Dehbozorgi, Low velocity impact analysis of functionally graded carbon nanotubes reinforced composite skew plates, Compos. Struct., 140 (2016), pp. 728-748
22 M. Mirzaei, Y. Kiani, Free vibration of functionally graded carbon nanotube reinforced composite cylindrical panels, Compos. Struct., 142 (2016), pp. 45-56
29 H.-S. Shen, Y. Xiang, Postbuckling of nanotube-reinforced composite cylindrical shells under combined axial and radial mechanical loads in thermal environment, Compos. B Eng., 52 (2013), pp. 311-322
38 Q. Wang, X. Cui, B. Qin, Q. Liang, Vibration analysis of the functionally graded carbon nanotube reinforced composite shallow shells with arbitrary boundary conditions, Compos. Struct., 182 (2017), pp. 364-379

https://doi.org/10.1016/j.euromechsol.2018.09.001
ABSTRACT: An elastically supported viscoelastic functionally graded (FG) microcantilever is considered and its nonlinear mechanics is analysed for the first time. Moreover, for the first time, energy transfer via internal resonances and motion complexity are analysed. A nonlinear spring model is incorporated as an elastic support which is representative of elasticity induced from neighbouring devices. Size effects are incorporated using the modified couple stress theory (MCST). Mori-Tanaka formula is utilised for FG-material-property variations. Kinematics/kinetics for an infinitesimal beam elements in conjunction with Hamilton's method are used for large curvatures. Galerkin's technique is used for reductions to truncations of the dynamic model of elastically supported viscoelastic FG microsystem. Both base-excitation/frequency continuations are performed and the dynamics is investigated.

References listed at the end of the paper:

10 C. Du, Y. Li, Nonlinear resonance behavior of functionally graded cylindrical shells in thermal environments, Compos. Struct., 102 (2013), pp. 164-174
27 X. Li, C.C. Du, Y.H. Li, Parametric instability of a functionally graded cylindrical thin shell subjected to both axial disturbance and thermal environment, Thin-Walled Struct., 123 (2018), pp. 25-35


ABSTRACT: In this research, the wave propagation in a viscoelastic composite thick plate resting on a Visco-Pasternak foundation is analyzed by means of sinusoidal shear deformation theory (SSDT). The viscoelastic properties of the plate are considered by using Kelvin–Voigt model. The material properties of composite plate are assumed viscoelastic based on Kelvin–Voigt model. The governing equations of motion are derived by Hamilton's principle. The analytical solution is applied to obtain the effects of the structural and foundation damping coefficients, wave number, aspect ratios, elastic properties and number of layers on the wave propagation behavior of the viscoelastic composite plate including the dimensionless phase velocity, cut-off and escape frequencies. The obtained results indicate that the dimensionless phase velocity and natural frequency decrease with increasing the damping coefficient. Also, it is observed that the effect of layups on the phase velocity becomes more sensible for small wave numbers. However, the effect of the damping coefficient on the dimensionless phase velocity and natural frequency is only observed at large dimensionless wave numbers.


ABSTRACT: In this paper, the free vibration characteristics of uniform and stepped annular-spherical shells are investigated by using a semi-analytical approach with general boundary conditions. The theoretical model of annular-spherical shell is established by using Flügge's thin shell theory, and the annular-spherical shells are divided into their segments along the axial direction. The displacement functions of shell segments are consist of the Jacobi polynomials along the axial direction and the standard Fourier series along the circumferential direction. The boundary conditions at the ends of the shells and the continuity conditions at two adjacent segments were enforced by penalty method of spring stiffness technique. Then, the accurate solutions about the vibration characteristics of uniform and stepped annular-spherical shells were solved by method of Rayleigh–Ritz. The accuracy and reliability of the proposed method are verified with the results of FEM and published
literatures. The results show that the present method has good convergence ability and excellent accuracy. In addition, some numerical results of uniform and stepped annular-spherical shells with various geometric parameters and boundary conditions are reported, which can be used as reference data for future researchers.


ABSTRACT: In this paper, the optimal locations of finite number of embedded magnetorheological fluid (MRF) pockets are calculated by using Single Objective Genetic Algorithm (SOGA) to suppress the supersonic flutter of an elastically supported sandwich beam with regular honeycomb interlayer. The structural formulation is based on the classical beam theory along with the Winkler-Pasternak foundation model, the MRF is modeled as a first order Kelvin-Voigt material, and the quasi-steady first order supersonic piston theory is employed to define the aerodynamic loading. The aeroelastic time response of honeycomb sandwich beams with different number of embedded MRF pockets are measured with/without foundation and flow stream under impact load. The simulation shows that by using MRF pockets in optimized locations in honeycomb sandwich structure, not only both lightness of honeycombs and variability of structural damping of MRF are considered, but also the supersonic flutter can be postponed to higher dynamic pressure compared to entirely honeycomb or MRF sandwich beams. Finally, in order to achieve the optimum compromise between mass and the flutter suppression, the best number of MR pockets along with the optimum magnetic field values in honeycomb sandwich structure is presented.


ABSTRACT: This article presents an approach to obtain refined beam models with optimal numerical efficiency. Hierarchical Legendre Expansions (HLE) and Node-dependent Kinematics (NDK) are used in combination to build efficient global-local FE models. By relating the kinematic assumptions to the selected FE nodes, kinematic refinement local to the nodes can be realized, and global-local models can be conveniently constructed. Without using any coupling approach or superposition of displacement field, beam models with NDK have compact and coherent formulations. Meanwhile, HLE is used in the local zone for the enrichment of the beam cross-sections to satisfy the requirement for high solution accuracy, leaving the global model with lower-order kinematic assumptions. Through the numerical investigation on slender laminated structures, it is demonstrated that the computational costs can be reduced significantly without losing numerical accuracy.


ABSTRACT: We demonstrate that layered shell elements in existing conventional finite element codes can be directly used for modeling thin structures with surface effects. Based on a recently published methodology for modeling a solid structure incorporated with surface effects by using both solid type and shell type elements, we propose that for thin structures, one type of element - layered shell type element is sufficient for incorporating surface effects. The results calculated from the proposed finite element method for simply supported plates agree with theoretical predictions. The surface effects on kirigami of a soft sheet are presented as an example application of the proposed method.


ABSTRACT: This paper presents a new numerical approach based on an effective meshfree method integrated with a refined inverse sin shear deformation plate theory to perform static bending, free vibration and buckling
analysis of functionally graded plates. The present formulation is based on a refined inverse sin shear deformation theory (R-ISSDT). Unlike other traditional plate theories, the theory presented gives rise to only four governing equations, does not require shear correction factor, and captures the parabolic variation of the transverse shearing stresses through the thickness of the plate. In the formulation of the meshfree method a new correlation function is proposed which effectively eliminates the correlation parameters. After proposing the formulation of the problem, numerical examples are provided and the obtained results are compared with those found in literature.

ABSTRACT: This paper deals with the propagation of singularities in thin elastic shells whose middle surface is not of an uniform nature. Numerical computations are performed using an adaptive mesh procedure proposed by the software Abaqus to refine the mesh inside the internal layers. The computation are done on three kinds of shells: hyperbolic-parabolic, hyperbolic-elliptic and parabolic-elliptic. The numerical results enable us to determine the propagation of singularities in such shells and to have information about their nature. In particular, when a singular force is applied in the hyperbolic part of a shell, the numerical computations show that a singularity propagates in the hyperbolic part and that a reflection occurs at the boundary with a part of a different nature (parabolic or elliptic).

ABSTRACT: A modified version of the Adomian decomposition method is applied to solve the differential equations of nonlinear bending of rectangular anisotropic thin plates. The von Kármán hypotheses are considered in the plate's kinematics. The nonlinear differential equations are decomposed into linear and nonlinear parts and the solution is expanded into series. Essentially, the approach is to embed the nonlinear effects into the anisotropic linear solution. Such incorporations are performed in a recursive fashion along with the Adomian's polynomials, which are responsible for the approximation of the nonlinear effects. In spite of the problem being three-dimensional, no partial solutions are required due to a modification of the standard method, which considers the inversion of the entire linear operator. As a result, the obtained solution respects the boundary conditions set and is independent of its symmetries. The pb-2 Rayleigh-Ritz method is used to obtain the plate's equilibrium path. A multistep procedure is proposed in order to increase the decomposition method convergence radius aiming at global convergence. Numeric results are obtained and compared to those found in the literature.

ABSTRACT: Based on nonlocal strain gradient theory (NSGT), transient behavior of a porous functionally graded (FG) nanoplate due to various impulse loads has been studied. The porous nanoplate has evenly and unevenly distributed pores inside its material structure. Impulse point loads are considered to be rectangular, triangular and sinusoidal types. These impulse loads lead to transient vibration of the nanoplate which is not studied before. NSGT introduces a nonlocal coefficient together with a strain gradient coefficient to characterize small size influences due to non-uniform stress and strain fields. Galerkin's approach has been performed to solve the governing equations and also inverse Laplace transform method is used to obtain transient response due to impulse loads. It is explained in this research that the transient response of a nanoplate is dependent on nonlocal coefficient, strain gradient parameter, pore dispersion, pore amount, type of impulse load and loading time.
ABSTRACT: A finite strip method was developed for buckling and free vibration analysis of piezoelectric laminated composite plates based on various plate theories such as Zigzag, Refined plate and other higher order shear deformation theory by variation of transverse shear strains through plate thickness in the form of parabolic, sine and exponential. The plate edge conditions are considered to be simply supported and the polynomial shape functions are used to evaluate the in–plane and out–of–plane deflection and rotation of the normal cross section of plates in transverse direction. Numerical results were obtained based on various shear deformation plate theories to verify the proposed method. The effects of length to thickness ratio and fiber orientation of cross–ply and angle–ply laminate were presented. Also, the effect of different electrical conditions on the critical buckling load under in–plane forces and strains is investigated and electrical buckling load and natural frequency of piezoelectric laminate composite plates are calculated through numerical examples. In addition, the new results on the effect of piezoelectric layers thickness, placement of piezoelectric layers and also the effect of length to thickness ratio in the interaction of biaxial in–plane loading on critical buckling load were studied.

ABSTRACT: In the current analysis, an attempt is made to develop a nonlinear size-dependent fluid-structure interaction model for the chaotic motion of nanofluid-conveying nanotubes subject to an external excitation. The material properties of the nanotube are assumed to be viscoelastic. Size effects in both solid and fluid nanoscale parts are taken into consideration. In addition, the effects of both centripetal and Coriolis accelerations are incorporated in the model. Using Hamilton's principle, the nonlocal strain gradient elasticity and the Beskok-Karniadaki theory, the nonlinear size-dependent governing equation is derived. For developing a precise solution approach, Galerkin's procedure and a direct-time-integration method are eventually used. Different parameters of the nanosystem are taken into consideration to study the size-dependent chaotic motion of the viscoelastic nanotube conveying nanofluid subject to a harmonic excitation.

ABSTRACT: In this paper, the nonlinear vibrations of a carbon fiber reinforced polymer (CFRP) laminated cylindrical shell are investigated with 1:2 internal resonance, primary parametric resonance and 1/2 subharmonic resonance. The radial line load and axial excitation are acting on the two free ends of the CFRP laminated cylindrical shell. The partial differential governing equations of motion for the CFRP laminated cylindrical shell are derived by utilizing the von-Karman type nonlinear geometric relationship, the first-order shear deformation theory and Hamilton principle. Galerkin method is used to obtain two-degrees-of-freedom nonlinear ordinary differential governing equations of motion along the radial displacement of the CFRP laminated cylindrical shell under the non-normal boundary conditions. The ordinary differential governing equations are solved as a system of four-dimensional average equations by the second-order approximate multiple scale method. The first two order dimensionless natural frequencies versus the ratio of length to thickness L/h, the frequency-response curves, the force-response curves, the bifurcation diagrams, the three-dimensional bifurcation diagrams, the maximum Lyapunov exponent diagrams, the phase portraits, the time history diagrams and the Poincare maps are obtained by numerical calculations. The influences of the radial line load, the axial excitation as well as the detuning parameter of the CFRP laminated cylindrical shell on the 1:2 internal resonant behaviors are investigated.

ABSTRACT: The main purpose of this paper is to provide a semi analytical method to analyze the free vibration of spherical-cylindrical-spherical shell subject to arbitrary boundary conditions. The formulations are established based on energy method and Flügge thin shell theory. The displacement functions are expressed by unified Jacobi polynomials and Fourier series. The arbitrary boundary conditions are simulated by penalty method about spring stiffness. The final solutions of spherical-cylindrical-spherical shell are obtained by Rayleigh–Ritz method. To sufficient illustrate the effectiveness of proposed method, some numerical example about spring stiffness, Jacobi parameters etc. are carried out. In addition, to verify the accuracy of this method, the results are compared with those obtained by FEM, experiment and published literature. The results show that the proposed method has ability to solve the free vibration behaviors of spherical-cylindrical-spherical shell.


ABSTRACT: The progressive non-linear mode of deformation known as steady-state kink band broadening is analysed for fibre composites and layered materials. The mode of deformation is investigated using an analytical, a semi-analytical model and a finite-element model. The semi-analytical model is based on a constitutive model, where independent material behaviour can be given for two constituents. The analytical model assumes rigid fibres and results in a transcendental equation for the kink band broadening state. Both the analytical and semi-analytical model use a Maxwell construction to determine the steady-state, which is done by equating the internal and external work. The influence of size-effects are explored and two case studies are performed; in the first case study the finite element model and semi-analytical model are used upon a carbon fibre-reinforced PEEK composite. The second case study is on a layered composite made from ultra high molecular-weight polyethylene fibres with a kink band developing on ply level.


ABSTRACT: Porous materials with functionally graded porosity are achieved by tailoring the size and density of the internal pores in one or more directions that leads the desired mechanical properties. Thus, due to the promotion of porous materials in engineering applications such as the foam core in sandwich plates, the compact heat exchangers, lightweight structures, biomedical systems and separation processes, in this paper, the free vibration of sandwich circular and annular plates with a core made of materials with functionally graded porosity are investigated. Different porosity distributions through the radial direction are introduced for the core of the plate. The governing equations of motion for the free vibration of a plate are obtained based on the first order shear deformation plate theory (FSDT). Clamped and simply supported edges are assumed for the plates. The collocation version of spectral method called the pseudo-spectral (PS) method using Chebyshev polynomials as the basis function is adopted to solve the equations of motion. Validation studies are also done to demonstrate the accuracy of the results. The natural frequencies of the clamped and simply-supported sandwich circular and annular plates with a porous core are calculated. The effects of different porosity distributions, porosity parameter, core thickness and geometric parameters on the results are investigated.

ABSTRACT: A geometrically nonlinear finite element model is developed for the bending analysis of micropolar Timoshenko beams using the principle of virtual displacements and linear Lagrange interpolation functions. The nonlinearity enters the model via a nonlinear von Kármán strain term that allows the micropolar beam to undergo moderate rotations. The nonlinear micropolar Timoshenko beam is used as an equivalent single layer model to study four different lattice core sandwich beams. A two-scale energy method is used to derive the micropolar constitutive equations for web, hexagonal, Y-frame and corrugated core topologies. Various bending cases are studied numerically using the developed 1-D finite element model. Reduced integration techniques are used to overcome the shear and membrane locking. The present 1-D results are in good agreement with the corresponding 2-D finite element beam frame results for global bending.


ABSTRACT: In the present study, the dynamics of the interaction between a Kirchhoff nanoplate and the surrounding fluid is investigated. Using non-local elasticity theory, the influence of small-scale parameter is considered in the governing equation of motion. The Navier-Stokes equations are utilized to model the fluid-solid interaction. The vibration behavior of nanoplate submerged in different viscous fluids with various aspect ratios are simulated in order to analyze the effects of fluid viscosity and density on the free vibration natural frequencies of the nanoplate. The results reveal that, for smaller size parameter, the fluid existence has a remarkable decreasing effect on the nanoplate natural frequencies. Moreover, it has been shown that the fundamental frequency ratio between two cases, first, when the nanoplate is assumed to be under viscous fluid interaction, and second, while the structure vibrates in vacuum environment, remains almost constant with the changes in small-scale parameter.


ABSTRACT: In this paper, an analytical method is presented in order to determine the static bending response of an axisymmetric thin circular/annular plate with different boundary conditions resting on a spatially inhomogeneous Winkler foundation. To this end, infinite power series expansion of the deflection function is exploited to transform the governing differential equation into a new solvable system of recurrence relations. Singular points of the governing equation are effectively treated by applying the Frobenius theorem in the solution, which in turn permits the use of more-general analytical functions to describe the variation of the foundation modulus along the radius of the plate. Moreover, no special limitation is imposed on the transverse loading function as applied to the system. On employing the proposed method, the deflection response is obtained through an illustrative example for various boundary conditions along the plate edges, considering free, clamped, hinged, and elastically restrained boundaries. In addition, analytical results are validated and compared with those obtained using a finite element analysis, where an excellent agreement is found. Finally, the extension of the method to solve the more-general case of a variable two-parameter (Pasternak) foundation is indicated.


ABSTRACT: Dielectric elastomers (DEs) are soft electromechanical devices, which operate under a high voltage. The majority of methods for calculating the nonlinear vibration of DEs are the numerical ones. However, the analytical methods may also be capable to achieve the reliable general and specific solutions for DEs. This paper investigates the vibration of a dielectric elastomer balloon (DEB) using the method of multiple scales (MMS). The equations of motion are derived by the method of Euler-Lagrange. Using the Taylor expansion, the governing equation of motion is transformed into a general form, then the MMS is applied to
solve the problem. Two cases of voltage are considered; in the first one, the balloon is under a static voltage while in the second one the balloon is under a sinusoidal voltage. When the voltage is static, the time-history responses and the phase diagrams are depicted using the MMS and the Runge-Kutta numerical integration to verify the accuracy of the proposed method. For the sinusoidal voltage, the effect of jump phenomenon and variations of pressure and electrical potential difference (Voltage) on the frequency-response curves are studied. The results show that the MMS is in a good agreement with the Runge-Kutta numerical method. Moreover, with the presentation of various values of the pressure and the electrical potential difference, the softening behavior and the jump phenomenon are observed in the frequency response curves.


ABSTRACT: In this paper, instability boundaries of axially accelerating plates with internal resonance are investigated for the first time. The relation between the acceleration and the longitudinally varying tensions are introduced. The governing equation and the corresponding boundary conditions are derived from the generalized Hamilton principle. The effects of internal resonances and the nonhomogeneous boundary conditions on the instability boundaries are highlighted. By the method of multiple scales, the modified solvability conditions in principal parametric and internal resonances are established. The Routh-Hurwitz criterion is introduced to determine the instability boundaries. The effects of the viscoelastic coefficient and the viscous damping coefficient on the instability boundaries are examined. Abnormal instability boundaries are detected when the internal resonance is introduced. The phenomenon of local zigzag and V-shape boundaries are explained from the viewpoint of modal interactions. The numerical calculations of the differential quadrature schemes about the first four complex interactions, the first four complex modes, and the stability boundaries are used to confirm the results of the analytical method.


ABSTRACT: This paper presents an exact analytical solution to the 3D transient dynamics of a linear elastic, isotropic homogeneous, curved beam, with uniform rectangular cross-section. The solution technique uses vector identities to decouple the governing equations. The decoupled equations are then solved by method of separation of variables. The solutions to the decoupled equations can be recombined to form a new equation. Solving this new equation yields the displacement field. To demonstrate the capabilities of the proposed solution technique, a generic case study was modeled and computed. A curved beam is subjected to a longitudinal impulse loading and the transient displacement field is calculated. This solution technique is valid for any curvature so long as the curvature is the same throughout the beam. This includes the limiting case where the inner radius of the beam goes to zero and the curved beam becomes a section of a disk. The presented solution results were compared with an approximate solution from the literature and experimental data from the literature. The solution is also compared with an explicit FEM solution conducted by the Authors. The presented solution agrees with the results from the literature and from the FEM solutions conducted by the Authors. This paper demonstrates that the accuracy and robustness of the proposed solution technique meets the needs of many potential applications.


ABSTRACT: In this study, the aerothermoelastic flutter analysis of pre-twisted tapered rotating blades reinforced with functionally graded carbon nanotubes (FG-CNTs) under supersonic flow is investigated. Based on the thin-walled Timoshenko beam theory and quasi-steady supersonic linear piston theory, the dynamic model of the supersonic rotating blades reinforced with FG-CNTs has been developed. The CNTs are
considered to be either uniformly or non-uniformly distributed in the matrix along the thickness direction. Three various CNTs distribution patterns namely, UD, FG-X and FG-O have been assumed. The properties of CNTs and polymer matrix are considered to be temperature-dependent. Based on the extended Hamilton's principle, the equations of motion as a system of coupled linear partial differential equations are found. The extended Galerkin method (EGM) is utilized to transform these coupled partial differential equations to a set of coupled ordinary differential equations. The influences of rotating speed, CNTs distribution, CNTs weight fraction, temperature, pre-twist and pre-setting angels, hub radius ratio, taper ratios and Mach number on the aero thermoelastic flutter responses of the system have been analyzed. The results indicate that the FG-X distribution pattern have predicted more strengthening the total bending of blade and the greatest flutter frequency for the composite blades. Furthermore, the pre-twist and pre-setting angles as well as taper ratio have significant effects on the flutter frequency of the thin-walled blade reinforced with CNTs.


ABSTRACT: Due to the superior mechanical properties of double-layer graphene sheets (DLGSs) for applications in nano devises, understanding the mechanical response and stability of such structural elements is essential and inevitable. In this paper a modified nonlocal continuum model is developed to consider the surface energy effects and to evaluate the size-dependent mechanical response of nanoscale structures. Moreover, an efficient nonlocal third order shear deformation plate theory (TSDT) is employed to analyze the vibrational behavior of DLGSs embedded in an elastic medium. An analytical method is introduced for determining the natural frequencies of DLGSs and an accurate exact solution could be found for the problem which is validated via comparing the results for some simpler problems found in the literature. Based on the results, the developed theory predicts the fundamental natural frequencies more accurately compared to the other common theories. Moreover, comprehensive numerical results are given for the obtained size-dependent natural frequencies of the DLGSs. The influences of surface effects, small scale coefficient, stiffness of the internal springs, external foundation parameters, temperature changes and different dimensions of nanosheet on the frequencies in both in-phase and anti-phase vibrational modes are studied.


ABSTRACT: The onset of yielding in Functionally Graded Sandwich Plates (FGSP) with ceramic core and Functionally Graded (FG) face sheets is presented in this paper. Full layer-wise theory which has been proved to be accurate and computationally efficient is developed for static analysis of these plates. The volume fraction of the ceramic phase is assumed to vary via a power-law function in the thickness direction of FG face sheets. TTO model which indicates the initials of the names of the authors who firstly introduced it as well as Rule of Mixture (ROM) are employed to determine the material properties variation through the FGSPs. The results associated with central deflection, and stress distribution through these structures were found to be significantly influenced by the utilized material models. After obtaining the stress fields, Von Mises yield criterion is implemented to find the first node(s) at which the yielding of FGSPs initiates. According to the final results, depending on the type of boundary conditions and core to face sheet thickness ratio, the yielding commencement could occur at the enriched metal or enriched ceramic surfaces. Power-law exponent however found to have no influence on the area at which yielding initiation occurs. Nevertheless, decreasing this parameter results in FGSPs with higher strength and postpones the yielding initiation of these structures. A comparison study is also presented which demonstrates how FGSPs are capable of undergoing bending loads, before yielding, up to twice as large as conventional Functionally Graded Plates (FGPs) while having the same weight and material constituents.
ABSTRACT: Analytical solutions for the nonlinear vibration of imperfect functionally graded nanocomposite (FG-CNTRC) double curved shallow shells on elastic foundations subjected to mechanical load in thermal environments are introduced in this paper. The double curved shallow shells are reinforced by single-walled carbon nanotubes (SWCNTs) which are assumed to be graded through the thickness direction according to the different types of linear functions. Motion and compatibility equations are derived using Reddy's higher order shear deformation shell theory and taking into account the effects of initial geometrical imperfection and temperature – dependent properties. The deflection – time curve and the natural frequency are determined by using Galerkin method and fourth – order Runge – Kutta method. The effects geometrical parameters, elastic foundations, initial imperfection, temperature increment, mechanical loads and nanotube volume fraction on the nonlinear thermal vibration of the nanocomposite double curved shallow shells are discussed in numerical results. The accuracy of present approach and theoretical results is verified by some comparisons with the known data in the literature.


ABSTRACT: Buckling or loss of stability of fibers in soft matrix composite is considered to be an enabling mechanism that can be exploited for enhanced multifunctional behavior. Small buckling deformation of fibers effectively prevents the permanent damage of material and makes the structure work better. This paper studies the post-buckling behavior of carbon fibers embedded in a functionally graded plate under pure bending. We employ the energy method to determine the indicators of degree of buckling deformation, such as the half-wavelength and maximum amplitudes of buckling fibers. Detailed discussions and comparisons are provided between the results obtained from this work and the ones derived by other researchers with plates composed of uniformly distributed fibers. It is shown that when the total volume fraction of fibers is the same, the half-wavelength and maximum amplitudes in functionally graded plates is smaller than those in plates with uniformly distributed fibers. Thus the design of functionally graded plates is superior to the plates with uniformly distributed fibers.


ABSTRACT: This paper introduces analytical solution for exponentially graded (EG) plates attached with a single-layer of piezoelectric fiber reinforced composite (PFRC) actuator. The plate is undergoing sinusoidal electromechanical loads and resting on Pasternak-Winkler's elastic foundations. The displacement components are expressed via a higher-order shear deformation theory. The distributions of the electric potential are vary linearly along the thickness direction. The equations of equilibrium and boundary conditions are established by applying the principle of virtual displacements. Navier's method is used to obtain the problem solution. The influences of various parameters like voltage amount, side-to-thickness ratio, Young's modulus ratio and elastic foundations parameters are investigated. The current formulations are validated by comparison with published results.


ABSTRACT: Thermal effect on size-dependent vibrational behavior of rotating microbeams made of functionally graded materials (FGMs) is investigated. It is assumed that the material properties of FGMs change...
smoothly through the thickness of the microbeam according to a power-law variation. Within the framework of Timoshenko beam theory (TBT) and Euler-Bernoulli beam theory (EBT), the governing equations and associated boundary conditions of rotating hinged-hinged, clamped-free, clamped-clamped and clamped-hinged microbeams are determined by using Hamilton's principle and modified couple stress theory. The axial nonlinear coupling deformation is taken into account to capture the centrifugal stiffening effect. An assumed-mode discretization approach is applied to solve these equations numerically. Convergence study and comparative examples are presented to verify the accuracy and reliability of the present model. A detailed numerical study is carried out to analyze the effects of dimensionless material length scale parameter, slenderness ratio, dimensionless angular velocity, temperature change and FG index on the vibrational behaviors of rotating FG microbeams. Numerical results indicate that the increasing value of temperature change leads to an increase in size dependency of rotating microbeams. The size dependency of rotating microbeams considerably differs from that of stationary microbeams. In addition, the gradient change in material properties greatly affects the size dependency of rotating FG microbeams.


ABSTRACT: This paper makes the first attempt to establish a size-dependent finite element formulation by combining isogeometric analysis and a re-modified couple stress theory (RMCST) for anisotropic elasticity. The flapwise vibration of rotation composite microbeam with geometrical imperfection connected to a hub is explored. This paper employs the NURBS function as the basis function to describe the geometry and overcomes the inherent difficulty of constructing higher order continuous displacement function for modified couple stress theory based finite element formulation. Besides the angular velocity, slender ratio, scale parameter, and maximum imperfection amplitude, the effect of ply angle on the flapwise vibration of rotation composite microbeam is investigated in this paper for the first time. This investigation demonstrates that we can control the natural frequencies of rotating beam by designing composite laminates in different stacking sequences.


ABSTRACT: A size–dependent model based on the modified couple stress theory is developed to study free vibration, static deflection, and pull-in instability of a fully-clamped functionally graded (FG) micro-plate covered by piezoelectric layers subjected to both electrostatic and casimir forces. Considering the geometrically nonlinearities, the governing equations of motion and boundary conditions are derived by means of Hamilton's principle. The system of equations is solved numerically using finite element method. A Comprehensive Verification study is carried out to ensure the accuracy of the proposed model. Obtained results show that the volume fraction exponent, piezoelectric voltage, residual stresses, and MLSP considerably affect the natural frequency, maximum static deflection, and the electro-mechanical behavior of fully-clamped rectangular micro-plates. The results also reveal that the pull-in voltage could be maintained within a desirable range through proper utilizing of material properties, residual stresses, and piezoelectric voltages.


ABSTRACT: In this paper we have discussed the frictional buckling behavior of a slender rod constrained in a horizontal cylinder. Buckling and post-buckling behaviors including the onset of helical buckling and subsequent axial force transfer are interpreted in a new way. Helical buckling and concomitant low force transfer efficiency which would prevent further axial extended reach is important to engineering structures, such as coiled tubing operations in petroleum industry. By means of the beam-column method, new governing
differential equation of frictional buckling are derived to predict critical buckling force. We also investigate the transfer efficiency of axial force quantifying the effect of axial friction on rod lockup phenomenon in post-buckling analyses by perturbation solution. The coupling effect between axial force and friction is solved for the first time in this paper. The bending moment at the lock-up limit which would cause the rod to rupture is also analyzed. Finally, we have compared the proposed model with experimental results to verify its validity. Through these analyses, we have provided another interpretation to the existing experiment and numerical simulation results of frictional buckling. The derived results are simple and convenient for a problem in industrial practice.


ABSTRACT: In the present study, stress-function Galerkin (SFG) method is employed to investigate the dynamic characteristics of a new sigmoid law based sandwich functionally graded plate (S-FGM) plates resting of Pasternak elastic foundation in the thermal environment. For modified sigmoid law, a new temperature profile is derived considering 1D steady state heat conduction equation. The Hamiltonian formulation is done to derive governing equations and nonlinearity, due to Von-Karman strains, is worked out using Airy's function in conjunction with Galerkin's method. The time and frequency domain analysis is then performed using a numerical integration scheme and harmonic balance method, respectively. The nonlinear rise in temperature is considered across the thickness due to the temperature difference between the top and the bottom surface of the simply supported plate with immovable edges. Wide-Ranging parametric studies for, linear and nonlinear, frequency and time domain analysis have been performed by taking into consideration the effect of thickness ratio, inhomogeneity parameter, thermal load, and foundation parameter for various configurations of the sandwich plates. Poincaré maps, phase-plane plots and time responses are demonstrated to study the nonlinear dynamics behavior of sandwich S-FGM plate under harmonic excitation. The variation of aspect ratios shows the route to chaos. With the Winkler foundation, the response is chaotic but becomes weakly chaotic with the introduction of the Pasternak type foundation. The dynamic response clearly shows the route to chaos with the varying thermal load from $\Delta T = 0$–600 K. It is observed that the periodicity of the plate behavior is primarily affected by considering different configurations of the sandwich S-FGM plate. The computed results and observations can be utilized as a validation study for future examination for sandwich S-FGM plates.


ABSTRACT: This paper deals with a classic but very difficult type of problems, i.e., pursuing analytic buckling solutions of biaxially loaded rectangular thin plates with two free adjacent edges that are characterized by having both the free edges and a free corner. The primary challenge is to find the solutions satisfying both the governing high-order partial differential equations (PDEs) and non-Lévy-type boundary constraints. Here, an up-to-date symplectic superposition method is developed for the issues, which yields the analytic solutions by converting the problems to be solved into the superposition of two elaborated subproblems that are solved by the symplectic elasticity approach. The distinctive merit of the method is that a direct rigorous derivation helps to access the analytic solutions without any assumptions/prior knowledge of the solution forms, which is attributed to the implementation in the symplectic space-based Hamiltonian system rather than in the classic Euclidean space-based Lagrangian system. As the important outputs, comprehensive new analytic results are obtained, with 1200 critical buckling loads and 100 buckling mode shapes presented, which are all well validated by the refined finite element analysis. The rapid convergence and favorable accuracy of the present method make it competent as a benchmark one for similar problems.

ABSTRACT: This study aims to investigate effects of the surface energy parameters on the nonlinear axial vibration and internal resonances of nanoscale rods. The surface energy parameters considered are the surface density and the surface Lamé constants. The nonlinear governing equation of motion is derived using the Hamilton’s principle which includes the strain energy and the kinetic energy of the nanorod surface and bulk. The strain and kinetic energies of the nanorod bulk are obtained using the classical theory of elasticity and those of the nanorod surface are obtained using the surface elasticity theory. Then, the nonlinear governing equation of motion is solved using the method of multiple scales and natural frequencies are obtained for fixed-fixed and fixed-free boundary conditions. Effects of the surface energy parameters on the frequencies are examined for various cases. It is observed that the type of effect of the surface energy parameters depends on their sign. It is also seen that the type of effect of the surface energy parameters on nonlinear frequencies may become different at higher frequency numbers. The observations of this study can be a useful reference for more accurate design and fabrication of nano-electro-mechanical systems in which rod-shaped nano-structures, carbon nanotubes, play a significant role.


ABSTRACT: The aim of this article is to study the influences of aerodynamic pressure and axially moving behavior on the size-dependent vibration of a sandwich structure. Here, the core of sandwich structure is a magnetorheological (MR) fluid and face layers are made of functionally graded material (FGM). In order to obtain the aerodynamic pressure due to supersonic flow over upper face of structure, the linear piston theory is considered. The displacement field of sandwich structure is written according to layerwise theory and the size-dependent strain energy is obtained based on modified first strain gradient theory (MFSGT). The Hamilton’s principle is applied to derive the governing equations of motion. In order to solve the partial differential equations, the Galerkin method is applied. To validate the presented formulation and solution method, the obtained results are compared with the available results in the literature, which shows a good agreement. The first set of results investigate the first five natural frequencies of MR sandwich beam based on the different MR materials. The variations of frequency and corresponding loss factor are plotted against aerodynamic pressure, length scale parameters, axially speed, intensity of external magnetic field, yaw angle, and power-law index, and the resulting trends in the plots are discussed in detail. Also, the parameters of critical aerodynamic pressure and critical axially speed in different conditions are tabulated.


ABSTRACT: In this paper we study the deformation and vibration of a pinned-pinned buckled beam constrained by a pair of springy walls of the Winkler type. Small deformation theory is adopted. Static analysis shows that the buckled beam contacts the springy wall in one segment first and then evolves to two-segment contact before the edge thrust reaches a maximum. This is different from the conventional case of rigid wall, in which only one-segment contact is possible before secondary buckling. The two-segment contact deformations before and after reaching the peak thrust are significantly different. Before reaching the peak, the free-of-contact segment in the middle stays close to the wall. After passing the peak, the free-of-contact segment moves away from the wall until the midpoint touches the opposite wall. In vibration analysis, both load control and displacement control are considered. For anti-symmetric vibration modes, the natural frequencies are the same for load and displacement controls. For symmetric modes, the natural frequencies of displacement control are in general higher than the corresponding ones in load control.


ABSTRACT: The present study investigates a nonlinear plastic buckling analysis of microplate by using the Mechanism-based Strain Gradient (MSG) plasticity. The MSG as a higher order theory is based on the Taylor
model of dislocation interaction, consisting a multiple plastic work hardening. It extends a virtual work
postulating the existence of higher-order stress work-conjugate at the in-plane traction of the microplate to
the plastic strain gradient. The energy minimizing method is applied to obtain plastic buckling critical forces per
each length scales and plastic hardening exponents. An iterative quadratic extrapolation (IQE) is implemented
for linearization of nonlinear terms generated due to spatial variations of constitutive equations. The results
indicate significant dependence of the critical force on the length scale as well as plastic work hardening
exponent. Verifications are carefully done among two limit states of the elastic case and particular plastic
analysis of a macro plate.

Arash Imani Aria, Timon Rabczuk, Michael Ian Friswell, “A finite element model for the thermo-elastic

ABSTRACT: In this study, for the first time, a nonlocal finite element model is proposed to analyse thermo-
elastic behaviour of imperfect functionally graded porous nanobeams (P-FG) on the basis of nonlocal elasticity
theory and employing a double-parameter elastic foundation. Temperature-dependent material properties are
considered for the P-FG nanobeam, which are assumed to change continuously through the thickness based on
the power-law form. The size effects are incorporated in the framework of the nonlocal elasticity theory of
Eringen. The equations of motion are achieved based on first-order shear deformation beam theory through
Hamilton's principle. Based on the obtained numerical results, it is observed that the proposed beam element
can provide accurate buckling and frequency results for the P-FG nanobeams as compared with some
benchmark results in the literature. The detailed variational and finite element procedure are presented and
numerical examinations are performed. A parametric study is performed to investigate the influence of several
parameters such as porosity volume fraction, porosity distribution, thermal loading, material graduation,
nonlocal parameter, slenderness ratio and elastic foundation stiffness on the critical buckling temperature and
the nondimensional fundamental frequencies of the P-FG nanobeams. Based on the results of this study, a
porous FG nanobeam has higher thermal buckling resistance and natural frequencies compared to a perfect FG
nanobeam. Also, the format of the porosity distribution is important, that uniform distributions of porosity result
in greater critical buckling temperatures and vibration frequencies, in comparison with functional distributions
of porosities.

Roshan Lal, Rahul Saini, “On radially symmetric vibrations of functionally graded non-uniform circular plate
including non-linear temperature rise”, European Journal of Mechanics - A/Solids, Vol. 77, Article 103796,

ABSTRACT: In this study, the free axisymmetric vibrations of functionally graded circular plate of linearly
varying thickness controlled by a taper parameter in radial direction and non-linear temperature rise along the
thickness have been investigated on the basis of classical plate theory. The plate material is graded in transverse
direction and its mechanical properties are temperature-dependent. The temperature over the top and bottom
surfaces is assumed to be uniformly distributed. Hamilton’s principle has been used to derive the governing
equations for thermo-elastic equilibrium and axisymmetric motion of such a plate model. The generalized
differential quadrature method has been employed to obtain the thermal displacements and characteristic
equations, for clamped and simply supported plates. The lowest three roots of these equations have been
computed and reported as the values of frequency parameter for the first three modes of vibration. Effect of
thickness parameter, volume fraction index and temperature difference has been analyzed on the vibration
characteristics of the plate. A study with temperature-independent material properties has also been performed.
Results have been compared with the published work.

Do Quang Chan, Tran Quoc Quan, Seung-Eock Kim, Nguyen Dinh Duc, “Nonlinear dynamic response and
vibration of shear deformable piezoelectric functionally graded truncated conical panel in thermal
environments”, European Journal of Mechanics - A/Solids, Vol. 77, Article 103795, September-October 2019,
https://doi.org/10.1016/j.euromechsol.2019.103795

ABSTRACT: The novelty of this study is using the analytical approach to investigate the nonlinear dynamic
response and vibration of shear deformable functionally graded truncated conical panel with piezoelectric
actuators, resting on Pasternak type elastic foundations in thermal environments. Material properties are graded
in the thickness direction according to a simple power law distribution in terms of the fractions of constituents.
The governing equations are derived based on the first order shear deformation shell theory with a von Karman–Donnell type of kinematic nonlinearity in which the Hamilton's principle is used to derive the equations of motion of piezoelectric functionally graded truncated conical panel. The those equations are solved by the Galerkin method and Runge–Kutta method to determine the nonlinear deflection amplitude – time curves and natural frequency of the functionally graded panel. In numerical results, the effects of applied actuator voltage, temperature increment, dimensional parameters, semi–vertex angle, material properties and elastic foundations on the nonlinear dynamic response and vibration of the piezoelectric functionally graded truncated conical panel are discussed in details. The approach are verified with the known results in the literature.


ABSTRACT: We consider the mechanics of fiber remodeling in a pressurized thick-walled cylinder where our focus is on the interaction between inflation and remodeling. The material is taken to consist of an incompressible neo-Hookean ground substance matrix in which the fibers are embedded. The fiber network is assumed to undergo a stretch mediated remodeling process, as suggested by experiments on enzymatic degradation of collagen fibers in biological soft tissues. In our treatment, such a remodeling process is defined in terms of a constant fiber-creation rate, and a fiber-dissolution rate that decreases with the amount of fiber stretch. Here we study how pressure loading of a tube affects this process within the cylindrical wall. The impact of two basic load carrying fibers models on the remodeling of the fiber network are explored, as well as the effect of two different choices for the fiber's natural configuration when replacement fibers are first synthesized.


ABSTRACT: Today nanotubes are main parts of nano-machines who withstand against axial and vibrational loads. So, in this paper a mathematical model is presented to predict behavior of a spinning nanotube under axial load. For this purpose, classical thin shell theory and first order shear deformation shell theory are combined with nonlocal stress theory. The effect of rotation is considered by adding centrifugal and Coriolis forces in the formulations. Also, effect of axial compressive load is added in the formulation by considering buckling energy term. Equations are solved for both theories and numerical results are compared with the literature for validation. In the case of buckling of spinning nanotube there is not sufficient numerical results for comparison. So, Molecular dynamics (MD) simulation is done and its results in stationary and rotating conditions are compared with the mathematical model. These comparisons approved validity and accuracy of the mathematical models. Finally, effect of changing different parameters on the behavior of nanotube is investigated.


ABSTRACT: The size dependent thermal buckling analysis of composite micro plate is studied in this paper based on modified couple stress theory (MCST) and sinusoidal shear deformation theory. The composite micro plate is composed of epoxy reinforced with functionally graded graphene nanoplatelets which is distributed along the thickness direction based on various distributions (parabolic, linear and uniform distributions). After calculation of effective material properties including modulus of elasticity and Poisson ratio of composite plate, Halpin-Tsai model and rule of mixture, the governing equations are derived based on principle of virtual work. The in-plane mechanical and thermal loads are included in the work of external loads. The novelty of this work is the application of a modified couple stress theory to predict the mechanical and thermal buckling loads of micro plate reinforced composites. The effect of weight fraction of graphene nanoplatelets and various distributions of reinforcement was studied on the mechanical and thermal buckling loads. It is concluded that with increase of weight fraction of graphene nanoplatelets, the mechanical buckling loads are increased for all
distributions, while the thermal buckling loads are increased for parabolic distribution, are decreased for linear distribution and are insensitive for uniform distribution.


ABSTRACT: This paper investigates the free vibrations of the rotating pretwisted functionally graded (FG) composite cylindrical panels reinforced with the graphene platelets (GPLs) by considering the cantilever boundary conditions. The weight fraction of the graphene platelets in each ply may be different, which leads to the layer-wise functionally graded composite cylindrical panels reinforced with the GPLs. The effective Young's modulus is calculated by the modified Halpin-Tsai model. The effective Poisson's ratio and mass density are derived by the rule of the mixture. The strain-displacement relationship is acquired by the Green strain tensor. Based on the first-order shear deformation theory, Chebyshev-Ritz method is used to obtain the natural frequencies of the rotating pretwisted functionally graded composite cylindrical panel reinforced with the GPLs. The natural frequencies are discussed by considering different material and geometry parameters of the rotating pretwisted functionally graded composite cylindrical panel reinforced with the GPLs, such as the GPL distribution pattern, the GPL weight fraction, the geometries of the GPLs, the pretwisted angle, the presetting angle and the rotating speed. Several validations are carried out, the numerical results are in good agreement with the results of the literature and ANSYS.


ABSTRACT: A tip-rub model is developed for nonlinear dynamics analysis of contact-induced vibrations of the rotating variable thickness plate under large deformations. Variable thickness, coupled with large deformations, contact-impact and centrifugal stiffening, increases complexity of the nonlinear system. Natural frequencies for different variable thickness are compared to indicate a great precision of the present method. Solution procedure for tip-rub has been proved to be in good agreement with existing experimental results. Numerical simulation for tip-rub reveals the requirement of large deformation analysis. Then special attention is given to nonlinear characteristics of the rotating rubbing plate with variable thickness. Results show that there are very rich and complex nonlinear dynamics of contact-induced vibrations of the rotating variable thickness plate under large deformations such as multi-period, bifurcation and chaotic motions. And effects of thickness strategies of exponential and linear decrease along the span used in engineering on nonlinear characteristics induced by tip-rub are investigated. Numerical results reveal that smaller thickness at the free end used to reduce centrifugal stress should not be too small to avoid aggravation of contact-induced bifurcation and chaos. Moreover, in order to obtain less centrifugal stress and weak chaotic behavior, there is an optimal thickness at the fixed end when the smaller thickness at the free end is unchanged. As the order of thickness function increasing, the trend of bifurcation and chaotic motions is gradually aggravated. It is better to choose a small order of thickness function to ensure stable operation.


ABSTRACT: Recent advances in the development of new engineering materials have led to the creation of different types of porous materials. These materials can be used to remove harmful compounds from soil, air, and water as a method of environmental remediation. This paper aims to study the mechanical behavior of Functionally Graded (FG) porous materials. In terms of engineering applications, these weight-efficient materials may allow for an improvement in the structural performance of certain mechanical systems. In this analysis, the effects of porosity distribution in curved thick panels made of FG porous materials are numerically investigated using the Differential Quadrature Method (DQM). Two types of porous materials, including both open-cell and saturated closed-cell panels with three symmetric, non-symmetric, and uniform porosity distributions, are considered. Elasticity theory is used to develop the governing differential equations of the curved panel. The physical behavior of a curved panel and the influences of porosity distribution, boundary
conditions, and geometrical characteristics (i.e., angle, length, radius, and thickness) of the panel are investigated.

ABSTRACT: The presence of an axial load changes the system stiffness of an infinite beam on a tensionless Winkler foundation, which also determines the solution form of the beam deflection. Five different closed form solutions depending on the axial load are analytically derived in this study. The beam deflections are systematically studied when it is subjected to various axial and transverse concentrated loads. Because the contact zone of a tensionless contact is not known a priori, it can cause a significant mathematical difficulty in solving various tensionless contact problems. In recent tensionless contact researches, the major efforts have been developing the efficient but complex algorithms to determine the contact zones. Five transcendental equations governing the contact zones, which are straightforward for numerical computations, are also analytically derived. The five closed form solutions can serve as a guide line for the further study of the beam tensionless contacts with more complex loading scenarios. Furthermore, the model of a beam on the Winkler foundation subjected to an axial load is also demonstrated to be applicable to various and different problems.

ABSTRACT: Nowadays, many vehicles and buildings are built using the structural concept of stiffened structure, in order to achieve greater strength with relatively less material. In the present work, a plate finite element with advanced higher-order kinematic field is proposed for the free-vibration analysis of stiffened thin-walled plate structures. A novel approach is introduced to simplify the modelization and assembling phase for the analysis of stiffened structures. The mechanical continuity between skin and stiffener deformed geometry is automatically verified with the present approach. On the basis of the Principle of Virtual Displacements, Equivalent-Single-Layer and Layer-Wise models related to linear up to fourth order variations of the unknown variables in the thickness direction are treated. The Mixed Interpolated Tensorial Components (MITC) method, in conjunction with the Finite Element Method (FEM), is employed to contrast the shear locking effect. Various stiffener shapes are considered for the assessment of the approach: T shape, double-T shape and Z shape. Several numerical investigations are carried out to validate and demonstrate the accuracy and efficiency of the present plate finite element for the modal analysis of stiffened structures, comparing the present results with those from classical finite element formulations based on solid elements available in commercial software.

ABSTRACT: This paper addresses the thermal buckling of actuated functionally graded piezoelectric porous nanoplates. Eringen's nonlocal elasticity theory with a higher-order shear deformation theory are used to obtain the analytical solution. The FGP porous nanoscale plate material possesses smooth continuous gradient transition of properties between materials as the dimension varies according to a modified power law function. The plate is under the influence of several thermal loadings (uniform, linear, nonlinear thermal difference) and electric voltages. A closed form solution of simply-supported FGP porous nanoplates is obtained using Navier's method. The critical thermal buckling of FGP porous nanoplates subjected to several thermal loadings and electric voltages is investigated. Numerical examples are presented to validate the present formulation. The influence of several porosity coefficients, small-scale parameters, thermal loadings, geometric parameters, power law exponents and external electrical voltages on the thermal buckling of FGP porous nanoplates are discussed.

Irwan Katili (1), Imam Jauhari Maknun (1), Jean-Louis Batoz (2) and Andi Makarim Katili (1)
(1) Universitas Indonesia, Civil Engineering Department, Depok 16424, Indonesia

ABSTRACT: The paper deals with plate bending triangular elements with shear effect included, having only three degrees of freedom at each corner node. In that category, we select four elements due to their appreciation in the academic world and performances for practical applications using industrial software. Those four elements are T3γ (1982) (equivalent to MITC3 (2004)), DST (1989), DKMT (1993), and MITC3+ (2014). The present paper focuses on the detailed formulation of those elements using the same notation and with emphasis on their theoretical difference. In particular, the paper shows that for very thick plates DKMT, and MITC3 are equivalent. The main other contribution deals with a detailed analysis of the numerical results for classical tests or dealing with convergence performance evaluation using s-norm tests for the whole range of extremely thick to thin plates. The best elements emerging from the present study are DKMT and MITC3+ with a slight advantage to the first due to its simplicity in formulation and performance in all tests.


ABSTRACT: In this paper, the performance of elliptical smart constrained layer damping treatments on active damping of geometrical nonlinear vibrations of smart laminated composite plates are analyzed. The constraining layers of the damping treatments are comprised of vertically/obliquely reinforced 1–3 piezoelectric composites, while the constrained layers are of isotropic viscoelastic material, modelled using the three dimensional fractional order derivative model. A meshfree model of the smart composite plate is developed for analyzing its nonlinear transient responses within the framework of a layerwise shear and normal deformation theory considering the von-Kármán type geometric nonlinearity. Thin composite plates integrated with elliptical/rectangular patches of the smart constrained layer damping treatments and having different stacking sequences and boundary conditions are considered for presenting the numerical results. The numerical analyses demonstrate the higher effectiveness of the elliptical patches over the rectangular ones in attenuating the nonlinear vibrations of laminated composite plates.


ABSTRACT: Based on the theories of the first-order shear deformation (FSDT) plate and the modified couple stress, a nonlinear micro-plate model is developed for steady state dynamics of harmonically excited micro-plates subjected to two-sided in-plane tension or compressive loads. The governing equations of motion and corresponding boundary conditions are derived using Hamilton's principle. The semi-analytical method of Galerkin's is utilized to discretize the governing equations of motion into ordinary differential equations. By performing complexification-averaging method and arc-length continuation techniques, semi-analytical approximations for nonlinear steady-state response is developed. For micro-plate with post-buckling deformation coexisting attractors are observed. These attractors have different nonlinear behaviors such as multi frequency, period doubling, intermittency, quasi-periodic and chaotic behaviors. The effects of different parameters such as in-plane load, load ratio, the material length scale parameter and aspect ratio on the nonlinear forced vibration are examined.

Huichao Liu (1), Baohui Li (2) and Yongshou Liu (1)
(1) School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, Xi'an 710129, China
(2) College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling 712100, China


ABSTRACT: The dynamic behavior of carbon nanotube conveying fluid has long been studied employing modified continuum models, especially Eringen's nonlocal model, which, however, is recently considered as ill-posed and leads to cantilever paradox. In this paper, the inconsistency of nonlocal effect, derived from Eringen's differential nonlocal model, on nanotube conveying fluid under various boundary conditions is detected. And then, to solve this, the local/nonlocal model is introduced as a better substitute. Both governing equations of the two models are derived. Then the integro-differential governing equation derived from local/nonlocal model is converted into a differential one with two supplementary boundary conditions. The two governing equations are deciphered by wave method, since equations in such form have been demonstrated to be impossible to obtain solutions directly. Nonlocal effect is recognized to be twofold: changing the stiffness of the nanotube itself and modifying the softening effect of inside fluid on the whole nanotube-conveying-fluid system. And it is the unusual effect of the first part, derived from Eringen's differential nonlocal model, on the fundamental frequency of fluid-conveying nanotube with clamped-free supports that leaks the inconsistency. On the contrary, nonlocal effect, derived from local/nonlocal model, consistently decreases the eigen-frequencies of all considered modes under whichever of the four boundary conditions. Besides, the first phase parameter can switch down the nonlocal effect disregarding the value of nonlocal parameter, while if the first phase parameter is out of the neighborhood of 1, it appears that the first phase parameter and nonlocal parameter don’t limit the modulating-nonlocal-effect ability of each other.

Jian Deng (1), Zilin Zhong (1,2) and Airong Liu (2)
(1) Department of Civil Engineering, Lakehead University, Thunder Bay, Ontario, P7B 5E1, Canada
(2) Guangzhou University-Tamkang University Joint Research Centre for Engineering Structure Disaster Prevention and Control, Guangzhou University, China


ABSTRACT: Stochastic stability of a viscoelastic plate in supersonic flow is investigated through both moment Lyapunov exponents and Lyapunov exponents, which are important indexes to characterize the moment stability and almost-sure stability of a stochastic dynamical system, respectively. The excitation is modelled as a bounded noise process. The plate is a typical example of a coupled non-gyrosopic system. By using the method of stochastic averaging, the equations of motion are decoupled into Itô differential equations, from which moment Lyapunov exponents are readily obtained. The Lyapunov exponents are obtained from the relation with moment Lyapunov exponents. Depending upon the relation among natural and excitation frequencies, parametric resonance can be categorized into no resonance, subharmonic resonance, combination additive resonance, and combination differential resonance. The diagrams of instability can provide insights on how to analyze and control parametric resonance in engineering applications.

Qingya Li (1), Di Wu (2), Wei Gao (1), Francis Tin-Loi (1), Zhenyu Liu (3) and Jin Cheng (3)
(1) Centre for Infrastructure Engineering and Safety (CIES), School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW, 2052, Australia
(2) Centre for Built Infrastructure Research (CBIR), School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NSW, Australia
(3) State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou, 310027, China


ABSTRACT: Organic solar cell (OSC), which is deemed to be the most promising third generation solar energy application, is developing vigorously. Based on the modified strain gradient theory (MSGT) and the refined shear deformation plate theory, static bending and free vibration of the size-dependent OSC are thoroughly
investigated in this paper. A Winkler-Pasternak elastic foundation is considered for the OSC. A multiscale suitable plate analysis framework (i.e., both macro- and micro plates can be handled) is developed herein. Three length scale parameters are incorporated in the presented analysis to capture the size-dependency of the OSC. By setting two or three of them into zero, the presented model could degenerate into the modified couple stress theory (MCST) and the classical plate theory (CPT). The derivation of the governing equations and the corresponding boundary conditions are conducted by Hamilton principle. The Navier-type solution is employed for solving the governing equations of the simply supported OSC. The accuracy of the presented method is validated. Extensive numerical experiments have been conducted to investigate the differences between the adopted MSGT, the MCST and the CPT. Moreover, the impacts of the geometrical configuration as well as the elastic foundation parameters on the static bending and free vibration characteristics are illustrated in the numerical studies. This paper also explores the thickness of the active layer effect on the free vibration behaviour in combination with the power conversion efficiency (PCE) of the OSC.

P. Phung-Van (1), Chien H. Thai (2,3), H. Nguyen-Xuan (4) and M. Abdel-Wahab (2,3)
(1) Faculty of Civil Engineering, Ho Chi Minh City University of Technology (HUTECH), Ho Chi Minh City, Viet Nam
(2) Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(3) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(4) CIRTECH Institute, Ho Chi Minh City University of Technology (HUTECH), Ho Chi Minh City, Viet Nam

https://doi.org/10.1016/j.euromechsol.2019.103851

ABSTRACT: This paper presents porosity-dependent analysis of functionally graded nanoplates, which are made of two kinds of porous materials, based on isogeometric approach for the first time. Material properties of the nanoplates are described by using a modified power-law function. The Eringen's nonlocal elasticity is used to capture the size effects. Using the Hamilton's principle, the governing equations of the porous FG nanoplates using the higher order shear deformation theory are derived. The obtained results demonstrate the significance effect of nonlocal parameter, material composition, porosity factor, porosity distributions, volume fraction exponent and geometrical parameters on static and free vibration analyses of nanoplates.

https://doi.org/10.1016/j.euromechsol.2019.103858

ABSTRACT: Two-phase cross-flow-induced instability and chaotic motions of a single tube in a rotated triangular tube array impacting on loose support was studied using an analytic model. The Hopf bifurcation velocities of the tube bundles within void fraction of the two-phase flow ranging from 0% to 80% were first investigated. The theoretical results have indicated that, with increasing void fraction, the tube bundles may become more stable verified by our previous experimental studies. To explore the post-instability dynamics characteristics of a single tube in tube bundles, a Runge-Kutta scheme was used to solve the nonlinear governing equations in five void fraction conditions. The numerical results that when the flow pitch velocity increases beyond the Hopf bifurcation velocity, the limit cycle motion occurs. And, the amplitude of the limit cycle motion grows until chaotic motion occurs at a sufficiently high flow pitch velocity. The effect of the void fraction on the global dynamics of a single tube in tube bundles system was also investigated.

Claude Boutin (1), Pascal Fossat (1,2), Christophe Droz (2) and Mohamed Ichchou (2)
(1) Université de Lyon, École Nationale des Travaux Publics de l’État, LTDS/LGCB UMR-CNRS 5513, Rue Maurice Audin, 69518, Vaulx-en-Velin, France
(2) École Centrale de Lyon, LTDS, UMR-CNRS 5513, 36 Avenue Guy de Collongue, 69134, Ecully, France

https://doi.org/10.1016/j.euromechsol.2019.103838

ABSTRACT: This paper deals with the theoretical, numerical and experimental behavior of periodic orthogonally ribbed plates. It extends the paper (Fossat et al., 2018) in which a comprehensive homogenized
model has been established for flexural and torsional motion of periodic 1D-ribbed plates. New theoretical results describing the out-of-plane behavior of cellular plates involving inner resonance phenomena, are derived using an asymptotic approach. In this aim, the out-of-plane model of beam grids accounting for local bending and torsion is first established through the asymptotic method of homogenization of periodic discrete media. Then, the coupling between the beam grid and the internal plates (fully or partially connected to it) is detailed. This lead to an explicit analytical formulation of the equivalent plate model whose effective parameters arise from the geometry and mechanical properties of the unit cell. The unconventional features of the flexural wave dispersion are shown to be straightforwardly related to inner-resonance phenomena. These theoretical results are successfully compared to numerical computations conducted using WFEM. Furthermore, experiments performed on two prototypes of ribbed plates evidence the ability of the homogenized model to describe their complex dynamic behavior. The latter is characterized by the co-existence of a dynamic regime at both the micro-scale of the period and the macro-scale of the whole structure, that results in an inhomogeneous kinematics where the plate and beam displacements differ at the leading order. These unique features depart from the usual assumptions retained in plate mechanics and generates the observed non-conventional features. In conclusion, it is stressed that the study yields design rules to tailor cellular panels having specific atypical features in a given frequency range.

References listed at the end of the paper:
17 A. Leissa, Vibration of Plates, NASA SP, National Aeronautics and Space Administration (1969)

ABSTRACT: The deflection of composite laminates and their maximum compressive and tensile strains under in-plane compression, buckling and post-buckling conditions are investigated in this study. For this purpose, different equivalent single layer and layer wise theories based on polynomial and trigonometric shape functions are used. Then the Rayleigh–Ritz approximation technique and the principle of minimum potential energy are applied to obtain the unknown coefficients of the displacement fields. The results are compared with a three-dimensional finite element analysis and an experimental program is conducted to produce data for validation of theoretical and numerical methods. Mesh independency is also studied to evaluate the accuracy of the finite element results. Regarding to the computational costs and agreement of the analytical and numerical results with the experimental ones, the layer wise higher order shear deformation theory (LHSDT) based on polynomial shape functions is the most efficient and flexible theory in calculation of the deflection and strains for the very thin to thick laminates in the buckling and post-buckling conditions.

References listed at the end of the paper:
1 ANSYS15 finite Element Commercial Software, element library, SOLID45.
2 M. Cvetkovic, D.J. Vuksanovic, Bending, free vibrations and buckling of laminated composite and sandwich plates using a layerwise displacement model, Compos. Struct., 88 (2009), pp. 219-227
8 F.A. Fazolian, J.R. Banerjee, M.B. School, Buckling of composite plate assemblies using higher order shear deformation theory: an exact method of solution, Thin-Walled Struct., 71 (2013), pp. 18-34
10 S.A.M. Ghanadpour, H.R. Ovesy, The application of an exact finite strip to the buckling of symmetrically laminated composite rectangular plates and prismatic plate structures, Compos. Struct., 89 (2009), pp. 151-158
References listed at the end of the paper:

17 N. Kharghani, C. Guedes Soares, Behaviour of composite laminates with embedded delaminations, Compos. Struct., 150 (2016), pp. 226-239
26 V. Ungherkorn, P. Singhathanadgid, Buckling analysis of symmetrically laminated composite plates by the extended Kantorovich method, Compos. Struct., 73 (2006), pp. 120-128

M. Xavier (1,2), C. Czarnota (2), D. Jouve (1), S. Mercier (2), J.L. Dequiedt (1) A. Molinari (2)
(1) CEA, DAM, DIF, 91297 Arpajon, France
(2) Laboratoire d’Etude des Microstructures et de Mécanique des Matériaux, LEM3, UMR CNRS 7239, Université de Lorraine, CNRS, ENSAM 7 rue Felix Savart, 57070 Metz, France


ABSTRACT: Being able to predict fragment distributions in terms of speed and size, following the fracture of ductile metals, this fracture process is initiated by plastic flow instability resulting in necking, i.e. the occurrence of local thinnings where the plastic deformation is localized. Since decades, linear stability analyses have been carried out to study the multiple necking formation via a perturbation of the fundamental state. The underlying assumption related to the linear stability analyses developed so far is the time scale separation (meaning that the development of the instability is much faster than the evolution of the fundamental state), see Fressengeas and Molinari (1994) or Shenoy and Freund (1999). The aim of the work is to propose an extended linear stability analysis which can tackle situations where the time scale separation hypothesis is no more satisfied (i.e. at very large strain rates). The proposed methodology is exemplified by considering the dynamic extension of a plate under plane strain condition: the material behavior being modeled adopting various constitutive laws from rate insensitive to thermo-viscoplastic ones. The role of initial perturbation (or defect) is discussed. While the role of the initial conditions is important at the early stage of the deformation process, their influence on the growth rate and on the dominant mode are negligible at large strain for moderate loading rate. One main feature of the proposed model is the estimation of the amplitude development of each mode. A strong difference in the amplitude predictions is revealed between the new model and the classical linear stability analysis of the literature, even if the growth rates are comparable for both approaches at late deformation stage. However, history effect related to the amplitude of a given mode, originating from the early stage process, may lead to strong amplitude differences which remain visible at the late stage. The benefit of the new theory is the fact that the spatio-temporal evolution of the mechanical and thermal parts of the perturbation can be captured naturally, even for cases where the plastic flow is initially stable and becomes unstable as the deformation progresses.

References listed at the end of the paper:


Xavier M., Etude analytique et numérique du développement de la striction multiple pour des cylindres métalliques en expansion dynamique., Université de Lorraine, France (2019)


Zhang H., Ravi-Chandar K., On the dynamics of necking and fragmentation- II. Effect of material properties, geometrical constraints and absolute size, Int. J. Fract., 150 (2008), pp. 3-36


ABSTRACT: The nonlinear primary resonances with 1:3:6 of symmetric rectangular honeycomb sandwich panels with simply supported boundaries along all four edges are studied. The nonlinear governing equations of the symmetric rectangular honeycomb sandwich panel subjected to transverse excitations are derived by using Hamilton's principle and Reddy's third-order shear deformation theory. These nonlinear partial differential equations are reduced into nonlinear ordinary differential equations by the Galerkin method. Based on the homotopy analysis method, the average equations of the primary resonance are obtained. For all the three primary resonances cases, the frequency-response curves of primary resonance are constructed. Comparison studies on the forced vibration of cubic non-linearity system are conducted to verify the correctness and accuracy of the homotopy analysis method. Effects of thickness-to-length ratio, width-to-length ratio and transverse excitation on the nonlinear primary response have been investigated for honeycomb sandwich panels.

M. Lezgy-Nazargah (1), P. Vidal (2) and O. Polit (2)
(1) Faculty of Civil Engineering, Hakim Sabzevari University, Sabzevar, 9617976487-397, Iran
(2) LEME, UPL, Univ Paris Nanterre, 50 rue de Sèvres, 92410, Ville d'Avray, France


ABSTRACT: A new multifiber finite element model is derived for the analysis of laminated composite and sandwich beams under combined transverse and torsional loads. The proposed model decouples the problem of 3D analysis of composite beams into 2D cross-sectional analysis and 1D beam analysis. The effects of transverse shear deformations and restrained warping due to torsion are included in the formulation. The interlaminar continuity requirements of the transverse shear stresses due to bending and torsion at the interfaces between layers are satisfied in the presented formulation. The boundary requirements of shear stresses on the exterior surfaces of the beam are also fulfilled. In the derivation of the proposed model, a 2D finite element based on penalty approach is firstly developed for the approximation of the warping function over the cross-section. Then, a 1D multifiber finite element model is derived for the approximation of unknown generalized
displacement of beams. Accuracy of the present multifiber finite element model is evaluated by comparing the present results with numerical and analytical results available in open literature, and 3D finite element solutions. The comparisons show that the presented formulation of this study gives quasi-3D results with a lower computational cost.


ABSTRACT: The present work is concerned with the modified Green–Lindsay thermoelasticity theory involving strain-rate. This theory has been proposed very recently to modify the Green–Lindsay (GL) model of thermoelasticity by introducing both temperature and strain-rate in the constitutive relations of coupled thermo-mechanics. We consider a problem involving coupled thermo-mechanical interactions inside a functionally graded hollow disk due to thermal shock applied at its stress-free inner and outer boundaries. The material properties of the disk are assumed to be non-homogeneous and changing along the radial direction according to a volume fraction rule with a power of non-homogeneity index term. We formulate the problem by considering the basic governing equations of GL and modified GL thermoelasticity theories in a unified form and derive a linear system of coupled partial differential equations with variable coefficients. The major aim of this work is to apply a complete finite element method to obtain the solution of the problem. We solve the system of equations by applying a Galerkin’s approach of FEM for the space domain and derive the time differential system of equations. To solve this time differential system of equations, we use two different approaches: (1) a Galerkin’s type FE approach and (2) the Newmark time integration scheme. We compare the results obtained from these two different approaches and find that the solution obtained by complete Galerkin’s approach of FEM perfectly matches with the corresponding solution obtained from Newmark time integration scheme. We further compare the CPU time taken by these two methods with the CPU time taken by the trans-finite element method and reveal the efficiency of the present method over trans-FE method. The variation of different physical field variables with space and time is discussed for various values of the non-homogeneity index by highlighting the difference in the results under the GL model and modified GL model.

José S. Moita (1), Aurélio L. Araújo (1), Victor Franco Correia (2), Cristóvão M. Mota Soares (1) and José Herskovits (3,4)
(1) IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal
(2) Escola Superior Náutica Infante D. Henrique, Av. Eng. Bonneville Franco, 2770-058, Paço de Arcos, Portugal
(3) COPPE-UFRJ, Universidade Federal do Rio de Janeiro, Brazil
(4) Department of Mechanical and Materials Engineering, Military Institute of Engineering, Rio de Janeiro, Brazil


ABSTRACT: In this work the formulation for linear buckling and for geometrically nonlinear analysis of laminated composite and functionally graded material (FGM) plates under mechanical uniaxial in-plane uniform loads, and thermal loads, is presented. An implemented finite element model based on a non-conforming triangular flat plate/shell element with three nodes and eight degrees of freedom per node, associated with a higher order shear deformation theory is used. The through the thickness variation of the material properties, discrete for laminated composite plates or continuous for FGM plates, as well as the through the thickness temperature distribution, originate a non-symmetry with respect to the middle-surface. Thus, in general, the occurrence of bifurcation-type buckling should be studied, and the transverse deflection at the centre of the plate could be a good indicator to anticipate this occurrence. The solutions of some illustrative examples involving different boundary conditions, composite lay-up, FGM variation of volume fractions, temperature distributions, material combinations, and boundary conditions are presented for benchmarking purposes, with emphasis for the plate transverse deflections. Linear solutions are compared with numerical alternative models. The occurrence of bifurcation-type buckling is discussed for several representative cases,
the validity of the linear buckling solutions is addressed and nonlinear analyses have been performed for confirmation purposes.

A.V. Savin (1), E.A. Korznikova (2,3), A.M. Krivtsov (4,5) and S.V. Dmitriev (2,6)  
(1) N.N. Semenov Federal Research Center for Chemical Physics, Russian Academy of Science (FRCCP RAS), Moscow, 119991, Russia  
(2) Institute for Metals Superplasticity Problems of RAS, 39 Khalturin St., Ufa 450001, Russia  
(3) Ufa State Aviation Technical University, 12 Karl Marx St., Ufa 450008, Russia  
(4) Peter the Great Saint Petersburg Polytechnical University, Polytechnicheskaya Street 29, Saint Petersburg, Russia  
(5) Institute for Problems in Mechanical Engineering RAS, Bolshoy pr. V.O. 61, Saint Petersburg, Russia  
(6) National Research Tomsk State University, 36 Lenin Prospekt, Tomsk 634050, Russia


ABSTRACT: The effect of graphene nanoribbon twist on its lateral buckling resistance to axial compression and on its thermal conductivity is analyzed with the help of molecular dynamics simulations. It is shown that the nanoribbon twisted by an angle close to \( \pi \) can withstand three times greater compressive force as compared to a flat nanoribbon. The explanation lies in the fact that such twist increases the effective area moment of inertia of the nanoribbon cross section. It is also found that the thermal conductivity coefficient of the nanoribbon increases monotonically up to 10% with increasing twist angle, in the regime of uniform twisting. This effect is due to the introduction of tensile strain in the twisted nanoribbon, which increases the contribution of the acoustic out-of-plane (ZA) phonon modes to thermal conductivity. Our results demonstrate that twist deformation of nanoribbons can improve their mechanical and physical properties. The reported effects can be observed for 2D materials other than graphene because they have simple mechanical explanation not related to a particular crystal structure.

Qiang Gao (1,3), Chin An Tan (2), Greg Hulbert (3) and Liangmo Wang (1)  
(1) Department of Automotive Engineering, School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, Jiangsu, China  
(2) Department of Mechanical Engineering, Wayne State University, Detroit, MI, 48202, USA  
(3) Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI, 482105, USA  


ABSTRACT: Double-V microstructure (DVM) is a type of auxetic cellular material with negative Poisson's ratio (NPR). Accurate predictions of the mechanical properties of these microstructures at large strains are critical for many engineering applications. In this paper, nonlinear theoretical models of two-dimensional (2D) and three-dimensional (3D) DVM based on a large beam deflection model are established to predict the normalized Young's modulus and Poisson's ratio in the principal directions. The theoretical solutions are compared to solutions obtained from numerical finite element analyses and quasi-static compression experiments of a 2D prototype manufactured using additive printing technique. It is found that there is good agreement between these results, validating the accuracy of the proposed theoretical model. Effects of geometry parameters on the mechanical properties of the DVM are also investigated to understand the mechanical behavior at large strains. This study provides validated models for predicting the behavior of these microstructures at large strains, useful for engineering designs.


ABSTRACT: In this paper, the Galerkin method is used to study the stability of cantilever functionally graded material (FGM) nanotube under thermo-magnetic coupling effect. The influences of external magnetic field and temperature on the stability of the FGM nanotube are investigated, and the influences of non-local parameters
(e), Knudsen number ($Kn$), elastic coefficient of elastic matrix ($k$) and volume fraction exponent ($n$) on the dynamic instability critical velocity ($u_n$) of FGM nanotube are discussed. It can be concluded that additional axial magnetic field, increase of temperature and increase of elastic coefficient will lead to the increase of critical instability velocity, while the increase of $Kn$, $n$ and $e$ will lead to the decrease of the critical instability velocity. Based on the conditions assumed in this paper, under the coupling effect of temperature, magnetic field and $k$ and the coupling effect of temperature, magnetic field and $n$, the $u_n$ increases by 29.63% and 26.28% respectively. However, under the coupling effect of temperature, magnetic field and $Kn$, the $u_n$ decreases by 16.95% and 10.25% respectively.

Vien Minh Nguyen-Thanh (3), Xiaoying Zhuang (3) and Timon Rabczuk (1, 2)
(1) Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(2) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(3) Institute of Continuum Mechanics, Leibniz Universität Hannover, Appelstraße 11, 30167, Hannover, Germany


ABSTRACT: We present a deep energy method for finite deformation hyperelasticity using deep neural networks (DNNs). The method avoids entirely a discretization such as FEM. Instead, the potential energy as a loss function of the system is directly minimized. To train the DNNs, a backpropagation dealing with the gradient loss is computed and then the minimization is performed by a standard optimizer. The learning process will yield the neural network's parameters (weights and biases). Once the network is trained, a numerical solution can be obtained much faster compared to a classical approach based on finite elements for instance. The presented approach is very simple to implement and requires only a few lines of code within the open-source machine learning framework such as Tensorflow or Pytorch. Finally, we demonstrate the performance of our DNNs based solution for several benchmark problems, which shows comparable computational efficiency such as FEM solutions.


ABSTRACT: In this paper, the influence of finite temperature on the axial buckling of double walled carbon nanotubes (DWCNTs) is investigated based on the non-local Timoshenko beam model. The double walled carbon nanotube with different nonlocal effects is considered as an elastic structure model of mechanics, which is composed of the Van der Waals' force between the two-layers/two walls of carbon nanotubes. Molecular structure mechanics model incorporating thermal temperature is developed to study the relation between Young's modulus and temperature. The temperature dependent Young's modulus is applied to study the mechanical property of double walled carbon nanotubes. It is found that the axial buckling properties of DWCNTs decrease with the increase of the finite temperature at high temperature, however, the axial buckling properties of DWCNTs increase with the increase of the finite temperature at low or room temperature. Moreover, it is noted that the continuous temperature has litter effect on the axial buckling property of DWCNTs at the low temperature. However, the influence of continuous temperature on the mechanical properties of DWCNTs can not be neglected at the high temperature.


ABSTRACT: Based on appropriate nonlocal continuum models, free vibrations of a group of double-walled carbon nanotubes (DWCNTs) with forest configuration are going to be studied carefully. The nanosystem has been embedded in an elastic material such that the exterior nanotubes interact with the adjacent environment. The constitutive tubes of the nanosystem are modeled via nonlocal Rayleigh and high-order beams and all existing van der Waals forces between the walls of different DWCNTs are appropriately included in the
developed models. Using the Hamilton's principle, the complex equations of motion of the nanosystem are obtained by exploiting two continuous and discrete models with some effort. For two conditions of the exterior tubes, the frequency analyses are carried out using assumed mode method and Galerkin approach based on discrete and continuous models. A close comparison of the results of the discrete models and those of the continuous ones demonstrates the success of the newly developed continuous models. These models would be very useful in the analysis of populous nanosystems. Finally, the crucial roles of the geometry of the nanotubes, intertube distance, lateral stiffness of the nearby matrix, and the nonlocality on the frequencies are investigated.

Bo Zhang (1,2), Heng Li (1), Liulin Kong (3), Xu Zhang (2) and Huoming Shen (2)
(1) Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong, China
(2) School of Mechanics and Engineering, Applied Mechanics and Structure Safety Key Laboratory of Sichuan Province, Southwest Jiaotong University, Chengdu, China
(3) Faculty of Engineering, China University of Geosciences, Wuhan, Hubei, 430074, China


ABSTRACT: This paper constructs a four-node Kirchhoff plate element considering dilatation, deviatoric stretch and rotation gradient effects to address the general boundary value problems of size-dependent isotropic thin micro-plates. This element benefits from the merits of differential quadrature method (DQM) and finite element method (FEM) and possesses four nodal displacement parameters at each node, i.e., deflection, its two first partial derivatives and one second mixed partial derivative with respect to two in-plane coordinates. To guarantee the C partial compatibility among neighboring elements, we establish a novel DQ-based geometric mapping scheme relating the deflection values at Gauss-Lobatto quadrature points to the displacement parameters at four nodes. By applying the DQ rule, the Gauss-Lobatto quadrature rule and the developed mapping scheme, the total potential energy of a generic gradient-elastic Kirchhoff plate element is represented as a function of nodal displacement parameters. The element formulation is derived using the minimum total potential energy principle. Several numerical examples are provided to demonstrate the validity of the proposed method and explore the static bending, free vibration and critical buckling behavior of thin micro-plates. It is validated that the size-dependence of vibration and critical buckling mode shapes of thin micro-plates can be observed in some cases.


ABSTRACT: Characterizing the local deformations and strain fields in ligaments of periodic honeycomb materials is instrumental to applications such as cores of sandwich structure as well as honeycomb shaped tunable phononic crystals, compliant metamaterials, and 4D printed shape memory materials. Such applications employ honeycomb shaped materials whose nonlinear behavior is controlled by localized deformations in their ligaments. These local deformations can exhibit values and complex non-uniform states that far exceed the overall macroscopic deformations and strains sustained by the honeycomb material in value and complexity. Each of the aforementioned applications can be better designed with an improved understanding of the evolution of local strain fields in honeycombs' ligaments during their deformation. This work aims to characterize the local strains and deformations developing in honeycomb ligaments near honeycombs’ macroscopic onset of yielding. Finite element computations and the full field strain measurement technique digital image correlation (DIC) are used to measure and characterize the local deformations in the ligaments of concaved and convex honeycombs. Results show nonlinear strain gradients and significant localization in deformed ligaments. Moreover, complex state of stress comprising biaxial normal stresses and shear stresses exists near plastic zones.

ABSTRACT: This work presents contact problems of laminated structures via the Carrera Unified Formulation (CUF). The modeling approach makes use of higher-order 1D elements accounting for transverse shear and stretching. The current work considers normal, frictionless contact based on a node-to-node formulation, and the penalty approach to enforce the contact constraints. Numerical assessments compare classical beam theories, higher-order CUF, and 3D finite element models regarding solution accuracy, computational size, and time required for the analysis. The results show the validity of Layer-Wise CUF models to capture both global and local deformations accurately, which is a shortcoming of classical beam theories, and require at least an order of magnitude fewer degrees of freedom and computational time than a full 3D finite element analysis. Particularly relevant are the accurate distributions of transverse shear stress and stretching along the thickness in the perspective of failure analyses.

Alexander O. Vatulyan (1,2), Vladimir V. Dudarev (1,2), Roman M. Mnukhin (2) and Rostislav D. Nedin (1,2)
(1) Southern Mathematical Institute of the Vladikavkaz Scientific Center of the Russian Academy of Sciences, 22 Markusa Street, 362027, Vladikavkaz, Russia
(2) Department of Theory of Elasticity, Institute of Mathematics, Mechanics and Computer Sciences named after I.I. Vorovich, Southern Federal University, 8a Milchakova Street, 344090, Rostov-on-Don, Russia

ABSTRACT: The present paper considers the direct and inverse problems on steady-state oscillations of functionally graded elastic pipe. The direct problem is reduced to solving a numerical set of canonical systems of first-order differential equations with variable coefficients. The influence of the variable Lamé parameters on the displacement functions and amplitude–frequency characteristics is estimated. The solution of the inverse problem on determination of the functions describing the change in the Lamé parameters is obtained numerically by inverting differential operators on the basis of the displacement field data gathered in a finite set of points at a fixed frequency. The results of computational experiments are discussed.

Isaac Elishakoff (1), Antoine Ajenjo (1,2) and David Livshits (3)
(1) Department of Mechanical Engineering, Florida Atlantic University, Boca Raton, FL, 33431, USA
(2) SIGMA Clermont, Aubiere, 63170, France
(3) Faculty of Aerospace Engineering, Technion-Israel Institute of Technology, Haifa, 32000, Israel

ABSTRACT: The Eringen’s result for random vibration of the simply-supported Bernoulli-Euler beam subjected to the “rain-on-the-roof” excitation is extended to the beam placed on Winkler elastic foundation. The normal mode approach is utilized. The attendant infinite series are summed up in the closed form.

Yahe Gao (1), Yufeng Xing (1), Zhiwei Huang (1), Min Li (1) and Yang Yang (2)
(1) Institute of Solid Mechanics, Beihang University (BUAA), Beijing, 100083, China
(2) Beijing Institute of Space Long March Vehicle, Beijing, 100076, China

ABSTRACT: The decoupled multiscale asymptotic expansion method (MsAEM) is applicable to the analysis of composite structures with periodic microstructures. When using the MsAEM to solve linear static problems, unit-cell influence functions must be solved from the microscale (or unit cell) problem with microscopic periodic boundary conditions, and homogenized displacements and their derivatives must be solved from the macroscale (or homogenized) problem with macrostructural boundary conditions. This paper compares the influence functions solved by using the normalization condition, the Dirichlet homogeneous boundary condition, and the oversampling technique or the super unit cell approach. It is concluded that the oversampling technique is a better way of dealing with periodic boundary conditions compared to the normalization condition. Another contribution of this work is to propose a combination method in which the MsAEM is used inside the structure and the multiscale eigenelement method (MEM) is used dealing with the boundary layer problem, and
it is shown that this combination method can achieve accurate microscopic results for structures with any boundary conditions. In addition, the paper reveals the effects of different order expansion terms and gives some practical suggestions on how to determine the expansion order. Numerical comparisons validate the present combination method and all conclusions.

ABSTRACT: Thermoelastic behavior of composite cylindrical panel reinforced with graphene platelets distributed along the radial direction uniformly (UD) or functionally graded, math, math, math and math pattern is studied in the frame work of elasticity theory. Functionally graded graphene platelets reinforced composite (FG-GPLRC) cylindrical panel with simply supported boundary conditions is subjected to constant temperature at its inner and outer surfaces. By applying Fourier series expansion to the physical quantities along the axial and circumferential coordinates and using state space technique along the radial direction, state space governing differential equations can be derived and solved analytically. Parametric study is conducted by considering the effects of weight fraction as well as geometry and size of GPLs, pattern of graphene platelets distribution, applied temperature on thermoelastic behavior of GPLRC cylindrical panel. From numerical illustration it is evident that adding a little content GPLs affects thermoelastic behavior of GPLRC cylindrical panel significantly.

ABSTRACT: By Weierstrass field theory in calculus of variations, stability of one inflexion Euler elastica with one end fixed and the other clamped in rotation is analyzed. Of particular interest in this paper is the question whether or not the potential energy holds a strong minimum value with respect to the angle of cross section. An analytical proof is presented that these Euler elastics are the strong minimizers for the potential energy. These Euler elastics with one inflexion are stable for the disturbance where derivative of the disturbance angle may be both continuous and discontinuous for the first kind.

A.V. Lopatin (1,2) and E.V. Morozov (3)
(1) Department of Aerospace Engineering, Siberian State University of Science and Technology, Krasnoyarsk, Russia
(2) Institute of Computational Technologies, SB RAS, Krasnoyarsk, Russia
(3) School of Engineering and Information Technology, University of New South Wales at the Australian Defence Force Academy, Canberra, Australia
ABSTRACT: The paper is concerned with the solution to the buckling problem of a plate having two opposite edges free and subjected to a uniform compressive load applied to another two fully clamped edges. At first glance, the problem might look simple, resembling the buckling of a compressed strip-beam. However, this is not the case. The buckled plate bends between the free edges as opposed to the beam buckling mode. The situation even more complicated when the plate material is not isotropic since the bending depends not only on the plate's aspect ratio but also on the elastic properties of the material. In this work, an analytical solution for such a buckling problem formulated for an orthotropic composite plate and based on the combined Kantorovich and generalised Galerkin methods is presented, and a compact analytical formula for the critical load is derived. The solution was verified by comparison with the finite element analysis.

Hamed Farokhi (1) and Mergen H. Ghayesh (2)
(1) Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK
Extremely large-amplitude dynamics of cantilevers under coupled base excitation

ABSTRACT: Extremely large-amplitude nonlinear dynamics of a cantilever with a mass at the tip under coupled base excitations is examined for the first time. An exact model of the centreline rotation of the cantilever is developed capable of accurately predicting the cantilever dynamic response even at extremely large amplitudes; a nonlinear static finite element analysis is conducted to verify the accuracy of the proposed model at very large deflection amplitudes. The proposed model is based on the theory of Euler-Bernoulli and the internal damping model of Kelvin-Voigt; the centreline of the cantilever is assumed to remain inextensible. The proposed model for the cantilever centreline rotation is discretised via the Galerkin modal decomposition method while keeping all terms exact. Extensive numerical simulations are conducted to examine the primary and parametric resonance of the cantilever due to transverse and axial base excitations, respectively. It is shown that under the same axial and transverse amplitudes of excitation, the parametric resonance is much stronger than the primary resonance.

Ru Tian (1,4), Jinxi Liu (2,3), Ernian Pan (4) and Yuesheng Wang (1)
(1) Institute of Engineering Mechanics, Beijing Jiaotong University, Beijing, 100044, PR China
(2) Department of Engineering Mechanics, Shijiazhuang Tiedao University, Shijiazhuang, 050043, PR China
(3) Hebei Key Laboratory of Mechanics of Intelligent Materials and Structures, Shijiazhuang Tiedao University, Shijiazhuang, 050043, PR China
(4) Department of Civil Engineering, University of Akron, Akron, OH 44325-3905, USA

SH waves in multilayered piezoelectric semiconductor plates with imperfect interfaces

ABSTRACT: In this paper, analytical solutions for SH waves in transversely isotropic multilayered piezoelectric semiconductor (PSC) plates with imperfect interfaces are obtained. The extended displacements and stresses are expressed in terms of the eigenvalues and eigenvectors by introducing the extended Stroh formalism. Making use of the dual variable and position (DVP) method and the imperfect interface conditions, the transfer matrix which relates the extended displacement and traction on the lower and upper interfaces of the multilayered plates is derived. Then the dispersion relation is obtained by using the boundary conditions on the top and bottom surfaces of the multilayered plates. Effect of the steady-state carrier density in single-layer ZnO plate, and effect of stacking sequences and imperfect interfaces in sandwich plates are discussed via numerical examples. Particularly, the critical elastic (E), piezoelectric (PE), and PSC wave domains are identified for the given carrier density, plate thickness and frequency, which could be very helpful as theoretical guidance for the design of PSC devices.

P. Bertolini (1,2) and L. Taglialegne (3)
(1) LM Wind Power, Jupitervej 6, 6000 Kolding, Denmark
(2) DTU Wind Energy, Frederiksbergvej 399, 4000 Roskilde, Denmark
(3) Department of Civil and Industrial Engineering, University of Pisa, Largo Lucio Lazzarino, 56122 Pisa, Italy

Analytical solution of the stresses in doubly tapered box girders

ABSTRACT: Lengthwise geometrical variations such as taper, are widely employed in engineering structures, e.g. in wind turbine blades, aircraft wings and bridges. Notwithstanding the effects of taper on the mechanical behaviour of beams, it is common design procedure to model such structures as prismatic beams. Indeed, the derivation of analytical solution of the stress components in tapered beams is not a trivial task. This work provides the above-mentioned analytical solution of the stresses in tapered box girders, whose width and height are varying along the longitudinal axis of the beam. The proposed solution deals with any arbitrarily oriented external forces and it is based on the hypothesis of homogeneous isotropic material. The analytical solution shows that a combination of even small vertical and horizontal tapers highly influences the stress distribution. A parametric study of the relation between taper and the von Mises stress was investigated. Furthermore, it is
evinced that disregarding taper effects might lead to an overestimation of the fatigue lifetime of the structures up to 12%.


ABSTRACT: The purpose of this paper is to present the exact analytical solution for the static deflection analysis of fully coupled composite Timoshenko beams. The system of governing equations and the boundary conditions are derived from variational principles. Using the method of direct integration, the exact analytical solution of the static deflection of a Timoshenko beam is obtained by solving this system of differential equations in terms of transverse displacements and cross-sectional rotations. Static deflection analyses of Timoshenko beams, subject to various boundary conditions and uniformly distributed and tip loads, are performed and the results are compared to those obtained from classical Euler–Bernoulli theory by using different values of length-to-thickness ratio. In addition, it is shown that for the case of a cantilevered composite beam subject to tip loads, the proposed exact analytical solution is equivalent to the exact solution from the intrinsic formulation. The Chebyshev collocation method is also employed to validate the obtained exact analytical solution. In the proposed formulation the stiffness properties of the composite beam are expressed by engineering constants, therefore is not limited by the cross-sectional shape of the beam, type of material and thus can be utilised for engineering applications and design purposes. The exact analytical solution can also be used as a benchmark for validating results obtained from various numerical methods.

Mikhail Yu. Gutkin (1,2,3), Anna L. Kolesnikova (1,2), Dmitry S. Mikheev (3) and Alexey E. Romanov (1)
(1) ITMO University, Kronverkskiy pr. 49, St. Petersburg, 197101, Russia
(2) Institute of Problems of Mechanical Engineering, Russian Academy of Sciences, Bolshoj 61, Vasil. Ostrov, St. Petersburg, 199178, Russia
(3) Department of Mechanics and Control Processes, Peter the Great St. Petersburg Polytechnic University, Polytekhnicheskaya 29, St. Petersburg, 195251, Russia


ABSTRACT: For the first time, we suggest a theoretical model, which describes the misfit stress relaxation in spherical core-shell nanoparticles with axisymmetric truncated spherical cores through the formation of circular prismatic loops of misfit dislocations at the core-shell interface. The special case of a semispherical core with base in the equatorial plane of the nanoparticle is considered and analyzed in detail. It is shown that the formation of misfit dislocation is energetically favorable when the misfit strain reaches its critical value, which depends on the system parameters. When forming, the misfit dislocation occupies in most cases its optimal position at the distance about of 1/4 of the core radius from the core base. Nanoparticles with cores of radius about of 3/4 of the shell radius are the less stable to generation of misfit dislocation loops.

Mir Abbas Roudbari (1,2,3,4), Tahereh Doroudgar Jorshari (5), Ali Ghorbanpour Arani (4), Chaofeng Lü (1) and Timon Rabczuk (6)
(1) Department of Civil Engineering, Zhejiang University, Hangzhou, 310058, PR China
(2) Department of Engineering Mechanics, Zhejiang University, China
(3) Department of Mechanical Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran
(4) Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
(5) Faculty of Mechanical Engineering, Islamic Azad University, Takestan, Qazvin, Iran
(6) Department of Computer Engineering, College of Computer and Information Sciences, King Saud University, Riyadh, Saudi Arabia


ABSTRACT: This paper reports a theoretical investigation on the dynamic behaviour of two mutually interacting single-walled boron nitride nanotubes (BNNTs) under a moving nanoparticle. Both the
electromechanical coupling effect and nonlocal effect are considered by employing respectively the theory of piezoelectricity and nonlocal elasticity. The interaction between the two BNNTs is considered by calculating the van der Waals (vdW) force between atoms on the respective nanotubes. The Hamilton's principle is then used to derive the governing equations of motion based on the Rayleigh and Timoshenko beam model. The incremental harmonic balance method, Galerkin method and the Newmark time integration method are jointly employed to numerically obtain the transient vibration responses of the nanotubes. The influences of the size effect, aspect ratio, inertial force, electrical potential, as well as the mass and velocity of the nanoparticle on the transient responses are discussed.


ABSTRACT: We in this article put forward a novel size-dependent beam model for static bending deformation of a functionally graded bi-semi-tube subjected to different boundary conditions based on the nonlocal strain gradient theory. The tube is formed by bonding together a ZrO/Ti–6Al–4V functionally graded lower semi-tube and a Si3N4/SUS304 functionally graded upper one. The effective material properties $P$ of FG bi-semi-tubes are assumed to vary along the radius of tube. We propose a refined shear model without requiring a shear correction factor for bars with circular cross section. Next the model is used to derive the governing equations of the tube based on the Hamilton's principle. The obtained equations form present a detailed analysis include a nonlocal parameter as well as a material length scale parameter, so much that they can account for the size-dependent in static bending of FG bi-semi-tubes. Later, these equations are resolved analytically by using an improved perturbation method. The analytical solutions are used to discuss the influence of various physical parameters on static mechanical performance of nanotubes, such as double volume fraction indexes, inner radius, the variation of temperature, strain gradient parameter, nonlocal parameter, scale parameter ratio. At last, compared with the conventional approaches, the novel approach is suggested in such work to lead to more accurate bending deformation in the same dimensionless size of tubes.


ABSTRACT: This paper studies the nonlinear vibration of a dielectric elastomer balloon considering both the strain-stiffening and the second invariant of the Cauchy-Green deformation tensor. To this end, the Gent-Gent hyperelastic model is proposed. The ordinary differential equation governing the motion of the system is derived using the Euler-Lagrange energy method. Then, it is solved with the application of a time integration-based solver. The chaotic interval for critical system parameters is identified, with and without considering the influence of the second invariant. This identification is conducted by depicting bifurcation diagrams of Poincaré sections and the largest Lyapunov exponent criteria. In order to better analyse different motions of the system, time histories, phase-plane diagrams, Poincaré maps, and power spectral densities are illustrated. Based on the obtained results, the second invariant parameter of the Gent-Gent model could suppress the chaotic motion of the system. Increasing this parameter, a transition from the chaos to the quasiperiodic attractor would happen.

Daoud S. Mashat (1), Ashraf M. Zenkour (1,2) and Ahmed F. Radwan (3)
(1) Department of Mathematics, Faculty of Science, King Abdulaziz University, P.O. Box 80203, Jeddah 21589, Saudi Arabia
(2) Department of Mathematics, Faculty of Science, Kafrelsheikh University, Kafrelsheikh 33516, Egypt
(3) Department of Mathematics and Statistics, Higher Institute of Management and Information Technology, Nile for Science and Technology, Kafrelsheikh 33514, Egypt


ABSTRACT: The present paper deals with the impacts of temperature and moisture on the bending behavior of functionally graded porous plates resting on elastic foundations. The impacts of transverse shear deformation as
well as the transverse normal strain are taken into consideration. The number of unknown functions involved here is only five as against six or more in case of other shear and normal deformation theories. The effects due to side-to-thickness ratio, aspect ratio, thermal and moisture loads, porosity factor and elastic foundation parameters as well as the volume fraction distribution on the functionally graded porous plates are investigated. Numerical outcomes are given and compared with those available in the literature. Discussions are made to show how the foundation stiffness and other parameters have significant effects on the bending response of the functionally graded porous plates under hygrothermal loading and porosities.

Yang Gao (1), Wan-shen Xiao (1) and Haiping Zhu (2)
(1) Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, 410082, China
(2) School of Engineering, Western Sydney University, Penrith, NSW, 2751, Australia

ABSTRACT: We in this paper dedicate to study the snap-buckling of functionally graded multilayer graphene platelet-reinforced composite curved beams with geometrical imperfections on the nanometer length. It is supposed that graphene platelets (GPLs) are uniformly distributed and randomly oriented in each layer, while its weight fraction varies from one layer to another based on various functionally graded patterns. The effective material properties of functionally graded multilayer GPLRC beams are evaluated via the model of the Halpin-Tsa. In the theoretical framework of the nonlocal strain gradient theory (NSGT) and the surface elasticity theory, a generalized nonlinear size-dependent curved beam model is established. The novel model includes not only a nonlocal parameter and a material length scale parameter of NSGT but also three surface constants of the surface elasticity theory, which can explore the coupling effect of nonlocal stress, strain gradient and surface energy on the snap-buckling of nanoarches. Furthermore, the present model can be transformed into the Euler-Bernoulli shallow arch model, the Timoshenko shallow arch model as well as the Reddy's higher-order shear deformation shallow arch model by choosing the appropriated shape function. Next, On the basis of the principle of Hamilton, the nonlinear governing equations of curved nanobeams are derived. Then to obtain the analytical solution of snap-buckling of curved beams, the nonlinear equations are solved by a two-step perturbation method. Finally, a detailed parametric study is carried out based on the analytical solution, aiming at analyzing the influences of respective physical parameters on the snap-buckling of such nanostructure.

Gen Liu (1), Gongfa Chen (1), Fangsen Cui (2) and An Xi (3)
(1) School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, 510006, PR China
(2) Institute of High Performance Computing, A*STAR, Singapore
(3) The Fifth Electronic Research Institute of MIIT, Guangzhou, 510610, PR China

ABSTRACT: A composite cantilever plate model with variable high speed rotating blade subject to transverse aerodynamic force and centrifugal force is established. Based on the third-order shear deformation theory, von Karman large deformation theory and Hamilton's principle, the nonlinear partial differential governing equations of motion are established for the rotating blade with variable rotating speed. The two-degree-of-freedom nonlinear ordinary differential equations of motion are obtained by using Galerkin method with Chebyshev polynomials for the rotating blade. The influences of different structural parameters on the natural frequencies of the blade with variation of the rotating speed are investigated. The method of multiple scales is applied to obtain the averaged equations with the primary parametric resonance-1/2 subharmonic resonance and the relationship of 1:2 internal resonance. Numerical simulations are performed to portray the frequency-response curves and the complex nonlinear dynamic behaviors of the rotating blade by discussing the effect of the aerodynamic force. The effects of the varying rotating speed, the centrifugal force, the pre-twist angle and the pre-setting angle are taken into account on the nonlinear dynamics of the rotating blade. It is observed from the frequency-response curves that the rotating blade exhibits the hardening nonlinear behaviors as well as the jumping phenomena. The bifurcation diagrams, the phase portraits and the waveforms are utilized to illustrate
the complex nonlinear dynamic behaviors of the rotating blade, such as the periodic, the quasi-periodic and the chaotic motions.


ABSTRACT: The present study deals with aeroelastic stability analysis of sandwich plates, containing magnetorheological fluid as the core layer, subjected to the supersonic airflow. The classical plate theory, Hamilton's principle and linear first-order piston theory have been employed to extract the governing equations of motion of the structure. The assumed mode method is used to solve the derived equations and identify the instability region of the sandwich plate. In order to demonstrate validity of the proposed solution, an experiment on a cantilever sandwich plate consisting of polyethylene terephthalate (PET) as the face layers and MR fluid (MRF 132DG) as the core layer is conducted. In this study, the primary attention is focused on the effect of MR fluid and aerodynamic damping on the stability of the MR sandwich plates. Furthermore, the effect of magnetic flux, boundary conditions and plate parameters on the flutter boundaries of the sandwich MR plates are investigated. The results highlight the significance of MR fluid and aerodynamic damping in the flutter suppression of the sandwich plate structures, in a wide range of aerodynamic pressure.


ABSTRACT: In this work, thermally induced dynamic behaviors of functionally graded flexoelectric nanobeams (FGFNs) are analyzed theoretically while considering the neutral surface concept and the von Karman nonlinearity induced by thermal environment. The temperature field is assumed to vary only in the thickness direction by solving a simple steady state heat transfer equation and to be constant in the plane of the beam. The temperature-dependent material properties of FGFNs are assumed to vary continuously throughout the thickness according to a power-law form. For such FGFNs, the nonlocal simplified strain gradient elasticity theory to capture the effect of size-dependent and, the higher order shear deformation beam theory to account for rotary inertia and transverse shear strains are adopted to formulate the governing equations and associated boundary conditions, which are solved by using a two-step perturbation method. In the numerical part, comparison study is also performed to verify the present theoretical model and the parametric analysis is systematically studied. It is also found that the thermally induced bending amplitude, nonlinear frequency and frequency ratio depend enormously on the material distribution profile, the flexoelectricity, the size-dependent effect and the imposed temperature field.


ABSTRACT: The effects of different boundary conditions on the composite laminate containing embedded and through-the-width delamination under bending load are investigated analytically based on a developed Layerwise Higher Order Shear Deformation Theory (LHSDT) and the results are compared with the three-dimensional Finite Element Method (FEM). Contact energy has been calculated. The results demonstrate the ability of the presented method of predicting the displacement fields of a composite laminate containing delamination and obtaining stress-strain curves in bending condition. Moreover, strain energy release rate can be achieved using the obtained displacements to evaluate the initiation of delamination propagation around the boundaries of the considered delaminated region. Furthermore, the failure of the laminate will be predicted using conventional theories such as Tsai-Wu.

Behrooz Keshtegar (1,2), Ahmad Farrokhian (3), Reza Kolahchi (4) and Nguyen-Thoi Trung (1,2)
ABSTRACT: Present research is conducted in order to assess dynamic stability behavior of a nanocomposite sandwich truncated conical shells (NSTCS). In fact, graphene platelets (GPLs)-reinforced as core layer is encompassed through magnetostrictive layers as face sheets. For modeling the core layer and face sheets mathematically, higher order shear deformation theory (HSDT) besides first order shear deformation theory (FSDT) are utilized, respectively. To presume this sandwich structure much more realistic, Kelvin-Voigt model will be used. According to Hamilton's principle with respect to continuity boundary conditions, the governing equations are obtained. Utilizing differential cubature (DC) as well as Bolotin procedures, the governing equations will be solved and the region related to the dynamic instability is achieved. In this novel work, different variables covering various boundary edges, controller, cone's semi vertex angle, damping, feedback gain, proportion of core to face sheets thickness, dispersion kinds of GPLs and its volume percent will be studied. So as to indicate the accuracy of applied theories as well as methods, the results are collated with another paper. It is found that increment of GPLs volume percent leads to rise of excitation frequency.


ABSTRACT: In this paper, a robust control method is proposed for the vibration suppression of the piezoelectric laminated composite cantilever rectangular plate subjected to the aerodynamic force in the hygrothermal environment. The laminated composite cantilever rectangular plate is placed on the piezoelectric actuator and sensor for the upper and lower surfaces. The classical laminated composite plate theory and Hamilton's principle are applied to derive the dynamic equation of motion for the piezoelectric laminated composite cantilever rectangular plate under the aerodynamic force and hygrothermal loads. The structural damping is considered for the piezoelectric laminated composite cantilever rectangular plate. Galerkin method is used to obtain a two-degree-of-freedom discrete ordinary differential control equation of motion. For the active vibration suppression, a robust controller for the uncertain systems is designed through the obtained ordinary differential equation of motion. Moreover, the full-dimensional state observer is constructed to calculate the close-loop system. The influences of the moisture, temperature and geometric parameters on the dynamics behaviors of the piezoelectric laminated composite cantilever rectangular plate are investigated. The accuracy and effectiveness of the robust controller are verified in terms of the moisture concentration, temperature, aspect ratio, damping and parameter uncertainty by numerical simulations.


ABSTRACT: The structural-acoustic interactions of a coupled multilayered composite cylindrical shell and internal equipment system immersed in an infinite fluid medium are analyzed. The internal equipment is installed on the cylindrical shell by a series of nonlinear compliant mounts, which are represented by nonlinear springs and linear viscous dampers. Both the translational and rotational vibrations of the internal equipment are considered, and they are strongly coupled together due to the nonlinear elastic mounts. The nonlinear dynamics model of the coupled cylindrical shell and internal equipment system is established using a modified variational method, and the fluid exterior to the shell is modeled by a time-domain boundary element method. A strongly coupled serially staggered procedure is adopted to solve the governing equations of the structural system and
the acoustic fluid as a coupled system. The results of the present analysis are validated by comparing with those obtained from the finite element method. The nonlinear structural vibration and acoustic wave behaviors of the coupled system containing compliant mounts with linear or nonlinear stiffnesses (including quadratic, cubic, quartic, quadratic-quartic types of stiffness) are analyzed. The effects of the translational and rotational motions of the internal equipment as well as their coupling on the nonlinear vibration and acoustic wave responses of the coupled system are examined. Physical insights into the super-harmonics in the vibration and sound pressure responses of the coupled system are provided.


ABSTRACT: This paper presents a stiffening method by which new inclined walls are added to the classical re-entrant honeycomb cell. This modification boosts the in-plane rigidity of the re-entrant cell without significant loss from auxetic behaviour. This study focuses on the in-plane elasticity moduli and negative Poisson's ratios along the principal axes. Analytical expressions that calculate the elasticity moduli and negative Poisson's ratios are derived; both finite element modelling and experiments reported in the literature validate the expressions of this work. Further, the variation in the in-plane elastic properties of the core cell is examined by altering the new wall's geometric, sectional, and material parameters. The results from the analytical expressions and the finite element models match very closely and demonstrate the boosted rigidity of the cell proposed in this work. This work also provides a benchmark of the new cell against the classical cell that can be used to tailor the in-plane elasticity moduli and negative Poisson's ratios to suit the needs of different applications.


ABSTRACT: In this paper, a double finite integral transform method is developed for analytical bending solutions of non-Lévy-type cylindrical shell panels without a free edge that were not obtained by classical semi-inverse methods. Three double finite integral transforms are imposed on the governing high-order partial differential equations, which, with some boundary conditions, yields the relationship between the transformed quantities and specific unknowns. Incorporating the inversions into the remaining boundary conditions leads to systems of linear algebraic equations, which determine the final analytical solutions. Comprehensive benchmark results for representative cylindrical shell panels with combinations of clamped and simply supported edges are presented, which are well validated by satisfactory agreement with other solution methods. Due to its rigorous and straightforward solution procedure, the developed method provides a solid easy-to-implement approach for exploring new analytical solutions.


ABSTRACT: In the present study, considering the random distribution of carbon nanotubes in polymethylmethacrylate (PMMA) polymer, a multi-scale finite element method has been developed to investigate the mechanical behavior of these materials. In order to make realistic assumptions, the interface zone between the nanotubes and the matrix is simulated using the interfacial zone model (IZM), with its parameters obtained by calibrating the finite element model results with the results of experimental tests. Tensile tests and scanning electron microscopy (SEM) were used to study the mechanical properties and morphology of the PMMA foam samples reinforced with 0 wt%, 1 wt% and 2 wt% carbon nanotubes. Experimental results show that by adding 1 wt% and 2 wt% carbon nanotubes to PMMA foam, the tensile strength of the foam increases by 8% and 22%, respectively, compared to pure foam. Based on the results of the finite element models, the optimum percentage of the carbon nanotubes is 3.3 wt%, which gives the optimum modulus and tensile strength of 87 MPa and 4.02 GPa, respectively. The finite element model developed in the present study shows good agreement with the experimental results. Therefore, the impact of effective
parameters on the mechanical properties of the foam can be easily studied based on the finite element method (FEM) results.


ABSTRACT: Natural frequencies of laminates during its progressive failure are investigated using finite element method. The finite element formulation is based on seven degrees of freedom displacement field, deduced for an orthotropic material. Free vibration analysis is carried out during ply-by-ply failure for a laminate subjected to uniformly distributed load. The variation of fundamental frequency with material and geometric properties is also presented. This study illustrates the effect of ply failure on the natural frequencies of a laminate. The prediction of failed ply and failure mode is accomplished via Hashin failure criterion. Ply-discount material degradation model is adopted to modify the elastic constants of the failed ply. The effect of fibre orientation, failure mode and failed-ply on natural frequencies is highlighted in this paper. Jacobi iterative method is used to evaluate the natural frequencies of laminate. For the analysis, a computer code is written using FORTRAN based on the finite element formulation.


ABSTRACT: A problem of reconstruction of multiple cracks in a beam by means of the natural frequencies corresponding to transverse vibration of the beam is considered. The cracks are simulated by massless rotational springs. It is proved that the cracks can be uniquely identified by three spectra corresponding to three different types of the end conditions. The problem is solved by reducing it to the inverse spectral problem for an ordinary differential equation of fourth order. A method for identifying damage caused by cracks has been developed. The method is based on minimization of the objective function, built with the knowledge of the three spectra. Numerical examples are considered.


ABSTRACT: The postbuckling and geometrically nonlinear behaviors of imperfect functionally graded carbon nanotube-reinforced composite (FG-CNTRC) shells under axial compression are investigated in this paper. For the first time, a new type of instability named “snap-backward” with the presence of three limit points on the equilibrium path is proposed. A novel formulation based on non-uniform rational B-Spline (NURBS) basis functions and the first-order shear deformation shell theory (FSDT) using the von Karman assumption and considering the initial deformation of the shells is presented. In addition, the advantage of NURBS in modeling exactly geometries of shells is exploited. In numerical implementation, the discrete nonlinear equation system is iteratively solved by a modified Riks method. The rule of mixture is used to estimate the effective material properties of FG-CNTRC shells. Some benchmark problems are solved to verify the high reliability of the proposed formulation. Effects of geometrical imperfection, CNTs distribution, volume fraction, CNTs orientation, thickness, radius of shell on the postbuckling and geometrically nonlinear behaviors of FG-CNTRC shells are rigorously investigated. Especially, some new and complex load-deflection curves of imperfect FG-CNTRC shells under axial compression are first provided that could be useful for future references.


ABSTRACT: Based on the Timoshenko beam theory, von Kármán geometric nonlinearity assumption and the modified couple stress theory, this paper presents linear and nonlinear free vibration analysis of rotating two-
dimensional functionally graded micro-beam with even and uneven porous distributions. The material properties vary along the axial and thickness directions. The NURBS function is employed as the basic one to overcome the inherent difficulty of constructing higher order continuous displacement function for modified couple stress theory based finite element formulation. The validity of the present simulation is validated by comparing numerical results with those available literatures for rotating functionally graded micro-beams. Finally, the effects of several parameters such as porosity, power law index, material length scale parameter, rotational speed and hub radius on dimensionless frequencies and nonlinear frequency ratios are discussed.


ABSTRACT: Based on the strain gradient elasticity theory with three independent length scale parameters, a size-dependent spherical microshell model is established. The governing equations, boundary conditions and initial conditions are derived by Hamilton's principle. Both the static bending and free vibration problems are solved. Some numerical results of the static bending and the free vibration are exhibited to investigate the mechanical behaviors based on the size-dependent model. It is demonstrated that the strain gradient elastic effect will stiffen the spherical microshell especially when the thickness is in the same order with the length scale parameter. When the strain gradient elastic effect is considered, the deflection at the center of the spherical microshell does not always decrease, which is different from the case in the flat circular plate. Effects of the three length scale parameters on the anomaly are separately investigated. In addition, the first natural frequency is found to significantly increase when the thickness approaches the length scale parameter.


ABSTRACT: In this article, a mathematical derivation is made to develop a nonlinear dynamic model for the nonlinear frequency, and chaotic responses of the graphene nanoplatelet (GPL) reinforced composite (GPLRC) doubly-curved panel subject to an external harmonic load. Using Hamilton's principle and the Von-Karman nonlinear theory, the nonlinear governing equations are derived. For developing an accurate solution approach, generalized differential quadrature method (GDQM) and perturbation approach (PA) are finally employed. The results show that GPL's pattern, radius to length ratio, harmonic load, and thickness to length ratio have important role in the chaotic motion of the doubly-curved panel. The fundamental and golden results of this paper is that the chaotic motion and nonlinear frequency of the panel is hardly dependent on the value of the smaller radius to length ratio (R1/a parameter) and viscoelastic foundation. It means that by increasing the value of R1/a parameter, and taking into account the viscoelastic foundation, the motion of the system tends to show the chaotic motion. Moreover, for GPL-A, GPL-V, and GPL-UD patterns, when the value of the R1/a parameter or the curvature shape of the doubly-curved panel increases, the chaoticity in motion response improves while for the GPL-O pattern, this matter reverses.

Tran Quoc Quan (1,2), Nguyen Van Quyen (3) and Nguyen Dinh Duc (3,4,5)
(1) Faculty of Mechanical Engineering and Mechatronics, Phenikaa University, Hanoi, 12116, Viet Nam
(2) Phenikaa Institute for Advanced Study (PIAS), Phenikaa University, Hanoi, 12116, Viet Nam
(3) Department of Engineering and Technology in Constructions and Transportation –VNU Hanoi, University of Engineering and Technology, 144 – Xuan Thuy, Cau Giay, Hanoi, Viet Nam
(4) International School of Vietnam National University, Hanoi G7 & G8 Building, 144 Xuan Thuy Street, Cau Giay, Hanoi, Viet Nam
(5) National Research Laboratory, Department of Civil and Environmental Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul, 05006, Republic of Korea
ABSTRACT: This paper deals with the nonlinear forced vibration of imperfect penta–graphene plates integrated with piezoelectric actuator layers. The plate is subjected to combination of mechanical, thermal, and electrical loadings. Based on the first order shear deformation plate theory, the governing equations are established taken into account the effect of the von Kármán type of geometrical nonlinearity, the Pasternak type elastic foundations, the damping and the piezoelectric-thermal effects. Four edges of the hybrid plate are assumed to be simply supported and immovable in the in-plane directions. The solution forms that satisfy the boundary conditions are assumed to be trigonometric. The closed form expressions of natural frequency, the deflection amplitude – time curves are obtained by using the Galerkin and Runge – Kutta methods. The numerical results show positive effects of elastic foundations, negative effect of temperature increment and initial imperfection, considerable effect of geometrical parameters as well as small effect of applied voltage on the nonlinear forced vibration of piezoelectric penta – graphene plate.

References listed at the end of the paper:


D.O. Brush, B.O. Almroth, Buckling of Bars, Plates and Shells, McGraw-Hill (1975)


Z.X. Lei, K.M. Liew, J.L. Yu, Buckling analysis of functionally graded carbon nanotube-reinforced composite plates using the element-free kp-Ritz method, Compos. Struct., 98


ABSTRACT: This paper investigates the nonlinear free vibration and nonlinear dynamic hygrothermal buckling behavior of imperfect functionally graded carbon nanotube-reinforced composite (FG-CNTRC) cylindrical panels under hygrothermal environment. The nonlinear temperature distribution is assumed along the thickness direction. The structure is resting on a generalized nonlinear viscoelastic foundation which is composed of a two-parameter Winkler-Pasternak foundation augmented by a Kelvin-Voigt viscoelastic model with a nonlinear cubic stiffness and damping considerations. The nonlinear von Kármán strain-displacement relations and the classical shell theory are considered to derive the governing equations of the cylindrical panels. The discretized...
equations of motion are obtained using the Galerkin method. The fourth order Runge-Kutta method is utilized to analyze the nonlinear dynamic hygrothermal buckling. The influences of the four CNTs distribution types, consist of the FG-O, FG-A, FG-X, and UD, are considered for the cylindrical panel. The effects of temperature, moisture, nonlinear viscoelastic foundations, initial imperfection, and material parameters on the nonlinear free vibration and nonlinear dynamic hygrothermal buckling behavior of the system are investigated.

References listed at the end of the paper:

B. Budiansky, Axisymmetric dynamic buckling of clamped shallow spherical shells, NASA TN-1510 (1962), pp. 597-606
S.M. Chorfi, A. Houmat, Non-linear free vibration of a functionally graded doubly-curved shallow shell of elliptical plan-form, Compos. Struct., 92 (2010), pp. 2573-2581
H. Matsunaga, Free vibration and stability of functionally graded shallow shells according to a 2D higher-order deformation theory, Compos. Struct., 84 (2008), pp. 132-146
F. Mohammadi, R. Sedaghati, Nonlinear free vibration analysis of sandwich shell structures with a constrained electro rheological fluid layer, Smart. Mater. Struct., 21 (2012), Article 075035
A.S. Volmir, Non-linear Dynamics of Plates and Shells, AS Science Edition M, USSR (1972)


ABSTRACT: In this paper, the nonlinear dynamic analysis of the circular truss equivalent to the cylindrical shell under the influence of the thermal excitation and the damping coefficient are studied. The annular truss structure is equivalent to the cylindrical shell structure based on the previous equivalent process, and the nonlinear dynamic equations of the equivalent cylindrical shell considering the effect of thermal excitation are established by using the first-order shear deformation theory. The natural frequencies and modes of the equivalent cylindrical shell are analyzed by the finite element method, and the frequency ratio between modes is calculated. Considering the fixed boundary condition of the equivalent cylindrical shell in the generatrix direction, the torsional mode function and the bending mode function of the equivalent cylindrical shell are selected by the Chebyshev polynomial approximation method and are truncated by Galerkin method. Based on the nonlinear ordinary differential equations of two degrees of freedom, the amplitude-frequency responses, bifurcation, and chaotic characteristics of the system are analyzed. The results show that under the influence of thermal excitation, the motions of the system are complex, and when the excitation amplitude is large, the system appears chaotic motion. The damping coefficient limits the possibility of complex motions of the system. With the influence of the damping coefficient, the motion of the system tends to be stable.
ABSTRACT: This paper investigates the thermal vibration and buckling of the functionally graded carbon nanotube reinforced composite (FG-CNTRC) quadrilateral plate using the meshless method. Four distributions of the reinforcements along the thickness direction are considered, which are the uniform distributions (UD), FG-V, FG-O and FG-X. The corresponding effective material properties including Young's modulus, mass density, Poisson's ratio and thermal expansion coefficients are estimated by the rule of mixture with the CNT efficiency parameters accounting for the size-dependence. The first-order shear deformation theory (FSDT) with the consideration of thermal effects is employed. Based on Hamilton's principle and the moving least square (MLS) approximation, the discrete governing equations for the vibration of the FG-CNTRC plate are derived. The free vibration of the regular and irregular plates with and without the temperature effect are considered respectively, and the corresponding natural frequencies and mode shapes are obtained by the eigenvalue problem. The stability analysis of the uniaxial and biaxial mechanical and thermal buckling are also conducted subsequently. The effects of the volume fraction, distribution pattern, geometrical characteristics and temperature on the buckling behaviors of the CNTRC quadrilateral plate are discussed in detail.

References listed at the end of the paper:

A. Alibeigloo, Coupled thermoelasticity analysis of carbon nanotube reinforced composite rectangular plate subjected to thermal shock, Compos. Part B, 153 (2018), pp. 445-455


H. Matsunaga, Thermal buckling of cross-ply laminated composite and sandwich plates according to a global higher-order deformation theory, Compos. Struct., 68 (2005), pp. 439-454


The displacements and deflection were approximated by the clamped surface of the panel. The corresponding governing system of equations is presented in terms of unknown orthotropic cylindrical shells. The interface surface between the ribs and the skin layer is adopted as a reference buckling of this two reinforcement of the panel is modelled as a layer with average effective stiffness characteristics. And the loading results in the biaxial compression of the panel due to Poisson's effect. The anisogrid lattice reinforcement of the panel is modelled as a layer with average effective stiffness characteristics. And the loading results in the biaxial compression of the panel due to Poisson's effect. The anisogrid lattice reinforcement of the panel is modelled as a layer with average effective stiffness characteristics. And the loading results in the biaxial compression of the panel due to Poisson's effect.


ABSTRACT: Buckling of a biaxially compressed anisogrid stiffened composite cylindrical panel with clamped edges is considered in this paper. The panel is subjected to compressive load applied to its curved sides. This loading results in the biaxial compression of the panel due to Poisson's effect. The anisogrid lattice reinforcement of the panel is modelled as a layer with average effective stiffness characteristics. And the buckling of this two-layered shallow panel has been modelled using the engineering theory of laminated orthotropic cylindrical shells. The interface surface between the ribs and the skin layer is adopted as a reference surface of the panel. The corresponding governing system of equations is presented in terms of unknown displacements and deflection of the reference surface. The equations have been solved using the Galerkin method in which the displacements and deflection were approximated by the clamped-clamped beam functions.
and their first derivatives. Based on this solution, an analytical formula has been derived for the critical compressive buckling load. Using this formula, the critical loads are calculated for the cylindrical and flat panels having different geometric parameters. The results of calculations have been verified by the finite-element analyses.

References listed at the end of the paper:

V.S. Gontkevich, Natural Vibrations of Plates and Shells. Kiev: Nauk Dumka, Transl. by Lockheed Missiles and Space Co. (1964)
A.V. Lopatin, E.V. Morozov, A.V. Shatov, Buckling of the composite anisogrid lattice plate with clamped edges under shear load, Compos. Struct., 159 (2016), pp. 72-80
MSC Nastran, Quick reference guide's: MSC. Software Corporation (2011)
S. Niemann, R. Wagner, M. Beerhorst, C. Hühne, Testing and analysis of anisogrid prepreg element specimens under uniaxial tension and compression, Compos. Struct., 160 (2017), pp. 594-603
L. Sorrentino, M. Marchetti, C. Bellini, A. Delfini, M. Albano, Design and manufacturing of an isogrid structure in composite material: numerical and experimental results, Compos. Struct., 143 (2016), pp. 189-201
L. Sorrentino, M. Marchetti, C. Bellini, A. Delfini, F. Del Sette, Manufacture of high performance isogrid structure by robotic filament winding, Compos. Struct., 164 (2017), pp. 43-50
G. Totaro, F. De Nicola, Recent advance on design and manufacturing of composite isogrid structures for space launchers, Acta Astronaut., 81 (2012), pp. 570-577
G. Totaro, Optimal design concepts for flat isogrid and isogrid lattice panels longitudinally compressed, Compos. Struct., 129 (2015), pp. 101-110
V.V. Vasiliev, V.A. Barynin, A.F. Rasin, Anisogrid lattice structures - survey of development and application, Compos. Struct., 54 (2001), pp. 361-370
V.V. Vasiliev, A.F. Rasin, Anisogrid composite lattice structures for spacecraft and aircraft applications, Compos. Struct., 76 (2006), pp. 182-189
V.V. Vasiliev, V.A. Barynin, A.F. Rasin, Anisogrid composite lattice structures – development and aerospace applications, Compos. Struct., 94 (2012), pp. 1117-1127


ABSTRACT: In the paper, free vibration analysis of tapered Functionally Graded Material (FGM) plate with the inclusion of porosity has been performed. The tapered porous FGM plate is considered resting on a two-parameter (Winkler and Pasternak) elastic foundation. The displacement model of the kinematic equation for the plates in the present formulation is based on the First-order shear deformation theory (FSDT). The
governing equation for free vibration analysis of FGM plates is obtained using Hamilton's principle. Simple power-law, Exponential Law, and Sigmoid law are used for tailored the material properties in the thickness direction of FGM plates. The solution of the resulting partial differential equation is obtained by using Galerkin-Vlasov's method with different boundary conditions. The solutions for uniform and uniform varying thick plates are investigated, and a comparative study is examined by comparing the results obtained with FSDT and Higher-order shear deformation theory (HSDT). The findings of the comparative study with the present approach provide pertinent outcomes for the vibration analysis of tapered FGM plates. The analytical solution for vibration analysis is presented to reveal the effects of porosity parameter, volume exponent, span ratio, aspect ratio, porosity distribution, and boundary conditions. Also, the elastic foundation parameter on tapered FGM plate increases the non-dimensional frequency, and the Pasternak foundation effect always dominates over the Winkler foundation.

References listed at the end of the paper:
D. Chen, S. Kitipornchai, J. Yang, Nonlinear free vibration of shear deformable sandwich beam with a functionally graded porous core, Thin-Walled Struct., 107 (2016), pp. 39-48, 10.1016/j.twss.2016.05.025
A. Gupta, M. Talha, B.N. Singh, Vibration characteristics of functionally graded material plate with various boundary constraints using higher order shear deformation theory, Compos. B Eng., 94 (2016), pp. 64-74, 10.1016/j.compositesb.2016.03.006
E. Magnucka-Blandzi, Axi-symmetrical deflection and buckling of circular porous-cellular plate, Thin-Walled Struct., 46 (2008), pp. 333-337, 10.1016/j.twss.2007.06.006
H. Matsunaga, Free vibration and stability of functionally graded plates according to 2-D higher-order deformation theory, Compos. Struct. - Compos STRUCT., 84 (2008), pp. 132-146, 10.1016/j.compositesstruct.2007.07.006
M. Pouladvand, Thermal stability of thin rectangular plates with variable thickness made of functionally graded materials, 1 (2009), pp. 171-189


A.M. Zenkour, A quasi-3D refined theory for functionally graded single-layered and sandwich plates with porosities, Compos. Struct., 201 (2018), pp. 38-48, 10.1016/j.compstruct.2018.05.147


ABSTRACT: The FG (functionally graded) curved beams are investigated in this paper. Starting from the general mode, the higher-order circumferential displacement is re-expressed in an orthogonal form by virtue of the assumptions and the shear stress free condition. On this basis, generalized stresses and strains are defined, and the uncoupled constitutive relationships are built for an FG curved beam as if the beam were homogeneous. According to the principle of virtual work, the higher-order beam theory is established, including equilibrium equations and corresponding boundary conditions. The lower-order beam theory is then established by ignoring the contributions of higher-order moment and higher-order shear force to the virtual wok, and hence it is correlated with the higher-order beam theory. A procedure is suggested to analytically solve FG curved beam problems with the lower-order theory. The results for the clamped-free and clamped-clamped curved beams
validate the present theory and the results for the simply-supported beam shed light on the nature of the Navier's solution.


ABSTRACT: A comprehensive understanding of the dynamic instability of shell structure is critical to avoid resonance damage. On the basis of that, an accurate and analytical method for investigation the dynamic instability of laminated functionally graded carbon nanotube reinforced composite (FG-CNTRC) conical shell surrounded by the elastic foundations is presented in this work based on the first-order shear deformation theory. In the analysis, uniform or functionally graded distributions of reinforcements across the shell thickness are considered and the extended Voigt model is employed to estimate the CNTRC material properties. The governing equations of conical shell subjected to parametric deformation are established by the Hamilton's principle considering first order shear deformation shell theory. Then the Mathieu-Hill equations describing the parametric stability of conical shell are obtained by generalized differential quadrature (GDQ) method, and the Bolotin's method is utilized to obtain the first-order approximations of principal instability regions of shell structure. By comparing the numerical results with the existing solutions in open literature, the validity of the proposed theoretical model is verified. Finally, the influences on volume fractions and types of CNTs, lamination angle, elastic foundations stiffness and lamination angle on the dynamic stability of laminated FG-CNTRC conical shell have been investigated.

References listed at the end of the paper:

K.Y. Lam, T.Y. Ng, Dynamic stability of cylindrical shells subjected to conservative periodic axial loads using different shell theories, J. Sound Vib., 207 (4) (1997), pp. 497-520
X. Li, C.C. Du, Y.H. Li, Parametric instability of a functionally graded cylindrical thin shell subjected to both axial disturbance and thermal environment, Thin-Walled Struct., 123 (2018), pp. 25-35
ABSTRACT: Present manuscript undergoes with the investigation of the wave propagation features of smart magnetostrictive sandwich nanoplates (MSNPs) with regard to the influences of small scale in the context of the so-called nonlocal strain gradient theory (NSGT) of elasticity. The under observation continuous system, i.e. a thin-type one, is modeled via the Kirchhoff-Love theorem incorporated with the dynamic form of the principle of virtual work considering the impacts of both thermal and viscose losses on the dispersion characteristics of the nanostructure. Once the modified size-dependent constitutive equations are inserted into the motion equations, the final governing equations of the problem are attained. Thereafter, an analytical dispersion solution will be employed for the purpose of solving the dynamic problem to extract the wave response of the system. In order to examine the accuracy of the presented results, the natural frequencies obtained from this methodology are compared with those reported in the open literature. According to the presented illustrations, it can be declared that the magnetostriction can affect the dispersion responses of the smart nanoplate in low wave numbers.

References listed at the end of the paper:
M. Arda, M. Aydogdu, Torsional statics and dynamics of nanotubes embedded in an elastic medium, Compos. Struct., 114 (2014), pp. 80-91
Ç. Demir, Ö. Civalek, A new nonlocal FEM via Hermitian cubic shape functions for thermal vibration of nano beams surrounded by an elastic matrix, Compos. Struct., 168 (2017), pp. 872-884
F. Ebrahimi, A. Dabbagh, Magnetic field effects on thermally affected propagation of acoustical waves in rotary double-nanobeam systems, Waves in Random and Complex Media (2018), pp. 1-21
The studied plate is supported by the two
medium.

(A) Department of Mathematics, Faculty of Science, King Abdulaziz University, P.O. Box 80203, Jeddah, 21589, Saudi Arabia
(B) Department of Mathematics, Faculty of Science, Kafrelsheikh University, Kafrelsheikh, 33516, Egypt
(C) Department of Mathematics, Faculty of Science, Bisha University, Bisha 61922, Saudi Arabia


ABSTRACT: Vibration of a simply supported rectangular composite laminated plate with four actuating magnetostrictive layers is analyzed in the current study. The studied plate is supported by the two-parameter
elastic (Pasternak's) foundations and subjected to a hygrothermal environment. Hamilton's principle and five theories are utilized to derive the kinematic equations considering the transverse shear strain with/without the transverse normal strain. The effects due to modes, lamination schemes, elastic foundations parameters, the magnitude of the feedback coefficient, position of the magnetostrictive layers, temperature rise, the degree of moisture concentration on the damping coefficients, damped natural frequencies, maximum deflection, vibration time and damping ratio, are investigated. Some conclusions about the effect of the temperature and moisture concentrations on the vibration behavior of the plate are formulated. The outcomes refer to that increasing the intelligent actuating layers in the advanced plates improves the vibration damping process, but also the position of these layers plays an effective role in reduction the time interval of damping and improving the vibration damping characteristics. Also, hygrothermal conditions reduce the ability of smart components to suppress the vibration of structures.

References listed at the end of the paper:
M. Anjanappa, J. Bi, Modelling, design and control of embedded Terfenol-D actuator, Smart Struct. Intel. Sys., 1917 (1993), pp. 908-918
M. Arefi, T. Rabczuk, A nonlocal higher order shear deformation theory for electro-elastic analysis of a piezoelectric doubly curved nano shell, Compos. B Eng., 168 (1) (2019), pp. 496-510
C.C. Hong, Rapid heating induced vibration of magnetostrictive functionally graded material plates, J. Vib. Acoust., 134 (2) (2012), Article 021019
J.S. Kumar, N. Ganesan, S. Swarnamani, C. Padmanabhan, Active control of simply supported plates with a magnetostrictive layer, Smart Mater. Struct., 13 (3) (2004), pp. 487-492

C.K. Kundu, J.-H. Han, Vibration characteristics and snapping behavior of hygro-thermo-elastic composite doubly curved shells, Compos. Struct., 91 (2009), pp. 306-317


B.P. Patel, M. Ganapathi, D.P. Makhecha, Hygrothermal effects on the structural behaviour of thick composite laminates using higher-order theory, Compos. Struct., 56 (2002), pp. 25-34


A.M. Zenkour, Hygro-thermo-mechanical effects on FGM plates resting on elastic foundations, Compos. Struct., 93 (2010), pp. 234-238


ABSTRACT: The paper deals with the finite bending analysis of transversely isotropic hyperelastic slender beams made of a neo-Hookean material with longitudinal voids. The fully nonlinear behavior of the structures is presented in the framework of three-dimensional finite elasticity. A semi-inverse approach is used to describe the beam kinematics, which includes the anticlastic effect. The theoretical framework is developed in both Lagrangian and Eulerian reference systems. Explicit formulas are obtained for stretches and stresses, in a general framework valid for transversely isotropic beams. The effect of porosity on the Piola-Kirchhoff and Cauchy stress components is then discussed. The results are all obtained and validated analytically, and could be helpful to model structural systems in the fields of bioengineering and soft robotics which exhibit both large displacements and deformations.

References listed at the end of the paper:


G. Searle, Experimental Elasticity: A Manual for the Laboratory, University Press (1908)


ABSTRACT: The submerged air-inflated membrane cylinder is studied through perturbation and numerical integration. The problem depends on the distance between the anchors and a parameter which quantifies the pressure difference. Partial similarity and full similarity solutions are found. The results show nonlinear phenomena such as instability, snap through and hysteresis, especially during the deflation process.

References listed at the end of the paper:

ABSTRACT: In this paper, the dynamic stability of axially transporting viscoelastic beams with two-frequency parametric excitation and 1:3 internal resonance is investigated for the first time. The governing equation and corresponding inhomogeneous boundary conditions are developed by the Newton's second law. The viscoelastic characteristic of the transporting Euler-Bernoulli beam obeys the Kelvin-Voigt model. The axial tension is considered to vary longitudinally. Direct method of multiple scales is employed to obtain the solvability conditions in principal parametric resonances. The stability boundary conditions are obtained by the Routh-Hurwitz criterion. Numerical examples are shown to illustrate the effects of relevant parameters on the stability boundaries. Unusual and interesting phenomena of stability boundaries occur in two-frequency parametric excitation and 1:3 internal resonance. The accuracies of the approximate analytical results are verified by comparing with the numerical results, which obtained by a differential quadrature method.

References listed at the end of the paper:
H. Ding, D.P. Li, Static and dynamic behaviors of belt-driven dynamic systems with a one-way clutch, Nonlinear Dynam., 78 (2) (2014), pp. 1553-1575
H.R. Öz, On the vibrations of an axially traveling beam on fixed supports with variable velocity, J. Sound Vib., 239 (2001), pp. 556-564
B. Sahoo, L.N. Panda, G. Pohit, Two-frequency parametric excitation and internal resonance of a moving viscoelastic beam, Nonlinear Dynam., 82 (4) (2015), pp. 1721-1742


More papers published in the journal, International Journal of Numerical Methods in Engineering (2019 and on);


SUMMARY: This paper presents the finite rotation exact geometry four-node solid-shell element using the sampling surfaces (SaS) method. The SaS formulation is based on choosing inside the shell N SaS parallel to the middle surface to introduce the displacements of these surfaces as basic shell unknowns. Such choice of unknowns with the consequent use of Lagrange polynomials of degree N−1 in the through-thickness
distributions of displacements, strains and stresses leads to a robust higher-order shell formulation. The SaS are located at only Chebyshev polynomial nodes that make possible to minimize uniformly the error due to Lagrange interpolation. The proposed hybrid-mixed four-node solid-shell element is based on the Hu-Washizu variational principle and is completely free of shear and membrane locking. The tangent stiffness matrix is evaluated through efficient 3D analytical integration and its explicit form is given. As a result, the proposed exact geometry solid-shell element exhibits a superior performance in the case of coarse meshes and allows the use of load increments, which are much larger than possible with existing displacement-based solid-shell elements.


SUMMARY: In this paper, we present novel techniques of using quadratic Bézier triangular and tetrahedral elements for elastostatic and implicit/explicit elastodynamic simulations involving nearly incompressible linear elastic materials. A simple linear mapping is proposed for developing finite element meshes with quadratic Bézier triangular/tetrahedral elements from the corresponding quadratic Lagrange elements that can be easily generated using the existing mesh generators. Numerical issues arising in the case of nearly incompressible materials are addressed using the consistent B-bar formulation, thus reducing the finite element formulation to one consisting only of displacements. The higher-order spatial discretization and the nonnegative nature of Bernstein polynomials are shown to yield significant computational benefits. The optimal spatial convergence of the B-bar formulation for the quadratic triangular and tetrahedral elements is demonstrated by computing error norms in displacement and stresses. The applicability and computational efficiency of the proposed elements for elastodynamic simulations are demonstrated by studying several numerical examples involving real-world geometries with complex features. Numerical results obtained with the standard linear triangular and tetrahedral elements are also presented for comparison.


SUMMARY: We are interested in the layer-wise modeling of composite cylindrical shell structures based on a variable separation method. The present study is focused on the use of a multiresolution strategy to decrease the computational cost of numerous analyses where some parameters can change. For this purpose, the displacement field is approximated as a sum of separated functions of the in-plane coordinates and the transverse coordinate. Thus, an iterative process that consists of solving a two-dimensional (2D) and a one-dimensional problem successively at each iteration is required. In the thickness direction, a fourth-order expansion in each layer is considered. For the in-plane description, a classical finite element method is used. In our framework of a multiresolution process, once a first computation is achieved, the previously built 2D functions can be used. Thus, the following problems to be solved can be limited to a one-dimensional problem. If needed, only few 2D functions might be built. The approach is assessed through mechanical tests on L-angle specimens by comparing with a quasi-three-dimensional layer-wise approach. It is illustrated by varying the geometry and the stacking sequences of the shell.

SUMMARY: This paper aims to revisit the effect of sloshing on the flutter characteristics of a partially liquid-filled cylinder. A computational fluid-structure interaction model within the framework of the finite element method is developed to capture fluid-structure interactions arising from the sloshing of the internal fluid and the flexibility of its containing structure exposed to an external supersonic airflow. The internal liquid sloshing is represented by a more sophisticated model, referred to as the liquid sloshing model, and the shell structure is modeled by Sanders' shell theory. The aerodynamic pressure loading is approximated by the first-order piston theory. The initial geometric stiffness due to prestresses in the initial configuration stemming from the fluid hydrostatic pressure, internal pressure, and axial compression load is also considered. The obtained results reveal that the sloshing of the internal fluid has little influence on the supersonic flutter boundary of a cylinder partially filled with liquid, at least for the case considered here. It is also shown that the critical freestream static pressure predicted by the sloshing model is negligibly larger than that calculated by the hydroelastic model of the internal fluid, which means that the sloshing of the internal fluid slightly overestimates the flutter boundary.


ABSTRACT: A variational framework is employed to generate inverse mass matrices for isogeometric analysis (IGA). As different dual bases impact not only accuracy but also computational overhead, several dual bases are extensively investigated. Specifically, locally discontinuous biorthogonal basis functions are evaluated in detail for B-splines of high continuity and Bézier elements with a standard C0 continuous finite element structure. The boundary conditions are enforced by the method of localized Lagrangian multipliers after generating the inverse mass matrix for completely free body. Thus, unlike inverse mass matrix methods without employing the method of Lagrange multipliers, no modifications in the reciprocal basis functions are needed to account for the boundary conditions. Hence, the present method does not require internal modifications of existing IGA software structures. Numerical examples show that globally continuous dual basis functions yield better accuracy than locally discontinuous biorthogonal functions, but with much higher computational overhead. Locally discontinuous dual basis functions are found to be an economical alternative to lumped mass matrices when combined with mass parameterization. The resulting inverse mass matrices are tested in several vibration problems and applied to explicit transient analysis of structures.


SUMMARY: The isogeometric formulation of the boundary element method (IGA-BEM) is investigated within the adaptivity framework. Suitable weighted quadrature rules to evaluate integrals appearing in the Galerkin BEM formulation of 2D Laplace model problems are introduced. The proposed quadrature schemes are based on a spline quasi-interpolation (QI) operator and properly framed in the hierarchical setting. The local nature of the QI perfectly fits with hierarchical spline constructions and leads to an efficient and accurate numerical scheme. An automatic adaptive refinement strategy is driven by a residual-based error estimator. Numerical examples show that the optimal convergence rate of the Galerkin solution is recovered by the proposed adaptive method.

SUMMARY: In this work, the recently proposed unsymmetric 4-node 12-DOF (degree of freedom) membrane element [1], which has demonstrated excellent performance for the classical elastic problems, is further extended for the modified couple stress theory, to account for the size effect of materials. This is achieved via two formulation developments. Firstly, by using the penalty function method, the kinematic relations between the element's nodal drilling DOFs and the true physical rotations are enforced. Consequently, the continuity requirement for the modified couple stress theory is satisfied in weak sense, and the symmetric curvature test function can be easily derived from the gradients of the drilling DOFs. Secondly, the couple stress field that satisfies \textit{a priori} the related equilibrium equations is adopted as the energy conjugate trial function to formulate the element for the modified couple stress theory. As demonstrated by a series of benchmark tests, the new element can efficiently capture the size–dependent responses of materials and is robust to mesh distortions. Moreover, as the new element uses only three conventional DOFs per node, it can be readily incorporated into the standard finite element program framework and commonly available finite element programs.

SUMMARY: This paper deals with layered plates and shells subjected to static loading. The kinematic assumptions are extended by a jump function in dependence of a damage parameter. Additionally, an intermediate layer is arranged at any position of the laminate. This allows numerical simulation of onset and growth of delaminations. The equations of the boundary value problem include besides the equilibrium in terms of stress resultants, the local equilibrium in terms of stresses, the geometric field equations, the constitutive equations, and a constraint which enforces the correct shape of a superposed displacement field through the thickness as well as boundary conditions. The weak form of the boundary value problem and the associated finite element formulation for quadrilaterals is derived. The developed shell element possesses the usual 5 or 6 degrees of freedom at the nodes. This is an essential feature since standard geometrical boundary conditions can be applied and the elements are applicable to shell intersection problems. With the developed model, residual load–carrying capacities of layered shells due to delamination failure are computed.

ABSTRACT: An improved eight noded isoparametric quadratic plate bending element based on refined higher order zigzag theory (RHZT) has been developed in the present study to determine the interlaminar stresses of multilayered composite laminates. The C\textsuperscript{0} continuous element has been formulated by considering warping function in the displacement field based on the refined higher order zigzag theory (RHZT). Shear locking phenomenon is avoided by considering substitute shear strain field. The continuity of transverse shear stresses cannot be ensured by the proposed zigzag formulation directly and hence the continuity conditions of transverse shear stresses have been established by using the three dimensional stress equilibrium equations in the present study. The transverse shear stresses are computed in a simplified manner using the differential equations of stress equilibrium. A finite element code is developed by using MATLAB software package. The performance of the present finite element model is validated by comparing the results with three–dimensional elasticity solutions. The superiority of the proposed element in view of computational efficiency, simplicity and accuracy has been examined by comparing the present solutions with those available in published literature using other elements.

SUMMARY: The buckling properties of thin-walled structures are sensitive to different sources of imperfections, among which the geometric imperfections are of paramount importance. This work contributes to the methodology of shell buckling analysis with respect to the following aspects: first, we propose an isogeometric analysis framework for the buckling analysis of shell structures which naturally eliminates the geometric discretization errors; second, we introduce a parameter-free Nitsche-type formulation for thin shells at large deformations that weakly enforces coupling constraints along trimmed boundaries. In combination with the finite cell method, the proposed conceptual modeling and analysis framework is able to handle engineering-related shell structures; and third, we introduce a NURBS modeling of measured geometric imperfection fields, which is much closer to the true imperfection shape compared to the classically used faceted FE models. We demonstrate with a number of benchmark problems and engineering models that our proposed framework is able to fully compete with established and highly sophisticated finite element formulations but at a significant higher level of accuracy and reliability of the analysis results.


SUMMARY: Stiffened composite structures are commonly composed of skins and stiffeners that are employed to transfer and carry load, respectively. An improved multiscale finite element method is presented for geometrically nonlinear bending analysis of composite grid stiffened laminates. In the developed method, two kinds of strategies for establishing stiffened multiscale models are presented, in which the stiffeners are modeled at different scale. By introducing a virtual degree of freedom and additional coupling terms, multiscale base functions are improved to consider the local effects of stiffeners and coupling effects of composites. To construct the multiscale base functions of stiffened multiscale models, an extended displacement boundary conditions are constructed, in which the displacements of stiffeners are imposed constraints based on the displacement continuous conditions between skin and stiffener. Incremental multiscale finite element formulations are derived based on Total-Lagrange description and von Karman's large deflection plate theory. The incremental displacement boundary conditions are constructed to consider the effect of microscopic unbalanced force on microscopic results. Numerical examples show high efficiency and applicability of the developed method for composite grid stiffened laminates.


ABSTRACT: An improved eight-noded isoparametric quadratic plate bending element based on refined higher-order zigzag theory (RHZT) has been developed in the present study to determine the interlaminar stresses of multilayered composite laminates. The $C^0$ continuous element has been formulated by considering warping function in the displacement field based on the RHZT. Shear locking phenomenon is avoided by considering substitute shear strain field. The continuity of transverse shear stresses cannot be ensured by the proposed zigzag formulation directly, and hence, the continuity conditions of transverse shear stresses have been established by using the three-dimensional (3D) stress equilibrium equations in the present study. The transverse shear stresses are computed in a simplified manner using the differential equations of stress equilibrium. A finite element code is developed by using MATLAB software package. The performance of the present finite element model is validated by comparing the results with 3D elasticity solutions. The superiority of the proposed element in view of computational efficiency, simplicity, and accuracy has been examined by comparing the present solutions with those available in published literature using other elements.
SUMMARY: We revisit compatible finite element formulations for Kirchhoff plates and propose a new general degree hybridized approach that strictly imposes C0 continuity. These new elements are triangular and based on nodal polynomial approximation functions that only use displacement and rotation degrees of freedom for assembly, and thereby “nearly” impose C0 continuity. This condition is then strictly enforced by adding appropriately chosen hybrid constraints and the corresponding Lagrange multipliers. Unlike all other existing approaches, this formulation allows for the definition of elements of arbitrary degree considering a single polynomial basis for each element, without using degrees of freedom associated with second-order derivatives. The convergence is compared with that of alternative approaches in terms of numbers of elements and degrees of freedom.

SUMMARY: A recent distortion-tolerant unsymmetric 8-node hexahedral solid-shell element US-ATFHS8, which takes the analytical solutions of linear elasticity as the trial functions, is successfully extended to geometric nonlinear analysis. This extension is based on the corotational (CR) approach due to its simplicity and high efficiency, especially for geometric nonlinear analysis where the strain is still small. Based on the assumption that the analytical trial functions can properly work in each increment during the nonlinear analysis, the incremental corotational formulations of the nonlinear solid-shell element US-ATFHS8 are derived within the updated Lagrangian (UL) framework, in which an appropriate updated strategy for linear analytical trial functions is proposed. Numerical examples show that the present nonlinear element US-ATFHS8 possesses excellent performance for various rigorous tests no matter whether regular or distorted mesh is used. Especially, it even performs well in some situations that other conventional elements cannot work.

SUMMARY: A novel smart hybrid-Trefftz finite element (HTFE) has been developed for the analysis of smart laminated composite plates. The substrates of the smart plates are symmetric and antisymmetric cross-ply plates. The derivation of this HTFE is devoid of the complicated task of finding the particular solutions of simultaneous governing partial differential equations. The Trefftz functions are constructed from the finite number of free-field exact solutions of the homogeneous simultaneous governing partial differential equations of the element domain in a straightforward manner without transforming them into a single governing equation. The HTFE is validated with the exact solutions of the smart composite plates. It is observed that this HTFE is an efficient finite element and can be utilized for the analysis of active control of smart composite structures.

SUMMARY: In this study, a locking-free n-sided C0 polygonal finite element is presented for nonlinear analysis of laminated plates. The plate kinematics is based on Reddy's third-order shear deformation theory (TSDT). The in-plane displacements are approximated using barycentric form of Lagrange shape functions. The weak-form Galerkin formulation based on the kinematics of TSDT requires the C0 approximation of the transverse displacement over the polygonal element. This is achieved by embedding the C0 Lagrange interpolants over a cubic Bernstein-Bezier patch defined over the n-sided polygonal element. Such an approach ensures the continuity of the derivative field at the inter-element edges. In addition, Eringen's stress-gradient nonlocal constitutive equations are used in the present formulation to account for nonlocality. The effect of geometric nonlinearity is taken by considering the von Kármán geometric nonlinearity. Examples are presented to show the effect of nonlocality, geometric nonlinearity, and the lamination scheme on the bending behavior of
laminated composite plates. The results are compared with analytical solutions, conventional FEM results, and with those available in the literature. Shear locking is addressed considering reduced integration and consistent interpolation techniques. The patch test is used to check the convergence of the element developed.

SUMMARY: We present a finite element (FE) formulation for the free vibration analysis of doubly curved laminated composite and sandwich shells having multiple delaminations, employing a facet shell element based on the efficient third-order zigzag theory and the region approach of modeling delaminations. The methodology, hitherto not attempted, is general for delaminations occurring at multiple interfacial and spatial locations. A recently developed hybrid method is used for satisfying the continuity of the nonlinear layerwise displacement field at the delamination fronts. The formulation is shown to yield very accurate results with reference to full-field three-dimensional FE solutions, for the natural frequencies and mode shapes of delaminated shallow and deep, composite and highly inhomogeneous soft-core sandwich shells of different geometries and boundary conditions, with a significant computational advantage. The accuracy is sensitive to the continuity method used at the delamination fronts, the usual point continuity method yielding rather poor accuracy, and the proposed hybrid method giving the best accuracy. Such efficient modeling of laminated shells with delamination damage will be of immense use for model-based techniques for structural health monitoring of laminated shell-type structures.

SUMMARY: The co-rotational formulation of quadrature planar beam element undergoing large displacement and large rotation is presented. A local frame co-rotates with the differential element and decomposes the motion into a rigid body movement and a strain-producing deformation. General explicit formulations of elemental vectors and matrices, including internal force vector, external force vector, tangent stiffness matrix, and mass matrix, are derived via the numerical integration together with the differential quadrature law. Thus, the element nodes and numerical integration method can be chosen arbitrarily based on the accuracy requirement and problem type. A number of case studies on the static, postbuckling, and dynamic response of beams and frame structures are conducted. The convergence study shows that the co-rotational quadrature element has an exponential rate of convergence and the reduced Gauss integration yield the highest accuracy. It is seen that the proposed co-rotational quadrature beam element is simple in formulations, computationally efficient, and capable of capturing the complex nonlinear behavior of beam and frame structures with high precision.

SUMMARY: This study aims to develop efficient numerical optimization methods for finding the optimal topology of nonlinear structures under dynamic loads. The numerical models are developed using the bidirectional evolutionary structural optimization method for stiffness maximization problems with mass constraints. The mathematical formulation of topology optimization approach is developed based on the element virtual strain energy as the design variable and minimization of compliance as the objective function. The suitability of the proposed method for topology optimization of nonlinear structures is demonstrated through a series of two- and three-dimensional benchmark designs. Several issues relating to the nonlinear structures subjected to dynamic loads such as material, geometric, and contact nonlinearities are addressed in the examples. It is shown that the proposed approach generates more reliable designs for nonlinear structures.
SUMMARY: Free vibration characteristics of thick skew plates reinforced by functionally graded carbon nanotubes (CNTs) reinforced composite are presented. Discrete singular convolution (DSC) method is used for the numerical solution of vibration problems via geometric mapping technique. Using the geometric transformation via a four-node element, the straight-sided quadrilateral physical domain is mapped into a square domain in the computational space. Then the method of discrete singular convolution with some singular kernels such as Regularized Shannon's delta (RSD) and Lagrange's delta kernels (LDK) have been used for spatial discretizing of the resulting governing equation of motion. Calculated results have been presented in order to show the effects of volume fraction of CNT, skew angles, CNT distribution types, plate aspect ratio and length-to-thickness ratio on the frequency of CNT reinforced skew plate. The current results are compared with the related results available in the literature and obtained by different methods. It is shown that reasonable accurate results are obtained for free vibration of nanocomposite plates with less computational effort for higher modes. Several test examples for different plate have been selected to demonstrate the convergence properties, accuracy, and simplicity in numerical implementation of DSC procedures. This approach has verified the accuracy, and applicability of DSC method to the class of problem considered in this study. Furthermore, in the numerical examples in the scope of the study, the results obtained with DSC method using a coarser grid are more accurate than the values obtained by finite elements and differential quadrature (DQ) methods. It is also revealed that the method of discrete singular convolution is a promising and potential approach for computational mechanics of nonrectangular plates with nanocomposite reinforced.

SUMMARY: This study presents a level set–based topology optimization with isogeometric analysis (IGA) for controlling high-frequency electromagnetic wave propagation in a domain with periodic microstructures (unit cells). The high-frequency homogenization method is applied to characterize the macroscopic high-frequency waves in periodic heterogeneous media whose wavelength is comparative to or smaller than the representative length of a unit cell. B-spline basis functions are employed for the IGA discretization procedure to improve the performance of electromagnetic wave analysis in a unit cell and topology optimization. Also, to keep the same order of continuity on the periodic boundaries as on other element edges in the domain, we propose the extended domain approach, while incorporating Floquet periodic boundary condition (FPBC). Two types of optimization problems are taken as examples to demonstrate the effectiveness of the proposed method in comparison with the standard finite element analysis (FEA). The optimization results provide optimized topologies of unit cells qualified as anisotropic metamaterials with hyperbolic and bidirectional dispersion properties at the macroscale.

SUMMARY: This article presents the design of a metamaterial for the shear layer of a nonpneumatic tire using topology optimization, under stress and buckling constraints. These constraints are implemented for a smooth maximum function using global aggregation. A linear elastic finite element model is used, implementing solid isotropic material with penalization. Design sensitivities are determined by the adjoint method. The method of moving asymptotes is used to solve the numerical optimization problem. Two different optimization statements are used. Each requires a compliance limit and some aspect of continuation. The buckling analysis is linear, considering the generalized eigenvalue problem of the conventional and stress stiffness matrices. Various symmetries, base materials, and starting geometries are considered. This leads to novel topologies that all achieve the target effective shear modulus of 10 MPa, while staying within the stress constraint. The stress-only
designs generally were susceptible to buckling failure. A family of designs (columnar, noninterconnected representative unit cells) that emerge in this study appears to exhibit favorable properties for this application.

SUMMARY: This article presents a novel formulation for sandwich beams with soft core based on a layerwise description of continuous transverse shear stress field. The transverse shear stress field is assumed to follow a quadratic distribution in thick face layers and a uniform distribution in soft core. Based on stress-strain relations, transverse shear strain is obtained, and in-plane displacement field is determined by taking the integral of the transverse shear strain. By enforcing interlaminar displacement continuity, an explicit displacement field expression containing only displacement variables is formulated. In this formulation, interlaminar continuity conditions of displacement and transverse shear stress are satisfied simultaneously, and transverse shear and crosssectional warping effects in thick face layers are accurately taken account. To show characteristics and advantages of the present model, some classical theoretical models are further developed under different kinematic assumptions. The governing equations are derived using Hamilton principle, and finite element solutions for static and dynamic analysis of sandwich beams are presented. Comparisons with exact solution and other well-known solutions, well demonstrate high accuracy of the present model for sandwich beams with different features. Besides, numerical discussions further reflect accuracy advantages of the present model in static and dynamic analysis of sandwich beams.

Takeki Yamamoto (1) and Takahiro Yamada (2)
(1) Department of Aerospace Engineering, Tohoku University, Aza-Aoba 6-6-01, Aramaki, Aoba-ku, Sendai 980-8579, Japan.
(2) Environment and Information Science, Yokohama National University, Kanagawa, Japan
SUMMARY: The authors proposed a quadrilateral shell element enriched with degrees of freedom to represent thickness-stretch. The quadrilateral shell element can be utilized to consider large deformations for nearly incompressible materials, and its performance is demonstrated in small and large deformation analyses of hyperelastic materials in this study. Formulation of the proposed shell element is based on extension of the MITC4 shell element. A displacement variation in the thickness direction is introduced to evaluate the change in thickness. In the proposed approach, the thickness direction is defined using the director vectors at each midsurface node. The thickness-stretch is approximated by the movements of additional nodes, which are placed along the thickness direction from the bottom to the top surface. The transverse normal strain is calculated using these additional nodes without assuming the plane stress condition; hence, a three-dimensional constitutive equation can be employed without any modification. In this work, the authors apply an assumed strain technique to the special shell element to alleviate volumetric locking for nearly incompressible materials. Several numerical examples are presented to examine the effectiveness of the proposed element.

Yan Shang (1), Chen-Feng Li (2) and Kang-Yu Jia (3)
(1) Mechanics and Control of Mechanical Structures, College of Aerospace Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China
(2) Zienkiewicz Centre for Computational Engineering and Energy Safety Research Institute, College of Engineering, Swansea University, Swansea, UK
(3) Hubei Key Laboratory of Advanced Textile Materials & Application, Wuhan Textile University, Wuhan, China
SUMMARY: A new C\(^0\) 8-node 48-DOF hexahedral element is developed for analysis of size-dependent problems in the context of the modified couple stress theory by extending the methodology proposed in our recent work (Shang et al., Int J Numer Methods Eng 119(9): 807-825, 2019) to the three-dimensional (3D) cases. There are two major innovations in the present formulation. First, the independent nodal rotation degrees of freedom (DOFs) are employed to enhance the standard 3D isoparametric interpolation for obtaining the displacement and strain test functions, as well as to approximatively design the physical rotation field for deriving the curvature test function. Second, the equilibrium stress functions instead of the analytical functions are used to formulate the stress trial function whilst the couple stress trial function is directly obtained from the curvature test function by using the constitutive relationship. Besides, the penalty function is introduced into the virtual work principle for enforcing the C\(^0\) continuity condition in weak sense. Several benchmark examples are examined and the numerical results demonstrate that the element can simulate the size-dependent mechanical behaviors well, exhibiting satisfactory accuracy and low susceptibility to mesh distortion.

David R. Brandyberry (1), Ahmad R. Najafi (2) and Philippe H. Geubelle (1)
(1) Department of Aerospace Engineering, University of Illinois at Urbana-Champaign, Champaign, Illinois
(2) Department of Mechanical Engineering and Mechanics, Drexel University, Philadelphia, Pennsylvania
SUMMARY: A computational framework is developed to model and optimize the nonlinear multiscale response of three-dimensional particulate composites using an interface-enriched generalized finite element method. The material nonlinearities are associated with interfacial debonding of inclusions from a surrounding matrix which is modeled using C\(^0\) continuous enrichment functions and a cohesive failure model. Analytic material and shape sensitivities of the homogenized constitutive response are derived and used to drive a nonlinear inverse homogenization problem using gradient-based optimization methods. Spherical and ellipsoidal particulate microstructures are designed to match a component of the homogenized stress-strain response to a desired constructed macroscopic stress-strain behavior.

SUMMARY: This work presents a generalized substructuring-based topology optimization method for the design hierarchical lattice structures to maximize the first eigenvalue. In this method, the macrostructure is assumed to be composed of substructures with a common artificial lattice geometry pattern. And two different yet connected scales are considered through a lattice geometry feature parameter. The feature parameter, which can control the material distribution of the substructure, determines the relative density of corresponding substructure. Each substructure is condensed into a super-element to obtain the associated density-related matrices. A surrogate model using cubic spline interpolation has been particularly built to map the density to stiffness and mass matrices of condensed super-elements. The derivatives of super-element matrices to the associated densities can be evaluated efficiently and accurately. Here, an augmented penalized density for this surrogate model is introduced. And the conventional optimality criteria method is selected as updating method of the density design variables. Numerical examples under two lattice patterns of substructures are shown to validate the correctness and superiority of this substructure-based topology optimization method.

SUMMARY: Modal expansion is a workhorse used in many engineering analysis algorithms. One example is the coupled boundary element-finite element computation of the backscattering target strength of underwater elastic objects. To obtain the modal basis, a free-vibration (generalized eigenvalue) problem needs to be solved, which tends to be expensive when there are many basis vectors to compute. In the above-mentioned
backscattering example it could be many hundreds or thousands. Excellent algorithms exist to solve the free-vibration problem, and most use some form of the Rayleigh-Ritz (RR) procedure. The key to an efficient RR application is a low-cost transformation into a reduced basis. In this work, a novel, inexpensive a priori transformation is constructed for solid-mechanics finite element models based on the notion of coherent nodal clusters. The inexpensive RR procedure then leads to significant speedups of the computation of an approximate solution to the free vibration problem.

SUMMARY: Composite laminate structures remain an important family of materials used in cutting-edge industrial areas. Building efficient numerical modeling tools for high-frequency wave propagation in order to represent ultrasonic testing experiments of these materials remains a major challenge. In particular, incorporating attenuation phenomena within anisotropic plies, and thin intermediate isotropic layers between the plies often represent significant obstacles for standard numerical approaches. In our work, we address both issues by proposing a systematic study of the fully discrete propagators associated to the Kelvin-Voigt, Maxwell, and Zener models, and by incorporating effective transmission conditions between plies using the mortar element method. We illustrate the soundness of our approach by proposing intermediate one-dimensional and two-dimensional numerical evidence, and we apply it to a more realistic configuration of a curved laminate composite structure in a three-dimensional setting.

SUMMARY: A new eight-node conforming quadrilateral element with high-order completeness, denoted as QH8-C1, is proposed in this article. First, expressions for the interpolation displacement function satisfying the requirements for high-order completeness in the global coordinate system are constructed. Second, the displacement function expression in global coordinates is transformed into isoparametric coordinates, and the relationships between the two series of coefficients for the two kinds of displacement function expressions are found. Third, the displacement function expression is modified to satisfy the requirements of nodal freedom and interelement boundary continuity. The key to the new element construction is the derivation of the linear relationship expressions among 12 coefficients of element displacement interpolation polynomials in the global and isoparametric coordinate systems. As a result, the relationship between quadratic completeness and interelement continuity is explicitly given, and a proof of the completeness and the continuity was conducted to theoretically guarantee the validity of the derivation results. Furthermore, in order to verify the correctness of the theoretical work, nine numerical examples were performed. The computation results from these examples demonstrate that QH8-C1 exhibited excellent performance, including high simulation accuracy, fast convergence, insensitivity to mesh distortion, and monotonic convergence.

ABSTRACT: Recent studies show that the unsymmetric finite element method exhibits excellent performance when the discretized meshes are severely distorted. In this article, a new unsymmetric 4-noded quadrilateral plane element is presented using both incompatible test functions and trial functions. Five internal nodes, one at the elemental central and four at the middle sides, are added to ensure the quadratic completeness of the elemental displacement field. Thereafter, the total nine nodes are applied to form the shape functions of trial function, and the Lagrange interpolation functions are adopted as the incompatible test shape functions of the internal nodes. The incompatible test displacements are then revised to satisfy the patch test. Numerical tests show that the present element can provide very good numerical accuracy with badly distorted meshes. Unlike the existing unsymmetric four-node plane elements in which the analytical stress fields are employed, the present element can be extended to boundary value problems of any differential equations with no difficulties.
SUMMARY: In this work, the finite rotation exact geometry four-node solid-shell element using the sampling surfaces (SaS) method is developed for the analysis of the second Piola-Kirchhoff stresses in laminated piezoelectric shells. The SaS method is based on choosing inside the layers the arbitrary number of SaS parallel to the middle surface and located at Chebyshev polynomial nodes in order to introduce the displacements and electric potentials of these surfaces as fundamental shell unknowns. The outer surfaces and interfaces are also included into a set of SaS. To circumvent shear and membrane locking, the hybrid-mixed solid-shell element on the basis of the Hu-Washizu variational principle is proposed. The tangent stiffness matrix is evaluated by 3D analytical integration throughout the finite element. This novelty provides a superior performance in the case of coarse meshes. A comparison with the SOLID226 element showed that the developed exact geometry SaS solid-shell element allows the use of load increments, which are much larger than possible with existing displacement-based finite elements. Thus, it can be recommended for the 3D stress analysis of doubly-curved laminated piezoelectric shells because the SaS formulation gives the opportunity to obtain the 3D solutions of electroelasticity with a prescribed accuracy.

SUMMARY: A new simulation method for the vibro-acoustic simulation of poro-elastic shells is presented. The proposed methods can be used to investigate arbitrary curved layered panels, as well as their interaction with the surrounding air. We employ a high-order finite element method (FEM) for the discretization of the shell structure. We assume that the shell geometry is given parametrically or implicitly. For both cases the exact geometry is used in the simulation. In order to discretize the fluid surrounding the structure, a variational variant of the method of fundamental solutions (MFS) is developed. Thus, the meshing of the fluid domain can be avoided and in the case of unbounded domains the Sommerfeld radiation condition is fulfilled. In order to simulate coupled fluid-structure interaction problems, the FEM and the MFS are combined to a coupled method. The implementation of the uncoupled FEM for the shell and the uncoupled MFS is verified against numerical examples based on the method of manufactured solutions. For the verification of the coupled method an example with a known exact solution is considered. In order to show the potential of the method sound transmission from cavities to exterior half-spaces is simulated.

References listed at the end of the paper:
49 Amado-Mendes Paulo, Costa Pedro Alves, Godinho Luis, Lopes Particia. 2.5D MFS-FEM model for the prediction of vibrations due to underground railway traffic. Engineering Structures. 2015;104:141–154.

ABSTRACT: This article presents a nonlinear augmented finite element method (N-AFEM) for the analysis of arbitrary crack initiation and propagation in large deformation plates and shells. The FE formulations for plate/shell elements and a shell-like cohesive zone element, both with explicit consideration of geometric nonlinearity, have been derived in detail. The geometrically nonlinear shell-like cohesive element has the essential feature of 3D but with crack displacements directly extracted from midplane shell element nodes, which enables an accurate description of crack propagation in shells and plates under large deformation. Furthermore, a novel augmentation process that can explicitly account for the discontinuous displacement fields of cracked elements without the need of extra nodes or nodal DoFs has been developed for a non-linear Newton-Raphson method. The numerical performance of the N-AFEM in modeling a number of benchmark shell/plate fracture problems demonstrates that the method is efficient, accurate, and robust.

SUMMARY: Peridynamics is a nonlocal theory which has been successfully applied to solid mechanics and crack propagation problems over the last decade. This methodology, however, may lead to large computational calculations which can soon become intractable for many problems of practical interest. In this context, a
technique to couple—in a global/local sense—three-dimensional peridynamics with one-dimensional high-order finite elements based on classical elasticity is proposed. The refined finite elements employed in this work are based on the well-established Carrera Unified Formulation, which the previous literature has demonstrated to provide structural formulations with unprecedented accuracy and optimized computational efficiency. The coupling is realized by using Lagrange multipliers that guarantee versatility and physical consistency as shown by the numerical results, including the linear static analyses of solid and thin-walled beams as well as of a reinforced panel of aeronautic interest.

SUMMARY: In this study, we integrate the advantages of differential quadrature method (DQM) and finite element method (FEM) to construct a C type four-node quadrilateral element with 48 degrees of freedom (DOF) for strain gradient Mindlin micro-plates. This element is free of shape functions and shear locking. The C continuity requirements of deflection and rotation functions are accomplished by a fourth-order differential quadrature (DQ) -based geometric mapping scheme, which facilitates the conversion of the displacement parameters at Gauss-Lobatto quadrature (GLQ) points into those at element nodes. The appropriate application of DQ rule to non-rectangular domains is proceeded by the natural-to-Cartesian geometric mapping technique. Using GLQ and DQ rules, we discretize the total potential energy functional of a generic micro-plate element into a function of nodal displacement parameters. Then, we adopt the principle of minimum potential energy to determine element stiffness matrix, mass matrix, and load vector. The efficacy of the present element is validated through several examples associated with the static bending and free vibration problems of rectangular, annular sectorial, and elliptical micro-plates. Finally, the developed element is applied to study the behavior of freely vibrating moderately thick micro-plates with irregular shapes. It is shown that our element has better convergence and adaptability than that of Bogner-Fox-Schmit (BFS) one, and strain gradient effects can cause a significant increase in vibration frequencies and a certain change in vibration mode shapes.

SUMMARY: A novel mixed shell finite element (FE) is presented. The element is obtained from the Hellinger-Reissner variational principle and it is based on an elastic solution of the generalized stress field, which is ruled by the minimum number of variables. As such, the new FE is isostatic because the number of stress parameters is equal to the number of kinematical parameters minus the number of rigid body motions. We name this new FE MISS-8. MISS-8 has generalized displacements and rotations interpolated along its contour and drilling rotation is also considered as degree of freedom. The element is integrated exactly on its contour, it does not suffer from rank defectiveness and it is locking-free. Furthermore, it is efficient for recovering both stress and displacement fields when coarse meshes are used. The numerical investigation on its performance confirms the suitability, accuracy, and efficiency to recover elastic solutions of thick- and thin-walled beam-like structures. Numerical results obtained with the proposed FE are also compared with those obtained with isogeometric high-performance solutions. Finally, numerical results show a rate of convergence between $h$ and $h^r$.

SUMMARY: In this work, we have developed a state-based peridynamics theory for nonlinear Reissner-Mindlin shells to model and predict large deformation of shell structures with thick wall. The nonlocal peridynamic theory of solids offers an integral formulation that is an alternative to traditional local continuum mechanics models based on partial differential equations. This formulation is applicable for solving the material failure problems involved in discontinuous displacement fields. The governing equations of the state-based peridynamic shell theory are derived based on the nonlocal balance laws by adopting the kinematic assumption of the Reissner and Mindlin plate and shell theories. In the numerical calculations, the stress points are
employed to ensure the numerical stability. Several numerical examples are conducted to validate the nonlocal structure mechanics model and to verify the accuracy as well as the convergence of the proposed shell theory.


SUMMARY: The primary objective of this study is threefold: (1) to present a general higher-order shell theory to analyze large deformations of thin or thick shell structures made of general compressible hyperelastic materials; (2) to formulate an efficient shell theory using the orthonormal moving frame, and (3) to develop and apply the nonlinear weak-form Galerkin finite element model for the proposed shell theory. The displacement field of the line normal to the shell reference surface is approximated by the Taylor series/Legendre polynomials in the thickness coordinate of the shell. The use of an orthonormal moving frame makes it possible to represent kinematic quantities (e.g., the determinant of the deformation gradient) in a far more efficient manner compared with the nonorthogonal covariant bases. Kinematic quantities for the shell deformation are obtained in a novel way in the surface coordinate described in the appendix of this study with the help of exterior calculus. Furthermore, the governing equation of the shell deformation has been derived in the general surface coordinates. To obtain the nonlinear solution in the quasi-static cases, we develop the weak-form finite element model in which the reference surface of the shell is modeled exactly. The general invariant based compressible hyperelastic material model is considered. The formulation presented herein can be specialized for various other nonlinear compressible hyperelastic constitutive models, for example, in biomechanics and other soft-material problems (e.g., compressible neo-Hookean material, compressible Mooney–Rivlin material, Saint Venant–Kirchhoff model, and others). A number of numerical examples are presented to verify and validate the formulation presented in this study. The scope of potential extensions are outlined in the final section of this study.


ABSTRACT: Non-ordinary state-based peridynamics (NOSBPD) has instability issue due to zero-energy modes during nodal integration. A zero-energy mode controlling scheme of NOSBPD for laminated composite materials is derived by using the linearized bond-based peridynamics, which forms a stable force state formulation corresponding to the non-uniform deformation. The proposed controlling scheme does not include any controlling parameter to avoid the complex parametric adjustment. A critical stretch continuously varying with the angle between fiber and bond directions is further proposed for the failure analysis of laminated composite materials with arbitrary fiber angles. The improved NOSBPD model adopts the explicit integration method to solve static problems. Several numerical examples are conducted to validate the proposed scheme suppressing the oscillation caused by zero-energy modes.


ABSTRACT: A three-dimensional (3D) method of analysis is presented for determining the free vibration frequencies of joined hemispherical–cylindrical shells of revolution with a top opening. Unlike conventional shell theories, which are mathematically two-dimensional (2D), the present method is based upon the 3D dynamic equations of elasticity. Displacement components u, w, and θ in the radial, circumferential, and axial directions, respectively, are taken to be periodic in θ and in time, and algebraic polynomials in the r and z directions. Potential (strain) and kinetic energies of the joined shells are formulated, and the Ritz method is used to solve the eigenvalue problem, thus yielding upper bound values of the frequencies by minimizing the frequencies. As the degree of the polynomials is increased, frequencies converge to the exact values. Convergence to four-digit exactitude is demonstrated for the first five frequencies. Natural frequencies are presented for different boundary conditions. The frequencies from the present 3D method are compared with those from 2D thin shell theories.

References listed at the end of the paper:


ABSTRACT: Based on Hamilton’s principle, a new accurate solution methodology is developed to study the torsional bifurcation behavior of functionally graded cylindrical shells in a thermal environment. The effective properties of functionally graded materials (FGMs) are assumed to be functions of the ambient temperature as well as the thickness coordinate of the shell. By applying Donnell’s shell theory, the lower-order Hamiltonian canonical equations are established, from which the eigenvalues and eigenvectors are solved as the critical loads and buckling modes of the shell of concern, respectively. The effects of various aspects, including the combined in-plane and transverse boundary conditions, dimensionless geometric parameters, FGM parameters and changing thermal surroundings, are discussed in detail. The results reveal that the in-plane axial edge supports do have a certain influence on the buckling loads. On the other hand, the transverse boundary conditions only affect extremely short shells. With increasing thermal loads, the material volume fraction has a different influence on the critical stresses. It is concluded that the optimized FGM mixtures to withstand thermal torsional buckling are Si_{3}N/SUS304 and Al_{2}O/SUS304 among the materials studied in this paper.

References listed at the end of the paper:


ABSTRACT: Tensegrity structures under certain conditions may be prone to snap-through buckling. The temporary loss of equilibrium due to snap-through normally results in a dynamic force being applied to each node associated with the snap-through. This paper presents a numerical study on the progressive collapse behavior of tensegrity structures due to the buckling of struts. Emphasis is given to the dynamic nature of the coupled member and nodal snap-through effects on the overall structural behavior. Member buckling is taken into consideration by carefully following the buckling load–displacement response of the member. It is assumed that the structure is subjected only to static gravitational load. Results of the present study allow one to assess the effects of various design parameters such as self-stress levels, effective-length factor of struts and damping characteristics on the propagation of snap-through buckling in these structures. The conclusions, drawn from this study, lead to the suggestion of some guidelines and recommendations for the design of such structures.

References listed at the end of the paper:
- B. Shekastehband, Dynamic Propagation of Local Collapse in Tensegrity Systems (Sahand University of Technology, Iran, 2012).

ABSTRACT: In this paper, we analyze the transverse vibration of a circular plate loaded by uniform pressure along its edge. The plate is supported by an elastic ring support being coaxial with the plate. At its edge the plate is clamped but the radial displacement is allowed. Apart from this problem, the heated plate cramped at its edge, but without the possibility of radial displacement, is also analyzed. The analytical solution of governing equation is obtained in the form of Bessel's functions. Using the analytical solution, the frequencies of transverse vibrations depending on loads, elastic ring stiffness and the location of ring are obtained. The results show that the lowest frequencies vibrations can be either symmetric or asymmetric having one or two nodal
diameters. It is also shown that multiple vibration frequencies can occur for special values of load and ring stiffness.

References listed at the end of the paper:
- T. M. Atanackovic and A. Guran, Theory of Elasticity for Scientists and Engineers (Birkhauser, Boston, 2000).


ABSTRACT: It has been observed that undulating periodic patterns formed on an initial flat annular plate that model the leaves of plants are a physical response to the expansion of the surface under a lateral restraint. They are not visible at the beginning but become apparent only when the plants continue to grow. The behavior can be explained via the inhomogeneous deformation of gel materials that behave in a similar manner to hyperelastic materials in solid mechanics. This paper compares the stability of thin annular plates clamped along the inner edge and free along the outer periphery using numerical simulations of the swelling of thin gel annular plate held along the inner edge as well as analysis of a similar class of structures by solid mechanics concept via energy principle. The trends of results from both approaches compare favorably. The buckling patterns of annular plates with various values of inner radius to outer radius ratio illustrate the relationship between the geometry of the annular plate and the inhomogeneous deformation of gels or buckling patterns of solid mechanics materials. The undulating patterns on leaves such as those of flowering cabbage can thus be explained via the buckling behavior of annular plates, which can be regarded as thin soft materials adhered to a stiffer core. The study can also be extended to cover other stimuli under different environmental conditions and the outcome may bring further insights into the evolution of plants.

References listed at the end of the paper:
- S. Ladet, D. David and A. Domard, Nature 452(7183), 76 (2008), DOI: 10.1038/nature06619.
- S. J. Kim et al., Nature Mater. 5(1), 48 (2005), DOI: 10.1038/nmat1553.

ABSTRACT: This paper is concerned with the nonlinear damped forced vibration problem of pre-stressed orthotropic membrane structure under impact loading. The governing equations of motion were derived based on the von Kármán large deflection theory and D’Alembert’s principle, and solved by using the Bubnov–Galerkin method and the Krylov–Bogolubov–Mitropolsky (KBM) perturbation method. The asymptotic analytical solutions of the frequency and lateral displacement of rectangular orthotropic membrane with fixed edges were obtained. In the computational example, the frequency results were compared and analyzed. Meanwhile, the vibration mode of the membrane and the displacement and time curves of each feature point on the membrane surface were analyzed. The results obtained herein provide a simple and convenient approach to calculate the frequency and lateral displacement of the nonlinear forced vibration of rectangular orthotropic membranes with low viscous damping under impact loading. In addition, the results provide some computational basis for the vibration control and dynamic design of membrane structures.

References listed at the end of the paper:


ABSTRACT: This paper investigates the free vibration of nanocomposite beams reinforced by single-walled carbon nanotubes (SWCNTs). The distribution of the SWCNTs may vary through the thickness of a beam and are aligned along the beam axial direction. The virtual strain and kinetic energies of the carbon nanotube (CNT) composite beam are obtained using the classical variational method of Hamilton's principle, and the geometric nonlinearity of von Kármán sense is also included. The eigenvalue equation for free vibration of the beam is derived by the p-Ritz method. Vibration frequency parameters for the uniformly distributed (UD) and functionally graded (FG) CNT beams based on the first-order and third-order beam theories are presented and the effects of CNT filler volume fraction, distribution, beam length to depth ratio and end support conditions on the nonlinear free vibration characteristics of the beams are discussed. Comparison studies for UD-CNT and
FG-CNT beams based on the first-order and the third-order beam theories are also performed and the differences in vibration frequencies and the nonlinear to linear frequency ratios between these two theories are highlighted.

References listed at the end of the paper:


ABSTRACT: An efficient hybrid modal-molecular dynamics method is developed for the vibration analysis of large scale nanostructures. Using the reduced order method, presented in this paper, linear and nonlinear vibrations of a suspended graphene nanoribbon (GNR) carrying an electric current in a harmonic magnetic field are investigated. The resonance frequencies as well as the nonlinear vibration response obtained by the present technique and direct molecular dynamic simulations are in very good agreement. Also, the obtained results illustrate the hardening behavior of nonlinear vibrations which is diminished by stretching the GNR.

References listed at the end of the paper:

- R. John and K. Petr, Nano Res. 3(7), 472 (2010).
- J. S. Bunch et al., Science 315(5811), 490 (2007), DOI: 10.1126/science.1136836.
...results are validated through convergence tests of frequencies and by comparison with the published results for simply-supported cracked rectangular plates. The solutions are further employed to determine the natural frequencies of cantilevered skewed rhombic and isosceles triangular plates and completely free circular plates, each with a crack of varying length, location and orientation. The numerical results are tabulated and some corresponding mode shapes are also presented, by means of nodal patterns. Most of the results shown here are new to the literature.

References listed at the end of the paper:

In this paper, an active controller is used to suppress the flutter vibration of a beam. The beam is made of Functionally Graded Material (FGM) and subjected to a follower force and arbitrary lumped mass. The properties of the FGM layer are functionally graded in the thickness direction according to the volume fraction power law distribution. The piezoelectric layers, which are attached to both sides of the beam, are used as sensors and actuators. The beam is fixed from one end and elastically restrained by a spring at the other end. To investigate the effect of the controller on the vibration response of the beam, parameters such as the follower force, spring stiffness, mass ratio and attachment location are included in the analysis based on the generalized function theory and Lagrange–Rayleigh–Ritz technique. The vibration responses of the system are presented in the simulation results, where excellent agreement of the controller scheme is observed.

References listed at the end of the paper:

- M. Şimşek, Compos. Struct. 92(4), 904 (2010), DOI: 10.1016/j.compstruc.2009.06.030.
ABSTRACT: In this paper, active flutter suppression of a simply supported circular sandwich cylindrical shell is investigated under supersonic flight conditions. The critical free stream static pressures at which unstable oscillations arise are calculated for selected cases using Fourier expansions. Simulation results demonstrate performance and effectiveness of the adopted ERF strategy is adopted to actively suppress the closed loop system dynamic response in supersonic flight condition. The Runge–Kutta time integration algorithm is used to determine the open-loop aeroelastic response of the system in two basic loading configurations, namely, a concentrated impulse point load and a sonic boom line load. Subsequently, a sliding mode control (SMC) strategy is adopted to actively suppress the closed loop system dynamic response in supersonic flight condition. Limiting cases are considered and good agreements with the data available in the literature are obtained.

References listed at the end of the paper:

- L. Librescu, J. de Mecanique 6, 133 (1967).
- A. Almeida et al., Compos. Struct. 94, 3601 (2012), DOI: 10.1016/j.compstruct.2012.06.008.

ABSTRACT: Buckling and post-buckling behaviors of piezoelectric nanobeams are investigated by using the nonlocal Timoshenko beam theory and von Kármán geometric nonlinearity. The piezoelectric nanobeam is subjected to an axial compression force, an applied voltage and a uniform temperature rise. After constructing the energy functionals, the nonlinear governing equations are derived by using the principle of minimizing the functional. The piezoelectric nanobeam is subjected to an axial compression force, an applied voltage and a uniform temperature rise. After constructing the energy functionals, the nonlinear governing equations are derived by using the principle of minimum total potential energy and discretized by using the differential quadrature (DQ) method. A direct iterative method is employed to determine the buckling and post-buckling responses of piezoelectric nanobeams with hinged–hinged, clamped–hinged and clamped–clamped end conditions. Numerical examples are presented to study the influences of the nonlocal parameter, temperature rise and external electric voltage on the size-dependent buckling and post-buckling responses of piezoelectric nanobeams.

References listed at the end of the paper:

- P. Fei et al., Nano Lett. 9, 3435 (2009), DOI: 10.1021/nl901606b.
- W. M. Zhang et al., Sensors 9, 3854 (2009), DOI: 10.3390/s9053854.
- R. Agrawal et al., Nano Lett. 8, 3668 (2008), DOI: 10.1021/nl801724b.
- A. C. Eringen, Nonlocal Continuum Field Theories ( Springer-Verlag , 2002).
ABSTRACT: This paper focuses on the effect of member geometric imperfection on geometrically nonlinear buckling and seismic performance of suspended dome structures. In this way, the influence of member imperfection on structural buckling and seismic performance of suspended dome structures can be estimated.

References listed at the end of the paper:


ABSTRACT: This paper focuses on the effect of member geometric imperfection on nonlinear geometrically buckling and seismic performance of a new style of space steel structure, suspended-dome, which is composed of a reticulated shell and cable-strut system. By supposing the initial curvature of members as half-wave sinusoids, a stiffness equation of imperfect truss elements is derived for the struts, while that of imperfect beam elements is derived for the reticulated shell members. The proposed imperfect elements are implanted into ANSYS finite element program. Three numerical examples are employed to validate the proposed imperfect elements and analysis method. An ellipsoidal suspended dome of Changzhou gymnasium is taken as an example. The results show that the imperfection value has relatively great influence on the structural stiffness. With the increase of member imperfection, the critical load decreases in a basically linear way. Under different prestress states, the relation curves between the critical load and imperfection are basically parallel. The nonlinear seismic analysis results show that when imperfection is included, the initial state responses are different, namely, the seismic displacement increases while the stress in rods and cables decreases. The proposed imperfection analysis method can be widely used in not only suspended-dome structures, but also other kinds of prestressed space grid structures. In this way, the influence of member imperfection on structural buckling and seismic performance can be estimated.

ABSTRACT: This paper presents an analytical study on the dynamic characteristics of castellated beams. The study focuses on the effect of web shear on the free vibration frequencies of castellated beams. By using the Hamilton's principle, a simple closed-form solution for determining the free vibration frequencies of simply supported castellated beams is developed. The results show that the shear effect on the free vibration frequencies increases with the cross-sectional area and distance between the centroids of the two tee sections of castellated beams, but decreases with respect to increasing web thickness or increasing beam length. The shear effect is also found to be greater in higher vibration modes.

References listed at the end of the paper:

- R. Redwood, W. Zaaour and J. Megharief, Web post buckling in castellated beams, Advances in Steel Structures (ICASS '96), eds.
- K. El-Sawy, A. Sweedan and M. Martini, Thin-Walled Struct. 47, 1295 (2009), DOI: 10.1016/j.twsw.2009.03.012.
- J. Li et al., Composite Struct. 97, 1 (2013), DOI: 10.1016/j.compstruct.2012.10.014.
- T. P. Vo and H. T. Thai, Composite Struct. 94(11), 3379 (2012), DOI: 10.1016/j.compstruct.2012.05.012.


ABSTRACT: This paper deals with the nonlinear dynamic analysis of smart laminated composite sandwich plates. A three dimensional energy based finite element (FE) model has been developed for the composite sandwich plates integrated with the patches of active constrained layer damping (ACLD) treatment. Von Kármán type nonlinear strain–displacement relations and the first-order shear deformation theory (FSDT) are adopted individually for each layer of the sandwich plate in developing the FE model. The constraining layer of the ACLD treatment is considered to be made of active fiber composite (AFC) material. The Golla–Hughes–McTavish (GHM) method is used to model the constrained viscoelastic layer of the ACLD treatment in the time domain. Sandwich plates with symmetric and antisymmetric laminated faces separated by HEREX core are considered for evaluation of the numerical results. The numerical results indicate that the ACLD patches significantly improve the damping characteristics of the composite sandwich plates for suppressing their
geometrically nonlinear transient vibrations. The effect of variation of piezoelectric fiber orientation angle in the AFC material on the control authority of the ACLD patches is also investigated.

References listed at the end of the paper:


ABSTRACT: A three-dimensional (3D) method of analysis is presented for determining the free vibration frequencies of complete (not truncated) conical shells with linearly varying thickness. The complete conical shells free or clamped at the bottom edge with a free vertex are investigated. Unlike conventional shell theories, which are mathematically 2D, the present method is based upon the 3D dynamic equations of elasticity. Displacement components u, θ, and z in the radial, circumferential and axial directions, respectively, are taken to be periodic in θ and in time, and expressed by algebraic polynomials in the r- and z-directions. Potential (strain) and kinetic energies of the complete conical shell are formulated. The Ritz method is used to solve the eigenvalue problem, yielding the upper bound values of the frequencies by minimization. As the degree of the polynomials is increased, frequencies converge to the exact values, with four-digit exactitude demonstrated for the first five frequencies. The frequencies from the present 3D method are compared with those from other 3D approaches and 2D shell theory by previous researchers.

References listed at the end of the paper:

ABSTRACT: In this paper, the thermoelastic transient behavior of a clamped circular plate composed of functionally graded material (FGM) is investigated. The material properties of the FGM circular plate are assumed to vary through the plate thickness according to a power law distribution of the volume fraction of constituent materials, except Poisson's ratio, which is assumed as constant. Based on the von Karman equation and classical theory of thin plates, the equation of motion for the FGM circular plate is derived by the Hamilton principle. The nonlinear governing equation is solved by the Galerkin method, along with Newmark's integration method, in an iterative manner. Numerical results reveal that the functional gradient index, ratio of thickness to radius, thermal and mechanical loads have significant effect on the thermoelastic transient behavior of the clamped FGM circular plate. The result presented herein may be used as a reference for solving other transient coupled problems of thermoelasticity.

References listed at the end of the paper:

- X. Zhao, Y. Y. Lee and K. M. Liew, Compos. Struct. 90(2), 161 (2009), DOI: 10.1016/j.compstruct.2009.03.005.

Amar Nath Roy Chowdhury (1), Chien Ming Wang (2) and Soo Jin Aadrain Koh (3)

(1) Department of Civil and Environmental Engineering, National University of Singapore, Kent Ridge, Singapore 119260, Singapore

ABSTRACT: In this paper, an equivalent thick cylindrical shell model is proposed for buckling loads for SWCNTs with different chiral angles. Extensive, molecular dynamics (MD) simulations are first performed using the adaptive intermolecular reactive bond order potential to determine the critical buckling loads. The MD simulations buckling results are then used as reference solutions to calibrate the properties of the thick cylindrical shell model. Central to this development is the establishment of an empirical expression for the Young's modulus that is a function of both the diameter and the chiral angle of the SWCNT. For the shell model, we have assumed that the Poisson ratio = 0.19 and the shell thickness h = 0.066 nm. It will be shown that the proposed shell model furnishes good estimates of the critical buckling loads for different chiral angles. The critical buckling strains are also evaluated from the strain relation of SWCNTs.

References listed at the end of the paper:

5. Y. Q. Xu, A. Barnard and P. L. McEuen, Nano Lett. 9(4), 1609 (2009), DOI: 10.1021/nl803861c.
31. H. Zhao, K. Min and N. R. Aluru, Nano Lett. 9(8), 3012 (2009), DOI: 10.1021/nl901448z.

ABSTRACT: Wind pressure measurements were carried out for dome roofs with different rise–span ratios (f/L = 1/4, 1/6, 1/8) in a boundary wind tunnel. A parametric study was conducted to investigate the influences of wind loading and structural parameters on the wind-induced response and the universal equivalent static wind loads (ESWLs) of single-layer reticular dome shells, including the span, rise–span ratio, roof mass and the mean wind velocity. Results show that the rise–span ratio has a significant influence on the wind pressure distribution of the roof. High suction appears at the top of the roof with a larger rise–span ratio f/L = 1/4, and it appears at the top and leading edge when f/L is 1/6 or 1/8. Many vibration modes should be included to analyze the wind-induced response of dome roof structures, and this makes it very difficult to analyze the ESWL. The resonant response is larger than the background response. A method to calculate the universal ESWL for the building code is proposed for easy understanding by practicing engineers. Based on the distribution characteristics of the ESWL, simple fundamental vectors are constructed to recalculate the universal ESWL. This method is employed to divide the dome roof into four zones, and it also means that four fundamental vectors are used to evaluate the ESWL. Simplified expressions of universal ESWL in these four roof zones are proposed for the engineering design. All nodal displacements and structural member stresses under the universal ESWL agree well with actual peak responses.

References listed at the end of the paper:


ABSTRACT: The stability and dynamics of an axially moving unidirectional plate partially immersed in a liquid and subjected to a nonlinear aerodynamic excitation are investigated. The method of singular functions is adopted to study the dynamic characteristics of the unidirectional plates with discontinuous characteristics. Nonlinearities due to large-amplitude plate motions are considered by using the classical nonlinear thin plate theory, with allowance for the effect of viscous structural damping. The velocity potential and Bernoulli's equation are used to describe the fluid pressure acting on the unidirectional plate. The effect of fluid on the vibrations of the plate may be equivalent to added mass of the plate. The formulation of added mass is obtained from kinematic boundary conditions of the plate–fluid interfaces. The system is discretized by Galerkin's method while a model involving two degrees of freedom, is adopted. Attention is focused on the behavior of the system in the region of dynamic instability, and several motions are found by numerical simulations. The effects of the moving speed and some other parameters on the dynamics of the system are also investigated. It shows that chaotic motions can occur in this system in several certain regions of parameter space.

References listed at the end of the paper:
ABSTRACT: The intrinsic relationship between deterministic system and stochastic system is profoundly revealed by the probability density evolution method (PDEM) with introduction of physical law into the stochastic system. On this basis, stochastic dynamic stability analysis of single-layer dome structures under stochastic seismic excitation is firstly studied via incorporating an energetic physical criterion for identification of dynamic instability of dome structures into PDEM, which yields to sample stability (stable reliability). However, dynamic instability is not identical to structural failure definitely, where strength failure can be experienced not only in the stable structure but also when the structure is out of dynamic stability. It is practically feasible to decouple the stochastic dynamic response of dome structures to be a stable one and an unstable one according to the generalized density evolution equation (GDEE). Consequently, the global failure probability can be investigated separately based on the corresponding independent stochastic response. For unstable failure probability assessment, the failure probability is the unstable probability if the dome's failure is attributed to instability, whereas inverse absorbing is firstly implemented to get rid of the stochastic response before instability and a complementary process is filled in the safe domain immediately to finally assess the probability of strength failure after dynamic instability.

References listed at the end of the paper:


ABSTRACT: This paper presents analytically obtained free vibration frequencies of castellated beams, that take into account the effects of both web shear and rotary inertia. The results show that the rotary inertia effect on the free vibration frequencies is very important for beams with no or weak effect from web shear. However, for beams where the web shear effect is dominant the rotary inertia effect can be almost ignored.

References listed at the end of the paper:
- J. Li et al., Compos. Struct. 97, 1 (2013), DOI: 10.1016/j.compstruct.2012.10.014.
- T. P. Vo and H. T. Thai, Compos. Struct. 94(11), 3379 (2012), DOI: 10.1016/j.compstruct.2012.05.012.


ABSTRACT: The physical interaction of fluids and solids is of practical significance in engineering (e.g. flutter of aerodynamic structures, vortex induced vibrations of sub-sea pipelines and risers, inflatable dams, parachute dynamics and blood flow through arteries). In this paper, a finite element formulation is developed for determining the vibration characteristics of beams in contact with inviscid incompressible fluid. The classical, first-order and third-order shear deformation beam theories are used to model the structural response. Numerical results for vibration frequencies are presented showing the parametric effect of thickness and immersion depth on the frequency response. The results indicate that the presence of fluid interaction has significant effect on the dynamic response. The formulation presented herein is also applicable to a vast number of vibration problems related to beams under a variety of excitations.

References listed at the end of the paper:

ABSTRACT: This paper presents the uniaxial and biaxial buckling analysis of rectangular plates based on new trigonometric shear and normal deformation theory. The theory accounts for the cosine distribution of the transverse shear strain through the plate thickness and on the free boundary conditions on the plate surfaces without using the shear correction factor. Governing equations and boundary conditions of the theory are derived by the principle of virtual work. The Navier type solutions for the buckling analysis of simply supported isotropic, transversely isotropic, orthotropic and symmetric cross-ply laminated composite rectangular plates subjected to uniaxial and biaxial compressions are presented. The effects of variations in the degree of orthotropy of the individual layers, side-to-thickness ratio and aspect ratio of the plate are examined on the buckling characteristics of composite plates. The present results are compared with those of the classical plate theory (CPT), first order shear deformation theory (FSDT) and exact three-dimensional (3D) elasticity theory wherever applicable. Good agreement is achieved of the present results with those of higher order shear deformation theory (HSDT) and elasticity theory.

References listed at the end of the paper:
12 L. Demasi, 16 mixed plate theories based on the generalized unified formulation. Part V: Results, Compos. Struct. 87 (2009) 1–16.
503–517.


32 T. Timarci and M. Aydogdu, Buckling of symmetric cross-ply square plates with various boundary conditions, Compos. Struct. 68 (2005) 381–389.


36 I. Shufrin, O. Rabinovitch and M. Eisenberger, Buckling of symmetrically laminated rectangular plates with general boundary conditions—A semi-analytical approach, Compos. Struct. 82 (2008) 521–531.

37 O. Barton, Buckling of simply supported rectangular plates under combined bending and compression using eigen sensitivity analysis, Thin Walled Struct. 46 (2008) 435–441.


ABSTRACT: In this paper, the nonlinear transient thermal stress analysis is conducted for temperature-dependent hollow cylinders subjected to a decaying-with-time thermal field. By the finite element method, the highly nonlinear governing equations are solved. The time histories of temperature, displacement, and stress due to the decaying-with-time thermal load are computed. A sensitivity analysis includes the effects of exponent of the decayed heat flux and temperature-dependency of density and material properties is carried out. Numerical results show some interesting characteristics of the thermoelastic behaviors of the hollow cylinders studied. In particular, the effect of temperature-dependency of the material properties on the thermoelastic parameters was demonstrated to be significant.

References listed at the end of the paper:


ABSTRACT: In this paper, the differential quadrature method (DQM) was extended to deal with the nonlinear thermal flutter problem of supersonic composite laminated panel. Based on Hamilton's principle, the nonlinear thermal flutter model of composite panels was first established. The model adopted the von Karman large deflection plate theory for the geometrical nonlinearity, and the third order piston theory for the supersonic aerodynamic loads. Convergence and accuracy studies were carried out to verify the proposed approach. Finally, the nonlinear thermal flutter characteristics of a supersonic composite panel were studied. Uniform temperatures were first applied to the model in order to determine general heating effects on the stability of the composite panel. Owing to the varying structural stiffness of composite panels when subjected to thermal stresses, the thermal load reduced the frequency of composite panel, as well as the frequency interval between the first frequency and the second frequency; thereby hastening the flutter of composite panel. The nonlinear thermal flutter velocity ratio was decreased with respect to increasing temperature load for all aspect ratios.
However, the influence of thermal loadings on flutter with various cross angles was different. Cases of unequal temperatures were considered. The average temperature load was kept constant which differs from the temperature gradient form of loading. The results show that the nonlinear thermal frequencies are affected in the presence of different temperature distributions. The changes in the temperature distribution have a slightly greater effect than changes in the average temperature. These effects due to temperature distribution changes do not have a substantial effect on the flutter dynamic pressure.

References listed at the end of the paper:


ABSTRACT: In this paper, buckling analysis of isotropic, orthotropic, laminated composite and sandwich plates utilizing trigonometric shear deformation theory and meshless method based on the finite point formulation using thin plate, polynomial and inverse multiquadric radial basis function is presented. The convergence of the present method is studied for isotropic and laminated composite plates for different radial basis functions with optimal value of shape parameter. Numerical examples of laminated and sandwich plates subjected to various types of in-plane loads are solved to demonstrate accuracy and applicability of present method. Several new results for variety of composite and sandwich plates are presented. The present results are
observed to be in good agreement with those available in literature. The effects of orthotropy ratio of material, span to thickness ratio, number of layers, core thickness and lamination scheme on the critical load of plates are also presented.

References listed at the end of the paper:

- S. Xiang et al., Compos. Struct. 91, 31 (2009).
- S. Xiang et al., Compos. Struct. 93, 299 (2011).
- L. M. S. Castro et al., Compos. Struct. 92, (2010).
- M. Aydogdu, Compos. Struct. 89, 94 (2009).

Cilmar Basaglia (Civil Eng., University of Campinas, Brazil) and Dinar Camotim (DECIVIL, ICIST, University of Lisbon, Portugal), “Buckling analysis of thin-walled steel structural systems using Generalized Beam Theory (GBT)”, International Journal of Structural Stability and Dynamics, Vol. 15, No. 1, 1540004, January 2015, https://doi.org/10.1142/S0219455415400040

ABSTRACT: This paper deals with the application of beam finite element models based on generalized beam theory (GBT) to analyze the buckling behavior of four thin-walled steel structural systems, namely (i) beams belonging to storage rack systems, (ii) pitched-roof industrial frames, (iii) portal frames built from cold-formed rectangular hollow section (RHS) profiles and (iv) roof-supporting trusses, exhibiting different support conditions and subjected to various loadings. In particular, taking advantage of the GBT unique and structurally clarifying modal features, it is possible to assess how different geometries and/or bracing arrangements affect (improve) the local, distortional and/or global buckling behavior of the above structural systems. The accuracy of the GBT-based buckling results is assessed through the comparison with values yielded by rigorous shell finite element analyzes carried out in the code ANSYS. In spite of the disparity between the numbers of degrees of freedom involved, which are orders of magnitude apart, there is a virtual coincidence between the critical loads and mode shapes provided by the GBT (beam) and ANSYS (shell) finite element analyses.

References listed at the end of the paper:

- C. Basaglia, D. Camotim and N. Silvestre, Thin-Walled Struct. 47(11), 1246 (2009).
- D. Camotim et al., Thin-Walled Struct. 46(9), 800 (2008).
- D. Camotim, C. Basaglia and N. Silvestre, Thin-Walled Struct. 48(11), 726 (2010).
- D. Dubina, Thin-Walled Struct. 46(9), 741 (2008).

ABSTRACT: An energetic criterion for identifying the global dynamic instability of structures subjected to any kind of excitations is proposed in the paper. The concept of dynamic stability for structures is firstly interpreted and distinguished from the stability concept in the Lyapunov sense. It is demonstrated that the dynamic instability depends not only on the properties of the structure, but also relates to the change of external excitations on the structure, which distinguishes the essence of dynamic instability from the pseudo static stiffness criterion. This background leads to a novel energetic criterion with which the first passage of the variation of intrinsic energy over the input energy manifests the dynamic instability of structures. The proposed criterion has been extensively tested and verified in the numerical examples, with its advantages clearly illustrated.

References listed at the end of the paper:


ABSTRACT: The paper is concerned with ultimate load behavior of steel–concrete composite plate girders subjected to combined action of shear and bending. An analytical method is presented to predict the interactive response of the girder. The method considers the tension field action in the plate girder web panel and shear failure of concrete slab. The method is approximate and can be applied to composite plate girders at the preliminary stages of design. Strength of composite plate girders is investigated by varying the moment/shear ratio. It is shown that ultimate load capacity of composite plate girder is influenced by moment/shear ratio. The predicted results are compared with the corresponding finite-element values.

References listed at the end of the paper:


ABSTRACT: This study investigates the vibration, buckling and dynamic instability characteristics of damaged cross-ply and angle-ply laminated plate like beam under follower loading using the finite element approach. The damage is anisotropic in nature and parametrically incorporated into the composite using the concept of reduction in stiffness. It has been observed that damage shows a strong orthogonality and in general deteriorates the vibration and buckling characteristics. For follower type of loading, analysis is carried out on plate like beam structure to obtain the flutter characteristics. The effects of damage and its location on flutter characteristics are studied. The desirable position of damage on the plate like beam structure based on different stability behavior is discussed. The results show that flutter is observed as primary modes of instability when damaged plate like beam is subjected to follower loads. The behavior of flutter characteristics for different damaged parameters is discussed.

References listed at the end of the paper:

ABSTRACT: Single-layer reticulated shells are widely used in spatial structures. One critical factor that has to be considered in the design of reticulated shells is the significant adverse impact of high temperature caused by fire on the structures. In order to study the variation of elasto-plastic bearing capacity under high temperature by fire, four types of single-layer reticulated shells (i.e. K6, Geodesic, Schwedler and Lamella) are investigated under two typical fire conditions (i.e. global nonuniform temperature distribution and local high temperature) by the geometrically and materially nonlinear analysis and statistical methods. Practical design formulae for calculating the elasto-plastic bearing capacity of reticulated shell structures under different fire conditions and ambient temperatures are proposed based on the numerical simulation results.

References listed at the end of the paper:

Mohammad Nezami and Behnam Gholami (Department of Mechanical Engineering, Firoozkooh Branch, Islamic Azad University, Firoozkooh, Iran), “Active flutter control of a supersonic honeycomb sandwich beam resting on elastic foundation with piezoelectric sensor/actuator pair”. International Journal of Structural Stability and Dynamics, Vol. 15, No. 3, 1450052, April 2015, https://doi.org/10.1142/S0219455414500527

ABSTRACT: In this paper, by using the piezoelectric material, the active aeroelastic flutter characteristics and vibration control of supersonic sandwich panels with different honeycomb interlayers, resting on an elastic foundation, are studied. Classical beam theory along with the Winkler–Pasternak foundation model, and the quasi-steady first order supersonic piston theory are employed in the formulation of the structural theory and aerodynamic loading, respectively. Hamilton's principle in conjunction with the generalized Fourier expansions and Rayleigh–Ritz (RR) method are used to develop the dynamical model of the structural systems in the state–space domain. The aeroelastic flutter bounds are obtained via the p-method. The classical Runge–Kutta integration algorithm is then used to calculate the open-loop aeroelastic response of the system under different loading excitations. Finally, two classical control strategies, including direct proportional feedback and linear-quadratic regulator (LQR) optimal control scheme, are used to actively suppress the closed loop system response, while increasing the flutter aerodynamic pressure.

References listed at the end of the paper:

- Z. G. Song and F. M. Li, J. Vib. Control 0(0), 1 (2013).

ABSTRACT: This paper presents an analytical study on the critical dynamic buckling load of cylindrical shells with arbitrary axisymmetric thickness variation under uniform external pressure which is a function of time. Based on the Donnell simplified principle, the equilibrium and compatibility equations of cylindrical shells with arbitrary axisymmetric wall thickness under dynamic external pressure were derived. By using the method of separation of variables, the equations were transformed into ordinary differential equations in nondimensional form. Combining Fourier series expansion and the regular perturbation method, as well as the Sachenkov–Baktieva method, analytical formulas of the critical buckling load of cylindrical shells with arbitrary axisymmetric thickness variation under dynamic external pressure that varies as a power function of time were obtained. Using these analytical formulas, the critical dynamic buckling load of cylindrical shells with linearly and parabolically varying thickness were computed. The influences of thickness variation parameter and loading speed of external pressure on the critical buckling load were also discussed. The method was also applied to cylindrical shells with a classical cosine form thickness variation, by introducing the reduction factor of critical dynamic buckling load. The buckling capacity of these cylindrical shells under dynamic external pressure was discussed considering the effects of loading speed and thickness variation parameter.

References listed at the end of the paper:
- Z. P. Chen et al., Thin Wall Struct. 60, 38 (2012).


ABSTRACT: The thermoelastoplastic behavior of a high strength low alloy (HSLA) steel plate subjected to low-velocity impact is investigated in this paper. A yield criterion related to the spherical tensor of stress is proposed to describe the mixed hardening of the orthotropic material. Based on the classical nonlinear thin plate theory, the incremental nonlinear motion equations are obtained, and are solved by the combination of finite difference method and Newmark method with iterations. To explain the contact process, a thermoelastoplastic contact criterion is developed, of which the validity has been proved. Numerical results show that the radius of the impactor, initial impact velocity, environment temperature, and the thickness of the HSLA steel plate all
have great influences on the thermoelastoplastic behavior of the HSLA steel plate subjected to low-velocity impact.

References listed at the end of the paper:
- R. Gunes et al., Compos. Struct. 93(2), 860 (2011).
- R. Gunes et al., Compos. Struct. 93, 860 (2011).

Sukses Chandra Mohanty, Rati Ranjan Dash and Trilochan Rout (First author is from: Department of Mechanical Engineering, National Institute of Technology, Rourkela, Odisha 769008, India), “Vibration and dynamic stability of pre-twisted thick cantilever beam made of functionally graded material”, International

ABSTRACT: In the present work, the vibration and dynamic stability of functionally graded ordinary (FGO) pre-twisted cantilever Timoshenko beam has been investigated. Finite element shape functions are established from differential equations of static equilibrium. Expressions for element stiffness and mass matrices are obtained from energy considerations. Floquet's theory is used to establish the stability boundary. The material properties along the thickness of the beam are assumed to vary according to the power law. Th

References listed at the end of the paper:
· J. J. Jensen , Int. J. Solids Struct. 9 , 1117 ( 1973 ) .


ABSTRACT: In this study, dynamic response of a micro- and nanobeams under electrostatic actuation is investigated using strain gradient theory. To solve the governing sixth-order partial differential equation, mode shapes and natural frequencies of beam using Euler–Bernoulli and strain gradient theories are derived and then compared with classical theory. Galerkin projection is utilized to convert the partial differential equation to ordinary differential equations representing the system mode shapes. Accuracy of proposed one degree of freedom model is verified by comparing the dynamic response of the electrostatically actuated micro-beam with analogue equation and differential quadrature methods. Moreover, the static pull-in voltages of micro-beams found by one DOF model are compared with the reported data in literature. The main advantage of proposed method based on the Galerkin method is its simplicity and also its low computational cost in analyzing the dynamic and static responses of micro- and nanobeams. Additionally, effect of axial force, beam thickness and applied voltage are analyzed. The results obtained based on strain gradient theory, are compared with classical
and modified couple stress theories which are the special cases of the strain gradient theory. It is shown that strain gradient theory leads to higher frequency and lower amplitude in comparison with two other theories. References listed at the end of the paper:

- M. Younis, E. Abdel-Rahman and A. Nayfeh, Syst. 12, 672 (2003).
- W. J. Poole, M. F. Ashby and N. A. Fleck, Scr. Mater. 34, 559 (1996).
- D. T. Haluzan et al., Micromachines 1, 68 (2010).


ABSTRACT: In this study, free vibration analysis of spherical shell is carried out. The structural model is based on a combination of thin shell theory and the classical finite element method. Free vibration equations using the hybrid finite element formulation are derived and solved numerically. Therefore, the number of elements chosen is function of the complexity of the structure. Convergence is rapid. It is not necessary to choose a large number of elements to obtain good results. The results are validated using numerical and theoretical data.
available in the literature. The analysis is accomplished for spherical shells of different geometries, boundary conditions and radius to thickness ratios. This proposed hybrid finite element method can be used efficiently for design and analysis of spherical shells employed in high speed aircraft structures.

References listed at the end of the paper:


ABSTRACT: This paper presents the post-buckling analysis of an edge cracked cantilever beam composed of functionally graded material (FGM) subjected to axial compressive loads by using the total Lagrangian Timoshenko beam element approximation. Material properties of the beam change in the height direction according to the exponential distribution. The cracked beam is modeled as an assembly of two sub-beams connected through a massless elastic rotational spring. For beams subjected to compression loads, the load rise causes compressible forces and therefore buckling and post-buckling phenomena occurs. It is known that post-buckling problems are geometrically nonlinear problems. The highly nonlinear problem considered herein is solved incrementally by using the finite element method in conjunction with the Newton–Raphson method, by which the full geometric nonlinearity is considered. There is no restriction on the magnitudes of deflections and rotations in contradistinction to the von Karman strain displacement relations of the beam. In the study, the effects of the location and depth of the crack, and different material distributions on the post-buckling behavior of the FGM beam are investigated in detail.

References listed at the end of the paper:

ABSTRACT: This paper investigates the effects of applying different buckling modes obtained by linearized eigenvalue buckling analysis as the initial imperfection for double domes free form space structures. Nonlinear elastic–plastic analysis of rigidly jointed single layer double domes are carried out using the finite element method. Having verified the finite element modeling, several different collapse analyses have been undertaken in order to examine the stability behavior of these structures. By using the approximate-perturbed method, the results of the analyses show that in free form double domes, the lowest buckling modes could not be considered as the effective modes to change the bifurcation equilibrium path into the limit equilibrium one. Therefore, the generalized conformable imperfection mode method has been suggested in the present study in order to apply geometric imperfections in free form double domes. Also, one step method has been suggested in order to eliminate 60% of buckling modes, which are nonsensitive, before applying the approximate-perturbed method. 

References listed at the end of the paper:
- I. M. Kani and A. Heidari, Collapse and post-collapse of shallow lattice domes, 7th Int. Congress on Civil Engineering (Tarbiat Modares University, Tehran, 2006).
REFERENCES listed at the end of the paper:


ABSTRACT: A nonclassical first-order shear deformation shell model is developed to analyze the axial buckling and dynamic stability of microshells made of functionally graded materials (FGMs). For this purpose, the modified couple stress elasticity theory is implemented into the first-order shear deformation shell theory. Unlike the classical shell theory, the newly developed shell model contains an internal material length scale parameter to capture efficiently the size effect. By using the Hamilton's principle, the higher-order governing equations and boundary conditions are derived. Afterward, the Navier solution is utilized to predict the critical axial buckling loads of simply-supported functionally graded (FG) microshells. Moreover, the governing equations are written in the form of Mathieu–Hill equations and then Bolotin's method is employed to determine the instability regions. A parametric study is conducted to investigate the influences of static load factor, axial wave number, dimensionless length scale parameter, material property gradient index, length-to-radius and length-to-thickness aspect ratios on the axial buckling and dynamic stability responses of FGM microshells. It is revealed that size effect plays an important role in the value of critical axial buckling load and instability region of FGM microshells especially corresponding to those with lower aspect ratios.

References listed at the end of the paper:

- M. J. Meschet et al., Sensors 1, 541 (2002).
- S. Sahmani and R. Ansari, Compos. Struct. 95, 430 (2013).
Sergey A. Bochkarev and Valery P. Matveenko (Institute of Continuous Media Mechanics, Perm Russia),
“Stability of rotating coaxial cylindrical shells interacting with flowing and rotating fluid”, International Journal of Structural Stability and Dynamics, Vol. 15, No. 5, 1450071, June 2015,
https://doi.org/10.1142/S02194554145000710

ABSTRACT: This paper is concerned with the numerical investigation of hydroelastic stability of stationary or rotating coaxial cylindrical shells, interacting with compressible fluid flows having the axial and tangential velocity components. The behavior of a flowing and rotating compressible fluid is considered in the framework of the potential theory. Elastic shells are described using the model of the classical shell theory. Numerical implementation was accomplished based on the semi-analytical variant of the finite element method. The paper presents the results of numerical experiments on the stability of shells interacting with different flow patterns for a variety of boundary conditions, geometrical dimensions, width of the annular gap between the outer and inner shell under the constraint of the outer shell rigidity. It has been shown that the elasticity of the outer shells has the greatest effect on the dynamic behavior of coaxial shells interacting with fluid flows having different combinations of velocity components.

References listed at the end of the paper:

Ali A. Yazdi (Department of Mechanical Engineering, Quan campus of University of Advanced Technology Engineering, P. O. Box 94717-84686, Quan campus, Iran), “Nonlinear flutter of laminated composite plates resting on nonlinear elastic foundations using homotopy perturbation method”, International Journal of Structural Stability and Dynamics, Vol. 15, No. 5, 150072, June 2015, https://doi.org/10.1142/S0219455415007222

ABSTRACT: In this paper, the applicability of the homotopy perturbation method (HPM) in analyzing the flutter of geometrically nonlinear cross-ply rectangular laminated plates resting on nonlinear elastic foundation is investigated. The piston theory is employed to evaluate the aerodynamic pressure acting on the plate. The von Karman geometric nonlinearity theory is used to construct the governing equations of the system. The Galerkin’s method is used to reduce the nonlinear partial differential equations to a nonlinear second-order ordinary differential equation, and the HPM is employed to study the effect of initial deflection, aspect ratio and stacking sequence on the flutter pressure of cross-ply laminated plates. The results show that the first approximation of the HPM leads to highly accurate solutions for the geometrically nonlinear flutter of cross-ply rectangular laminated plates subjected to the aerodynamic pressure.

References listed at the end of the paper:


ABSTRACT: This paper presents a numerical technique to determine the full pre-buckling and post-buckling equilibrium path for elastic funicular arches. The formulation includes the effects of shear deformations and geometric nonlinearity due to large deformations. The Timoshenko beam hypothesis is adopted for incorporating shear. Finite strains are considered without approximation. The finite strains are defined in terms of the normal and shear component of the longitudinal stretch. The constitutive relations for the internal actions are based on a hyperelastic constitutive model. Using the differential equilibrium equations and the constitutive laws, the nonlinear buckling behavior of some typical funicular arches are investigated using the trapezoid method with Richardson extrapolation enhancement. The results are validated by using the finite element package ANSYS and solutions available in the literature. Examples include parabolic arches under a uniformly distributed gravity load, a catenary under a distributed load along the arch and a catenary arch under an overburden load. Parametric studies are performed to identify the factors that influence the nonlinear buckling of funicular arches. The axial to shear rigidity ratio is shown to have a significant effect on the buckling load and the buckling mode shape.

References listed at the end of the paper:
· A. N. Dinnik, Buckling and Torsion. 1955, Moscow: Lzd-vo Akademii nauk SSSR.

ABSTRACT: FASTMast (Folding Articulated Square Truss Mast) deployable structure is the main bracing structure for the flexible solar array of the international space stations. This study investigates the buckling of FASTMast deployable structures. To this end, the buckling modes and the stiffness characteristics of this structure using the flex batten as an elastic bearing member were theoretically analyzed. The analytical results show that (1) the buckling mode of a FASTMast deployable structure is similar to the elbow joint movement failure when the stiffness of the flex batten is below a critical stiffness value. Once this critical stiffness is reached, the buckling mode takes on the form of Euler buckling. (2) The stiffness of the flex batten is proportional to its cross-sectional second moment of area. Furthermore, an experimental study was carried out to validate the accuracy of the theoretical analysis. The results from experimental work agree fairly well with those from theoretical analysis. The research findings herein are expected to be useful for future studies on similar structures.

References listed at the end of the paper:

- M. S. Lake and M. R. Hachkowski, Design of mechanisms for deployable, optical instruments: Guidelines for reducing hysteresis, National Aeronautics and Space Administration (NASA) (Langley Research Center, USA, 2000).
- J. F. Shaker, 3-Bay FASTMast shear test and analysis, National Aeronautics and Space Administration (NASA) (Lewis Research Center, USA, 1993).
- J. F. Shaker, PV structural analysis space station tension test of FASTMast elbow joint, National Aeronautics and Space Administration (NASA) (Lewis Research Center, USA, 1993).

Eugenio Ruocco and Vincenzo Minutolo (Department of Ingegneria Civile, Design, Edilizia e Ambiente (DICDEA), Second University of Naples, Via Roma 29, 81031, Aversa, Ce, Italy), “Buckling analysis of Mindlin plates under the Green–Lagrange strain hypothesis”, International Journal of Structural Stability and Dynamics, Vol. 15, No. 6, 1450079, August 2015, https://doi.org/10.1142/S021945541500795
ABSTRACT: In the present paper, the influence of Green–Lagrange nonlinear strain-displacement terms, usually considered negligible under the von Kármán hypothesis, on the buckling of isotropic, moderately thick plates and shells, is investigated. The first order shear deformation plate theory is applied and the governing equations, containing nonlinear terms related to both in-plane displacement and out-of-plane rotations usually ignored in the literature, are derived using the principle of minimum of the strain energy. The general Levy type solution method is employed, and exact buckling loads and mode shapes are derived. To verify the accuracy of the solution obtained, comparisons with existing data are first made. Then, through graphics and tables, the effect of the nonlinear strain-displacement terms for a range of boundary and load conditions, variations of aspect ratio, thickness ratio and changes in geometry is presented. The results obtained show that the von Kármán's model can sensibly overestimate the critical load for structures characterized by the modes involving comparable in-plane and out-of-plane displacements.

References listed at the end of the paper:

- M. H. Aliabadi and P. M. Baiz, Buckling and Postbuckling Structures 1, 375 (2008).


ABSTRACT: Nonlinear dynamic behavior of a cantilever cylindrical shell is studied experimentally using non-contact type of electromagnetic shaker, acceleration measurements, and imaging of vibrating shell using two high speed 3D cameras. The response history and frequency spectrum are measured at different locations along the circumference of the free end of the shell for different excitation amplitudes and mode of vibration. The frequency response obtained from acceleration measurements is found to be in good agreement with the simulated response in ANSYS. The response histories from acceleration data and digital image correlation are
compared for one case and found to match very well. The traveling wave phenomenon along with participation of higher harmonics and softening nonlinearity are observed. The traveling wave response is observed for certain range of forcing frequency for the shell excited in modes with number of circumferential waves $n = 3$ and 5. It is shown that the traveling wave response can be detected based on the phase angle difference of response at different circumferential locations.

References listed at the end of the paper:


ABSTRACT: This article deals with the free axisymmetric vibration of two-directionally functionally graded annular plates. Ceramic and metal are considered two constituents of the functionally graded material (FGM), which are graded through thickness and radial directions of the plate. The Chebyshev collocation technique and differential quadrature method are employed to derive the frequency equations for an annular plate with both edges clamped and another one with both edges simply supported. The results for nonhomogeneous isotropic annular plates are also presented. The accuracy and efficiency of the present approach are confirmed through comparison of the frequencies obtained for homogeneous isotropic annular plates. Identical results are obtained for the two methods used. The effects of volume fraction index, coefficient of radial variation, exponent of power law, inner to outer radii ratio, and boundary conditions are discussed on the first three natural frequencies. It is found that the frequency of a functionally graded annular plate is greater than that of a homogeneous annular plate.

References listed at the end of the paper:
Shanshan Cheng, Qi-Wu Yan, Long-Yuan Li and Boksun Kim (primarily School of Marine Science and Engineering, University of Plymouth, UK), “Thermal buckling analysis of axially loaded columns of thin-walled open section with nonuniform sectional properties”, International Journal of Structural Stability and Dynamics, Vol. 15, No. 6, 1450088, August 2015, https://doi.org/10.1142/S0219455414500886

ABSTRACT: This paper presents an analytical study on the thermal buckling analysis of axially loaded columns of thin-walled open section with nonuniform sectional properties. Obtained herein are critical loads related to flexural, torsional and flexural-torsional buckling of an I-section column subjected to an axial compressive load applied at the geometric centroid, and under linearly varied non-uniform temperature distribution scenarios. The analysis is accomplished using traditional energy methods. The influences of thermal strain, nonuniform distribution of pre-buckling stresses, and variation of pre-buckling stresses along the longitudinal axis of the column on critical buckling loads are examined. The present results highlight the importance of nonuniform sectional properties in the buckling analysis of columns of doubly symmetric section.

References listed at the end of the paper:
· R. E. Erkmen and M. Mohareb, Thin-Walled Struct. 46(6), 618 (2008).
· L. Y. Li, Thin-Walled Struct. 42(7), 995 (2004).
· X. T. Chu et al., Thin-Walled Struct. 43(4), 531 (2005).
· Z. M. Ye et al., Thin-Walled Struct. 40, 853 (2002).


ABSTRACT: A circumferentially enhanced Hermite reproducing kernel (HRK) meshfree method is developed for the buckling analysis of Kirchhoff–Love cylindrical shells. In this method, in order to accurately represent the circumferential periodicity of cylindrical shells, the shell mid-surface is first discretized by a set of physical nodes in the two-dimensional parametric space, thereafter another set of dummy nodes are added by a straightforward periodic translation of the physical nodes. Subsequently the meshfree shape functions are constructed using both the physical nodes and the dummy nodes through a periodically linked relationship. The resulting meshfree shape functions exhibit the desired circumferential periodicity. The meshfree shape functions are formulated in the HRK framework which can be degenerated to the standard reproducing kernel (RK) shape functions just by removing the rotational terms. Meanwhile, the cylindrical shell buckling equations are rationally derived from the consistent linearization of the internal virtual work. During the meshfree discretization, the in-plane shell displacements are represented by the conventional RK shape functions, while the out-of-plane shell deflection is approximated by the Hermite meshfree shape functions with both directional and rotational degrees of freedom. The numerical integration of the material as well as the geometric stiffness matrices are carried out by the strain smoothing sub-domain stabilized conforming integration (SSCI) method. Numerical examples show that the proposed approach yields very favorable results for the buckling analysis of cylindrical shells.

References listed at the end of the paper:
It is shown that the finite element problem can be transformed into a system of finite continuum. The analogy between the finite numerical approach and the finite element method applied to continuous beam dynamics problems, can be asymptotically investigated. The computation of eigenfrequencies of beams using finite difference and finite element methods, has been widely studied. The finite element method is used for solving complex engineering problems, but it can be computationally expensive and may suffer from locking phenomena. In contrast, the finite difference method is simpler and more efficient, but it may not handle complex geometries as well. A hybrid meshfree formulation can provide a balance between the two methods, offering the advantages of both. This approach has been applied to the study of nonlocal effects in materials, which are important in micro- and nanoscale structures. The study presented here aims to compare the finite element method and the finite difference method, focusing on their asymptotic behavior and their application to the computation of eigenfrequencies of beams.
difference equations. The convergence rate of the finite numerical approaches is quantified by an equivalent Rayleigh's quotient. We also present some exact analytical solutions for a first-order finite difference method, a higher-order finite difference method or a cubic Hermitian finite element, valid for arbitrary number of nodes or segments. The comparison between the exact numerical solution and the approximated nonlocal approaches shows the efficiency of the continualization methodology. These analogies between enriched continuum and finite numerical schemes provide a new attractive framework for potential applications of enriched continua in computational mechanics.

References listed at the end of the paper:

- J. L. Lagrange, Mécanique Analytique (Paris, 1788).
- H. Hencky, Der Eisenbahn 11, 437 (1920).

ABSTRACT: This paper investigates the free vibration and elastic buckling of sandwich beams with a stiff core and functionally graded carbon nanotube reinforced composite (FG-CNTRC) face sheets within the framework of Timoshenko beam theory. The material properties of FG-CNTRCs are assumed to vary in the thickness direction, and are estimated through a micromechanical model. The governing equations and boundary conditions are derived by using Hamilton’s principle and discretized by employing the differential quadrature (DQ) method to obtain the natural frequency and critical buckling load of the sandwich beam. A detailed parametric study is conducted to study the effects of carbon nanotube volume fraction, core-to-face sheet thickness ratio, slenderness ratio, and end supports on the free vibration characteristics and buckling behavior of sandwich beams with FG-CNTRC face sheets. The vibration behavior of the sandwich beam under an initial axial force is also discussed. Numerical results for sandwich beams with uniformly distributed carbon nanotube-reinforced composite (UD-CNTRC) face sheets are also provided for comparison.

References listed at the end of the paper:


ABSTRACT: Understanding the mechanical behaviors of graphene under different stress states is crucial to their applications. Comparing with the buckling behavior of free standing graphene under compression, the monolayer graphene embedded in the polymer matrix has a higher critical buckling load and smaller atomic length scale wavelengths as well as buckling amplitudes. In this paper, the molecular dynamics (MD) method is adopted to study the buckling behaviors of embedded graphene under uniaxial compression. Two MD models are built, namely the hybrid MD/continuum nanomechanics model and the full MD model. Periodical boundary conditions are applied in the MD simulations. Graphene sheets with different aspect ratios are considered and it is observed that the critical buckling strain of graphene sheets embedded in polymer matrix is independent of their aspect ratios. The current simulation results match well with the reported experimental results.
Furthermore, it is demonstrated that the current simulation method can produce clear buckling shapes, which are difficult to observe in nanoscale experiments.

References listed at the end of the paper:
- O. Frank et al., ACS Nano 4 (6), 3131 (2010).


ABSTRACT: In the present paper, the geometrically nonlinear behavior of piezoelectric thin plates is studied. First, the governing equations for the electromechanically coupled problem are derived based on the von Karman–Tsien kinematic assumption. Here, the Berger approximation is extended to the coupled piezoelectric problem. The general equations are then reduced to a single nonlinear partial differential equation for the special case of simply supported polygonal edges. The nonlinear equations are approximated by using a problem-oriented Ritz Ansatz in combination with a Galerkin procedure. Based on the resulting equations the buckling and post-buckling behavior of a polygonal simply supported plate is studied in a nondimensional form, where the special geometry of the polygonal plate enters via the eigenvalues of a Helmholtz problem with Dirichlet boundary conditions. Single term as well as multi-term solutions are discussed including the effects of piezoelectric actuation and transverse force loadings upon the solution. Novel results concerning the buckling, snap through and snap buckling behavior are presented.

References listed at the end of the paper:

ABSTRACT: This paper presents an analytical study on the nonlinear vibration of rectangular piezoelectric nanoplates resting on the Winkler foundation. The piezoelectric nanoplate is assumed to be simply supported on all four edges and is subjected to an external electric voltage and a uniform temperature rise. Based on von Karman nonlinear strain–displacement relations and the nonlocal constitutive relations, the nonlinear governing equations and corresponding boundary conditions are derived by employing Hamilton's principle. The Galerkin method is used to obtain the nonlinear ordinary equation, which is then solved by the direct integration method. An extensive parametric study is conducted to examine the effects of the nonlocal parameter, external electric voltage, temperature rise and Winkler parameter on the nonlinear vibration characteristics of piezoelectric nanoplates.

References listed at the end of the paper:

- A. C. Eringen, Nonlocal Continuum Field Theories (Springer-Verlag, New York, 2002).
- S. C. Pradhan and A. Kumar, Composite Struct. 93, 774 (2011).

ABSTRACT: Functionally graded carbon nanotube reinforced nanocomposites have drawn great attention in both research and engineering communities. The weak interfacial bonding between carbon nanotubes and the matrix, which traditionally hinders the application of carbon nanotube reinforced nanocomposites, can be remarkably improved through the graded distribution of carbon nanotubes in the matrix. Within the framework of classical beam theory, this paper investigates the dynamic buckling behavior of functionally graded nanocomposite beams reinforced by single-walled carbon nanotubes and integrated with two surface bonded piezoelectric layers. The governing equations of the beam subjected to an applied voltage, a uniform temperature and an axial periodic force are derived by applying Hamilton's principle. Numerical results are presented for beams with different distribution patterns and volume fractions of carbon nanotubes and end support conditions. The influences of the beam geometry, temperature change, applied voltage, static axial force component, boundary condition, carbon nanotube volume fraction and its distribution on the unstable regions of FG-CNTRC piezoelectric beams are discussed in detail.

References listed at the end of the paper:
- R. Ansari et al., Compos. Struct. 113, 316 (2014).


ABSTRACT: This paper reports the results of an investigation on the use of Generalized Beam Theory (GBT) to assess the buckling and vibration behaviors of thin-walled members and frames built from cold-formed steel circular hollow section (CHS) profiles. Initially, the concepts and procedures involved in performing GBT buckling and vibration analyses are presented, paying particular attention to the derivation of the mass tensors that account for the influence of the inertia forces. Then, the formulation, numerical implementation and validation of a GBT-based beam finite element for isolated members are described. Next, the determination of the frame linear stiffness, geometric stiffness and mass matrices, which incorporate the influence of the frame joints, is addressed. Finally, in order to illustrate the application and capabilities of the proposed GBT finite element formulation, numerical results are presented and discussed — they concern the buckling and vibration
behaviors of an "L-shaped" frame. For validation purposes, most GBT-based results are compared with values yielded by shell finite element analyses carried out in the code ANSYS.

References listed at the end of the paper:
- D. Camotim, C. Basaglia and N. Silvestre, Thin Wall. Struct. 48(11), 726 (2010).
- N. Silvestre and D. Camotim, Steel Compos. Struct. 6(3), 231 (2006).


ABSTRACT: This paper presents the results of an investigation concerning the free vibration behavior (undamped natural frequencies and vibration mode shapes) of thin-walled beams with rectangular multi-cell cross-section (assemblies of parallel rectangular cells in a single direction). Besides local (plate-type) and global (flexural, torsional and extensional) vibration modes, attention is paid to the relatively less-known distortional vibration modes, which involve cross-section out-of-plane (warping) and in-plane deformation, including displacements of the wall intersections. A computationally efficient semi-analytical Generalized Beam Theory (GBT) approach is employed to obtain insight into the mechanics of the problem. In particular, the intrinsic modal decomposition features of GBT — the fact that the beam is described using a hierarchical set of relevant cross-section deformation modes — are exploited to identify and categorize the most relevant vibration modes and deformation mode couplings.

References listed at the end of the paper:
- C. Basaglia et al., Thin Wall. Struct. 72, 217 (2013).
- R. Gonçalves and D. Camotim, On distortion of symmetric and periodic open-section thin-walled members, Thin-Walled Structures, accepted for publication (2015).

ABSTRACT: Field observations reveal that very long members such as railway tracks and pipelines which are subjected to axial compression, induced usually by temperature and/or pressure increases, experience localized buckling. This paper presents a solution for the antisymmetric post-buckling of such members when restrained by a nonlinear foundation that includes softening effects. The principle of minimum total potential is invoked in order to develop the governing differential equations of buckling, as well as the non-linear equations of equilibrium in the post-buckling range of structural response. In order to solve these equations, a semi-analytical solution is proposed based on a perturbation technique, as well as a numerical technique based on a single shooting procedure for the solution of boundary value problems. The results of the analysis show that the post-buckling configuration of the column changes from a lengthwise periodic mode at the initial stages of loading to an isolated sinusoidal mode at the later stages of post-buckling, which represents a localization in the post-buckling range. This response is typical of that observed often in practice. Comparisons between the results of the perturbation technique and those of the numerical approach indicate that the semi-analytical perturbation solution predicts the initial post-buckling response of a column on a nonlinear foundation quite accurately.

References listed at the end of the paper:

ABSTRACT: Presented herein is a new method for the analysis of plates with clamped edges. The solutions for the natural frequencies of the plates are found using static analysis. The starting are the equations of motion of an isotropic rectangular plate supported on Winkler elastic foundation, with a positive or negative value. In either case, one can solve the displacements of such a plate under a given concentrated load. This deflection will be infinite if the plate losses its stiffness, or in other words, the generalized foundation is causing the plate to be unstable. The solution for the vibration frequencies of the plate is equivalent to finding the values of the negative elastic foundation that will yield infinite deflection under a point load on the plate. The solution for a clamped plate is decomposed as the sum of three cases of plates resting on elastic foundation: simply supported plate with a concentrated load, and two cases of distributed moments along opposite edges. The solution for simply supported plates with elastic foundation is found using Navier's method. For zero force, the vibration frequencies are found up to the desired accuracy by careful calculations at the neighborhood of the roots.

References listed at the end of the paper:


Dilum Fernando (University of Queensland, Australia), Tao Yu (University of Wollongong, Australia) and J.G. Teng (Hong Kong Polytechnic University, China), “Behavior and modeling of CFRP-strengthened rectangular steel tubes subjected to a transverse end bearing load”, International Journal of Structural Stability and Dynamics, Vol. 15, No. 8, 1540031, December 2015, [https://doi.org/10.1142/S0219455415400313](https://doi.org/10.1142/S0219455415400313)

ABSTRACT: The end bearing capacity of a rectangular hollow section (RHS) steel tube can be substantially increased through local strengthening using bonded carbon fiber reinforced polymer (CFRP) plates. This paper presents a combined experimental and numerical study into the behavior of such CFRP-strengthened RHS steel tubes with particular attention to debonding failure in such tubes. The results of an experimental study are first presented, which showed that debonding failure occurred in all the CFRP-strengthened steel tubes and the effectiveness of strengthening depended significantly on the slenderness of the webs. A finite element approach for modeling the behavior of such CFRP-strengthened steel tubes is next presented, in which a coupled cohesive zone model is employed to depict the response of FRP-to-steel bonded interfaces with a linear or a nonlinear adhesive. The finite element approach, which is shown to provide close predictions for CFRP-strengthened RHS steel tubes under an end bearing load, offers a valuable tool for understanding the behavior of these CFRP-strengthened steel tubes.

References listed at the end of the paper:

- D. Fernando et al., Thin Wall Struct. 47(10), 1020 (2009).
- D. Fernando et al., J. Compos. Constr. 17(6), 04013012 (2013).
- D. Fernando, Bond behaviour and debonding failures in CFRP-strengthened steel structures, PhD thesis, Department of Civil and Structural Engineering, Hong Kong Polytechnic University, Hong Kong, China (2010).

ABSTRACT: Geometrically nonlinear free vibrations of thin rectangular plates are studied using the recently developed weak form quadrature element method (QEM). The nonlinear von Karman plate theory is employed to express the strain-displacement relations. The weak form description of the plate is formulated on the basis of the variational principle. The integrals involved in the variational description are evaluated by an efficient numerical integration scheme, and the partial derivatives at the integration points are approximated by differential quadrature analogs. A system of algebraic equations is eventually derived, and the nonlinear frequencies and mode shapes are extracted from solving the equations. The efficiency of the method is demonstrated by a convergence study. The accuracy of the method is illustrated by comparing the computed nonlinear to linear frequency ratios with those available in the literature. The influences of the nonlinearity on higher order frequencies and mode shapes are exhibited as well.

References listed at the end of the paper:

ABSTRACT: This paper focuses on the dynamic characteristics of inflatable reflectors considering the effects of assembly of gores. A model is established to properly predict the assembled shape of planar gores, and nonlinear finite element method and subspace iteration method are adopted to analyze the dynamic characteristics of reflectors. A comparative study is carried out based on the dynamic analysis with ideal reflector and assembled reflector to illustrate the impacts of assembly on mode shapes and natural frequencies of the reflectors. The results show that the presence of assembly of gores and seaming tapes has significant effects on mode shapes and natural frequencies of reflectors, which will influence the shape control of reflectors.

References listed at the end of the paper:

Bo Yang, Gang Xiong, Kang Ding, Shidong Nie, Weifu Zhang, Ying Hu and Guoxin Dai (First author is from: College of Civil Engineering, Chongqing University, Chongqing 400045, P. R. China), “Experimental and numerical studies on lateral-torsional buckling of GJ structural steel beams under a concentrated loading condition”, International Journal of Structural Stability and Dynamics, Vol. 16, No.1, 1640004, January 2016, https://doi.org/10.1142/S0219456716400046

ABSTRACT: GJ structural steel has been applied in many high-rise buildings and large-span structures, such as New CCTV Building and Beijing Olympic Stadium (Birds Nest). However, the design methods of GJ structural steel members are not covered by the current design codes. This paper describes the lateral-torsional buckling behavior of welded sections based on a series of flexural tests performed on H-sections fabricated from GJ
Furthermore, this paper makes a random simulation test for ZZF membrane material which is commonly nonlinear stochastic governing differential equation, solve it according to the perturbation method and the rectangular orthotropic membranes under stochastic impact loading. The numerical simulations and parametric study results were compared with multiple design codes, including Chinese steel structure design codes (GB50017-2003, GB50017-201X). The comparisons indicate that GB50017-201X can predict appropriate flexural strengths of GJ structural steel beams. Also, it is found that the predictions of EC3 are too conservative, while for certain cases ANSI/AISC360-10 predictions are too high for the design flexural strength of GJ structural steel beams.

References listed at the end of the paper:

- 12. H. Ban, G. Shi, Y. Shi and Y. Wang, Residual stress of 460MPa high strength steel welded box section: Experimental investigation and modeling, Thin-Walled Struct. 64 (3) (2013a) 73–82.


ABSTRACT: This paper studies the calculation method about the displacement response mean function of rectangular orthotropic membranes with four edges fixed under stochastic impact loading. We set up the nonlinear stochastic governing differential equation, solve it according to the perturbation method and the random vibration theory and obtain the displacement response mean value function of the membrane surface. Furthermore, this paper makes a random simulation test for ZZF membrane material which is commonly used.
applied in the membrane structural engineering and obtains abundant deflection response sample curves about
the feature points of the membrane surface. For sample curves statistical analysis at some fixed time, sample
means can be obtained, which verify the correctness of the theoretical calculation method. The calculation
method provides a theoretical basis for vibration control of building membrane structures to control the
occurrence of natural disasters.
References listed at the end of the paper:
- 11. E. L. Jansen, A perturbations method for nonlinear vibration of imperfect structures: Application to cylindrical shell vibrations,*
741–745.
1705.


**ABSTRACT:** An analytical investigation is performed to study the secondary instability and dynamic aspects of
the mode jumping in hygrothermally buckled angle-ply laminated plates. The governing partial differential
equations (PDEs) and constitution relations are derived rigorously from an asymptotically correct,
geometrically nonlinear theory. A novel and relatively simpler solution approach is developed to solve the two
coupled fourth-order PDEs, namely, the compatibility equation and the dynamic governing equation. The von
Kármán plate equation, namely, the coupled nonlinear governing equation, is reduced to a system of nonlinear
ordinary differential equations (ODEs) by expressing the transverse deflection as a series of linear buckling
modes. The ODEs, combined with the nonlinear algebraic constraint equations obtained from in-plane boundary
conditions, are then solved numerically under the parametric variation of the temperature and moisture. The
comparison between the present method and the FEA shows that the secondary bifurcation point of the
hygrothermally loaded plate is far beyond the primary buckling point, and the jump behavior cannot be
predicted correctly without sufficient assumed modes, while the present method has the capability of exploring
deeply into the post-secondary buckling realm and capture the mode jumping phenomenon for various
combinations of plate configurations boundary conditions. Furthermore, by monitoring free vibration along the
stable primary postbuckling and the jumped equilibrium paths, we find that a mode shifting phenomenon (the
exchange of vibration modes) exists in the primary post-buckling regime.

References listed at the end of the paper:
Administration, 1959).

ABSTRACT: This paper presents an analytical solution of vertical dynamic response of a concrete-filled steel tube (CFST) due to transient impact loading. Both the concrete and steel are modeled by linear elastic material. The impact load is simulated by a semisinusoidal impulse. Three-dimensional (3D) wave equations those considering the vertical displacement are established. By combining the initial and boundary conditions, the frequency-domain analytical solution of displacement is deduced by Laplace transformation and separation of variables methods. The time-domain dynamic response is then obtained by numerical inverse Fourier transformation (IFT). Numerical examples are presented to verify the validity of the analytical solution developed in this study. The results indicate that the analytical solution proposed in this study shows good consistence with the existing solutions.

References listed at the end of the paper:


ABSTRACT: Postbuckling and collapse phenomenon of a thick closed ring subjected to external pressure on its outer surface is analyzed in this research. Ring is made of a linearly elastic polar orthotropic material. Constitutive law of linear elasticity under plane stress conditions is used. Virtual work principle is implemented to obtain the governing equations. Unlike the available noncompressible ring theories, a two-dimensional elasticity solution including the complete nonlinear Green strain field is used. The finite element method is used to solve the highly nonlinear coupled equilibrium equations. The well-known Newton–Raphson iterative technique is applied to the matrix representation of the equilibrium equations to trace the post-buckling response of the ring up to the collapse point where two antipodal points on the interior side of the ring are collided with each other. It is shown that, including the complete Green strain field is necessary in accurate estimation of the post-buckling path, especially for higher load levels and collapse load. Furthermore, orthotropic rings under external pressure load follow the bifurcation type of buckling accompanied with a stable post-buckling path.

References listed at the end of the paper:

ABSTRACT: The vibration characteristics of an axially moving vertical plate immersed in fluid and subjected to a pretension are investigated, with a special consideration to natural frequencies, complex mode functions and critical speeds of the system. The classical thin plate theory is adopted for the formulation of the governing equation of motion of the vibrating plates. The effects of free surface waves, compressibility and viscosity of the fluid are neglected in the analysis. The velocity potential and Bernoulli’s equation are used to describe the fluid pressure acting on the moving plate. The effect of fluid on the vibrations of the plate may be regarded as equivalent to an added mass on the plate. The formulation of added mass is obtained from kinematic boundary conditions of the plate–fluid interfaces. The effects of some system parameters such as the moving speed, stiffness ratios, location and aspect ratios of the plate and the fluid-plate density ratios on the above-mentioned vibration characteristics of the plate–fluid system are investigated in detail. Various different boundary conditions are considered in the study.

References listed at the end of the paper:

References listed at the end of the paper: sandwich hybrid CNTRC and piezoelectric plates may be used as the benchmark solutions to assess the ones piezoelectric plates are in excellent agreement with the exact 3D ones available in the literature, and those for sandwich hybrid CNTRC and piezoelectric plates with an embedded either a functionally graded (FG) carbon nanotube-reinforced composite (CNTRC) core or a multilayered fiber-reinforced composite (FRC) one are presented. Three different distributions of carbon nanotubes (CNTs) through the thickness of the CNTRC core, i.e. uniformly distributed and FG V-, rhombus- and X-type variations, are considered, and the effective material properties of the CNTRC core are estimated using the rule of mixtures. The Pagano method, which is conventionally used for the analysis of multilayered FRC plates, is modified to be feasible for the study of sandwich hybrid CNTRC and piezoelectric ones, in which Reissner mixed variational theorem, the successive approximation and transfer matrix methods, and the transformed real-valued solutions of the system equations are used. The modified Pagano solutions for the stability and free vibration of multilayered hybrid FRC and piezoelectric plates are in excellent agreement with the exact 3D ones available in the literature, and those for sandwich hybrid CNTRC and piezoelectric plates may be used as the benchmark solutions to assess the ones obtained by using various 2D theories and numerical models.


ABSTRACT: Quasi-three-dimensional (3D) stability and free vibration analyses of bi-axially loaded, simply-supported, sandwich piezoelectric plates with an embedded either a functionally graded (FG) carbon nanotube-reinforced composite (CNTRC) core or a multilayered fiber-reinforced composite (FRC) one are presented. Three different distributions of carbon nanotubes (CNTs) through the thickness of the CNTRC core, i.e. uniformly distributed and FG V-, rhombus- and X-type variations, are considered, and the effective material properties of the CNTRC core are estimated using the rule of mixtures. The Pagano method, which is conventionally used for the analysis of multilayered FRC plates, is modified to be feasible for the study of sandwich hybrid CNTRC and piezoelectric ones, in which Reissner mixed variational theorem, the successive approximation and transfer matrix methods, and the transformed real-valued solutions of the system equations are used. The modified Pagano solutions for the stability and free vibration of multilayered hybrid FRC and piezoelectric plates are in excellent agreement with the exact 3D ones available in the literature, and those for sandwich hybrid CNTRC and piezoelectric plates may be used as the benchmark solutions to assess the ones obtained by using various 2D theories and numerical models.

References listed at the end of the paper:

method. It was shown through numerical examples that combining CR formulation and ANDES elements can
be used to the geometric nonlinear analysis of shell structures with large rotations and small strains. By taking
variations of the internal energy with respect to nodal freedoms, the equations for the CR nonlinear finite
element, including the tangent stiffness matrix and the internal force vector in the global coordinate system,
were derived. The nonlinear equations were solved by using the generalized displacement control (GDC)
method. It was shown through numerical examples that combining CR formulation and ANDES elements can

40. T. Mori and K. Tanaka, Average stress in matrix and average elastic energy of materials with misfitting inclusions, Acta
Metallurgica 21 (1973) 571–574.
41. P. Zhu, Z. X. Lei and K. M. Liew, Static and free vibration analyses of carbon nanotube-reinforced composite plates using finite
element method with first order shear deformation plate theory, Compos. Struct. 94 (2012) 1450–1460.
42. Z. X. Lei, K. M. Liew and J. L. Yu, Buckling analysis of functionally graded carbon nanotube-reinforced composite plates using
the element-free kp-Ritz method, Compos. Struct. 98 (2013) 160–168.
44. A. M. Zenkour, On vibration of functionally graded plates according to a refined trigonometric plate theory, Int. J. Strab.
Dynam. 05 (2005) 279.
45. D. K. Jha, T. Kant and R. K. Singh, Free vibration of functionally graded plates with a higher-order shear and normal
46. S. Brischetto and E. Carrera, Analysis of nano-reinforced layered plates via classical and refined two-dimensional theories,
48. E. Carrera, Developments, ideas and evaluation based upon Reissner’s mixed variational theorem in the modelling of
49. E. Carrera, Theories and finite elements for multilayered plates and shells: A unified compact formulation with numerical
50. E. Carrera and S. Brischetto, Analysis of thickness locking in classical, refined and mixed multilayered plate theories, Compos.
51. C. P. Wu, S. J. Chen and K. H. Chiu, Three-dimensional static behavior of functionally graded magneto-electro-elastic plates
52. C. P. Wu and Y. C. Lu, A modified Pagano method for the 3D dynamic responses of functionally graded magneto-electro-elastic
53. C. P. Wu and T. C. Tsai, Exact solutions of functionally graded piezoelectric material sandwich cylinders by a modified Pagano
55. S. Kapuria and G. G. S. Achary, Exact 3D piezoelectricity solution for buckling of hybrid cross-ply plates using transfer
56. P. Heyliger and D. A. Saravanos, Exact free-vibration analysis of laminated plates with embedded piezoelectric layers, J.
57. E. Carrera and M. Boscolo, Classical and mixed finite elements for static and dynamic analysis of piezoelectric plates, Int. J.

Yi Zhou (1), Yuan-Qi Li (1), Zu-Yen Shen (1) and Ying-Ying Zhang (2)

(1) Department of Building Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China
(2) China University of Mining and Technology, Jiangsu Xuzhou, China

“Corotational formulation for geometric nonlinear analysis of shell structures by ANDES elements”,
International Journal of Structural Stability and Dynamics, Vol. 16, No. 3, 1450103, April 2016,
https://doi.org/10.1142/S021945541450103X

ABSTRACT: The corotational (CR) kinematic description was a recent method for formulation of geometric
nonlinear structural problems. Based on the consistent symmetrizable equilibrated (CSE) CR formulation, a
linear triangular flat shell element with three translational and three rotational degrees of freedom (DOFs) at
each of the three nodes was derived by the assumed natural deviatoric strain (ANDES) formulation, which can
be used to the geometric nonlinear analysis of shell structures with large rotations and small strains. By taking
variations of the internal energy with respect to nodal freedoms, the equations for the CR nonlinear finite
element, including the tangent stiffness matrix and the internal force vector in the global coordinate system,
were derived. The nonlinear equations were solved by using the generalized displacement control (GDC)
method. It was shown through numerical examples that combining CR formulation and ANDES elements can
accurately solve complex geometric nonlinear problems with large body motions. As revealed by the efficiency and reliability of the ANDES elements in tracing the nonlinear structural load–deflection response, it is demonstrated that some membrane elements and plate elements give better performance in the geometric nonlinear analysis of shell structures.

References listed at the end of the paper:

Mohammad Ebrahim Torki (1) and Junuthula N. Reddy (2)

(1) Aerospace Eng., Texas A&M University, College Station, Texas, USA
(2) Mechanical Eng., Texas A&M University, College Station, Texas, USA

“Buckling of functionally-graded beams with partially delaminated piezoelectric layers”, International Journal of Structural Stability and Dynamics, Vol. 16, No. 3, 1450104, April 2016,
https://doi.org/10.1142/S0219455414501041

ABSTRACT: The critical buckling load of a functionally-graded simply-supported beam with partially delaminated piezoelectric layers is discussed. The governing equations of motion are derived using two different, i.e. Euler–Bernoulli and Timoshenko beam theories, and the buckling load was evaluated from the exact solution to the corresponding eigenvalue equation. The equations were simplified to some extent by shifting the coordinate origin such that there is zero bending-extension coupling. Effects induced by the delaminated length, asymmetry, piezoelectric thickness, voltage, and the functionally graded materials (FGMs) volume fraction are evaluated. The validity of results and the invoked assumptions were successfully verified with existing results and finite element calculations. There is some difference between the analytical buckling load and that calculated with the finite element method (FEM), proven small in amount but predictable in terms of the piezoelectric thickness. Further, a general formula is derived to evaluate the dimensionless critical buckling load with the parameters obtained from regression analysis of the solution that can be utilized for all cases where the materials are not far different in their mechanical properties. The results can be utilized as benchmark design tool.

References listed at the end of the paper:

ABSTRACT: Large amplitude vibration problem of laminated composite spherical shell panel under combined temperature and moisture environment is analyzed in this paper. A general nonlinear mathematical model of laminated composite panel is developed based on higher-order shear deformation theory (HSDT) by taking the geometric nonlinearity in the Green–Lagrange sense. The sets of nonlinear governing differential equations are obtained using Hamilton’s principle and discretized via finite element steps. The nonlinear vibration responses are computed using a direct iterative method by incorporating hygral and/or temperature dependent material properties for laminated composite. The convergence behavior of the developed model has been checked and validated by comparing the responses with those available published results. Finally, some new examples are computed for different parameters (geometry, support condition and lamination scheme, etc.) and their effects on nonlinear free vibration responses under uneven environment are discussed.

References listed at the end of the paper:

ABSTRACT: Flapwise flexural vibration of rotating beams has been extensively studied since the 1970s. Existing methods for solving the aforementioned vibration problem range from the conventional finite element method to variable-order finite element method, Frobenius method, differential transformation method and dynamic stiffness method (DSM). Although various approximation methods are available, most of these methods are based on perturbation or discretization of the governing equation, often leading to tedious calculations. This paper re-examines flapwise flexural vibration of rotating beams using the method of variational iteration, which is relatively new and capable of providing accurate solutions for eigenvalue problems. The extracted natural frequencies and mode shapes for sample rotating beams with various rotational speeds and hub radii are compared with existing results that were published in the open literature.

References listed at the end of the paper:

1. S. V. Hoa, Vibration of a rotating beam with tip mass, J. Sound Vib. 67 (3) (1979) 369–381.
Majid Abedi and Alireza Asnafi (First author is from: School of Mechanical Engineering, Shiraz University, 71348–13668, Iran), “Instability and bifurcation behavior of orthotropic S-FGM plates under lateral stochastic loads considering variation of material properties”, International Journal of Structural Stability and Dynamics, Vol. 16, No. 3, 1450108, April 2016, https://doi.org/10.1142/S0219455414501089

ABSTRACT: In this paper, all the parameters affecting the nonlinear behavior of S-FGM plates under lateral stochastic white noise excitations are investigated. First the governing equation for a general S-FGM plate is derived for the assumed problem. Then it is rewritten by introducing some nondimensional parameters such that the results are applicable for a wide range of plates. Without loss of generality and using an example, the effective parameters on the instability and bifurcation of the transverse vibration of plates are studied, including the mean value of the lateral load with the in-plane forces and the material property. Especially, the role of material property is highlighted and some analytical figures are drawn to compare the behavior of the FGM plates with the homogenous ones. It is shown that the material property can affect the behavior of instability and bifurcation of the plate and its occurrence.

References listed at the end of the paper:


ABSTRACT: A thermal buckling analysis is presented for simply-supported rectangular symmetric cross-ply laminated composite plates that are integrated with surface-mounted piezoelectric actuators and subjected to the combined action of thermal load and constant applied actuator voltage. The material properties of the composite and piezoelectric layers are assumed to be functions of temperature. Derivations of the equations are based on the classical laminated plate theory, using the von-Karman nonlinear kinematic relations. The Ritz method is adopted to obtain closed-form solutions for the critical buckling temperature. Numerical examples are presented to verify the proposed method. The effects of the applied actuator voltage, plate geometry and stacking sequence of laminates are investigated.

References listed at the end of the paper:

11. H. Matsunaga, Thermal buckling of cross-ply laminated composite and sandwich plates according to a global higher-order deformation theory, Compos. Struct. 68 (2005) 439–454.
References listed at the end of the paper:


ABSTRACT: The transverse vibrations of cracked beams with rectangular cross sections resting on Pasternak and generalized elastic foundations are considered. Both the Euler–Bernoulli (EB) and Timoshenko beam (TB) theories are used. The open edge crack is represented as a rotational spring whose compliance is obtained by the fracture mechanics. By applying the compatibility conditions between the beam segments at the crack location and the boundary conditions, the characteristic equations are derived, from which the nondimensional natural frequencies are solved as the roots. Sample numerical results showing the effects of crack depth, crack location, foundation type and foundation parameters on the natural frequencies of the beam are presented. It is observed that the existence of crack reduces the natural frequencies, whereas the elasticity of the foundation increases the stiffness of the system and thus the natural frequencies. It is also observed that the type of elastic foundation has a significant effect on the natural frequencies of the cracked beam.
References listed at the end of the paper:


ABSTRACT: The free vibration of rotating tapered Timoshenko beams (TBs) made of the axially functionally graded materials (FGMs) is studied. The Chebychev polynomials multiplied by the boundary functions are selected as the admissible functions in the Ritz minimization procedure, which is called the Chebychev–Ritz method. As such, the geometric boundary conditions are satisfied, while the numerical robustness is guaranteed through use of the Chebychev polynomials. The Ritz approach provides an upper bound of the exact frequencies. The effectiveness of the method is confirmed in the case study and comparison studies. The effects of hub radius ratio, rotational speed ratio, taper ratios, rotary inertia and material gradient on the natural frequencies of the TBs for six different sets of boundary conditions are studied in detail.

References listed at the end of the paper:


errors are possible because no higher merit of the proposed approach is that it only requires simple differential and matrix operations. No hidden rule for the beam, another set of condition equations for the state matrix is derived. From these two sets of deriving the state matrix is derived. Next, by enforcing the rigid body transformation and quadrature methods.


ABSTRACT: Based on force equilibrium and rigid body considerations, a novel approach is proposed for deriving the state equations and then the buckling equations of pretwisted spatially curved beams. Based on statical consideration of an infinitesimal element from the last calculated configuration to the current configuration, a set of condition equations for the state matrix is derived. Next, by enforcing the rigid body rule for the beam, another set of condition equations for the state matrix is derived. From these two sets of equations, the state matrix of the beam is derived that leads directly to the buckling differential equations. The merit of the proposed approach is that it only requires simple differential and matrix operations. No hidden errors are possible because no higher-order terms need to be treated. In addition, a direct link is established.
between the straight and curved beam theories. Finally, examples are provided to demonstrate the application of the theory to the buckling analysis of various curved beams, including the helical ones.

References listed at the end of the paper:


**ABSTRACT:** In this paper, the free vibration of rotating laminated composite beams (LCBs) with general lay-ups and single through-the-width delamination is analytically investigated. The Hamilton’s principle is used to derive the coupled governing differential equations and boundary conditions for the rotating delaminated beam, considering the effects of shear deformation, rotary inertia, material couplings (bending–tension, bending–twist and tension–twist couplings), and Poisson’s effect. Both the free mode and constrained mode assumptions are adopted. Analytical solution for the natural frequencies and mode shapes are presented by incorporating the constraint conditions using the Lagrange multipliers method. The accuracy is assured by the convergence of the natural frequencies, as well as by comparison with published results. The effects of various factors such as delamination parameter, fiber angle, hub radius, material anisotropy, end mass and rotating speed are studied in detail. The difference between the results based on the free mode and constrained mode assumptions is also investigated.

References listed at the end of the paper:

Laplace transform inversion scheme is employed to obtain the response spectrum. The optimum parameters of vibration absorbers are proposed for suppressing the dynamic vibration and acoustic pressure. A steady-state and transient acoustic radiation characteristics of clamped-free annular plate with tuned mass damper (TMD) device is studied. Galerkin’s procedure is employed to obtain the transverse vibration of the annular disk. Based on the Rayleigh integral approach, acoustic pressure radiation is obtained and subsequently the modal sound power and modal radiation efficiency are obtained. A new formulation for the transient acoustic pressure in Laplace domain is presented for the first time in this paper. Durbin’s numerical Laplace transform inversion scheme is employed to obtain the response spectrum. The optimum parameters of vibration absorbers are proposed for suppressing the dynamic vibration and acoustic pressure. A parametric study is carried out and the effects of vibration absorber characteristics are investigated using the analytical procedure. Limiting cases are considered and good agreements with the finite element solution, as well as with those available in the literature, are achieved.

References listed at the end of the paper:
ABSTRACT: In this study, a finite element method (FEM) based on the size dependent nonlocal integral elasticity theory is implemented for buckling analysis of nanoscaled beams with various boundary conditions. The method is based on the principle of total potential energy. The variations of buckling load with respect to the scaling effect parameter and to the length-to-thickness ratio are investigated. Furthermore, the effect of attenuation function type on the buckling load is examined. The results are compared with the corresponding solutions of governing stability equations which are derived in the context of nonlocal differential elasticity theory. It is found that the small scale coefficient has a noticeable effect on the buckling load of nanobeams.

References listed at the end of the paper:

ABSTRACT: The stability of a nonuniform column subjected to a tip force and axially distributed loading is investigated based on the Timoshenko beam theory. An emphasis is placed on buckling of a standing column with varying cross-section and variable material properties under self-weight and tip force. Four kinds of columns with different taper ratios are analyzed. A new initial value method is suggested to determine critical tip force and axial loading at buckling. The effectiveness of the method is confirmed by comparing our results with those for Euler–Bernoulli columns for the case of sufficiently large shear rigidity. The effects of shear rigidity, taper ratio, and gravity loading on the buckling loads of a heavy standing or hanging column are examined.

References listed at the end of the paper:


J. Chen and Q.S. Li (First author is from: Shenzhen Research Institute, City University of Hong Kong, Shenzhen Hi-Tech Industrial Park, Nanshan District, Shenzhen 518057, P. R. China), “Analysis of flutter and nonlinear dynamics of a composite laminated plate”, International Journal of Structural Stability and Dynamics, Vol. 16, No. 6, 1550019, August 2016. https://doi.org/10.1142/S0219455415500194

ABSTRACT: This paper presents the analysis of flutter and nonlinear dynamics of an orthotropic composite laminated rectangular plate subjected to aerodynamic pressures and transverse excitation. The first-order linear piston theory is employed to model the air pressures. Based on Reddy’s third-order shear deformation plate
theory and von Karman-type equation for the geometric nonlinearity, the nonlinear governing equations of motion are derived for the composite laminated rectangular plate by applying the Hamilton’s principle. The Galerkin method is utilized to discretize the partial differential governing equations to a set of nonlinear ordinary differential equations. The critical Mach number for occurrence of the flutter of the composite laminated plate is investigated by solving the eigenvalues problem. The relationship between the limit cycle oscillation and the critical Mach number is analyzed based on the nonlinear equations. The numerical simulation is conducted to study the influences of the transverse excitation on the nonlinear dynamics of the composited laminated plate. The numerical results, which include bifurcation diagram, phase plots and waveforms, demonstrate that there exist the bifurcation and chaotic motions of the composited laminated plate subjected to the aerodynamic pressures and the transverse excitation.

References listed at the end of the paper:


ABSTRACT: Approximate numerical solutions are obtained for the vibration response of a functionally graded (FG) micro-scale beam entrapped within an axially-directed magnetic field using the differential transformation method (DTM). Idealized as a one-dimensional (1D) continuum with a noticeable microstructural effect and a thickness-directed material gradient, the microbeam’s behavior is studied under a range of nonclassical boundary conditions. The immanent microstructural effect of the micro-scale beam is accounted for through the modified couple stress theory (MCST), while the microscopic inhomogeneity is smoothed with the classical rule of mixture. The study demonstrates the robustness and flexibility of the DTM in providing benchmark results pertaining to the free vibration behavior of the FG microbeams under the following boundary conditions: (a) Clamped-tip mass; (b) clamped-elastic support (transverse spring); (c) pinned-elastic support (transverse spring); (d) clamped-tip mass-elastic support (transverse spring); (e) clamped-elasitcally supported (rotational and transverse springs); and (f) fully elastically restrained (transverse and rotational springs on both boundaries). The analyses revealed the possibility of using functional gradation to adjust the shrinking of the resonant frequency to zero (rigid-body motion) as the mass ratio tends to infinity. The magnetic field is noted to have a negligibly minimal influence when the gradient index is lower, but a notably dominant effect when it is higher.

References listed at the end of the paper:


Farzad Ebrahimi, Gholam Reza Shaghaqhi and Mahya Boreiry (Mechanical Engineering, Imam Khomeini International University, Qazvin, Iran), “A semi-analytical evaluation of surface and nonlocal effects on buckling and vibrational characteristics of nanotubes with various boundary conditions”, International Journal of Structural Stability and Dynamics, Vol. 16, No. 6, 1550023, August 2016, https://doi.org/10.1142/S0219455415500236

ABSTRACT: In the present paper, the vibrational and buckling characteristics of nanotubes with various boundary conditions are investigated considering the coupled effects of nonlocal elasticity and surface effects, including surface elasticity and surface tension. The nonlocal Eringen theory is adopted to consider the effect of small scale size, and the Gurtin–Murdoch model the surface effect. Hamilton’s principle is employed to formulate the governing equation and differential transformation method (DTM) is utilized to obtain the natural frequency and critical buckling load of nanotubes with various boundary conditions. The results obtained match the available ones in the literature. Detailed mathematical derivations are presented and numerical investigations are performed. The emphasis is placed on the effects of several parameters, such as the nonlocal parameter, surface effect, aspect ratio, mode number and beam size, on the normalized natural frequencies and critical buckling loads of the nanotube. It is explicitly shown that the vibration and buckling of a nanotube is significantly influenced by these effects. Numerical results are presented which may serve as benchmarks for future analysis of nanotubes.

References listed at the end of the paper:
ABSTRACT: For the analysis of dynamic characteristics of fluid-conveying pipes with piecewise linear support, a fluid–structure coupling dynamic model based on the finite element method is proposed. A user-defined pipe element based on Euler–Bernoulli beam is developed for modeling the pipes, considering the dynamic flow conditions. A nonlinear spring element is utilized to model the clamp between the pipe and the base. The dynamic responses of the system are obtained through the direct time integration. The stiffness of the clamp support is investigated by the analytical method and the experimental method, in which it is found that the clamp stiffness is piecewise linear. For different pipe geometries the user-defined element model, analytical model and measurement data are compared. The results show high quality of the element developed in this paper. Finally, the dynamic characteristics of the pipe system with piecewise linear support subjected to base harmonic excitation are calculated and the effects of the system parameters on pipe behaviors have also been studied. As a consequence, the model proposed in this paper can represent the piecewise linear nonlinearity of the clamp support and be used conveniently to investigate the effects of the fluid–structure coupling on the system behaviors.

References listed at the end of the paper:


ABSTRACT: This paper is concerned with the development of a theoretical model for predicting the dynamics and pull-in instability of magnetically actuated pipes conveying fluid. The equation of motion of the pipe is constructed in the presence of nonlinear magnetic forces. The lateral displacement of the pipe comprises two parts, namely, a static displacement and a perturbation displacement about the static. Based on the finite element method (FEM), the static deflection of the pipe is calculated numerically first. The computed static deflection is then used to solve the equation governing the perturbed displacement. Consequently, the pull-in and flow-induced instabilities can be determined for clamped–clamped or cantilevered boundary conditions. Results show that the flow speed can significantly affects the static deflection of the pipe and hence the pull-in magnetic force. The magnetic force, on the other hand, has a great impact on the dynamics of the pipe system.

References listed at the end of the paper:


Structures

Such parameters as the length of the plastic plateau, ultimate stress and the plastic hardening module play an important role as well.

ABSTRACT: The paper presents the results of numerical analyses of elasto-plastic buckling of steel reinforcing bars. Bars with different geometrical parameters made of steel with various mechanical characteristics were analyzed. The commercial program COSMOS/M based on the finite element method was used. It follows from the results that slenderness is not the only parameter that affects the elasto-plastic buckling of reinforcing bars. Such parameters as the length of the plastic plateau, ultimate stress and the plastic hardening module play an important role as well.

References listed at the end of the paper:


ABSTRACT: The paper presents the results of numerical analyses of elasto-plastic buckling of steel reinforcing bars. Bars with different geometrical parameters made of steel with various mechanical characteristics were analyzed. The commercial program COSMOS/M based on the finite element method was used. It follows from the results that slenderness is not the only parameter that affects the elasto-plastic buckling of reinforcing bars. Such parameters as the length of the plastic plateau, ultimate stress and the plastic hardening module play an important role as well.

References listed at the end of the paper:


ABSTRACT: The paper presents the results of numerical analyses of elasto-plastic buckling of steel reinforcing bars. Bars with different geometrical parameters made of steel with various mechanical characteristics were analyzed. The commercial program COSMOS/M based on the finite element method was used. It follows from the results that slenderness is not the only parameter that affects the elasto-plastic buckling of reinforcing bars. Such parameters as the length of the plastic plateau, ultimate stress and the plastic hardening module play an important role as well.

References listed at the end of the paper:


ABSTRACT: The paper presents the results of numerical analyses of elasto-plastic buckling of steel reinforcing bars. Bars with different geometrical parameters made of steel with various mechanical characteristics were analyzed. The commercial program COSMOS/M based on the finite element method was used. It follows from the results that slenderness is not the only parameter that affects the elasto-plastic buckling of reinforcing bars. Such parameters as the length of the plastic plateau, ultimate stress and the plastic hardening module play an important role as well.

References listed at the end of the paper:
ABSTRACT: The free vibration of functionally graded (FG) beams with various boundary conditions resting on a two-parameter elastic foundation in the thermal environment is studied using the third-order shear deformation beam theory. The material properties are temperature-dependent and vary continuously through the thickness direction of the beam, based on a power-law distribution in terms of the volume fraction of the material constituents. In order to discretize the governing equations, the differential quadrature method (DQM) in conjunction with the Hamilton’s principle is adopted. The convergence of the method is demonstrated. In order to validate the results, comparisons are made with solutions available for the isotropic and FG beams. Through a comprehensive parametric study, the effect of various parameters involved on the FG beam was studied. It is concluded that the uniform temperature rise has more significant effect on the frequency parameters than the nonuniform case.

References listed at the end of the paper:

ABSTRACT: The aim of this paper is to investigate the free vibration of hybrid composite moving beams embedded with shape memory alloy (SMA) fibers. The nonlinear equations of motion are derived based on the Euler–Bernoulli beam theory in conjunction with the von Karman type of nonlinearity in strain–displacement relations via the extended Hamilton principle. Also, the recovery stress induced by the SMA fibers is computed by applying the one-dimensional Brinson model and Reuss scheme. Then, an analytical approach is used to solve the nonlinear equation of motion for the simply supported shape memory alloy hybrid composite (SMAHC) moving beams. Based on the analytical solution, several parametric studies are presented to show the effects of various parameters such as volume fraction, pre-strain in the SMA fibers, temperature rise and velocity on the fundamental frequency of the SMAHC moving beams. Due to the lack of similar results in the specialized literature on the subject of interest, this paper is likely to fill a gap in the state of the art of the related research.

References listed at the end of the paper:


ABSTRACT: The paper presents the application of the differential transformation method (DTM) to the stability analysis of nonuniformly loaded beams under bending. The main advantage of the method is the possibility to obtain the semi-analytical solution for the critical loads of the beam undergoing lateral-torsional buckling. To determine the critical load, the system of two coupled ordinary differential equations with variable coefficients and parameters have to be solved. Numerical analyses were carried out for three different types of load functions: (i) Uniformly distributed load, (ii) linearly varying load and (iii) sinusoidally distributed load. The results were compared with the solutions computed by the finite element method (FEM) and those obtained by the authors using the variational iterative method (VIM). In each case, it was found that the difference with reference to the existing one does not exceed 3%, which testifies the effectiveness of the DTM used. Nevertheless, it should be emphasized that the number of terms of the approximation series used is fairly large and therefore the calculation of higher critical loads can be very time-consuming.

References listed at the end of the paper:
ABSTRACT: The mechanical behavior and buckling failure of sharp-notched 6061-T6 aluminum alloy tubes with different notch depths subjected to cyclic bending are experimentally and theoretically investigated. The experimental moment–curvature relationship exhibits an almost steady loop from the beginning of the first cycle. However, the ovalization–curvature relationship exhibits a symmetrical, increasing, and ratcheting behavior as the number of cycles increases. The six groups of tubes tested have different notch depths, from which two different trends can be observed from the relationship between the controlled curvature and the number of cycles required to ignite buckling. Finite element software ANSYS is used to simulate the moment–curvature and ovalization–curvature relationships. Additionally, a theoretical model is proposed for simulation of the controlled curvature-number of cycles concerning the initiation of buckling. Simulation results are compared with experimental test data, which shows generally good agreement.

References listed at the end of the paper:

ABSTRACT: The motivation of this study is to meet the requirement of cutout reinforcements in aerospace industry by using the design flexibility of curvilinearly stiffened panels. The reason is that the load path and tension field caused by curvilinear stiffeners can increase the load-carrying capacity of stiffened panels. The inherent superiority of such structures was examined in detail by comparison with those having straight stiffeners. Due to the large computational burden caused by post-buckling analysis, the optimum design of curvilinearly stiffened panels with single cutout was obtained based on surrogate model. On this basis, variable symmetrization and reduction methods were developed for different design cases, aimed at reducing the number of dependent variables in the optimization. Illustrative examples show the superiority of curvilinearly stiffened panels for cutout reinforcement, and demonstrate the effectiveness of the proposed optimization framework.

References listed at the end of the paper:


Peng Hao (1), Bo Wang (1), Kuo Tian (1), Gang Li (1) and Xi Zhang (2)
(1) Engineering Mechanics, Dalian Universit of Technology, China
(2) Beijing Institute of Astronautical Systems Engineering, China

“Optimization of curvilinearly stiffened panels with single cutout concerning the collapse load” , International Journal of Structural Stability and Dynamics, Vol. 16, No. 7, 1550036, September 2016,
https://doi.org/10.1142/S0219456715500364
References listed at the end of the paper:


ABSTRACT: The majority of the existing literature on the lateral stability of castellated beams deals with experimental and/or numerical studies. This paper presents a comprehensive analytical study of the lateral–torsional buckling of simply supported castellated beams subject to pure bending and/or a uniformly distributed load. Using the principle of total potential energy, analytical expressions for the critical buckling moments and loads are derived and applied for various beam lengths. The three different locations of the applied load are used: At the top flange, shear center and bottom flange. The results show that the influence of web openings on properties. The present analytical solutions are verified using 3D finite element analysis results.

References listed at the end of the paper:


ABSTRACT: Elastic distortional buckling is one of the essential buckling modes of a moment and (3) the effect of shear deformation of the web. The proposed method has been compared with applied forces and lateral/torsional restraint stiffness of the bottom flange of the beam. This paper investigates the equivalent lateral and torsional restraint stiffnesses of the bottom flange of the ISCCB under the gradient of negative moment. The relations for estimating the lateral and torsional restraint stiffnesses are used to determine the critical distortional buckling stress and associated buckling moment of the beam under the gradient of negative moment. A new method is proposed for assessing the buckling of the elastic-foundation beam, by which the related factors are considered: (1) The coupling effect between the applied forces and lateral/torsional restraint stiffness of the bottom flange of the beam, (2) the effect of gradient of a moment and (3) the effect of shear deformation of the web. The proposed method has been compared with those available by using the data of 15 cases under different loading conditions; the results show that the present method is much more accurate and reliable than the existing ones. The method as proposed herein is recommended for further research in relation to the buckling of the ISCCB.

References listed at the end of the paper:

ABSTRACT: In the present study, we investigate the statistical nonlinear dynamic behaviors of a single-walled carbon nanotube (SWCNT) subjected to a longitudinal magnetic field by considering the effect of geometric nonlinearity. We consider both the Young’s modulus of elasticity and mass density of the SWCNT as stochastic with respect to the position to actually characterize the random material properties of the SWCNT. In addition, we use the theory of nonlocal elasticity to investigate the small scale effect on the nonlinear vibration of the SWCNT. By using the Hamilton’s principle, the nonlinear governing equations of the SWCNT subjected to a longitudinal magnetic field are derived. We utilize the stochastic finite element method along with the perturbation technique to compute the statistical response of the SWCNT. Some statistical dynamic response of the SWCNT, such as the mean values and standard deviations of the midpoint deflections, are computed and checked by the Monte Carlo simulation, besides, the effects of the small scale coefficients, magnetic field and the elastic stiffness of matrix on the statistical dynamic response of the SWCNT are studied and discussed.

References listed at the end of the paper:

32. M. Simsek, Large amplitude free vibration of nanobeams with various boundary conditions based on the nonlocal elasticity theory, Compos. Part B 56 (2014) 621–628.

ABSTRACT: Beams and columns subjected to the axial pressure are studied. Critical buckling loads are established for stepped beams clamped at one end and elastically fixed at the other end. The beams under consideration are of piecewise constant thickness and are weakened by cracks emanating from re-entrant corners of steps. The cracks are assumed to be stable part-through surface cracks. The influence of a crack on the stability of the beam is modeled by the method of distributed line spring known in the elastic fracture mechanics. Numerical results are presented for beams with a single step making use of different stress correction functions.

References listed at the end of the paper:
- B. Gross and J. E. Srawley, Stress intensity factors for single-edge notch specimens on bending or combined bending and tension by boundary collocation of a stress function, NASA Technical Note D-2603 (1965).


ABSTRACT: This paper studies the eigenbuckling of Mindlin plate with two adjacent edges clamped and the remaining edges simply supported or clamped by using the separation of variables method, and the concise and explicit closed-form solutions are obtained for the first time. The cases involving free edges can also be dealt with if there are two opposite edges simply supported. The closed-form solutions are in good agreement with
the existing solutions, thus the validity of present method and accuracy of the obtained solutions are verified. This paper proves to be a major development of analytical method since it has long been acknowledged that the eigenbuckling of rectangular plates without two parallel edges simply supported are not amenable to analytical solutions.

References listed at the end of the paper:


Z.X. Li (1), T. Zheng (1), L. Vu-Quoc (2) and B.A. Izzuddin (3)
(1) Civil Eng., Zhejiang University, Hangzhou, China
(2) Mech. and Aerospace Eng., Univeristy of Florida, Gainesville, Florida, USA
(3) Civil and Environmental Eng., Imperial College London, UK


ABSTRACT: A 4-node co-rotational quadrilateral composite shell element is presented. The local coordinate system of the element is a co-rotational framework defined by the two bisectors of the diagonal vectors
generated from the four corner nodes and their cross product. Thus, the element rigid-body rotations are excluded in calculating the local nodal variables from the global nodal variables. Compared with other existing co-rotational finite-element formulations, the present element has two features: (i) The two smallest components of the mid-surface normal vector at each node are defined as the rotational variables, leading to the desired additive property for all nodal variables in a nonlinear incremental solution procedure; (ii) both element tangent stiffness matrices in the local and global coordinate systems are symmetric owing to the commutativity of the nodal variables in calculating the second derivatives of strain energy with respect to the local nodal variables and, through chain differentiation with respect to the global nodal variables. In the modeling of composite structures, the first-order shear deformable laminated plate theory is adopted in the local element formulation, where both the thickness deformation and the normal stress in the direction of the shell thickness are ignored, and an assumed strain method is employed to alleviate the membrane and shear locking phenomena. Several examples involving composite plates and shells with large displacements and large rotations are presented to testify to the reliability and convergence of the present formulation.

References listed at the end of the paper:

ABSTRACT: An explicit time integration method is presented for the linear and nonlinear dynamic analyses of structures. Using two parameters and employing the Taylor series expansion, a family of second-order accurate methods for the solution of dynamic problems is derived. The proposed scheme includes the central difference method as a special case, while damping is shown to exert no effect on the solution accuracy. The proposed method is conditionally stable, it has an appropriate region of stability, and is self-starting. The numerical tests indicate the improved performance of the proposed technique over the central difference method.

References listed at the end of the paper:
rotations and displacements

10.1007/s00366-30-178-·
Mater. Struct.
·
 nonlinear structural dynamics
224-·
Struct. Eng. ASCE
·
(·

·
deformation: Hypoelastic/hypoelastic
·
calculations and comparison with o
·
theory
·

·
algorithms in structural dynamics
1450055-1-1450055-20.


ABSTRACT: The Hp-Cloud meshless method was developed to study the dynamic analysis of arbitrarily shaped thin plates with intermediate point supports. By proposing a special pattern for the influence radius of nodes and a polynomial type of enrichment function, the Hp-Cloud shape functions with Kronecker delta property were constructed. They can satisfy the zero deflection conditions for the field nodes at the point supports. The results obtained from these shape functions agree well with the previous ones, showing good accuracy and convergence. For plates with sharp corners, it is not possible to construct the Hp-Cloud shape function with Kronecker delta property. To this end, the Lagrange multiplier method was used for enforcing the boundary conditions. The computations were carried out by the Ritz method, and the cell structure method is refined to improve the speed and accuracy of numerical integration on the subscription surface of clouds intersecting with the plate boundaries. Using the algorithm developed, the natural frequencies of plates of various shapes and support patterns were computed. By increasing the number of point supports on the plate edges, the natural frequencies computed of the plate tend to those of the simply supported plate. Appropriate pattern of point supports distribution was presented for modeling the simply supported plates of various shapes by comparing the corresponding natural frequencies.

References listed at the end of the paper:
ABSTRACT: This paper studies the thermomechanical stability of a cantilevered pipe spinning along its longitudinal axis and carrying an internal axial flow. The pipe, made of functionally graded materials (FGMs), is subjected to an axial force at the free end operating in a high temperature environment. It is modeled by the Rayleigh beam theory and is considered as a hollow thin-walled beam. The equation of motion, along with the boundary conditions, for the pipe is derived by using the extended Hamilton’s principle. Further, the extended Galerkin’s method (EGM) in conjunction with a proper representation of the displacements of the pipe is used to solve the eigenvalue problem. Depending upon the nature of the eigenvalues, i.e. real or complex-conjugate, the conditions for occurrence of instability by flutter or by divergence are derived. The effects of spin rate and velocity of fluid flow are studied on the stability regions, i.e. the critical flutter and divergence boundary, by the numerical method. Also, the effects of parameters, such as fluid mass ratio, compressive axial force, volume fraction index of the FGM and temperature gradient through the pipe thickness, are considered in developing the stability map for the spinning cantilever pipe. The results are compared with those available in the literature and good agreement has been achieved.

References listed at the end of the paper:


ABSTRACT: Pipelines in the oil and gas industry are prone to extensive internal corrosion which leads to premature failures. Furthermore, corrosion defects within certain proximity interact to reduce the overall strength of a pipe and are termed as interacting corrosion defects. Pipelines may also experience complex loadings due to geotechnical movements such as landslides and internal pressure. Therefore, an understanding of the behavior of corroded pipelines under multiple loadings is important for the safe operation of pipelines. Extensive literature review indicates that major design codes only consider the effect of interacting corrosion defects on the burst pressure of pipes, with less attention paid to the structural behavior of steel pipes under multiple loadings. Therefore, this study focuses on the effect of interacting corrosion defects of equal depth on the local buckling strength of X46 steel pipes using the finite element analysis (FEA). Results showed that the corrosion defects interact to reduce the overall buckling strength of the pipe. Furthermore, circumferentially aligned corrosion defects are more critical than axially aligned corrosion defects, due to the greater loss of material along the circumference of the pipe. Besides, the effect of interactions of corrosion defects on the buckling strength decreases as the internal pressure increases. Lastly, as the depth of the defects increases, their interactions become more severe, which can significantly reduce the overall buckling strength of the steel pipe.

References listed at the end of the paper:


ABSTRACT: This study developed a passive vibration reduction method to provide the damping capability for precision manufacturing equipment in an economical manner. The structure of the damping device is simple, which does not require changes in the frequency of the external force. An elastic medium was sandwiched between the bottom of the main component and the underlying plate or membrane. This combination results in a damper capable of reducing vibrations in the precision manufacturing equipment. We analyzed the influence of the elastic modulus and geometry of the elastic medium in the plate–plate or plate–membrane system on the damping capability. Among the various dampers considered herein, the combinations that include stiffer foams and a flexible membrane provide the greatest damping capability, far exceeding that of the metal plates. The results also show that the damping capacity of the rectangular frame with a diagonal x-shaped elastic medium is close to that of a full sheet.

References listed at the end of the paper:


ABSTRACT: Huang presented first in 1961 the characteristic equations and normal mode equations for all six common types of simple, finite Timoshenko beams in closed-form. Unfortunately, there exist several errors, not typographical, in the frequency in the characteristic equations for a Timoshenko beam free at both ends. In this paper, the exact characteristic equations in closed-form for completely free Timoshenko beams are derived based on Ref. 1. In order to justify the solutions obtained by amending herein Huang’s equations, both the closed-form exact solution and the one obtained by the Ritz method will be adopted as the references. Using the characteristic equations derived by Huang, we can obtain only frequencies for the flexural modes, while using the closed-form exact method and Ritz method, we can obtain frequencies for the thickness-shear modes, as well as for the bending modes. The purpose of the present study is to identify the errors in Ref. 1, correct them, and provide some numerical results.

References listed at the end of the paper:

ABSTRACT: On the basis of Reissner’s mixed variational theorem (RMVT), a nonlocal Timoshenko beam theory (TBT) is developed for the stability analysis of single-walled carbon nanotube (SWCNT) embedded in an elastic medium, with various boundary conditions and under axial loads. Eringen’s nonlocal elasticity theory is used to account for the small length scale effect. The strong formulations of the RMVT-based nonlocal TBT and its associated possible boundary conditions are presented. The interaction between the SWCNT and its surrounding elastic medium is simulated using the Pasternak foundation models. The critical load parameters of the embedded SWCNT with different boundary conditions are obtained by using the differential quadrature (DQ) method, in which the locations of \( n_p \) sampling nodes are selected as the roots of \( n_p \)-order Chebyshev polynomials. The results of the RMVT-based nonlocal TBT are compared with those obtained using the principle of virtual displacement (PVD)-based nonlocal TBT available in the literature. The influences of some crucial effects on the critical load parameters of the embedded SWCNT are examined, such as different boundary conditions, Winkler stiffness and shear modulus of the foundation, aspect ratios, and the nonlocal parameter.

References listed at the end of the paper:

8. Eringen A. C., Nonlocal Continuum Field Theories (Springer-Verlag, New York, 2002).
various boundary conditions

- Various theories

- Multilayered plates and shells

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.

- Compos. Struct.
52. Wu C. P. and Li H. Y., RMVT-based finite cylindrical prism methods for multilayered functionally graded circular hollow cylinders with various boundary conditions, Compos. Struct. 100 (2013) 592–608.

Lingzhi Wang, Zhitaoy Yan, Zhengliang Li and Zhimiao Yan (First author is from: School of Civil Engineering, Chongqing University, Chongqing 400045, China), “Vibration of a rectangular plate carrying a massive machine with elastic supports”, International Journal of Structural Stability and Dynamics, Vol. 16, No. 10, 1550069, December 2016, https://doi.org/10.1142/S0219455415500698
ABSTRACT: In engineering practice, a massive machine may be placed on a plate supported by beams considered as elastic boundary conditions. The vibration of the plate due to the periodic excitation of the massive machine will cause noises or damages to the building in which the machine is housed. An analytical approach for the vibration analysis of a rectangular plate carrying a massive machine with uniform elastic supports is presented. The machine is simplified as a distributed mass. The transverse plate displacement is determined by the superposition of a two-dimensional (2D) Fourier cosine series and several supplementary functions. All the unknown Fourier coefficients are calculated directly from the Rayleigh–Ritz formulation. To validate the present approach, several numerical examples with classical boundary conditions are presented. The results reveal good agreement between the analytical results and those based on the finite element analysis (ANSYS). The effects of the plate size, location of the machine, and support stiffness on the modal, and transient response of the plate are investigated. From the results it is found that the transient displacement amplitude of the plate decreases almost linearly as the thickness increases, it increases nonlinearly along with the increase in the support stiffness, and that the optimal position for deploying the transformer is the center of the plate.

References listed at the end of the paper:
ABSTRACT: An advanced technique for damage detection in beam structures, using a vibration characteristic tuning procedure is developed by an optimal design of piezoelectric materials. Piezoelectric sensors and actuators are mounted on the surface of the host beam to generate excitations for the tuning via a feedback process. The excitations induced by the piezoelectric effect are used to magnify the effect of the damage in the vibration characteristics of the damaged structure to realize an effective damage detection process. To describe the detection process, theoretical models of the cantilevered beams with and without tuning induced by piezoelectric effect are built first, while the damage is represented by a crack at the fixed end. From the established models, the natural frequencies of the tuned beams with and without the crack are obtained to study the sensitivity of the proposed technique. As a result of the tuning process, more obvious changes on the natural frequencies due to the existence of a crack are observed. The results also indicate a shorter distance from the piezoelectric actuators to the crack leads to a higher detection sensitivity. An optimal length of the piezoelectric actuators to the crack leads to a higher detection sensitivity. An optimal length of the piezoelectric actuators to the crack leads to a higher detection sensitivity.
ABSTRACT: This paper studies the compressive buckling of near-square rippled monolayer graphene sheets in thermal environments by using molecular dynamics simulations. Armchair and zigzag graphene sheets are both considered and the four edges of a graphene sheet are either simply supported or clamped. Compressive force instead of the commonly used compressive strain is gradually applied to the edges of the graphene sheet until the graphene sheet is crushed. It is found that ripples in the graphene are formed owing to thermal fluctuations even before the compressive force is applied. The amplitude of ripples is reduced when the compressive force is applied to the graphene. The buckling mode of the graphene may show local or global mode shape features, depending on the chirality, the support conditions and the size of the graphene. Most buckling modes of the graphene sheets are very different from the global (1,1) mode of a uniaxially loaded and simply supported or clamped square plate as predicted by continuum mechanics models. A clamped graphene can take significantly
more compressive force after the occurrence of initial buckling and before the graphene is completely crushed. A zigzag graphene has a larger initial buckling force than its armchair counterpart. Raising the environmental temperature may either increase or decrease the initial buckling force of the graphene depending on the support conditions and the chirality of the graphene.

References listed at the end of the paper:

ABSTRACT: This paper presents an analytical approach for investigating the dynamics and stability of an outer cylindrical shell subjected to viscous annular flow and thermal load", International Journal of Structural Stability and Dynamics, Vol. 16, No. 10, 1550072, December 2016, https://doi.org/10.1142/S0219455415500728

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: The objective of this study is to develop and validate similitude requirements and scaling laws for studying the real characteristics of structures easily and economically, especially for large structures. The generalized similitude requirements and the scaling law of orthogonally stiffened cylindrical panels and shells for buckling and free vibration are derived by applying the similitude transformation to the total energy of the structural system directly. In practice, due to either the difficulty of satisfying all of the similitude requirements simultaneously or to save experimental cost and time, distorted models with partial similarity are necessarily employed and approximate scaling laws are proposed. The partial similitude is mainly investigated first by using specific formulas of stiffness parameters and corresponding scaling laws are given. Also discussed herein are particular models with relaxations in the material properties of stiffeners, the materials of both the skin and the stiffeners and the material properties and geometry. The obtained results indicate that the distorted models are able to accurately predict the behavior of the prototype.


ABSTRACT: The paper deals with a three-dimensional problem on natural vibrations and stability of thin-walled cylindrical shells with arbitrary cross sections, containing a quiescent or flowing ideal compressible fluid. The motion of compressible non-viscous fluid is described by a wave equation, which together with the impermeability condition and corresponding boundary conditions is transformed using the Bubnov–Gal’erkin method. A mathematical formulation of the problem of thin-walled structure dynamics has been developed based on the variational principle of virtual displacements. Simulation of shells with arbitrary cross sections is performed under the assumption that a curvilinear surface is approximated to sufficient accuracy by a set of plane rectangular elements. The strains are calculated using the relations of the theory of thin shells based on the Kirchhoff–Love hypothesis. The developed finite element algorithm has been employed to investigate the influence of the fluid level, the ratio of the ellipse semi-axes and types of boundary conditions on the eigenfrequencies, vibration modes and the boundary of hydroelastic stability of thin-walled circular and elliptical cylindrical shells interacting with a quiescent or flowing fluid.

References listed at the end of the paper:


ABSTRACT: This paper is concerned with the surface effect on the buckling behavior of double nanobeam system using the nonlocal Timoshenko beam theory. The size effect is taken into consideration by using the Eringen’s nonlocal elasticity theory and the exact solution for buckling loads for simply supported boundary condition is presented. Influences of various parameters such as stiffness constant, nonlocal parameter, shear effect and buckling mode number are investigated. Also for the sake of validation, the present results are compared with those obtained from the Euler–Bernoulli model. It is shown that the proposed nonlocal model is able to produce results with high accuracy and it can be used as a benchmark in future studies on buckling of nano-sandwich structures.

References listed at the end of the paper:

ABSTRACT: The dynamic characteristics of hybrid composite plates under an arbitrary periodic load in hygrothermal environments are investigated. The material properties of the plate are assumed to be dependent on the temperature and moisture. The governing equations of motion of the Mathieu-type are established based on the Galerkin method with reduced eigenfunction transforms. The periodic stress is taken to be a combination of the pulsating axial and bending stress in the example problem. Based on Bolotin’s method, the dynamic instability behaviors of hybrid composite plates are determined. The effects of layer thickness ratio, fiber volume fraction, temperature rise, moisture concentration and dynamic load on the instability regions of hybrid composite plates are studied, along with the dynamic instability index discussed. The results reveal that the layer thickness ratio and hygrothermal conditions have a significant impact on the dynamic instability of hybrid composite plates.

References listed at the end of the paper:

ABSTRACT: The present study highlights the parametric instability characteristics of delaminated woven fabric composite curved panels under in-plane harmonic loadings exposed to the thermal environment. The equation of motion of the delaminated curved panel is reduced to a system of Mathieu–Hill equations with periodic coefficients. The development of the region of instability arises from Floquet’s theory and the solution is obtained using Bolotin’s approach by the finite element method (FEM). An eight-noded isoparametric finite
References listed at the end of the paper:

22. Park T. and Lee S-Y., Parametric instability of delaminated composite spherical shells subjected to in-plane pulsating forces, Compos. Struct. 91 (2) (2009) 196–204.
ABSTRACT: This paper presents a nonlocal nonlinear first-order shear deformable magneto-electro-thermo elastic (METE) nanoplate model for investigating the buckling and postbuckling of magneto-electro-thermo-mechanical loadings. The nonlocal elasticity theory within the framework of the first-order shear deformation plate theory along with the von Kármán-type geometrical nonlinearity is used to derive the size-dependent nonlinear governing partial differential equations and associated boundary conditions, in which the effects of shear deformation, small scale parameter and thermo-electro-magneto-mechanical loadings are incorporated. The generalized differential quadrature (GDQ) method and pseudo arc-length continuation algorithm are used to determine the critical buckling loads and postbuckling equilibrium paths of the METE nanoplates with various boundary conditions. Finally, the influences of the nonlocal parameter, boundary conditions, temperature rise, external electric voltage and external magnetic potential on the critical buckling load and postbuckling response are studied.

References listed at the end of the paper:

ABSTRACT: Elevated pipelines are commonly encountered in petro-chemical and industrial applications. Within these applications, pipelines normally span hundreds of meters and are thus analyzed using one-dimensional (1D) beam-type finite elements when the global behavior of the pipeline is sought at a reasonably low computational cost. Standard beam-type elements, while computationally economic, are based on the assumption of rigid cross-section. Thus, they are unable to capture the effects of cross-sectional localized deformations. Such effects can be captured through shell-type finite element models. For long pipelines, shell models become prohibitively expensive. Within this context, the present study formulates an efficient numerical modeling which effectively combines the efficiency of beam-type solutions while retaining the accuracy of shell-type solutions. An appealing feature of the model is that it is able to split the global analysis based on simple beam-type elements from the local analysis based on shell-type elements. This is achieved through domain-decomposition procedure within the framework of the Bridging multi-scale method of analysis. Solutions based on the present model are compared to those based on full shell-type analysis. The comparison demonstrates the accuracy and efficiency of the proposed method.

References listed at the end of the paper:

method are compared with those from a 2D exact method, a 2D thick shell theory, and a 3D finite element method of analysis. Unlike conventional shell theories, which are mathematically two dimensional (2D), the present method is based upon the 3D dynamic equations of elasticity. Displacement components $u\phi$, $u\theta$, and $uz$ in the meridional, circumferential, and normal directions, respectively, are taken to be periodic in theta and in time, and algebraic polynomials in the phi and z directions. Potential (strain) and kinetic energies of the shallow spherical domes with non-uniform thickness are formulated, and the Ritz method is used to solve the eigenvalue problem, thus yielding upper bound values of the frequencies by minimizing the frequencies. As the degree of the polynomials is increased, frequencies converge to the exact values. Convergence to four-digit exactitude is demonstrated for the first five frequencies. Natural frequencies are presented for different boundary conditions. The frequencies from the present 3D method are compared with those from a 2D exact method, a 2D thick shell theory, and a 3D finite element
method by previous researchers.

References listed at the end of the paper:


https://doi.org/10.1142/S0219455417500201

ABSTRACT: This paper applies the Chebyshev collocation method to finding accurate solutions of natural frequencies for circular cylindrical shells. The shells with different boundary conditions are considered in the parametric study. By using the method to solve the coupled differential equations of motion governing the vibration of the shell, numerical results are obtained from the algebraic eigenvalue equation using the Chebyshev differentiation matrices. And the results satisfy both the geometric and force boundary conditions. Based on the numerical examples, the proposed method shows its capacity and reliability in predicting accurate frequency results for circular cylindrical shells with various boundary conditions as compared to some exact solutions available in the literature.

References listed at the end of the paper:


https://doi.org/10.1142/S0219455417500341

ABSTRACT: In this paper, the axial compression buckling problem of castellated columns about the major axis when exposed to a fire is investigated. An analytical formula for calculating the critical buckling load of castellated columns is derived, which considers not only the shear deformation effect of web openings but also the non-uniform cross-section temperature distribution due to non-symmetric fire exposure. The results show
that for the same average temperature, the critical buckling load of a castellated column with non-uniform temperature distribution is smaller than that of a castellated column with uniform temperature distribution. The web shear effect caused due to web openings can significantly reduce the critical buckling load of the castellated column, particularly for the columns with shorter lengths or wider flanges. However, the change of the shear effect on the critical load with different temperature distributions is very small and can be generally ignored.

References listed at the end of the paper:

https://doi.org/10.1142/S0219455417710031

ABSTRACT: This paper presents the dynamic modeling of a piezolaminated plate considering geometrical nonlinearities. The piezo-actuator and piezo-sensor are connected via proportional derivative feedback control law. The Hamilton’s principle is used to extract the strong form of the equation of motion with the reflection of the higher order strain terms by means of the strain–displacement relationship of the von Karman type. Then the nonlinear partial differential equation (PDE) obtained is converted to a nonlinear algebraic equation by employing the combination of harmonic balance method and single-mode Galerkin’s technique. Finally, the vibration suppression performance and sensitivity of the dynamic response is evaluated for various control parameters and magnitudes of external disturbance.

References listed at the end of the paper:
https://doi.org/10.1142/S0219456717500468

ABSTRACT: The modal analysis of rotating cantilevered rectangular Mindlin plates with variable thickness is studied. The Ritz method is used to derive the governing eigenfrequency equation by minimizing the energy functional of the plate. The admissible functions are taken as a product of the Chebyshev polynomials multiplied by the boundary functions, which enable the displacements and rotational angles to satisfy the geometric boundary conditions of the plate. The Chebyshev polynomials guarantee the numerical robustness, while the Ritz approach provides the upper bound of the exact frequencies. The effectiveness of the present method is confirmed through the convergence and comparison studies. The effects of the dimensionless rotational speed, taper ratio, aspect ratio and thickness ratio on modal characteristics are investigated in detail. The frequency loci veering phenomenon along with the corresponding mode shape switching is exhibited and discussed.

References listed at the end of the paper:
ABSTRACT: The vibration analysis of composite pipes with internal wall defects due to erosion-induced surface degradation is investigated. The surface defects are treated as discontinuities. The geometry of the discontinuity is permitted to vary within the cross-section both in the angular and radial directions, and to occupy any length of the pipe span. A B-spline wavelet-based finite element method (BWFE) that takes advantage of the localization properties of wavelets is invoked; thus utilizing its effectiveness in modeling of crack problems and local damages. The composite pipe was treated as beam elements that obey the Euler–Bernoulli beam theory. Unlike the conventional finite element method (FEM), the developed BWFE uses fewer elements without compromising the accuracy. Numerical simulations are performed to demonstrate the accuracy and efficiency of the developed element through comparison with available results in the literature, as well as results obtained using ANSYS. Some benchmark solutions are obtained for the composite pipe with internal surface defects of different geometries.

References listed at the end of the paper:
32. Laminated Composites-I (viewed on 28/04/2015; Available from: http://nptel.ac.in/courses/105108124/pdf/Lecture_Notes/LNm5.pdf).
ABSTRACT: A hybrid analytical and numerical method is presented for the mid-frequency vibration analysis of a class of plate structures with discontinuities based on the concept of structural partitioning. The type of structures considered includes rectangular plates with internal property discontinuity, homogeneous but non-rectangular plates, or built-up structures composed of rectangular homogenous plates with complex joints. Compared with the conventional finite element (FE) method, the present method has the advantage of high accuracy and high efficiency in the analysis of mid-frequency vibration of the structures of concern. The main idea of the proposed approach is to divide the whole structure into uniform rectangular plate regions and other non-rectangular regions. The vibration behavior of the rectangular regions is accurately and efficiently described by analytical wave solutions so that the FE modeling for these regions is not necessary. The other non-rectangular regions are modeled by the conventional FE method. The analytical waves used to describe the rectangular regions are obtained by the symplectic method, thereby avoiding the limitation of the conventional analytical method in dealing with plates having two opposite edges simply supported. By enforcing the displacement continuity and force equilibrium at the connection interfaces, the dynamic coupling is established between the rectangular regions described in terms of the analytical waves and the regions modeled by FEs. Furthermore, the hybrid solution formulation for the mid-frequency vibration of the entire structure is proposed. The high accuracy and efficiency of the present method are demonstrated by several numerical examples, with the effect of element size of the FE regions investigated. Finally, the applicability of the proposed method is analyzed.

References listed at the end of the paper:


ABSTRACT: In this paper, the effectiveness of a saturation control strategy in suppressing vibration of a rotating composite thin walled beam is studied. The mathematical model of the flexible beam takes into account a shear deformation effect, a warping function, a centrifugal force and the Coriolis acceleration. To extend the generality of the proposed formulation an inertia of the hub is also considered. Adaptive capability of the beam is achieved through the implementation of the saturation control algorithm. Within the performed tests, the discussed control strategy is applied for different magnitudes of flexural–torsional vibration modes resulting from different orientations of beam laminate-reinforcing fiber’s. The obtained results prove the applied nonlinear control to be the effective method for beam vibration suppression in near-by resonance zones for all studied cases. Parametric studies considered different rotating speeds of the system. It is shown that the vibration of the beam can be suppressed to similar levels independently of the transportation motion rotating speed. However, significant differences in the width of vibration suppression zones are observed.

References listed at the end of the paper:

2. A. Preumont and K. Seto, Active Control of Structures (John Wiley, Chichester, UK., 2008).
ABSTRACT: Free vibrations of a composite membrane with a hexagonal lattice circular inclusion are investigated. We aim at a study of the lower frequency spectrum, i.e. it is assumed that the minimum space period of the eigenform is essentially larger than the characteristic dimension of the cell periodicity of the analyzed structure. This implies a possibility of approximating the composite structure by the homogenized one with effective characteristics. The latter is yielded by the multi-scale homogenization approach. Introduction of slow and fast variables yields both counterpart quasistatic local problem regarding the periodically repeated cell and global (homogenized) dynamic problem for homogeneous material with effective properties. The most complicated part of this approach concerns in finding a solution to the local problem. It has been analytically found in the presented paper for relatively large inclusion sizes using lubrication approach. The performed numerical validation of the obtained results shows high accuracy of the implemented approach.

References listed at the end of the paper:


ABSTRACT: Composite materials, with characteristics of light weight and high strength, are useful in manufacturing. Therefore, precise design and analysis is the first key procedure in composite applications,
improper analysis or use of composite materials may cause serious failures. In this paper, wavelet finite element method (WFEM) based on B-spline wavelet on the interval (BSWI) is constructed for precise analysis of laminated plates and shells, which gives a guidance in design and application of composite structures. First, FEM formulations are derived from the generalized potential energy function based on the generalized variational principle and virtual work principle. Then, BSWI scaling functions are used as interpolation function to discretize the solving displacement field variables. At the same time, transformation matrix is constructed and used to translate the meaningless wavelet coefficients into physical space. At last, the static analysis results can be obtained by solving the FEM formulations. Due to the excellent features of BSWI, such as multiresolution, multiscale, localization and excellent numerical approximation characteristics etc., BSWI-based FEM can achieve accurate and efficient analysis by comparing with traditional methods. In the end, the effectiveness of the constructed BSWI WFEM is verified through several numerical examples.

References listed at the end of the paper:
ABSTRACT: Buckling and free vibration behavior of functionally graded carbon nanotube reinforced polymer composite plate subjected to nonuniformly heated functionally graded carbon nanotube reinforced polymer composite plate are analyzed. The effective material constants of the plate are obtained using the extended rule of mixture along with the extended rule of mixture along with efficiency parameters of the carbon nanotube (to include geometry-dependent material properties). Influence of boundary conditions, aspect ratio, functional grading of the carbon nanotube, nonuniform thermal loading on thermal buckling and free vibration behavior of the heated plate are analyzed. It is observed that temperature fields and functional grading are influenced on the critical buckling temperature of the plates. Further, nature of functional grading showed significant change in buckling mode shapes irrespective of the boundary conditions. The first few natural frequencies of the plate under thermal load decreases as the temperature increases and they are influenced significantly by the nature of temperature field. Variations in free
vibration mode shapes of the square plates found with not significant change as temperature increases. However, free vibration modes of the rectangular plates are sensitive to the nature of temperature field whenever there is a free edge associated with the boundary condition. Influence of functional grading on the free vibration mode shapes is not significant in contrast with the free vibration natural frequencies. The magnitude of free vibration natural frequencies of functional grade-X type carbon nanotube reinforcement showed higher in comparison with other two types of reinforcements considered here.

References listed at the end of the paper:
edges, continuous conditions at the driving force locations, and coupling conditions at the line junction between several rectangular plates are established and solved simultaneously. Then the flexural and in-plane vibrations of the finite coupled Mindlin plate are obtained by using the MRRM, which are verified by comparing the results obtained with those by the finite element method (FEM). The vibration behaviors of coupled plates such as L-shaped structure, T-shaped structure and box-shaped structure are calculated and verified.

References listed at the end of the paper:


ABSTRACT: Pipelines are one of the most efficient means for transporting hydrocarbons from one point to the other. However, there is a great risk of pipelines operation failure due to the detrimental effects of corrosion. At the point of corrosion, the pipe wall becomes thinner and loses its mechanical resistance. In such cases, reliable defect assessment methods are necessary to decide whether to resume continual operation or to shut down for maintenance or replacement. However, the available assessment methods are over-conservative, which enforce either unnecessary maintenance or premature replacement. Furthermore, the defect assessment methods should not only ensure safe operation, but also optimized operation cost. Therefore, a new assessment method was developed based on the nonlinear finite element (FE) analysis and a parametric study of geometric parameters related to the corrosion defect. The new method was validated with burst test database, which can predict the burst pressure of corroded pipelines with better accuracy and consistency.

References listed at the end of the paper:


ABSTRACT: The paper investigates the elastoplastic buckling of thin circular shells subjected to nonproportional loading consisting of axial tensile stress and external pressure. The governing equations of buckling for cylindrical shells derived by Flugge serve as the basis of analysis. To capture the elastic/plastic behavior, two plasticity theories are considered; the flow theory and the deformation theory of plasticity. Plastic buckling pressures for cylinders with various combinations of boundary conditions are presented for which no analytical solutions are available. The results obtained from the flow and deformation theories confirm that, under over-constrained kinematic assumptions, the deformation theory tends to provide lower values of buckling pressure and the discrepancies in the results from the two plasticity theories increase with increasing thickness-to-radius ratios, tensile stresses, boundary clamping and $E/\sigma_y$.

References listed at the end of the paper:
cylindrical shells made of functionally graded materials (FGMs) under combined axial and torsional loads. The

ABSTRACT: The dynamic stability of bidirectional woven fiber laminated glass/epoxy composite shallow shells subjected to harmonic in-plane loading in hygrothermal environment is considered. An eight-noded isoparametric shell element with five degrees of freedom is used in the analysis. In the present finite element formulation, a composite doubly curved shell model based on first-order shear deformation theory (FSDT) is used for the dynamic stability analysis of shell panels subjected to hygrothermal loading. A program is developed using MATLAB for the parametric study on the dynamic stability of shell panels under the hygrothermal field. The effects of various parameters like static load factor, curvature, shallowness, temperature, moisture, stacking sequence and boundary conditions on the dynamic instability regions of woven fiber glass/epoxy shell panels are investigated. The location of dynamic instability regions is shown to affect significantly due to presence of the hygrothermal field.

Huawei Huang, Yongqiang Zhang and Qiang Han, “Inelastic buckling of FGM Cylindrical shells subjected to combined axial and torsional loads”, International Journal of Structural Stability and Dynamics, Vol. 17, No. 9, 1771010, November 2017

ABSTRACT: A semi-analytical procedure is presented to solve the elastoplastic buckling problem of cylindrical shells made of functionally groded materials (FGMs) under combined axial and torsional loads. The
elastoplastic properties are assumed to vary smoothly according to the power law distribution rule, introduced in the J2 deformation theory for formulation of the constitutive relation of FGMs in the framework of the Tamura–Tomota–Ozawa (TTO) model, which is a volume fraction-based material model. The critical condition is deduced by the Ritz method. Assuming the uniform prebuckling strain, a biaxial stress state analysis is conducted to determine the analytical position of the elastoplastic interface, which is used in the integration of the elastoplastic internal force and all the material-related structural parameters. Finally, an iterative procedure is adopted to find the exact elastoplastic critical load. Numerical results indicate the effects of the inhomogeneous parameter and the elastoplastic material properties of their constituents on the stability region and plastic flow region of the materials.

References listed at the end of the paper:
15. H. W. Huang and Q. Han, Elastoplastic buckling of axially loaded functionally graded material cylindrical shells, Compos. Struct. 117 (2014) 135–142.


ABSTRACT: Owing to their superior mechanical and thermal properties, carbon nanotube (CNT) reinforced composite materials have wide range of applications in various technical areas such as aerospace, automobile, chemical, structural and energy. In this paper, the nonlinear axisymmetric dynamic behavior of sandwich spherical and conical shells made up of CNT reinforced facesheets is studied. The shell is subjected to thermal loads and discretized with three-noded axisymmetric curved shell element based on field consistency approach. The in-plane and the rotary inertia effects are included within the transverse shear deformation theory in the
element formulation. The present model is validated with the available analytical solutions from the literature. A detailed parametric study is carried out to showcase the effects of the shell geometry, the volume fraction of the CNT, the core-to-face sheet thickness and the environment temperature on the dynamic buckling thermal load of spherical caps.

References listed at the end of the paper:
References listed at the end of the paper:

X.D. Zhi and M.G. Stewart, “Damage and risk assessment for single-layer reticulated domes subject to explosive blast loads”, International Journal of Structural Stability and Dynamics, Vol. 17, No. 9, 1750108, November 2017

ABSTRACT: In order to provide a better understanding of the dynamic behavior of single-layer reticulated domes subjected to explosive blast loads, a number of analyses are carried out on structures with different standoff distances ($R$), explosive weights ($W$), rise-span ratios ($f/L$) and other parameters. An equation for a structural damage factor is proposed to evaluate structural damage quantitatively. The damage states for single-layer reticulated domes are defined based on their structural dynamic performance and corresponding damage factors. Structural reliabilities for different standoff distances are obtained using the Monte-Carlo Analysis. A typical protective measure is bollards which are used to help ensure a minimum standoff distance. To illustrate the cost-effectiveness of such a protective measure, structural damage states and various losses, including direct and indirect economic loss and maimed and fatality loss, are considered for assessing the risk reduction, costs and benefits. It was found that the bollards significantly reduce the likelihood of structural progressive collapse or severe damage, and the optimal standoff distance can be determined.

References listed at the end of the paper:

15. UFC-3-340-02, Unified facilities criteria: Structures to resist the effects of accidental explosions, Department of Defense (USA, 2008).

ABSTRACT: This paper introduces a mathematical model for optimizing the dynamic performance of thin-walled functionally graded box beams with closed cross-sections. The objective function is to maximize the natural frequencies and place them at their target values to avoid the occurrence of large amplitudes of vibration. The variables considered include fiber volume fraction, fiber orientation angle and ply thickness distributions. Various power-law expressions describing the distribution of the fiber volume fraction have been implemented, where the power exponent was taken as the main optimization variable. The mass of the beam is kept equal to that of a known reference beam. Side constraints are also imposed on the design variables in order to avoid having unacceptable optimal solutions. The mathematical formulation is carried out in dimensionless quantities, enabling the generalization to include models with different cross-sectional types and beam configurations. The optimization problem is solved by invoking the MatLab optimization Toolbox routines, along with structural dynamic analysis and eigenvalue calculation routines. A case study on the optimization of a cantilevered, single-cell spar beam made of carbon/epoxy composite is considered. The results for the basic case of uncoupled bending motion are given. Conspicuous design charts are developed, showing the optimum design trends for the mathematical models implemented in the study. It is concluded that the natural frequencies, even though expressed in implicit functions, are well-behaved, monotonic and can be treated as explicit functions in the design variables. Finally, the developed models can be suitably used in the global optimization of typical composite, functionally graded, thin-walled beam structures.

References listed at the end of the paper:

ABSTRACT: Free vibration analysis of a sandwich plate with viscoelastic material core and functionally graded material (FGM) constraining layer under centrifugal force field is investigated herein. One edge of the sandwich plate is fixed to a rotating hub. The first-order shear deformation theory (FSDT) is used in the finite element modeling of the problem. The effects of strains due to the longitudinal and transverse deformations are also considered in addition to the shear deformation of the core. Various parametric studies are carried out to examine the effects of volume fraction index, setting angle, hub radius and rotational speed on the vibration characteristics of the sandwich plate. It is found that the fundamental frequency of the plate decreases with an increase in the volume fraction index of the FGM layer, viscoelastic core thickness and setting angle. The first mode loss factor increases with respect to the increasing volume fraction index. Increase in rotational speed and hub radius lead to an increase in the natural frequencies and a decrease in the modal loss factors. References listed at the end of the paper:


ABSTRACT: Member failure due to low cycle fatigue may occur for steel structures under strong earthquakes. In this paper, the seismic response of single-layer latticed domes composed of welded round pipes is analyzed by the software Open System for Earthquake Engineering Simulation (OpenSees) incorporating low cyclic fatigue, in which the equations of initial camber for members are obtained from the buckling coefficient curve of compression members in Chinese codes. Single-layer latticed domes composed of welded round pipes with different parameters are modeled, and the seismic responses of the domes with and without material fatigue are compared by the incremental dynamic analysis. The results show that under strong earthquakes, the seismic responses including the maximum displacements and plastic development of the domes with fatigue are larger than those of the domes without fatigue. The collapsed PGAs decrease by 10–25% if low cycle fatigue is
incorporated. Therefore, the low cycle fatigue of material should be taken into account in the seismic analyses of single-layer latticed domes under strong earthquakes.

References listed at the end of the paper:


**ABSTRACT:** Generalized Beam Theory (GBT), intended to analyze the structural behavior of prismatic thin-walled members and structural systems, expresses the member deformed configuration as a combination of cross-section deformation modes multiplied by the corresponding longitudinal amplitude functions. The determination of the latter, usually the most computer-intensive step of the analysis, is almost always performed by means of GBT-based conventional 1D (beam) finite elements. This paper presents the formulation, implementation and application of the so-called “exact element method” in the framework of GBT-based linear buckling analyses. This method, originally proposed by Eisenberger (1990), uses the power series method to solve the governing differential equation and obtains the buckling eigenvalue problem from the boundary terms. A few illustrative numerical examples are presented, focusing mainly on the comparison between the combined accuracy and computational effort associated with the determination of buckling solutions with the exact and standard GBT-based (finite) elements. This comparison shows that the GBT-based exact element method may lead to significant computational savings, particularly when the buckling modes exhibit larger half-wave numbers.

References listed at the end of the paper:
ABSTRACT: This paper proposes the discrete analytical method (DAM) to determine exactly and efficiently the fully nonstationary random responses of rectangular Kirchhoff plates under temporally and spectrally nonstationary acceleration excitation of earthquake ground motions. First, the fully nonstationary power spectral density (PSD) model is suggested by replacing the filtered frequency and damping of Gaussian filtered white-noise model with the time-variant ones. The exact solutions of free vibration of thin plates with two opposite edges simply supported boundary conditions are introduced. Then, the full analytical procedure for random vibration analysis of the plate is established by using a pseudo excitation method (PEM) that can consider all modal auto-correlation and cross-correlation terms. Owing to involving a series of Duhamel time integrals of single degree of freedom systems, it is difficult to fully analytically evaluate the PSD of time-variant responses such as the transverse deflection, velocity, acceleration and stress components. Thus, DAM that combines the PEM with precise integration technique is developed to enhance the computational efficiency. Finally, comparison of the results by the DAM with Monte Carlo simulations and the analytical stationary random vibration analysis demonstrates the high efficiency and accuracy of DAM. Moreover, the fully nonstationary excitation imposes a remarkable effect on the response PSD of rectangular Kirchhoff plates.

References listed at the end of the paper:


ABSTRACT: In this paper, we investigate the in-plane stability and post-buckling response of deep parabolic arches with high slenderness ratios subjected to a concentrated load on the apex, using the finite element implementation of a geometrically exact rod model and the cylindrical version of the arc-length continuation method enabled with pivot-monitored branch-switching. The rod model used here includes geometrically exact kinematics of the cross-section, exact kinetics, and a linear elastic constitutive law; and advantageously employs quaternion parameters to treat the cross-sectional rotations and to compute the exponential map in the configurational update of rotations. The evolution of the Frenet frame along the centroidal curve is used to determine the initial curvature of the rod. Three sets of boundary conditions, i.e. fixed–fixed (FF), fixed–pinned (FP) and pinned–pinned (PP), are considered, and arches with a wide range of rise-to-span ratios are analyzed for each set. Complete post-buckling response has been derived for all cases. The results reveal that although all the PP arches and all the FF arches (with the exception of FF arches with rise-to-span ratio less than 0.3) considered in this study buckle via bifurcation, the nature of stability of the different solution branches in the post-buckling regime differs from case to case. All FP slender parabolic arches exhibit limit-point buckling,
again with several markedly different post-buckling behaviors. Also, some arches in the FF and PP case are shown to exhibit a clear bistable behavior in the post-buckled state.

References listed at the end of the paper:


ABSTRACT: The vibration behavior of a functionally graded Timoshenko beam is investigated by applying the transformed-section method. The material properties of a functionally graded (FG) beam are assumed to vary across the thickness according to a simple power law. The cross section of FG beam with two constituents is first transformed into an equivalent cross section of the material on the top. Then, the lateral and longitudinal vibration equations of a homogeneous Timoshenko beam are separately applied to the beam with the transformed section. The bending natural frequencies of FG beam are evaluated using the Chebyshev collocation method, and the longitudinal natural frequencies are also obtained from the known closed-form solutions. Some of the analytical results are compared with the existing numerical data to validate the present model accuracy. Good agreement has been observed between the analytical and numerical data. The effects of aspect ratio, volume fraction, and boundary conditions on the free-vibration behavior of FG beam are discussed. The present analytical solutions provide an insight to the effects of various parameters on the vibration behavior of the beam. They also serve as benchmarks for testing the vibration results obtained by other analytical or approximate methods.

References listed at the end of the paper:


ABSTRACT: This paper examines the influence of porosities on the flexural and free vibration response of functionally graded material (FGM) plates based on the authors’ recently developed non-polynomial higher-order shear and normal deformation theory. The theory accommodates the nonlinear variation in the in-plane and transverse displacements in the thickness coordinates. It also contains the hyperbolic shear strain shape function in the displacement field with only four unknowns. A new mathematical model has also been proposed to incorporate the effects of porosity in the FGM plate. Various numerical examples have been solved to ascertain the accuracy, efficiency, and applicability of the present formulation. The effects of porosity, volume fraction index, plate thickness, aspect ratio, boundary conditions and temperature have been discussed in details. The obtained results can be treated as a benchmark for future studies.

References listed at the end of the paper:
45. H. Matsunaga, Free vibration and stability of functionally graded plates according to a 2-D higher-order deformation theory, Compos. Struct. 82 (2008) 499–512.

Parvaneh Mortazavi, Hamid Reza Mirdamadi and Ali Reza Shahidi, “Post-buckling, limit point, and bifurcation analyses of shallow nano-arches by generalized displacement control and finite difference considering small-scale effects”, International Journal of Structural Stability and Dynamics, Vol. 18, No. 1, 1850014, January 2018

ABSTRACT: Post-buckling of shallow nano-arches is examined numerically in this study. The small-scale effect is taken into account by using the nonlocal theory. The variational formulation is employed to derive the equilibrium equations of the arch based on the Euler–Bernoulli beam hypothesis. Moderate rotations are considered by including the von Karman nonlinear strains. The governing equations are discretized by the finite difference method and are solved iteratively by the generalized displacement control algorithm. In the buckling analysis, the effects of different factors, such as load distribution, initial height, arch span, and nonlocal parameter, on the buckling loads are investigated. The behavioral analysis of the arch with respect to its initial height follows and detailed analyses for the limit point and bifurcation buckling are presented. It is concluded that the value of nonlocal parameters can influence the arch model in two ways: apparently changing its initial rise and switching its buckling mechanism. There is also a comparison between the use of secant and tangent stiffness moduli for tracing the equilibrium paths.

References listed at the end of the paper:


ABSTRACT: Laminated plates are loading-bearing components that are generally connected to flexible pads and exhibit complicated mechanical responses. To investigate the geometrically nonlinear transient responses of a laminated plate with flexible pad supports, a varied constraint reaction model and a systematic numerical procedure are presented in this paper. The flexible pad supports of the plate were treated as viscoelastic boundary conditions, wherein the strip-type pad per unit length was modeled as a cantilever beam. The nonlinear Kelvin–Voigt model was developed to simulate the nonlinear viscoelastic behaviors of the flexible pads. The dynamically varied constraint reactions generated by the viscoelastic supports, which depend upon the displacement and velocity of the nodes along the plate edge, were determined by the deflection and slope equations of the beam theory used, and they were applied on the plate edges by using the nonlinear load functions. Thus, the dynamical responses of the laminated plate with viscoelastic supports were obtained. Numerical results show that the present method can effectively treat the geometrically nonlinear transient response of the laminated plate with viscoelastic supports, and it is essential to consider the effects of non-ideal boundary conditions in the nonlinear transient analysis.

References listed at the end of the paper:

ABSTRACT: We present an analytical procedure for the exact, explicit construction of Euler–Bernoulli beams with given values of the first $N$ buckling loads. The result is valid for pinned–pinned (P–P) end conditions and for beams with regular bending stiffness. The analysis is based on a reduction of the buckling problem to an eigenvalue problem for a vibrating string, and uses recent results on the exact construction of Sturm–Liouville operators with prescribed natural frequencies.

References listed at the end of the paper:
carrying capacity. The geometrically nonlinear FE analyses allowed understanding in further depth the ultimate behavior of the panels, providing further insights about their failure mechanisms.

References listed at the end of the paper:
16. ASC, Pre-standard for load and resistance factor design (LRFD) of pultruded fibre polymer (FRP) structures (Final), American Composites Manufacturer Association (ACMA) (2010).

**ABSTRACT:** This paper introduces a new shell element formulation and investigates the buckling behavior of thin-walled beams composed of fiber-reinforced polymer composite-laminates, which is a primary design concern for thin-walled beams composed of fiber-reinforced polymer composite-laminates due to their slenderness. Although global buckling behavior can be captured using beam-column type two-node simple finite element formulations, shell-type more sophisticated elements are needed in order to be able to capture the effects due to cross-sectional deformations. Pursuit of an efficient shell element formulation continues to date and in this study, a new flat rectangular shell element formulation is developed for the buckling analysis of thin-walled composite-laminated members. The plate component of the shell is locking-free and based on the twist-Kirchhoff theory. For the membrane component of the shell element, variational formulation employing drilling degrees of freedom is adopted. Convergence studies were presented to illustrate the numerical performances of the element. A broad class of problems including distortional as well as global buckling cases were solved and compared with solutions from the literature to validate the use of the developed shell element for the buckling analysis of thin-walled composite-laminated members.

**References listed at the end of the paper:**


ABSTRACT: The research reported herein follows the increased interest in buckling-induced functionality for novel materials and devices with a focus on cylindrical shells as a suitable structural prototype. The paper proposes the concept of using patterned thickening patches on the surface of cylindrical shells to modify and control their elastic postbuckling response. Cylindrical shells with non-uniform thickness distributions (NTD) were fabricated through 3D printing to understand rules for pattern designs and then tested under loading-unloading cycles. Strategic thickening patches act as governing imperfections that modify the response type, the number, the location and the sequence of the localized buckling events. The use of patterned thickening patches and their layout provides diverse design opportunities for a desired elastic postbuckling response and can be potentially used in design materials and structures with switchable functionalities.

References listed at the end of the paper:

· 6. Z. Chen, L. Yang, G. Cao and W. Guo, Buckling of the axially compressed cylindrical shells with arbitrary axisymmetric thickness variation, Thin-Walled Struct. 60 (2012) 38–45.
ABSTRACT: An energy-based solution is developed for the lateral torsional buckling (LTB) analysis of wooden beams with flexible mid-span lateral bracing offset from section mid-height and subjected to uniformly distributed or mid-span point load. The study shows that such beams are prone to two potential buckling modes; symmetric or anti-symmetric. The symmetric mode is shown to govern the capacity of the beam for low bracing stiffness while the anti-symmetric mode governs the capacity when the bracing stiffness exceeds a threshold value. Using the present formulation, the threshold bracing stiffness required to suppress the symmetric mode and maximize the critical moments is directly obtained by solving a special eigenvalue problem in the unknown design variables.

References listed at the end of the paper:

41. Forest Products Laboratory (FPL) Wood handbook — Wood as an engineering material, Wisconsin, USA (2010).
42. Q. Xiao, Lateral torsional buckling of wood beams, M.A.Sc. thesis, Department of Civil Engineering, University of Ottawa, Ontario, Canada (2014).
44. Y. Hu, Lateral torsional buckling of wooden beams with mid-span lateral bracing, Master Thesis, Department of Civil Engineering, University of Ottawa, Ottawa, ON (2016).
47. APA (2013), Allowable depth-to-width ratios for glulam beams, Technical Topic TT-085B, Tacoma, Washington, USA.
48. SIMULIA [Computer software]. Dassault Systemes Simulia Corp (2011), Providence, RI.

ABSTRACT: This paper examines the nonlinear dynamics of a translational functionally graded material (FGM) plate. The plate is composed of nickel and stainless steel, and its property is graded in the thickness direction that obeys a power-law distribution. By adopting the Kármán nonlinear geometrical relations, the equation of motion is derived from the D’Alembert’s principle by considering the dynamic equilibrium relationships for the out-of-plane vibration of the plate. The equation of motion is discretized by using the Galerkin method and thus a series of ordinary differential equations with mode-coupling terms are obtained. These ordinary differential equations are then solved by utilizing the method of harmonic balance. The analytical results are verified by the adaptive step-size fourth-order Runge–Kutta technique. The stability analysis of analytical solutions is also carried out by introducing small perturbation for steady state solutions. Both natural frequency and nonlinear frequency-amplitude characteristics are presented. In the translational FGM plate, strong nonlinear mode interaction phenomenon has been detected. The nonlinear frequency response shows intensive hardening-spring characteristics. Moreover, various system parameters such as power-law distribution, translating speed of the plate, in-plane tension force, damping coefficient and external excitation amplitude are selected as the controlled variables to present parametric study. Their effects on the nonlinear dynamical response of the translational FGM plate are highlighted.

References listed at the end of the paper:

revisited the derivations of the frequency
however, the latter are not as accurate because of the ill

ABSTRACT: Wind

Ning Su, Zhenggang Cao and Yue Wu, “Fast frequency

process

domain methods are computationally more expensive than frequency-domain algorithms;
however, the latter are not as accurate because of the ill-treatment of the modal coupling effects. This paper revisited the derivations of the frequency-domain algorithm and proposed a fast algorithm for estimating the
dynamic wind-induced response considering duly the modal coupling effects. With the wind load cross-spectra modeled by rational functions, closed-form solutions to the frequency-domain integrals can be calculated by Cauchy’s residue theorem, rather than by numerical integration, thereby reducing the truncation errors and enhancing the efficiency of computation. The algorithm is applied to the analysis of a grandstand roof and a spherical dome. Through comparison with time domain analyses results, the algorithm is proved to be reliable. A criterion of the coupling modal combination was suggested based on the cumulative modal contribution rate of over 70%.

References listed at the end of the paper:

ABSTRACT: This paper investigates the buckling behavior of graphene platelets (GPL) reinforced composite cylindrical shells with cutouts via finite element method (FEM) simulation. Young’s modulus of the composites is determined by the modified Halpin–Tsi micromechanics model while the mass density and Poisson’s ratio of the composites are approximated by the rule of mixture. Comprehensive parametric study is conducted to investigate the effects of the weight fraction and the shape of GPL fillers, the geometry of the shell and the position and orientation of the cutout on the buckling behaviors of the cylindrical structures. The results demonstrate that the addition of GPLs can significantly increase the load bearing capacity of the cylindrical shells. Larger sized GPLs with fewer single graphene layers are favorable reinforcing fillers in enhancing the buckling performances of the structures. The buckling load is sensitive to the location of the cutout with larger aspect ratio. Moreover, the orientation of the cutout is found to have significant effects on the buckling load when the orientation angle $\theta$ is falling within the ranges (math follows…)

References listed at the end of the paper:

modal frequencies. But the free surface effect will decrease when the immersion depth of the cylindrical shell
is considered by satisfying the pressure release boundary condition. The accuracy of the
numerical results are verified through comparison with the finite element solution. To throw light on the influence of the
mechanical behavior of two normally intersecting cylindrical shells with cutouts subjected to internal pressure and

with thickness variation under axial pressure, Thin Wall Struct. 101 (2016) 213–221.

41. A. Tafreshi, Buckling and post-buckling analysis of composite cylindrical shells with cutouts subjected to internal pressure and


44. R. Guzmán de Villoria and A. Miravete, Mechanical model to evaluate the effect of the dispersion in nanocomposites, Acta


47. Q. X. Pei, Y. W. Zhang and V. B. Shenoy, A molecular dynamics study of the mechanical properties of hydrogen functionalized


49. M. W. Hilburger, A. M. Waas and J. H. Starnes, Response of composite shells with cutouts to internal pressure and compression

50. V. Palermo, L. A. Kinloch, S. Ligi and N. M. Pugno, Nanoscale mechanics of graphene and graphene oxide in composites: A

51. F. Wang, L. T. Drzal, Y. Qin and Z. Huang, Mechanical properties and thermal conductivity of graphene nanoplatelet/epoxy


ABSTRACT: An analytical solution is proposed for the free flexural vibration of a finite cylindrical shell
submerged in half-space bounded by a free surface in the low frequency range. The motion of the shell is
described by the Flügge shell theory and the fluid surrounding the shell is assumed to be an acoustic media. The
free surface effect is considered by satisfying the pressure release boundary condition. The accuracy of the
present method is verified through comparison with the finite element solution. To throw light on the influence
mechanism of free surface on the coupled modal frequencies, a modal added mass is introduced and calculated.
Numerical results show that when the shell is close to the free surface, the presence of free surface will make a
negative contribution to the modal added mass and finally result in the corresponding increase of the coupled
modal frequencies. But the free surface effect will decrease when the immersion depth of the cylindrical shell
increases. Finally, the free surface effect can be neglected if the immersion depth is higher than four times the shell radius. This conclusion is helpful to select proper test environment for an experiment on the dynamic characteristics of submerged cylindrical shells.

References listed at the end of the paper:


ABSTRACT: This paper is concerned with the development of the Hencky bar-net model (HBM) for free vibration analyses of rectangular plates with mixed boundary conditions and point supports. The HBM is a two-
dimensional discrete net system composed of rigid segments connected by frictionless hinges and rotational springs. In the model, bending is accommodated by rotational springs at each joint while the twisting by a diagonal spring system in each grid cell. The total mass of the plate is distributed as lumped mass at each joint and the continuous boundary stiffness of plate is simulated by springs located at the edge joints. Owing to the discrete property of HBM, it is able to readily handle any boundary conditions of plates including mixed boundary conditions and point supports. The HBM is herein used to solve some vibration problems of rectangular plates with mixed boundary conditions and point supports to demonstrate its accuracy and convenience for plate analyses.

References listed at the end of the paper:

1. H. Hencky, Über die angenäherte Lösung von Stabilitätsproblemen im Raum mittels der elastischen Gelenkkette, Der Eisenbau 11 (1920) 437–452.
ABSTRACT: Tensegrity structures are classified as kinematically determinate ones with two subcases and kinematically indeterminate ones with three subcases in view of their respective stability properties. How the stiffness of a tensegrity structure changes as the level of prestress changes is explored for different scenarios using six carefully chosen samples. For a tensegrity structure merely satisfying the prestress-stability condition, a new optimization model is presented to determine its critical buckling state corresponding to zero stiffness. A real-coded genetic algorithm (RCGA) is then developed to solve this problem, featured by the fact that a special control technique is embedded in the fundamental genetic operations, which is applied to determine the critical buckling state of various tensegrity structures solved by real-coded genetic algorithm (RCGA). Several numerical examples are tested to validate the efficiency of the present approach.

References listed at the end of the paper:


ABSTRACT: This paper deals with the free vibration and buckling analysis of functionally graded material (FGM) plates, resting on the Winkler–Pasternak elastic foundation. The higher order shear deformation plate theory (HSPT) is adopted for the realistic variation of transverse displacement through the thickness, using the power law distribution to describe the variation of the material properties. Both the effects of shear deformation and rotary inertia are considered. In the present model, the plate is discretised into Co eight node serendipity quadratic elements with seven nodal degrees of freedom (DOFs). The validation study is carried out by comparing the calculated values with those given in the literature. The effects of various parameters like the Winkler and Pasternak modulus coefficients, volume fraction index, aspect ratio, thickness ratio and different boundary conditions on the behaviour of the FGM plates are studied.

References listed at the end of the paper:

ABSTRACT: In this paper, an analytical Hamiltonian-based model for the dynamic analysis of rectangular nanoplates is proposed using the Kirchhoff plate theory and Eringen’s nonlocal theory. In a symplectic space, the dynamic problem is reduced to solving a unified Hamiltonian dual equation formed by a total unknown vector consisting of displacements, rotation angles, bending moments and generalized shear forces. The exact solutions for free vibration, buckling and steady state forced vibration are established by the eigenvalue analysis and expansion of eigenfunction without any trial functions. In addition, the explicit expressions of the characteristic equations, mode functions and steady state response of the nanoplate with two opposite edges that are simply supported or guided supported are obtained. To verify the accuracy and reliability of the present method, numerical results are compared with published solutions and excellent agreement is obtained. Comprehensive benchmark results that consider the nonlocal effect on the dynamic behaviors of rectangular nanoplates are also presented in dimensionless tabular and graphical forms.

References listed at the end of the paper:

5. A. C. Eringen , Nonlocal Continuum Field Theories (Springer-Verlag, New York, 2002).

ABSTRACT: Buckling loads of laminated panels calculated by analytical approaches are usually based on the assumptions that the panels are subjected to uniform in-plane edge loads without cutouts, despite of the fact that real structural components are subjected to various kinds of non-uniform in-plane edge loads along with different sized cutouts. The main objective of this paper is to study the effects of reinforced/unreinforced circular cutouts and non-uniform in-plane edge loads on the buckling behavior of composite panels with different ply-orientations by the finite element technique. Furthermore, it addresses the effects of different boundary conditions and thickness of panels. To carry out the analyses, a nine-noded heterosis plate element and a compatible three-noded beam element are developed, including the effect of shear deformation and rotary inertia for both the plate and the stiffeners. In structural modeling, the plate and the stiffener elements are treated separately, with their displacement compatibility maintained using transformation matrices. It has been illustrated in this study that presence of larger-sized reinforced cutouts predominantly increases the buckling strength of the panel as compared to those with smaller sized cutouts.

References listed at the end of the paper:

5. X. Wang, Y. Wang and L. Ge, Accurate buckling analysis of thin rectangular plates under locally distributed compressive edge stresses, Thin-Walled Struct. 100 (2016) 81–92.


ABSTRACT: The thermal buckling characteristics of non-uniformly heated tapered laminated composites plates with ply drop-off have been investigated numerically. Detailed parametric studies have been carried out for the effects of taper configuration, temperature variation, aspect ratio and structural boundary conditions on critical buckling temperatures and buckling mode shapes. It is found that the nature of taper as well as the applied temperature field have considerable effects on the critical buckling temperatures of laminated composite tapered plates. Square plates buckle at the highest temperature when subjected to the decreasing temperature profile. Additionally, it is noted that Taper B and Taper C plates show the best behavior under buckling for most structural boundary conditions. Moreover, the change in buckling mode shapes with respect to temperature profile and taper configuration is significant for rectangular plates in comparison with square plates.

References listed at the end of the paper:

ABSTRACT: Based on the nonlocal theory, this paper develops the Kirchhoff nanoplate and Mindlin nanoplate models for the wave propagation analysis of piezoelectric nanoplates. The effects of small scale parameter and thermo-electro-mechanical loads are incorporated in the nanoplate models. The Hamilton’s principle is employed to derive the governing equations of the nanoplate, which are solved analytically to obtain the dispersion relation for piezoelectric nanoplates. The results show that the nonlocal parameter, temperature change, mechanical load and external electric potential have significant influence on the wave propagation characteristics of the piezoelectric nanoplates. The cut-off wave number is observed to exist for piezoelectric nanoplates subjected to positive electric potential, axial tensile force and temperature rise.

References listed at the end of the paper:

 Numerical results show that the effect of elastic foundation parameter plays a dominant role on the critical load of the pile is discussed, and the effect of axial load on the natural frequencies of the pile is also explored. The buckling response and free vibration of pile are examined. Finally, the effect of elastic foundation parameter on the critical load buckling pile when the axial load exceed the pile, and the shear parameter affects the critical load directly. The axial load


Buckling analysis of a piezoelectric nanobeam with the consideration of surface effects and nonlocal elasticity theory, Nonlinear vibration of nonlocal piezoelectric nanoplates


Surface effect on the buckling of piezoelectric nanoplates considering surface and nonlocal effects, Compos. Struct. 140 (2016) 758–775.


formulation. In addition, a triangular membrane element with drilling rotations and the discrete Kirchhoff formulation is proposed which is simpler and has more clear physical characteristics than the traditional pure deformational method into the element level. The membrane elements are derived and discuss this method saves time for computing stresses, internal forces and stiffness matrices. A flat shell element is advantages over the conventional finite element method for linear and nonlinear problems. In the el

ABSTRACT: Proposed herein is a novel pure deformational method for triangular shell elements that can decrease the element quantities and simplify the element formulation. This approach has computational advantages over the conventional finite element method for linear and nonlinear problems. In the element level, this method saves time for computing stresses, internal forces and stiffness matrices. A flat shell element is formed by a membrane element and a plate element, so that the pure deformational membrane and plate elements are derived and discussed separately in this paper. Also, it is very convenient to incorporate the proposed pure deformational method into the element-independent co-rotational (EICR) framework for geometrically nonlinear analysis. Thus, on the basis of the pure deformational method, a novel EICR formulation is proposed which is simpler and has more clear physical characteristics than the traditional formulation. In addition, a triangular membrane element with drilling rotations and the discrete Kirchhoff
triangular plate element are used to verify the proposed pure deformational method, although several benchmark problems are employed to verify the robustness and accuracy of the proposed EICR formulations. References listed at the end of the paper:


8. J. L. Meek and H. S. Tan, Large Deflection and Post-Buckling Analysis of Two and Three Dimensional Elastic Spatial Frames (University of Queensland, 1983).


32. H. Goldstein, Classical Mechanics (Addison-Wesley, Tokyo, 1950).

ABSTRACT: This paper is concerned with the dynamic response of a nonuniform Timoshenko beam with elastic supports subjected to a moving spring-mass system. The modal orthogonality of nonuniform Timoshenko beams and the corresponding overall matrix of undetermined coefficients are derived. Then the natural frequencies and mode shapes of nonuniform Timoshenko beams are obtained by the Runge–Kutta method and cubic spline interpolation method. By using the Newmark-β method and the mode summation method, the vibration equation of Timoshenko beams subjected to a moving spring-mass system was established. A comparison of results between the proposed method and finite element method reveals that this method possesses favorable accuracy for dynamic response analysis. In numerical examples, the effects of the support spring and moving spring-mass system on Timoshenko beams have been examined in detail.

References listed at the end of the paper:


ABSTRACT: Generalized Beam Theory (GBT), intended to analyze the structural behavior of prismatic thin-walled members and structural systems, expresses the member deformed configuration as a combination of cross-section deformation modes multiplied by the corresponding longitudinal amplitude functions. The determination of the latter, often the most computer-intensive step of the analysis, is almost always performed by means of GBT-based “conventional” 1D (beam) finite elements. This paper presents the formulation, implementation and application of the so-called “exact element method” in the framework of GBT-based elastic free vibration analyses. This technique, originally proposed by Eisenberger (1990), uses the power series method to solve the governing differential equations and obtains the vibration eigenvalue problem from the boundary terms. A few illustrative numerical examples are presented, focusing mainly on the comparison between the combined accuracy and computational effort associated with the determination of vibration solutions with the exact and conventional GBT-based (finite) elements. This comparison shows that the GBT-based exact element method may lead to significant computational savings, particularly when the vibration modes exhibit large half-wave numbers.

References listed at the end of the paper:

1. R. Schardt, Verallgemeinerte Technische Biegetheorie (Springer-Verlag, Berlin, German, 1989).
ABSTRACT: We present a computational study that develops isogeometric analysis based on higher-order smooth NURBS basis functions for the analysis of in-plane laminated composites. Focusing on the stress, vibration and stability analysis of angle-ply and cross-ply 2D structures, we compare the convergence of the strain energy error and selected stress components, eigen-frequencies and buckling loads according to overkill solutions. Our results clearly demonstrate that for in-plane laminated composite structures, isogeometric analysis is able to provide the same accuracy at a significantly reduced number of degrees of freedom with respect to standard Co finite elements. In particular, we observe that the smoothness of spline basis functions enables high-quality stress solutions, which are superior to the ones obtained with conventional finite elements. References listed at the end of the paper:

ABSTRACT: In this paper, we present new results of natural frequencies for the functionally graded beams based on Chebyshev collocation method and the third-order shear deformation theory (TSHT), without requiring any shear correction factors. The beams are assumed to be elastically supported by translational and rotational springs, or simply known as elastically restrained ends. The material compositions of the beams across the gradient direction are described by different mathematical models including the simple power law, exponential and Mori–Tanaka models, and their effects on the response of beams are analyzed. We first present the Chebyshev collocation formulation of the coupled differential equations of motion for free vibration of FGM beams considering different boundary conditions, and then verify the results obtained by the proposed approach against reference ones. A parametric study is also performed for parameters such as thickness, spring constant factor, material volume fraction index, etc. The present numerical results reveal that the proposed method can offer accurate frequency results for the FGM beams as compared with those available in the literature. The results also indicate that the spring constant factors have a significant effect on the frequencies of the beams.

References listed at the end of the paper:


ABSTRACT: This paper addresses the compressive local buckling behavior of an infinitely long laminated composite plate resting on a tensionless elastic foundation (Winkler foundation). The analytical solution to the contact buckling coefficient of a laminated composite plate is derived using a one-dimensional analytical method. Numerical examples are considered to investigate the influence of the ply angle and foundation stiffness on the contact buckling coefficients of laminated composite plates under uniaxial compression. The lateral boundary conditions including clamped and simply-supported edges are treated. Finally, finite element (FE) analysis is conducted to provide an independent check on the analytical solutions.

References listed at the end of the paper:

the differential quadrature method nonaxial and lateral loading buckling of thin and moderately thin short cylindrical shells, which may even reverse the reported predictions by the flow and deformation theories of plasticity. This fact overestimates the plastic buckling load of plates and shells, whereas Hencky’s deformation of plasticity. The present study goes deeper into the problem and reveals that in the case of short cylinders under combined loading, which have long been the object of extensive research in the elastic range, a different modeling of the material behavior can also trigger a mode jumping from the initial imperfection, which may even reverse the reported predictions by the flow and deformation theories of plasticity. This fact must be taken in maximum consideration when performing nonlinear FE analyses for estimating the plastic buckling of thin and moderately thin short cylindrical shells.

References listed at the end of the paper:
ABSTRACT: In this paper, we analyze the nonlinear equilibrium equation corresponding to the two-parameter bifurcation problem arising in the stability analysis of an elastic simply supported beam on the Winkler type elastic foundation for the case when bimodal buckling occurs. We perform the bifurcation analysis of the nonlinear problem, by using Lyapunov–Schmidt reduction, thus obtaining the number of the nontrivial solutions to the nonlinear problem and qualitatively characterizing the solution patterns. We also give the formulation of the problem and bifurcation analysis from the total energy viewpoint and determine the energy of each bifurcating solution. We assert that the solution with the smallest energy is the one that will be observed in the post-critical state. For specific choice of parameters, the bifurcating solution in the form of the second buckling mode has the smallest total energy. The numerical results illustrating the theory are also provided.


References listed at the end of the paper:

2. E. Winkler, Die Lehre von der Elastizität und Festigkeit (Dominicus, Prague, 1867).
ABSTRACT: The dynamic behavior of singly and doubly curved panels of the rectangular planar form subjected to different types of loadings is presented. The mathematical formulation is based on the higher order shear deformation theory, and the principle of virtual work is used to derive the equations of motion. The fast converging finite double Chebyshev series and Houbolt time-marching scheme are used for evaluating the dynamic response of the panel. The effect of the magnitude and duration of pulse loadings on the transverse central displacement and bending moment responses is evaluated for different parameters. The accuracy of the present solution methodology is established by the convergence study of non-dimensional central deflection and central moments and comparison of the present results with those available in the literature. Some new results are presented for the hyperboloidal panels.

References listed at the end of the paper:


ABSTRACT: The dynamic behavior of singly and doubly curved panels of the rectangular planar form subjected to different types of loadings is presented. The mathematical formulation is based on the higher order shear deformation theory, and the principle of virtual work is used to derive the equations of motion. The fast converging finite double Chebyshev series and Houbolt time-marching scheme are used for evaluating the dynamic response of the panel. The effect of the magnitude and duration of pulse loadings on the transverse central displacement and bending moment responses is evaluated for different parameters. The accuracy of the present solution methodology is established by the convergence study of non-dimensional central deflection and central moments and comparison of the present results with those available in the literature. Some new results are presented for the hyperboloidal panels.

References listed at the end of the paper:
2471.


Qingfei Meng, Wensu Chen and Hong Hao, “Vulnerability analyses of structural insulated panels with OSB skins strengthened by basalt fiber cloth subjected to windborne debris impact”, International Journal of Structural Stability and Dynamics, Vol. 18, No. 6, 1850088, June 2018, https://doi.org/10.1142/S021945671850088X

ABSTRACT: In this study, numerical simulations are conducted with a verified model to develop damage threshold curves for structural insulated panels (SIPs) with OSB skins strengthened by basalt fiber cloth subjected to windborne debris impact. Numerical models of the SIP with OSB skins strengthened by basalt fibre cloth at the front or back side are developed by using LS-DYNA. The accuracy of the numerical model is verified by comparing numerical results with laboratory testing data. Using the verified numerical model, intensive simulations are conducted to examine the influence of various parameters, including thickness of basalt fiber, location of basalt fiber layer, bonding strength between the basalt fiber cloth and the OSB skin, on the dynamic responses of the SIP. The debris penetration or fracture of the strengthened SIP that creates an opening is defined as failure of the panel in this study. Empirical formulae are derived on the basis of the numerical results to predict the thresholds of penetration velocity and projectile mass that lead to failure of the SIP. The empirical formulae can be straightforwardly used to assess the performance of the SIP with OSB skins strengthened by basalt fiber cloth subjected to windborne debris impact. References listed at the end of the paper:
ABSTRACT: In this study, the impact damage resistance of carbon/basalt hybrid fiber reinforced polymer pipes was experimentally investigated under low velocity impact loading. The composite pipes, composed of thin plastic liner of HDPE wrapped with eight layers of plies at constant winding angle of \( \pm 55/90^\circ \) or \( \pm 55/90^\circ \), were fabricated through filament winding technique. Eight pipe configurations with different stacking sequence and fiber content proportion were studied. Specimens cut from the original pipes were tested in a drop weight impact machine under two levels of impact energies, 50J and 100J, in order to predict the impact response and induced damage resistance of the pipe. The damage of the tested pipes was assessed based on the force-displacement, force-time histories, the energy absorption mechanism, as well as the micrographs captured by scanning electron microscope (SEM) for the specimens. The results indicate that the impact resistance behavior
was highly affected by the stacking sequence of the layers and partly affected by the fiber content ratio. Positioning the basalt fiber on the impacted side enhances the energy absorption mechanism for both levels of imposed energies, while improving the impact resistance. The addition of 50% basalt fiber can slightly increase the impact resistance compared to the addition of 25% basalt fiber. However, specimens with 25% basalt fiber showed lower peak force, lower damage area and lower energy absorption.

References listed at the end of the paper:
ABSTRACT: A new type of high performance steel (HPS), designated WGJ steel, with high strength as well as improved fire and corrosion resistance, was recently developed by Wuhan Iron and Steel (Group) Company. This paper investigated the lateral-torsional buckling behavior of beams fabricated of WGJ steel through experimental and numerical analysis. Welded I-section beams were tested under concentrated loads, which indicated that lateral-torsional buckling was the dominant failure mode. A finite element model was established and validated by the experimental results. Parametric analyses were conducted to further understand the effect of steel strength on the lateral-torsional buckling capacity of steel beams. The numerical results were compared with design values obtained from the clauses in Eurocode 3 and GB50017. It is found that the design equations in GB50017 give less safe margins for the overall stability design of welded I-section beams fabricated of WGJ high performance steel, whereas Eurocode 3 appears to be more conservative in all conditions.

References listed at the end of the paper:

comparing the natural frequencies of the continuous models calibrated with respect to the element size of the microstructured plate, is structure small length scale coefficient. As expected, it is found that the continualized models lead to a constant coefficient, whereas for the phenomenological nonlocal approaches, the coefficient, for capturing the small length scale effect of microstructured (or lattice) thick plates by associating the small length scale coefficient introduced in the nonlocal approach to some length scale coefficients given in a Taylor series expansion. The nonlocal phenomenological approach for the vibration of lattice plates including both shear and bending interactions is well established in the literature. The propagation of waves in the transverse vibrations of bars and plates, Akad. Nauk. SSSR Prikl. Math. Mech. 12 (1948) 287–461.


ABSTRACT: The present study investigates the dynamical behavior of lattice plates, including both bending and shear interactions. The exact natural frequencies of this lattice plate are calculated for simply supported boundary conditions. These exact solutions are compared with some continuous nonlocal plate solutions that account for some scale effects due to the lattice spacing. Two continualized and one phenomenological nonlocal UflyandMindlin plate models that take into account both the rotary inertia and the shear effects are developed for capturing the small length scale effect of microstructured (or lattice) thick plates by associating the small length scale coefficient introduced in the nonlocal approach to some length scale coefficients given in a Taylor or a rational series expansion. The nonlocal phenomenological model constitutes the stress gradient Eringen’s model applied at the plate scale. The continualization process constructs continuous equation from the one of the discrete lattice models. The governing partial differential equations are solved in displacement for each nonlocal plate model. An exact analytical vibration solution is obtained for the natural frequencies of the simply supported rectangular nonlocal plate. As expected, it is found that the continualized models lead to a constant small length scale coefficient, whereas for the phenomenological nonlocal approaches, the coefficient, calibrated with respect to the element size of the microstructured plate, is structure-dependent. Moreover, comparing the natural frequencies of the continuous models with the exact discrete one, it is concluded that the continualized models provide much more accurate results than the nonlocal UflyandMindlin plate models.

References listed at the end of the paper:


ABSTRACT: The free vibration and buckling of a rotating annular plate with constant angular speed free at the inner edge and fixed at the outer edge subjected to a compressive centrifugal body force are analyzed using the Ritz method. Exact stress components and radial displacement of the rotating annular plate are obtained via the plane elasticity. Convergence studies in the frequencies and the critical buckling angular speed are made up to four significant figures. The natural frequencies and the corresponding mode shapes and the critical buckling angular speeds are presented for the rotating annular plates with various angular speeds and ratios of the inner radius to the outer radius.

References listed at the end of the paper:


ABSTRACT: This paper presents a closed form solution for the vibration and acoustic problem of orthotropic plates under a thermal environment. Hamilton’s principle is utilized to derive the governing equation of motion for the orthotropic plate with thermal loads, which is then solved by the method of separation of variables. The frequency equations and mode functions obtained for the orthotropic heated plates with at least two adjacent edges clamped are much simpler than those by the conventional methods. Several numerical examples are carried out for the modal, dynamic and acoustic analysis of orthotropic heated plates with different
combinations of thermal loads and boundary conditions. The results of the parametric study for the orthotropic plate with different thermal loads are discussed in detail. The validity of the present formulation is confirmed by comparing the results obtained with the numerical ones. Due to its accuracy, efficiency and versatility, the present method offers an efficient tool for the structural and acoustic analysis of the orthotropic plate under the thermal environment.

References listed at the end of the paper:
7. H. C. Chan and O. Foo, Vibration of rectangular plates subjected to in-plane forces by the finite strip method, J. Sound Vib. 64 (4) (1979) 583–588.

ABSTRACT: This paper presents the stability analysis of a perforated plate with sector geometry made of composite materials. The sector of concern is a compound of graphite-epoxy and glass-epoxy with identical ply thickness but different fiber angles for each layer. The mechanical load conditions considered include uniform axial, circumferential, and biaxial pressure, while the thermal loading is specified to be uniform temperature increase over the whole sector. The existence of one or two circular holes has increased the complexity of analysis. To obtain solutions of high accuracy, the three-dimensional elasticity theory relations have been employed. Using the finite element method along with the stability condition of Trefftz, the buckling equation of the structure is derived. Green nonlinear strain-displacement relations are used to form the geometrical stiffness matrix. Unlike the finite element method used by other researches, a novel curved 3D B-Splined element is used to more accurately trace the displacement and stress variations of the structure. This element can be used in solution domains with geometric discontinuities, such as perforated plates and also meshed in the thickness direction. Moreover, instead of using the common von Karman assumptions, the most general form of the strain tensors in the curvilinear coordinates is adopted. The buckling load is obtained by extremizing the second variations of the total potential energy. The finite element formulation is coded in the MATLAB software. The effects of various parameters such as sector dimensions, dimensions of the hole, mechanical load directions, and fiber angles of each layer on the thermomechanical buckling is investigated.

References listed at the end of the paper:

15. N. D. Duc and H. V. Tung , Mechanical and thermal postbuckling of higher order shear deformable functionally graded plates on elastic foundations, J. Compos. Struct. 93 (2011) 2874–2881.


ABSTRACT: Pipe-in-pipe (PIP) system can be considered as a structure-tuned mass damper (TMD) system by replacing the hard centralizers by the softer springs and dashpots to connect the inner and outer pipes. With properly designed connecting devices, PIP system therefore has the potential to mitigate the subsea pipeline vibrations induced by various sources, such as earthquake or vortex shedding. This study proposes using rotational friction hinge dampers with springs (RFHDSs) to connect the inner and outer pipes. The rotational friction hinge dampers (RFHDSs) are used to absorb the energy induced by the external vibration sources and the springs are used to provide the stiffness to the TMD system and to restore the original locations of the inner and outer pipes. To investigate the effectiveness of this new design concept, detailed three-dimensional (3D) finite element (FE) model of the RFHD is developed in ANSYS and the hysteretic behavior of RFHD is firstly studied. The calculated hysteretic loop is then applied to the 3D PIP FE model to estimate the seismic responses. The effectiveness of the proposed system to mitigate seismic induced vibrations is examined by comparing the seismic responses of the proposed system with the conventional PIP system. The influences of various parameters, such as the preload on the bolt, the friction coefficient and the spring stiffness, on the RFHD hysteresis behavior and on the seismic responses of PIP system are investigated and some suggestions on the RFHDS design are made.

References listed at the end of the paper:


ABSTRACT: This technical note presents a static–dynamic relationship for the flexural free vibration analysis of beams in tension with some specific boundary conditions. It is shown to be possible that a free vibration system can be solved via a static analysis approach to determine the natural frequencies of the beam with tension forces. The key idea of this study is to substitute the real natural frequency parameters with zero or negative elastic foundation stiffness, thereby allowing one to obtain the natural frequencies of the beam with tension forces. The key idea of this study is to substitute the real natural frequency parameters with zero or negative elastic foundation stiffness, thereby allowing one to obtain the natural frequencies of the beam with tension forces.

References listed at the end of the paper:

2. M. Hetényi, Beams on elastic foundation: Theory with applications in the fields of civil and mechanical engineering, University of Michigan (1971).

ABSTRACT: This paper presents a three-dimensional (3D) analysis for the natural frequencies of completely free, toroidal shells of revolution with hollow circular cross-sections by the Ritz method. The displacement components $u_r$, $u_\theta$, and $u_z$ in the radial, circumferential, and axial directions, respectively, are taken to be sinusoidal in time, periodic in $\theta$, and of the ordinary algebraic simple polynomials in the $r$ and $z$ directions. The potential (strain) and kinetic energies of the torus are formulated, and the upper bound values of the frequencies are obtained by a minimization procedure. As the degree of the polynomials increases, the frequencies computed converge to the exact values. Convergence to four-digit exactitude is demonstrated for the first five frequencies of the torus. Comparisons are made between the frequencies from the present 3D method, a 3D finite element method, experimental methods, and thin and thick ring theories.

References listed at the end of the paper:


ABSTRACT: Based on the classical thin plate theory, this paper proposes new sets of enriched basis functions for in-plane and out-of-plane displacements of square plates that can yield admissible functions for the Ritz method using the moving least-squares (MLS) approach. These admissible functions display the discontinuities of displacement and slope across a crack; give the correct singularity order for the stress resultants at the crack
Developments in Mechanics, 4, Proc. 10th Midwestern Mechanics Conference

Struct. 44.

(4)

(36)

References listed at the end of the paper:


11. R. Seifi and N. Khoda-yari, Experimental and numerical studies on buckling of cracked thin-plates under full and partial compression edge loading, Thin-Walled Struct. 49 (2011) 1504–1516.


14. A. A. Rad and D. Panahandeh-Shahraki, Buckling of cracked functionally graded plates under tension, Thin-Walled Struct. 84 (2014) 26–33.


References listed at the end of the paper:


ABSTRACT: This paper is concerned with the lateral and torsional coupled vibration of monosymmetric I-beams under moving loads. To this end, a train is modeled as two subsystems of eccentric wheel loads of constant intervals to account for the front and rear wheels. By assuming the lateral and torsional displacements to be restrained at the two ends of the beam, both the lateral and torsional displacements are approximated by a series of sine functions. The method of variation of constants is adopted to derive the closed-form solution. For the most severe condition when the last wheel load is acting on the beam, both the conditions of resonance and cancellation are identified. Once the condition of cancellation is enforced, the resonance response can always be suppressed, which represents the optimal design for the beam. Since the condition for suppressing the torsional resonance is exactly the same as that for the vertical resonance, this offers a great advantage in the design of monosymmetric I-beams, as no distinction needs to be made between the suppression of vertical or torsional resonance.

References listed at the end of the paper:
ABSTRACT: This paper investigates the free vibration and dynamic response of functionally graded sandwich beams resting on elastic foundation under harmonic moving loads. The governing equation of motion of the beam, which includes the effects of shear deformation and rotary inertia based on the Timoshenko beam theory, is derived from Lagrange’s equations. The Ritz and Newmark methods are employed to solve the equation of motion for the free and forced vibration responses of the beam with different boundary conditions. The results are presented in both tabular and graphical forms to show the effects of layer thickness ratios, boundary conditions, length to height ratios, spring constants, etc. on natural frequencies and dynamic deflections of the beam. It was found that increasing the spring constant of the elastic foundation leads to considerable increase in natural frequencies of the beam; while the same is not true for the dynamic deflection. Additionally, very large dynamic deflection occurs for the beam in resonance under the harmonic moving load.

References listed at the end of the paper:

ABSTRACT: A cable-stiffened single-layer latticed shell is an efficient and lightweight structural system in the category of spatial structures. In the past, much emphasis was placed on determining the static stability behavior...
of this structural system. Relatively little research was attempted on the seismic behavior of cable-stiffened single-layer latticed shells. The article aims to investigate numerically the seismic behavior of this structural system and to compare the behavior of the cable-stiffened single-layer latticed shell with that of the conventional unstiffened shell. The natural vibration characteristics, including the vibration modes and natural frequencies, were examined initially by modal analysis. Subsequently, a time-history analysis was conducted to analyze the nonlinear behavior of the cable-stiffened single-layer latticed shell under the El Centro earthquake. It was demonstrated that the seismic behavior of single-layer latticed shells can be greatly enhanced by the cable-stiffening system. In addition, the effects of pretension in cables, cross-sectional area, and other parameters relating to the seismic behavior of the cable-stiffened latticed shell have also been investigated.

References listed at the end of the paper:

7. M. Fujimoto, S. Kushima, K. Imai, S. Kato and T. Ogawa, Numerical study on buckling behavior of single layer two-way grid dome with tension member as diagonals, in Proc. IASS 2010 (Shanghai, China, 2010).

ABSTRACT: In this paper, the parametric resonance of pipes with soft and hard segments induced by pulsating fluids is investigated. The lowest six natural frequencies and mode shapes of the soft–hard combination pipe simply supported at both ends are obtained by the modified Galerkin's method. The Floquet method is used to numerically determine the parametric resonance regions, including subharmonic resonance regions and combination resonance regions. The parametric resonance results are verified by comparison with published ones, which confirm the validity of the present model establishment and numerical calculation. Compared with a uniform pipe conveying fluid simply supported at both ends, the soft–hard pipe conveying fluid is found to reveal different dynamical behaviors. Decreasing the length of the soft pipe, while increasing the stiffness ratio of the hard pipe compared to the soft one, can effectively improve the stability of the pipe system. The parametric resonance results show that the mean flow velocity and pulsation amplitude of the fluid have a great influence on the width of the parametric resonance regions. It is advisable that the ratio (the soft pipe/the whole pipe) of the length may be designed to be 0.4–0.5 for a flexural rigidity ratio (the hard pipe/soft pipe) of 2. As the stiffness ratio (the hard pipe/soft pipe) increases beyond 26, the hard pipe may be regarded as a rigid pipe. The probability of parametric resonance occurrence will be smallest if the soft–hard combination pipe is supported in a clamped–pinned way. For certain application cases, the safety design length of the two pipes with different materials can be determined through numerical calculation.

References listed at the end of the paper:

ABSTRACT: This article investigates the flexural properties of temperature-dependent and carbon nanotube-reinforced (CNT) cylindrical shells made of functionally graded (FG) porous materials under various kinds of thermal loadings. The equivalent material properties of the cylindrical shell of concern are estimated using the rule of mixture. Both the cases of uniform distribution (UD) and FG distribution patterns of reinforcements are considered. Thermo-mechanical properties of the cylindrical shell are supposed to vary through the thickness and are estimated using the modified power-law rule, by which the porosities with even and uneven types are approximated. As the porosities occur inside the FG materials during the manufacturing process, it is necessary to consider their impact on the vibration behavior of shells. The present study is featured by consideration of different types of porosities in various CNT reinforcements under various boundary conditions in a single model. The governing equations and boundary conditions are developed using Hamilton's principle and solved by the generalized differential quadrature method. The accuracy of the present results is verified by comparison with existing ones and those by Navier's method. The results show that the length to radius ratio and temperature, as well as CNT reinforcement, porosity, thermal loading, and boundary conditions, play an important role on the natural frequency of the cylindrical shell of concern in thermal environment.

References listed at the end of the paper:


Ngoc-Duong Nguyen, Trung-Kien Nguyen, Thuck P. Vo and Huu-Tai Thai, “Ritz-based analytical solutions for bending, buckling and vibration behavior of laminated composite beams”, International Journal of Structural
Stability and Dynamics, Vol. 18, No. 11, 1850130, November 2018, https://doi.org/10.1142/S0219455418501304

ABSTRACT: In this paper, the Ritz-based solutions are developed for the bending, buckling and vibration behaviors of laminated composite beams with arbitrary lay-ups. A quasi-3D theory, which accounts for a higher-order variation of both the axial and transverse displacements, is used to capture the effects of both shear and normal deformations on the behaviors of composite beams. Numerical results for various boundary conditions are presented and compared with existing ones available in the literature. Besides, the effects of fiber angle, span-to-height ratio, material anisotropy and Poisson’s ratio on the displacements, stresses, natural frequencies and buckling loads of the composite beams are investigated.

References listed at the end of the paper:

23. F. Canales and J. Mantari, Buckling and free vibration of laminated beams with arbitrary boundary conditions using a refined HSDT, Compos. Part B. 100 (2016) 136–145.
ABSTRACT: Presented herein is a novel computational approach using the moving element method (MEM) for simulating the dynamic response of Mindlin plate resting on viscoelastic foundation and subjected to moving loads. The governing equations and the element mass, damping and stiffness matrices are formulated in a convected coordinate system in which the origin is attached to the point of the moving applied load. Thus, the method simply treats moving loads as ‘stationary’ at the nodes of the plate to avoid updating the locations of moving loads due to the change of the contact points on the plate. To verify the accuracy of the proposed computational approach, static and free vibration analyses of plates are investigated first. Next, the dynamic response of plate resting on a viscoelastic foundation subjected to a moving load is examined. A parametric study is performed to determine the effects of the load’s velocity, foundation damping and foundation stiffness on the dynamic response of a plate. Finally, the comparisons of the dynamic response of plates resting on viscoelastic foundation and subjected to moving vehicles with three models of load (single-wheel, single-axle and tandem-axle) are discussed.

References listed at the end of the paper:
ABSTRACT: The vibration of a rotating sandwich beam with magnetorheological elastomer (MRE) as a core between two elastic layers is theoretically analyzed in this paper. This study is focused on the bending vibration along the edgewise direction of a sandwich beam of rectangular cross-section, which, to the best of our knowledge, has not been addressed yet. The classical Euler–Bernoulli beam theory is used to model the dynamic behavior of the elastic layers. In the modeling, the effect of the MRE layer is considered by incorporating its shear strains and the inertia due to shear deformation and bending motion. The governing equations of motion of the rotating sandwich beam are derived by using the Ritz method and the Lagrange’s equations. The effects of the applied magnetic field, core layer thickness, rotational speed, setting angle and hub radius on the natural frequencies and the corresponding loss factors are investigated parametrically. The results show the significant effect of the magnetic field intensity and the MRE layer thickness on the modal characteristics of the MRE sandwich beam.

References listed at the end of the paper:

ABSTRACT: In the present study, the thermoeelastic vibration of shear deformable functionally graded material (FGM) curved beams with microstructural defects (porosity) has been analyzed by the finite element method. The formulation is based on the higher-order shear deformation theory. The material properties of FGM beams are allowed to vary continuously in the thickness direction by a simple power-law distribution in terms of the volume fractions of the constituents. Even and uneven distributions of porosities in the beam have been considered with temperature-dependent material properties. Comparison and convergence study has been performed to validate the present formulation. Parametric studies have been done to study the effect of different influencing parameters on the frequency of the FGM curved beam, i.e., porosity, temperature rise, volume fraction index and opening angle. Some new results are presented which can be used as benchmark solutions for future research.

References listed at the end of the paper:


35. P. Malekzadeh , Two-dimensional in-plane free vibrations of functionally graded circular arches with temperature-dependent properties, Compos. Struct. 91 (2009) 38–47.


ABSTRACT: An analytical approach for predicting the free vibration and elastic critical load of functionally graded material (FGM) thin cylindrical shells filled with internal pressured fluid is presented in this study. The vibration of the FGM cylindrical shell is described by the Flügge shell theory, where the internal static pressure is considered as the prestress term in the shell equations. The motion of the internal fluid is described by the acoustic wave equation. The natural frequencies of the FGM cylindrical shell under different internal pressures are obtained with the wave propagation method. The relationship between the internal pressure and the natural frequency of the cylindrical shell is analyzed. Then the linear extrapolation method is employed to obtain the elastic critical load of the FGM cylindrical shell from the condition that the increasing pressure has resulted in zero natural frequency. The accuracy of the present method is verified by comparison with the published results. The effects of gradient index, boundary conditions and structural parameters on the elastic critical load of the FGM cylindrical shell are discussed. Compared with the experimental and numerical analyses based on the external pressure, the present method is simple and easy to carry out.

References listed at the end of the paper:

ABSTRACT: This paper presents a novel closed-form analytical approximate solution for the local buckling behavior of composite laminated beams. The current analysis approach is based on Reddy’s third-order shear deformation theory (TSDT). The idealization of the discrete plate approach, meaning that the individual segments are separated from the beam cross-section, and the local buckling behavior is analyzed by performing a TSDT-based plate buckling analysis by assuming adequate boundary conditions for webs and flanges. At those edges where the segment under consideration has been separated from the cross-section, elastic restraints are applied to the stiffness values of which depend on the geometric and material properties of the adjacent segments. The analysis approach uses the principle of minimum elastic potential of the considered discrete plate in the buckled state and relies on rather simple shape functions for the buckling modes, thus eventually enabling a closed-form analytical approximate solution that does not necessitate any numerical means of evaluation. Results are generated for a number of I-beam configurations and are compared to results generated in the framework of classical laminated plate theory (CLPT) and first-order shear deformation theory (FS-DT). It is shown that the present new approach delivers reliable results without any significant computational effort and thus can be recommended for all engineering analysis tasks where computational time and effort are deciding factors in day-to-day engineering work, such as systematic optimizations or extensive parametric studies.

References listed at the end of the paper:

ABSTRACT: This paper proposes a novel functionally graded (FG) concrete slab and investigates its thermal buckling and postbuckling performance using the finite-element (FE) method. The concrete slab consists of three homogeneous thick layers — a fiber-reinforced concrete layer, a geopolymer concrete layer, and a plain Portland cement (PPC) layer — with a thin FG layer between the thick layers. The mechanical properties of the thin FG layers are exponentially graded across the thickness direction. The effects of initial imperfection, the self-weight of the slab, and the friction between the slab and rigid foundation are considered in the analysis. The FE model is validated against the results reported in the literature. A comprehensive parametric study is conducted to examine the effects of the thickness and volume fraction index of the FG layer, initial imperfection, self-weight, friction, and slab slenderness ratio on the thermal buckling and postbuckling behaviors of the concrete slab. The numerical results demonstrate that the proposed FG slab exhibits remarkably better buckling and postbuckling resistance than a conventional PPC concrete slab and that the influences of both self-weight and friction are important and cannot be neglected.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: The present study deals with numerical and experimental investigations on the vibration behavior of fiber-metal-laminated (FML) plates, a new aircraft material. A finite element (FE)-based formulation is established for the plate using the first-order Reissner–Mindlin theory, including both fibers and metals of different material properties in alternate layers. A four-node isoparametric quadratic element with five degrees of freedom per node is adopted in the analysis. Convergence studies and comparison with previous studies are made to validate the present FE formulation. A set of experiments was conducted to get natural frequencies of vibration for glass FML (GFML) plates using Brueel and Kjaer (B&K) Fast Fourier Transform (FFT) analyzer with PULSE platform. The effects of different parameters such as aspect ratio, side-to-thickness ratio, ply orientation, and boundary conditions on the dynamic behavior of the FMLs are studied. Good agreement is achieved between the numerical and experimental results. Both results indicate that increasing the aspect ratio can increase the natural frequency of the FML plate, while the increase in the side-to-thickness ratio decreases the natural frequency of vibration. The boundary conditions can significantly affect the natural frequency of the FML plates due to the restraint effect at the edges.

References listed at the end of the paper:

ABSTRACT: In the present work, the nonlinear free flexural vibration of thick curvilinear fibre composite laminates is investigated using a higher-order shear flexible eight-noded quadrilateral element developed considering the variation of in-plane and transverse displacement through the thickness. The formulation includes both the geometric nonlinearity and inertia effects. The governing equations, derived based on Lagrange’s equations of motion, are solved iteratively through an eigenvalue approach. The formulation is tested against various problems for which the solutions are available in the literature. A detailed analysis is made to assess the influence of fiber angles, lamination schemes, boundary conditions, thickness, and aspect ratios on the nonlinear frequency ratio at large amplitude vibrations of the laminates. A comparative study is also done along with the first-order and simple higher-order theory deduced from the present model by neglecting the thickness stretching effects. The present analysis shows the degree of hardening behavior getting affected noticeably compared to those of the traditional straight fibers, thus exhibiting the occurrence of drop off in frequency ratio and redistribution of mode shapes at certain amplitudes of vibration.

References listed at the end of the paper:


ABSTRACT: The dynamic stability behavior of rotating functionally graded carbon nanotube reinforced composite (FG-CNTRC) cylindrical shells under combined static and periodic axial forces is investigated. The governing equations are derived based on the first-order shear deformation theory (FSDT) of shells. The initial mechanical stresses due to the steady state rotation of the shell are evaluated by solving the dynamic equilibrium equations. The equations of motion under different boundary conditions are discretized in the spatial domain and transformed into a system of Mathieu governing equations. The influences of both the initial mechanical stresses and Coriolis acceleration are considered. Then, the parametric resonance is analyzed and the dynamic instability regions are determined by employing the Bolotin’s first approximation. After validating the approach, the effects of rotational speed, Coriolis acceleration, carbon nanotubes (CNTs) distribution in the thickness direction, CNTs volume fraction, length and thickness-to-mean radius ratios on the principal dynamic instability regions are examined in detail.

References listed at the end of the paper:

ABSTRACT: Flexible roof structures, such as membranes, are sensitive to wind action due to their flexibility and light weight. Previously, the effect of added mass on the vibration frequency of membrane structures has been experimentally tested. However, the effect of added mass on wind-induced vibration remains unclear. The purpose of this paper is to investigate the effect of added mass on the wind-induced vibration of a circular flat membrane based on wind tunnel tests. First, wind tunnel tests were conducted to obtain wind pressure distribution from the rigid model and wind-induced vibration from the aeroelastic model of a circular flat membrane. Secondly, a dynamic finite element analysis for the proposed added mass model was conducted to obtain the wind-induced vibration of the membrane structure. Then, with the wind pressure distribution obtained from the rigid model tests, dynamic analysis was conducted either with or without consideration of the effect of added mass. According to the dynamic analysis results and the wind tunnel test results, it is clear that considering the effect of added mass in dynamic analysis can significantly improve the accuracy of a wind-induced response. Such an effect is more significant at the windward than the central zone. The inclusion of added mass can result in a larger displacement response as wind velocity increases but a smaller response as the prestress level increases.

References listed at the end of the paper:

ABSTRACT: Steel-reinforced concrete-filled stainless steel tubular (SRCFSST) columns combine the advantages of concrete-filled stainless steel tubular (CFSST) columns and steel-reinforced concrete (SRC) columns, resulting in excellent corrosion resistance, good economy, good ductility, and excellent fire resistance. Thus, SRCFSST columns have many potential structural engineering applications, especially in offshore structures. The performance of SRCFSST columns at elevated temperatures is investigated by finite element (FE) analysis in this paper. Firstly, FE models capable of capturing the full load-deformation response of structural members at elevated temperatures are developed and validated against relevant published tests on CFSST and SRC columns under fire conditions. Based on the validated FE models, the behavioral mechanisms of the SRCFSST columns under fire are explained by analysis of the sectional temperature distribution, typical failure modes, axial deformation versus time response, and load redistribution. Finally, the fire resistance of SRCFSST columns is evaluated in comparison to CFSST columns with equivalent sectional load-bearing capacity at ambient temperature or equivalent steel ratios. The results lay the foundation for the development of fire resistance design rules for SRCFSST columns.

References listed at the end of the paper:

ABSTRACT: The compressive deformation is mainly contributed by axial compressive deformation and high-order in-plane and out-of-plane global buckling deformation for conventional buckling-restrained braces (BRBs). A novel type of all-steel BRBs with perforated core plates, termed as perforated BRBs (PBRBs), are proposed in this study, where shear deformation can occur in addition to the aforementioned deformations in a conventional BRB under compression. Experimental study was carried out using five specimens with different configurations of holes under cyclic loading. Stable hysteretic properties, high ductility, and energy dissipation capacity were obtained for the PBRBs. The effects of two parameters, i.e. the slenderness ratio of the chord and hole spacing factor defined as the ratio of the hole length to the hole spacing, on seismic performance of the specimens were investigated. The compressive deformation mechanisms of the PBRBs were further investigated through a numerical study. The compressive deformation was found to be composed of axial compressive deformation, flexural deformation owing to in-plane and out-of-plane global buckling, and in-plane shear deformation of the latticed core plate.

References listed at the end of the paper:

form of the governing equation. The precision and competency of the present procedure in stability analysis are
power series form. At the end, the elastic and buckling stiffness matrices are exactly determined by the weak
shape functions are gained by altering the deformation shape of the AFG nonprismatic Timoshenko beam i
is solved numerically with the help of the power series a

coupling between the t
beam theory, the equilibrium equations are derived in the context of small displacements, considering the
static and buckling stiffness matrices for the linear stability analysis of axially fu

Dynamics, Vol. 19, No. 2, 1950002, 2019


C. L. Wang, T. Usami, J. Funayama and F. Imase , Low-cycle fatigue testing of extruded aluminium alloy buckling-restrained


C. Black, N. Makris and I. Aiken , Component testing, seismic evaluation and characterization of buckling-restrained braces, J.


M. Hagimoya, T. Taguchi, T. Nagao and T. KAMIYA , Experimental studies on buckling properties for buckling-restrained braces


T. Usami, H. B. Ge and A. Kasai , Overall buckling prevention condition of buckling restrained braces as a structural control
damper, in Proc. 14th World Conf Earthquake Engineering (Beijing, China, 2008).

AISC Seismic Provisions for Structural Steel Buildings, ANSI/AISC 341-10 (IL: American Institute for Steel Construction,
Chicago, 2010), pp. 249–258.


L. A. Fahnestock, R. Sause, J. M. Ricles and L. W. Lu , Ductility demands on buckling restrained braced frames under earthquake

L. J. Jia and H. Kuwamura , Prediction of cyclic behaviors of mild steel at large plastic strain using coupon test results, J. Struct.
Eng. (ASCE) 140 (2) (2014) 04013056.

L. J. Jia and H. Kuwamura , Ductile fracture simulation of structural steels under monotonic tension, J. Struct. Eng. (ASCE) 140

L. J. Jia and H. Kuwamura , Ductile fracture model for structural steel under cyclic large strain loading, J. Construct. Steel Res.

P. Xiang, L. J. Jia, K. Ke, Y. Y. Chen and H. B. Ge , Ductile cracking simulation of uncracked high strength steel using an energy


L. J. Jia, H. B. Ge, K. SHINOHARA and H. Kato , Experimental and numerical study on ductile fracture of structural steels under

L. J. Jia, T. Ikai, K. SHINOHARA and H. B. Ge , Ductile crack initiation and propagation of structural steels under cyclic combined

Masoumeh Soltani and Behrouz Asgarian (First author is from: Department of Civil Engineering, Faculty of
Engineering, University of Kashan, Kashan, Iran), “Finite element formulation for linear stability analysis of
axially functionally graded nonprismatic Timoshenko beam”, International Journal of Structural Stability and
ABSTRACT: An improved approach based on the power series expansions is proposed to exactly evaluate the
static and buckling stiffness matrices for the linear stability analysis of axially functionally graded (AFG)
Timoshenko beams with variable cross-section and fixed–free boundary condition. Based on the Timoshenko
beam theory, the equilibrium equations are derived in the context of small displacements, considering the
clipping between the transverse deflection and angle of rotation. The system of stability equations is then
converted into a single homogeneous differential equation in terms of bending rotation for the cantilever, which
is solved numerically with the help of the power series approximation. All the mechanical properties and
displacement components are thus expanded in terms of the power series of a known degree. Afterwards, the
shape functions are gained by altering the deformation shape of the AFG nonprismatic Timoshenko beam in a
power series form. At the end, the elastic and buckling stiffness matrices are exactly determined by the weak
form of the governing equation. The precision and competency of the present procedure in stability analysis are
References listed at the end of the paper:


ABSTRACT: This paper presents a dynamical model of a fluid-conveying pipe spinning about an eccentric axis. The coupled bi-flexural–torsional free vibration and stability are analyzed for such a doubly gyroscopic system. The partial differential equations of motions are derived by the extended Hamilton principle, and are then truncated by a 4-term Galerkin technique. The frequency and energy evolutions and representative mode shapes in the two transverse directions and torsional direction are investigated to unveil the essential dynamical attributes of the system. It is indicated that the stability of the present system mainly depends on spinning speed, flow velocity and eccentricity, while the torsional frequencies are almost immune to the flow velocity. The pipe reveals ‘traveling-wave’ modal vibrations in both transverse directions, and a general ‘standing-wave’ modal vibration in the torsional direction.

ABSTRACT: A three-dimensional (3D) method of analysis is presented for determining the natural frequencies and the mode shapes of combined hemispherical–cylindrical shells of revolution with and without a top opening by the Ritz method. Instead of mathematically two-dimensional (2D) conventional thin shell theories or higher-order thick shell theories, the present method is based upon the 3D dynamic equations of elasticity. Mathematically, minimal or orthonormal Legendre polynomials are used as admissible functions in place of ordinary simple algebraic polynomials which are usually applied in the Ritz method. The analysis is based upon the circular cylindrical coordinates instead of the shell coordinates which are normal and tangent to the shell mid-surface. Strain and kinetic energies of the combined shell of revolution with and without a top opening are formulated, and the Ritz method is used to solve the eigenvalue problem, thus yielding upper bound values of the frequencies by minimizing the frequencies. As the degree of the Legendre polynomials is increased, frequencies converge to the exact values. Convergence to four-digit exactitude is demonstrated for the first five frequencies. Numerical results are presented for the combined shells of revolution with or without a top opening, which are completely free and fixed at the bottom of the combined shells. The frequencies from the present 3D Ritz method are compared with those from 2D thin shell theories by previous researchers. The present analysis is applicable to very thick shells as well as very thin shells.

References listed at the end of the paper:


ABSTRACT: In this paper, we investigate parametric instability of Bresse–Timoshenko columns subjected to periodic pulsating compressive loads. The results are derived from three theories, namely the Bernoulli–Euler
model for thin beams and two versions of the Bresse–Timoshenko model valid for thick beams: The truncated Bresse–Timoshenko model and the Bresse–Timoshenko model based on slope inertia. The truncated Bresse–Timoshenko model has been derived from asymptotic analysis, whereas the Bresse–Timoshenko model based on slope inertia is an alternative shear beam model supported by variational arguments. These models both take into account the rotary inertia and the shear effect. Simple supported boundary conditions are considered, so that the time-dependent deflection solution can be decomposed into trigonometric spatial functions. The instability domain in the load–frequency space is analytically characterized from a Meissner-type parametric equation. For small slenderness ratio, these last two Bresse–Timoshenko models coincide but for much higher slenderness ratio, the parametric instability regions in the load–frequency space shift to the left and widen them as compared to the Bernoulli–Euler model. The importance of these effects differs between the models.

References listed at the end of the paper:

ABSTRACT: In this paper, the size-dependent nonlinear pull-in behavior of rectangular microplates made from functionally graded materials (FGMs) subjected to electrostatic actuation is numerically studied using a novel approach. The small scale effects are taken into account according to Mindlin’s first-order strain gradient theory (SGT). The plate model is formulated based on the first-order shear deformation theory (FSDT) using the virtual work principle. The size-dependent relations are derived in general form, which can be reduced to those based on different elasticity theories, including the modified strain gradient, modified couple stress and classical theories (MSGT, MCST and CT). The solution of the problem is arrived at by employing an efficient matrix-based method called the variational differential quadrature (VDQ). First, the quadratic form of the energy functional including the size effects is obtained. Then, it is discretized by the VDQ method using a set of matrix differential and integral operators. Finally, the achieved discretized nonlinear equations are solved by the pseudo arc-length continuation method. In the numerical results, the effects of material length scale parameters, side-length-to-thickness ratio and FGM’s material gradient index on the nonlinear pull-in instability of microplates with different boundary conditions are investigated. A comparison is also made between the predictions by the MSGT, MCST and CT.

References listed at the end of the paper:

ABSTRACT: This study deals with the generalized second moment of area (GSMA) of regular polygon cross-sections for the Ludwick type material and its application to cantilever column buckling. In the literature, the GSMA for the Ludwick type material has only been considered for rectangular, elliptical and superellipsoidal cross-sections. This study calculates the GSMA of regular polygon cross-sections other than those mentioned above. The GSMA calculated by varying the mechanical constant of the Ludwick type material for the equilateral triangle, square, regular pentagon, regular hexagon and circular cross-sections are reported in tables and figures. The GSMA obtained from this study are applied to cantilever column buckling, with results shown in tables and figures.

References listed at the end of the paper:
10. A. Borboni and D. D. Santis, Large deflection of a nonlinear, elastic, asymmetric Ludwick cantilever beam subjected to horizontal force, vertical force and bending torque at the free end, Meccanica 49 (6) (2014) 1327–1336.
ABSTRACT: The circular truss antenna of the large aperture is considered to be a flexible structure which may cause vibration in space and may affect its performance. The frequency analysis of the circular truss antenna is an important problem for understanding its vibration mechanism. In this paper, we investigate the frequency characteristics of a beam–ring structure which is proposed for the first time to model the circular truss antenna in the case of the antenna expended and locked. Based on describing the displacements of the beam–ring system in detail, the kinetic energy and potential energy are calculated. The partial differential governing equations of motion and boundary conditions for the beam–ring structure are derived by Hamilton principle. From the linear parts of the governing equations of motion and the corresponding boundary conditions, the linear frequencies of the beam–ring structure are theoretically obtained. The effects of the physical parameters on the frequency characteristics of the beam–ring structure are studied, which are further verified by the numerical results. The finding phenomena of this paper are helpful for designing and controlling the beam–ring structure such as the circular truss antenna.

References listed at the end of the paper:
Flutter of the wing are investigated. The results show that the aeroelastic stability region is limited by increasing equations. Also, Peter’s finite state model is used to simulate the aerodynamic loads on the wing. Effects of motions of the engine are considered in this paper. Dynamics of the engine are simulated by two torsional and longitudinal springs at the wing elastic axis. One flap is attached to the wing degree of freedom (5DOF) wing section carrying a flexibly mounted unbalanced engine. The wing flexibility is flexural vibration by Ritz’s method. A. H. Behbahani and R. T. M’Closkey, Frequency analysis of a uniform ring perturbed by point masses and springs, J. Sound Vib. 397 (2017) 204–221.


ABSTRACT: In this paper, both experimental and analytical flutter analyses are conducted for a typical 5-degree of freedom (5DOF) wing section carrying a flexibly mounted unbalanced engine. The wing flexibility is simulated by two torsional and longitudinal springs at the wing elastic axis. One flap is attached to the wing section by a torsion spring. Also, the engine is connected to the wing by two elastic joints. Each joint is simulated by a spring and damper unit to bring the model close to reality. Both the torsional and longitudinal motions of the engine are considered in the aeroelastic governing equations derived from the Lagrange equations. Also, Peter’s finite state model is used to simulate the aerodynamic loads on the wing. Effects of various engine parameters such as position, connection stiffness, mass, thrust and unbalanced force on the flutter of the wing are investigated. The results show that the aeroelastic stability region is limited by increasing the engine mass, pylon length, engine thrust and unbalanced force. Furthermore, increasing the damping and stiffness coefficients of the engine connection enlarges the stability domain.

References listed at the end of the paper:


sequences, damage, material properties and thermal loads, are also discussed in detail.

remarkable with the increased shell thickness. However, this effect can be reduced by optimizing the ply angles of the stacking laminas. More factors, such as geometric parameters, numbers of fiber layers, lamina stacking sequences, damage, material properties and thermal loads, are also discussed in detail.
ABSTRACT: The dynamics of a thin rod under the action of compressive force is considered. The compressive force increases abruptly and then remains constant. The compression of the rod is assumed to take place instantly throughout its length. The motion of the rod is studied, depending on the magnitude and time of action of the compressive force defined by the phase of the initial free oscillation of the rod. Only the initial stage of the process is investigated, for which the linear bending theory is valid. The friction forces are not taken into account. An essential relationship is shown to exist between the dynamics of the rod and the initial conditions determined by the phase of the bending oscillations at the instant of impact. Relatively weak impact leads to excitation of the bending oscillations. Rearrangement of harmonics develops with time under specified initial maximum deflection from a straight line and zero velocity. The fastest buckling takes place at some initial deflection with the velocity directed toward the increasing bend.

References listed at the end of the paper:

1. C. Koning and J. Taub, Stossartige Knickbeanspruchung schlanker Stäbe im elastischen Bereich bei beiderseits glänzender Lagerung, Luftfahrtforschung 10 (2) (1933) 17.
ABSTRACT: The natural frequencies and mode shapes of enclosed shell type structures with variable thickness (hemispherical-cylindrical-hemispherical shells and complete hollow spherical shells) are determined by the Ritz method using a three-dimensional (3D) analysis. However, in the conventional shell analysis, mathematically two-dimensional (2D) thin shell theories or higher order thick shell theories are often employed, which adopt limiting assumptions about the displacement variation through the shell thickness. While most researchers have adopted the 3D shell coordinates that are normal and tangential to the shell mid-surface, the present analysis is based upon the circular cylindrical coordinates. By the Ritz method, the Legendre polynomials, which are mathematically orthonormal and minimal, are used as the admissible functions, instead of the ordinary algebraic polynomials. The strain and kinetic energies of the combined shell structures are formulated, and upper bound solutions of the frequencies are obtained by minimizing the solution for frequencies. As the degree of the Legendre polynomials is increased, frequencies converge to the exact values. Convergence to four-digit exactitude is demonstrated for the first five frequencies. The frequencies from the present 3D method are compared with those from other 3D approach and 2D thin and thick shell theories existing in the literature. The present 3D analysis is applicable to both very thick shells and very thin shells.

References listed at the end of the paper:


ABSTRACT: Two higher-order analytical models based on a new higher-order theory for sandwich plates with flexible cores are developed considering the effect of the core material density and skin-to-core-stiffness-ratio (SCSR). The main difference between the two models is the role of the flexible core in the dynamic response of sandwich plates with cores of different stiffnesses. Firstly, the governing equations of a simply supported sandwich plate with a flexible core are derived based on the two models, and the analytical solutions are determined by using Navier’s approach. Then, the free vibration, static, dynamic bending and stress field characteristics of the sandwich plates with different SCSRs are investigated. The results obtained by the proposed method are compared with other published results. In particular, an accuracy assessment of the present dynamic models is conducted for different SCSRs. Finally, conclusions on the applicability of the proposed method and other theories on sandwich plates with different SCSRs are drawn.

References listed at the end of the paper:

ABSTRACT: Cylindrical shells containing flowing fluid have wide applications in various industries. They can be enhanced as smart structures through inclusion of piezoelectric layers, of which the dynamic behavior, however, has not been fully understood. In this paper, the vibration and dynamic analysis of a laminated composite hollow cylinder with piezoelectric layers, subjected to an internal incompressible fluid flow is investigated. It is assumed that the shell is simply supported and the fluid is inviscid and irrotational. The differential equations of the elastic layers, piezoelectric layers, and flowing fluid are derived by the three-dimensional (3D) theory of elasticity, theory of piezoelectricity, and potential flow theory, respectively. A well-known recursive method is applied and extended for the first time to solve the fluid-conveying pipes using 3D theory. This approach makes it possible for the solutions to converge to the exact ones with reasonable computational cost. After validating the results against those available in the literature, the vibrational behavior of the system is examined for various cases with the effect of each parameter investigated. Also, the influence of fluid on the vibration and stability of the shell has been analyzed. The present method can be used to analyze and design hybrid shells conveying fluid with high accuracy and low computational cost.

References listed at the end of the paper:
Finally, the presented results can be used as a benchmark solution. The critical buckling loads are calculated using the proposed analytical model. A parametric study is performed to investigate the effects of transverse crack location and magnitude, length and degree of partial longitudinal delamination. Part I: Stability, J. Sound Vib. 225 (4) (1999) 655–699.


ABSTRACT: In the present study, free vibration and buckling characteristics of a sandwich functionally graded material (FGM) plate resting on the Pasternak elastic foundation have been investigated. The formulation is based on non-polynomial higher-order shear deformation theory with inverse hyperbolic shape function. A new modified sigmoid law is presented to compute the effective material properties of sandwich FGM plate. The governing equilibrium equations have been derived using Hamilton’s principle. Non-dimensional frequencies and critical buckling loads are evaluated by considering different boundary conditions based on admissible functions satisfying the desired primary and secondary variables. Comprehensive parametric studies have been performed to analyze the influence of geometric configuration, volume fraction exponent, elastic medium parameter, and non-dimensional load parameter on the non-dimensional frequency and critical buckling load. These parametric studies have been done for various boundary conditions and different configurations of the sandwich plate. The computed results can be used as a benchmark for future comparison of sandwich S-FGM plates.

References listed at the end of the paper:
5. H. S. Shen, Large deflection of composite laminated plates under transverse and in-plane loads and resting on elastic foundations, Compos. Struct. 45 (1999) 115–123.


52. T. Kant and K. Swaminathan, Analytical solutions for free vibration of laminated composite and sandwich plates based on a higher order refined theory, Compos. Struct. 53 (2001) 73–85.


ABSTRACT: This paper presents a novel approach for determining the critical lateral-torsional buckling loads of beams subjected to arbitrarily transverse loads. This new method is developed based on the classical energy method. However, the difference of the present method from the traditional energy methods is the formulation of potential energy of external loads, which is expressed in terms of the internal bending moment and internal shear force in the pre-buckling stage regardless of the type of loading. Compared to the traditional formulations of the potential energy of external loads, not only is the present formula simple in the form, easy and convenient in the calculation, but it also provides a unified form for calculating accurate critical load of lateral-torsional buckling of the beams.

References listed at the end of the paper:


ABSTRACT: The free and forced vibration characteristics of three-layered sandwich plates with thin isotropic faces and *Leptadenia pyrotechnica* rheological elastomer (LPRE) core are studied in this investigation. The LPRE core is fabricated and experimented to determine its shear storage modulus and loss modulus. It is observed that the stiffness and damping characteristics of the LPRE core is significantly higher than those of the room-temperature vulcanized silicone rubber elastomer (RTVE) core. The governing equation of motion for the sandwich plate is derived by the Lagrange principle and given in finite element form. The natural frequencies and loss factors of the three-layered sandwich plate are studied by varying the thicknesses of the core and the constraining isotropic layer, and material of the constraining layer with different boundary conditions. The results are compared with those of similar structures with different core materials and boundary conditions. In addition, a LPRE-based sandwich plate is fabricated and its fundamental frequency is determined experimentally and compared with the finite element result. The forced vibration response of the three-layered sandwich plate is also explored under a harmonic excitation force. This study provides supports for the application of the LPRE-based sandwich plates potentially to the passive vibration suppression of structures.

References listed at the end of the paper:

ABSTRACT: This paper investigates the nonlinear flexural vibration of sandwich beams with functionally graded (FG) negative Poisson’s ratio (NPR) honeycomb core in thermal environments. The novel constructions of sandwich beams with three FG configurations of re-entrant honeycomb cores through the beam thickness direction are proposed. The temperature-dependent material properties of both face sheets and core of the sandwich beams are considered. 3D full-scale finite element analyses are conducted to investigate the nonlinear vibration, and the variation of effective Poisson’s ratio (EPR) of the sandwich beams in the large deflection region. Numerical simulations are carried out for the sandwich beam with FG-NPR honeycomb core in different thermal environmental conditions, from which results for the same sandwich beam with uniform distributed NPR honeycomb core are obtained as a basis for comparison. The effects of FG configurations, temperature changes, boundary conditions, and facesheet-to-core thickness ratios on the nonlinear vibration ratio curves and EPR–deflection curves of sandwich beams are discussed in detail.

References listed at the end of the paper:


2. C. Kasapoglou, Design and Analysis of Composite Structures: With Applications to Aerospace Structures (Wiley, West Sussex, 2010).


ABSTRACT: Based on the Eringen nonlocal elasticity theory and multiple time scale method, an asymptotic nonlocal elasticity theory is developed for cylindrical bending vibration analysis of simply-supported, \(N\)-layered, and uniformly or nonuniformly-spaced, graphene sheet (GS) systems embedded in an elastic medium. Both the interactions between the top and bottom GSs and their surrounding medium and the interactions between each pair of adjacent GSs are modeled as one-parameter Winkler models with different stiffness coefficients. In the formulation, the small length scale effect is introduced to the nonlocal constitutive equations by using a nonlocal parameter. The nondimensionalization, asymptotic expansion, and successive integration mathematical processes are performed for a typical GS. After assembling the motion equations for each individual GS to form those of the multiple GS system, recurrent sets of motion equations can be obtained for various order problems. Nonlocal multiple classical plate theory (CPT) is derived as a first-order approximation of the current nonlocal plane strain problem, and the motion equations for higher-order problems retain the same differential operators as those of nonlocal multiple CPT, although with different nonhomogeneous terms. Some nonlocal plane strain solutions for the natural frequency parameters of the multiple GS system with and without being embedded in the elastic medium and their corresponding mode shapes are presented to demonstrate the performance of the asymptotic nonlocal elasticity theory.

References listed at the end of the paper:

25. A. C. Eringen , Nonlocal Continuum Field Theories (Springer Verlag, New York, 2002).

Erol Demirkan and Reha Artan (First author is from: Department of Civil Engineering, Technical University of Istanbul, Maslak-Istanbul 34469, Turkey), “Buckling analysis of nanobeams based on nonlocal Timoshenko beam model by the method of initial values”, International Journal of Structural Stability and Dynamics, Vol. 19, No. 4, 1950036, April 2019, https://doi.org/10.1142/S0219455419500366

ABSTRACT: Investigated herein is the buckling of nanobeams based on a nonlocal Timoshenko beam model by the method of initial values within the framework of nonlocal elasticity. Since the nonlocal Timoshenko beam theory is of higher order than the nonlocal Euler–Bernoulli beam theory, it is known to be superior in predicting the small-scale effect. The buckling determinants and critical loads for bars with various kinds of supports are presented. The Carry-Over matrix (Transverse Matrix) is presented and the priorities of the method of initial values are depicted. To the best of the researchers’ knowledge, this is the first work that investigates the buckling of nonlocal Timoshenko beam with the method of initial values.

References listed at the end of the paper:

Mohitrajhu Lingan Kumaraian, Jayamanideep Rebbagondla, Tittu Varghese Mathew and Sundararajan Natarajan (First author is from: Integrated Modelling and Simulation Lab, Department of Mechanical Engineering, Indian Institute of Technology-Madras, Chennai 600036, India), “Stochastic vibration analysis of

ABSTRACT: A cell-based smoothed finite element method with discrete shear gap technique is used to study the stochastic free vibration behavior of functionally graded plates with material uncertainty. The plate kinematics is based on the first-order shear deformation theory and the effective material properties are estimated by simple rule of mixtures. The input random field is represented by the Karhunen–Loève expansion and the polynomial chaos expansion is used to represent the stochastic output response. The accuracy of the proposed approach in terms of the first- and the second-order statistical moments are demonstrated by comparing the results with the Monte Carlo Simulations. A systematic parametric study is carried out to bring out the influence of the material gradient index, the plate aspect ratio and the skewness of the plate on the stochastic global response of functionally graded plates. It is inferred that all the considered parameters significantly influence the statistical moments of the first fundamental mode.

References listed at the end of the paper:

Alireza Habibi and Shaahin Bidmeshki (First author is from: Department of Civil Engineering, Shahed University, Tehran, Iran), “An optimized approach for tracing pre- and post-buckling equilibrium paths of space

ABSTRACT: In this paper, a novel optimization-based method is proposed to analyze steel space truss structures undergoing large deformations. The geometric nonlinearity is considered using the total Lagrangian formulation. The nonlinear solution is obtained by introducing and minimizing an objective function subjected to the displacement-type constraints. The proposed approach can fully follow the equilibrium path of the geometrically nonlinear space truss structures not only before the limit point, but also after it, namely, including both the pre- and post-buckling paths. Moreover, a direct estimation of the buckling loads and their corresponding displacements is possible by using the method. Particularly, it has been shown that the equilibrium path of a structure with highly nonlinear behavior, multiple limit points, snap-through, and snap-back phenomena can be traced via the proposed algorithm. To demonstrate the accuracy, validity, and robustness of the proposed procedure, four benchmark truss examples are analyzed and the results compared with those by the modified arc-length method and those reported in the literature.

References listed at the end of the paper:

ABSTRACT: The static stability of slender concrete-filled steel tubular (CFST) columns has been explored thoroughly while few researches have been carried out on the dynamic stability of CFST columns even if all applied loadings are naturally time-dependent. This paper presents an analytical procedure for evaluating the dynamic stability of CFST columns of various composite cross-sections under general boundary conditions. This paper is featured by the following facts: (1) proportional damping is considered in derivation of the governing equations on the lateral parametric vibration of the CFST columns subject to axial excitation; (2) Bolotin’s method is used to determine the boundaries of the regions of dynamic instability for the CFST columns with general supports; (3) the relationship of static and dynamic stability, and the effects of boundary conditions and cross-sectional forms are uncovered. New findings of this investigation are (1) larger amplitude or constant component of excitation make it easier for the dynamic instabilities of the CFST columns to occur,
while increasing the constant component of excitation reduces the critical value of frequency ratio for the dynamic instability to occur; (2) the dynamic stability analysis can determine the critical loads for both the static and dynamic instability of CFST columns, and the critical instability load decreases with increasing disturbance on the static load; (3) under the same consumptions of steel and concrete, the square columns have better performance of dynamic stability than the circular columns, but there is no definite conclusion on the effect of hollow size on the dynamic stability of double-skin columns.

References listed at the end of the paper:
- 5. Y. An, L. Han and X. Zhao , Behaviour and design calculations on very slender thin-walled CFST columns, Thin-Walled Struct. 53 (2012) 161–175.
interesting features of the various configurations of the catenary riser under various end forces were evaluated. The beam theory was extended to large sag analysis of a catenary riser. With this, some

ABSTRACT: This paper focused on a simply supported beam under uniform self-weight, subjected to an axial force at the roller end. The principle of virtual work-energy was used to formulate the equation for the nonlinear deformation of the beam, which involves the bending strain energy, the virtual work due to self-weight, and the virtual work of the axial force applied at the free-sliding roller end. The work-energy functional was expressed in terms of the arc-length coordinate. The functional vanished, yielding the static equilibrium configuration of the beam — a highly nonlinear problem. Finite element and Newton–Raphson iterative methods were used to solve the problem. The beam theory was extended to large sag analysis of a catenary riser. With this, some interesting features of the various configurations of the catenary riser under various end forces were evaluated. References listed at the end of the paper:


Ong-Art Punjarat and Somchai Chucheepsakul (Department of Civil Engineering, Faculty of Engineering, King Mongkut’s University of Technology Thonburi, Bangkok 10140, Thailand), “Post-buckling analysis of a uniform self-weight beam with application to catenary riser”, International Journal of Structural Stability and Dynamics, Vol. 19, No. 4, 1950047, April 2019, https://doi.org/10.1142/S0219455419500470

ABSTRACT: This paper focused on a simply supported beam under uniform self-weight, subjected to an axial force at the roller end. The principle of virtual work-energy was used to formulate the equation for the nonlinear deformation of the beam, which involves the bending strain energy, the virtual work due to self-weight, and the virtual work of the axial force applied at the free-sliding roller end. The work-energy functional was expressed in terms of the arc-length coordinate. The functional vanished, yielding the static equilibrium configuration of the beam — a highly nonlinear problem. Finite element and Newton–Raphson iterative methods were used to solve the problem. The beam theory was extended to large sag analysis of a catenary riser. With this, some interesting features of the various configurations of the catenary riser under various end forces were evaluated. References listed at the end of the paper:

References listed at the end

ABSTRACT: A closed-form solution based on the Reddy third-order shear deformation plate theory is proposed for the buckling of both flat and stiffened plates, simply supported on two opposite edges. The effect of the nonlinear strain–displacement terms, usually neglected under the von Kármán hypothesis, on the buckling of thick plates is investigated, and the equations governing the critical behavior considering the full Green–Lagrange strain tensor and the second Piola–Kirchhoff stress tensor are derived using the principle of minimum potential energy. The general Levy-type approach is employed, and the accuracy and effectiveness of the proposed formulation is validated through direct comparison with analytical and numerical results available in the literature. The parametric analyses performed for different geometrical ratios show that the von Kármán hypothesis holds only for thin flat plates whereas it can significantly overestimate buckling loads for stiffened plates, for which the buckling mode entails comparable in-plane and out-of-plane displacements.

References listed at the end of the paper:

References listed at the end of the paper:

formulation · nodal coordinates · Sound Vib. · plates · Struct. · solution and Galerkin · Eng. Sci. · microbeams based on a modified couple stress theory · problem · 150 · 16 · Struct. · 41 · Micromech. Microeng. · of metal thin film · Thin Solid Films. · 437(1–2) · 2003 · 182–187.


29. M. Raffée, F. Nitsche and M. Labrosse · Rotating nanocomposite thin-walled beams undergoing large deformation, Compos. Struct. · 150 · 2016 · 191–199.


31. C. Liu, Q. Tian and H. Y. Hu · Dynamics of a large scale rigid-flexible multibody system composed of composite laminated plates, Multibody Syst. Dyn. · 26(3) · 2011 · 283–305.


35. M. Berzner and A. A. Shabana · Development of simple models for the elastic forces in the absolute nodal co-ordinate formulation, J. Sound Vib. · 235(4) · 2000 · 539–565.


ABSTRACT: The main objective of presented work is a rectangular plate subjected to dynamic in-plane load generated by magnetic field. The plate is made of polyethylene (PE). There are two pockets on each of the two opposite edges of the plate. These pockets with porous structure are filled in with ferrofluid. The coil system consists of two magnetic field coil subsystems. These systems are built of Helmholtz (MC) and Golay coils (GC) and generate nonhomogeneous magnetic field. If the magnetic field is more homogeneous, the compression load is induced. In other cases, local tensile load occurs (compression load dominates). For presented coil systems, the intensity of load was examined for two variants. For the first of them, the intensity of load was dependent on the radius of Golay coil arcs. The change of the radius of saddle coils also influences on the strength of the gradient of the magnetic field. The second one describes the intensity of load which depends on the change of GC radius without changing the strength of magnetic field (the strength of magnetic field is compensated with changing the current flowing through the coils wires or with changing the number of wires). In this paper, the analytical model of the plate is presented. The model of the plate was formulated with the use of classical Kirchhoff–Love hypothesis. Elastic strain energy, kinetic energy as well as work of load were formulated. The equation of motion was derived based on the Hamilton’s principle. The numerical studies were related to the analysis of the intensity of load distribution.


ABSTRACT: The maximum vibration transmissibility of paper honeycomb sandwich structures with different sizes of honeycomb core under various static stresses was investigated using the sine frequency sweep test. The effects of the cell length of the honeycomb, the thickness of the sandwich structure, and the static stress on the maximum vibration transmissibility were evaluated and a linear polynomial equation for evaluating the maximum vibration transmissibility was obtained. The results show that the maximum vibration transmissibility increases steadily with the increase in the cell length of the honeycomb, the thickness of the sandwich structure, and the static stress. The proposed equation for the maximum vibration transmissibility is suitable for predicting the maximum vibration transmissibility of paper honeycomb sandwich structures. In addition, the fitted three-dimensional diagrams of the effects of the factors on the maximum vibration transmissibility derived from the evaluation equation were shown to be in good agreement with the experimental results.
ABSTRACT: Investigated herein are the small- and large-amplitude vibrations of a thermally postbuckled graphene-reinforced composite (GRC) laminated beam supported by an elastic foundation. The piecewise GRC layers are arranged in a functionally graded (FG) pattern along the thickness direction of the beam. The temperature-dependent material properties of functionally graded graphene-reinforced composites (FG-GRCs) are estimated through the extended Halpin–Tsai micromechanical model. The nonlinear governing differential equations are derived from the higher-order shear deformation beam theory and the von Kármán-type strain–displacement relationships. The thermal effect, the beam–foundation interaction and the initial deflection caused by thermal postbuckling are also included. A two-step perturbation approach is applied to determine the thermal postbuckling equilibrium paths as well as the nonlinear vibration solutions for the FG-GRC laminated beams. Results are presented to demonstrate the nonlinear vibration responses of thermally postbuckled FG-GRC laminated beams under a uniform temperature field. The effects of the FG reinforcement patterns and the foundation stiffness on the nonlinear vibration responses of FG-GRC laminated beams are examined and discussed.

References listed at the end of the paper


ABSTRACT: This paper presents an investigation on the nonlinear dynamic behavior of three-phase rectangular composite plates made of cross-ply macro fiber composites (MFC) in the polymer with graphene...
(GP) skins, which are uniformly dispersed at the top and bottom surfaces of the plates. According to the mixture rules for multi-components of composite materials, the constitutive laws for MFC-GP composite materials can be obtained. A simply-supported rectangular plate model subjected to a transversal excitation in thermal environments is considered. The governing equations are formulated by using the first-order shear deformation theory, von Kármán geometrical kinematics and Hamilton’s principle. The Galerkin approach is used to discretize the governing equations for analysis. The vibration frequencies of MFC-GP composite plates with different modes are presented and the case of 1:2 internal resonance is selected to be investigated here. Three different coupled forms (i.e. uncoupled, weakly coupled and strongly coupled cases) of two vibration modes are presented. In addition, the influences of various parameters, including volume fraction of graphene, applied voltage, temperature effect and external excitation, on the nonlinear dynamic characteristics of MFC-GP composite plates are also examined.

References listed at the end of the paper:


ABSTRACT: This paper studies the structural stability of circular steel tubular stub columns at elevated temperatures under axial compression. Fifty-one specimens are subjected to high-temperature treatment and axial compression. The variables of the specimen are temperature, wall thickness of steel tube and duration of high temperature. The displacement–load curve, strain–load curve, ultimate load, axial compressive stiffness and failure characteristics of the specimens were analyzed. Test results show that after exposure to high temperatures, the specimens’ failure phenomenon in the axial compression loading test is consistent with that at room temperature, the bearing capacity decreases considerably, the ductility decreases slightly and the axial compressive stiffness changes irregularly. Temperature is the determining factor of the ultimate load of the specimen, and the reducing extent of ultimate load increases with the temperature. When the temperature reaches 1000 C, its maximum reducing extent exceeds 50%. Among the three parameters considered in this study, the duration of high temperature has the least influence on the specimen.

References listed at the end of the paper:

ABSTRACT: The stability characteristics of web panels in two built-up members, i.e. box-sections and I-sections, are investigated here using a higher order plate bending element. At the beginning, the critical buckling loads of rectangular flat panels under various theoretical states-of-stress (pure shear, in-plane bending, shear and in-plane bending and combined stresses) and boundary conditions (simply supported and restrained by flange panels) are investigated. Then, the buckling behavior of an isolated flat panel is correlated with the stability characteristics of the web panels of built-up members under various loading conditions. The results on the stability behavior of the web panels are presented in nondimensional form for easy reference to designers and researchers.

References listed at the end of the paper:

ABSTRACT: Given the unique and extremely valuable properties, research has significantly focused on graphene sheets (GSs). To premeditate the small-scale effect, the present work applies the nonlocal theory to study the buckling behavior of a double-layered GS (DLGS) embedded in an elastic foundation. To derive the equation, classical plate theory is adopted. For the elastic foundation, Pasternak-type model is used. In terms of buckling response, a meshless method is utilized to compute simulation results. Accordingly, we examine the effects of aspect ratio, geometry, boundary conditions and nonlocal parameters on the buckling responses of DLGSs.

References listed at the end of the paper:


ABSTRACT: A novel thermal-resistance film is proposed, and its thermal post-buckling behavior is studied by using the meshless method. The Von Kármán plate model together with the nonlocal theory is adopted for the formulation of the problem. The post-buckling curve of the graphene sheet (GS) film is obtained. The effect of
the parameters, such as nonlocal parameters, geometric size, geometric shape and elastic medium, on the thermal post-buckling response of the GSs film is examined. It is found that it is important to design proper geometric size and geometric shape and control the radius of tensionless area. This study provides theoretical guidance for fire resistance design of thermal-resistance films attached to glass façade.

References listed at the end of the paper:


ABSTRACT: This paper proposes the radial point interpolation method (RPIM) for studying the dynamic behaviors of rotating Mindlin plates. By considering nonlinear coupling deformation, that is, the in-plane longitudinal shortening terms caused by transverse deformation, the first-order approximation coupled (FOAC) dynamic model is established using Lagrange’s equations of the second kind. The effectiveness of RPIM is first demonstrated in some static cases and then extended for dynamic analysis of a rectangular plate subjected to a large overall motion. The simulation results were compared with those obtained with zero-order approximation coupled (ZOAC) dynamic model, and it was observed that results obtained with FOAC dynamic model are more accurate, especially for cases involving high rotating speed. Furthermore, the influence of the radial basis shape parameters is discussed and the optimal parameters for plates are recommended. An approach to overcome the shear locking issue is also provided.


ABSTRACT: The geometrically nonlinear response of sandwich functionally graded cylindrical shells reinforced by orthogonal and/or spiral stiffeners and subjected to axial compressive loads is investigated in this paper. Two types of sandwich functionally graded material models are considered. The formulations are based on the Donnell shell theory considering geometrical nonlinearity and Pasternak’s elastic foundation. The improved Lekhnitskii’s smeared stiffener technique is used to account for the stiffener effects with both mechanical and thermal stresses. The results obtained indicate that the spiral stiffeners have significantly beneficial influences in comparison with orthogonal stiffeners on the nonlinear buckling behavior of shells. The relatively large effects of temperature change, geometrical and material parameters are also demonstrated in the numerical investigations.

References listed at the end of the paper:
27. H. Huang and Q. Han, Nonlinear dynamic buckling of functionally graded cylindrical shells subjected to time-dependent axial load, Compos. Struct. 92 (2010) 593–598.


ABSTRACT: Great attention has been given in the last few years to steel–concrete composite beams due to the gains in strength that can be obtained with the small cost of installing a shear connection between the steel profile and the concrete slab. In continuous and semicontinuous composite beams close to the internal supports, hogging bending moments are developed and the compressed bottom flange may buckle laterally in an unstable way known as the lateral-distortional buckling, characterized by a horizontal displacement and twist of the bottom flange with an out-of-plane distortion of the web. In the literature, several formulations were proposed to determine the critical moment for this type of buckling. Among them, some of the most relevant are presented by [K. Roik, G. Hanswille and J. Kina, Solution for the lateral torsional buckling problem of composite beams (in German), Stahlbau59 (1990)] and [G. Hanswille, J. Lindner and D. Munich, Lateral torsional buckling of composite beams (in German), Stahlbau67 (1998)]. In the present work, a new procedure is developed to determine the elastic critical moment of lateral–distortional buckling of composite beams under uniform hogging moment. To assess and calibrate this procedure, 7772 numerical models were analyzed by the finite element code ANSYS and the results were compared with the ones obtained from the new proposed formulas. The procedure presented excellent agreement with the numerical results, with an average deviation of 2.33% from the computational simulations. The formulations of [K. Roik, G. Hanswille and J. Kina, Solution for the lateral torsional buckling problem of composite beams (in German), Stahlbau59 (1990)] and [G. Hanswille, J. Lindner and D. Munich, Lateral torsional buckling of composite beams (in German), Stahlbau67 (1998)] did not lead to such satisfactory results, presenting an average deviation of 12.41% and 16.51%, respectively.

References listed at the end of the paper:


ABSTRACT: A novel size-dependent coupled symplectic and finite element method (FEM) is proposed to study the steady-state forced vibration of built-up nanobeam system resting on elastic foundations. The overall system is modeled as a combination of nonlocal Timoshenko beams. A new analytical subsystem modeling with formulation and another numerical subsystem modeling are developed and discussed. In the analytical subsystem model, the uniform nanobeams are modeled and solved by a new approach based on a series of analytical symplectic eigensolutions. The numerical subsystem model applies a nonlocal FEM to solve nonuniform nanobeams. Analytical and numerical solutions are presented, and a proper comparison between the two approaches is established. Comprehensive and accurate numerical result is subsequently presented to illustrate the accuracy and reliability of the coupled method. The new results established are expected to have reference values for future studies.


ABSTRACT: The stability characteristics of shear deformable trapezoidal composite plates are studied here. The strain smoothing technique is employed to approximate the membrane strains and curvatures of the edge-based smoothing cells. The transverse shear strains within the Reissner–Mindlin quadrilateral element are obtained using the edge-consistent interpolation approach. At the beginning, the performance of the present numerical technique is examined for the buckling analysis of trapezoidal panels under in-plane compressive or shear stresses. Thereafter, new results on the buckling and postbuckling behaviors of trapezoidal composite plates are presented, for which comparable numerical results are rare in the literature. Representative numerical results are presented to highlight the interaction between the higher pre-buckling stresses and increased stiffness near the shorter edge with fiber orientation and loading direction on the buckling resistance of trapezoidal panels.

References listed at the end of the paper:

33. R. Mania, Buckling analysis of trapezoidal composite sandwich plate subjected to in-plane compression, Compos. Struct. 69 (2005) 482–490.
ABSTRACT: This paper investigates the nonlinear instability of eccentrically stiffened functionally graded (ES-FG) sandwich truncated conical shells subjected to the axial compressive load. The core of the FG sandwich truncated conical shells, assumed to be thin, is made of pure metal or ceramic materials and the two skin layers are made of a FG material. The shell reinforced by orthogonal stiffeners (stringers) is also made of FG materials. The change of spacing between the stringers in the meridional direction is considered. The governing equations are derived using the Donnell shell theory with von Karman geometrical nonlinearity along with the smeared technique for stiffeners. The resulting coupled set of three nonlinear partial differential equations with variable coefficients in terms of displacement components are solved by the Galerkin’s method. The closed-form expressions for determining the critical buckling load and for analyzing the postbuckling load-deflection curves are obtained. The accuracy of present formulation is verified by comparing the results obtained with available ones in the literature. The effects of various parameters such stiffeners, foundations, material properties, geometric dimensions on the stability of the shells are studied in detail.

References listed at the end of the paper:


This paper investigates the nonlinear instability of eccentrically stiffened functionally graded (ES-FG) sandwich truncated conical shells subjected to the axial compressive load. The core of the FG sandwich truncated conical shells, assumed to be thin, is made of pure metal or ceramic materials and the two skin layers are made of a FG material. The shell reinforced by orthogonal stiffeners (stringers) is also made of FG materials. The change of spacing between the stringers in the meridional direction is considered. The governing equations are derived using the Donnell shell theory with von Karman geometrical nonlinearity along with the smeared technique for stiffeners. The resulting coupled set of three nonlinear partial differential equations with variable coefficients in terms of displacement components are solved by the Galerkin’s method. The closed-form expressions for determining the critical buckling load and for analyzing the postbuckling load-deflection curves are obtained. The accuracy of present formulation is verified by comparing the results obtained with available ones in the literature. The effects of various parameters such stiffeners, foundations, material properties, geometric dimensions on the stability of the shells are studied in detail.
30. A. H. Sofiyev , On the dynamic buckling of truncated conical shells with functionally graded coatings subjected to a time dependent axial load in the large deformation, Compos. Part B 58 (2014) 524–533.


ABSTRACT: A mathematical model using the fiber approach is presented in this paper for quantifying the strength and fire-resistance of eccentrically loaded slender concrete-filled steel tubular (CFST) columns with rectangular sections incorporating the interaction of local and global buckling. The model utilizes the thermal simulator to ascertain the temperature distribution in cross-sections, and the nonlinear global buckling analysis
to predict the interaction responses of local and global buckling of loaded CFST slender columns to fire effects. The initial geometric imperfection, air gap between the concrete and steel tube, tensile concrete strength, deformations caused by preloads, and temperature-dependent material behavior are included in the formulation. The computational theory, modeling procedure and numerical solution algorithms are described. The computational model is verified by existing experimental and numerical results. The structural responses and fire-resistance of CFST columns of rectangular sections exposed to fire are investigated. The mathematical model proposed is demonstrated to be an efficient computer simulator for the fire-performance of slender CFST columns loaded eccentrically.

References listed at the end of the paper:

7. ACI-318-11, Building Code Requirements for Reinforced Concrete (American Concrete Institute, Detroit, MI, 2011).
ABSTRACT: Based on the modified couple stress theory, an attempt is made in this study to analyze the nonlinear snap-through instability of FGM shallow micro-arches with integrated surface piezoelectric layers based on modified couple stress theory. The governing equations of the piezo-FGM sandwich arch are established with the aid of virtual displacement method and the uncoupled thermoelasticity theory. The obtained governing differential equations are based on the first-order shear deformation theory of arches. The microstructure-dependent functionally graded material (FGM) arch with surface bonded piezoelectric actuator layers is analyzed. The piezo-FGM sandwich arch is subjected to uniform transverse pressure load in thermoelectrical environment. All material properties of the FGM micro arch are assumed to be temperature- and position-dependent. The non-dimensional governing equations are solved for the cases of piezo-FGM sandwich arch with immovable ends. Comparison is made with the existing results for the cases of FGM arch without couple stress and piezoelectric layers, where good agreement is obtained. The nonlinear behavior of the sandwich arches is highly affected by the couple stress, piezoelectric layers, temperature change, volume fraction index, and geometrical properties of the arch.

References listed at the end of the paper:
ABSTRACT: The present study aims to analyze the buckling and post-buckling behavior of the geometrically imperfect functionally graded pin-ended tube. Imperfect FGM tube is surrounded by nonlinear elastic medium and is subjected to the axial compression or various thermal loads. Pinned-pinned boundary conditions are movable or immovable for the FGM tube under axial compression or thermal loads, respectively. In thermal analysis, different types of thermal loads such as uniform temperature rise, linear temperature distribution, and heat conduction are analyzed and contrasted. Displacement field of the FGM tube satisfies the tangential traction-free boundary conditions on the inner and outer surfaces. Properties of the FGM tube are assumed to be temperature-dependent and are distributed through the radial direction of tube using a power law function. The governing equilibrium equations of the FGM tube are obtained by means of the virtual displacement principle. These are nonlinear coupled differential equations based on a higher order shear deformation tube theory and the von Kármán nonlinear assumption. The coupled nonlinear dimensionless differential equations are solved using the two-step perturbation method. These asymptotic solutions are as explicit functions of the axial compression or different types of thermal load. Numerical results are provided to explore the effects of the linear and nonlinear spring stiffness of elastic medium and imperfection parameter of the tube. The effects of the volume fraction index and two geometrical parameters of the FGM tube are also included.

References listed at the end of the paper:

ABSTRACT: There exist various potential energy formulations dealing with the linear buckling and second-order nonlinear analysis of framed structures with different degrees of refinement in the kinematic model. However, the geometric stiffnesses derived often give rise to different structural behaviors, which indeed represents a confusion regarding their qualified usage in bifurcation and post-buckling analysis. This study aims to carry out a comprehensive evaluation of the validity of the geometric stiffness for use at the predictor and corrector phrases of an incremental analysis based on the rigid-body motion test. To remove the unbalanced element forces caused by the nonqualified geometric stiffness, a supplementary correction matrix is developed according to simple kinematic and static analysis in the context of rigid rotations. An updated Lagrangian approach-based force recovery procedure (FRP) is presented for updating the element forces with improved reliability and efficiency, when using relatively large step size. Some benchmark problems which exhibit


ABSTRACT: There exist various potential energy formulations dealing with the linear buckling and second-order nonlinear analysis of framed structures with different degrees of refinement in the kinematic model. However, the geometric stiffnesses derived often give rise to different structural behaviors, which indeed represents a confusion regarding their qualified usage in bifurcation and post-buckling analysis. This study aims to carry out a comprehensive evaluation of the validity of the geometric stiffness for use at the predictor and corrector phrases of an incremental analysis based on the rigid-body motion test. To remove the unbalanced element forces caused by the nonqualified geometric stiffness, a supplementary correction matrix is developed according to simple kinematic and static analysis in the context of rigid rotations. An updated Lagrangian approach-based force recovery procedure (FRP) is presented for updating the element forces with improved reliability and efficiency, when using relatively large step size. Some benchmark problems which exhibit
compound three-dimensional nonlinear behavior of framed structures are solved to clarify the capabilities of rigid-body qualified and nonqualified geometric stiffnesses along with the existing FRPs for different mesh sizes, step sizes and load patterns. It is shown that the proposed procedure can be adopted to predict correct buckling loads and post-buckling equilibrium paths without adding extra computational costs.


ABSTRACT: This paper presents an improved generalized procedure for dealing with the stability of thin-walled beams under combined symmetric loads based on the energy method. The differential equations for the case of complex loading conditions were developed using an axis transformation matrix. The work caused by external loads was related to the work of internal forces to simplify the computational procedure. The thin-walled beam subjected to axial force \( F \), bending moment \( M \) at both ends, and concentrated load \( P \) at midspan was examined. The case of a concentrated load \( P \) replaced by a distributed load \( q \) over partial beam length was also examined. The stability region boundary of the beam was derived by two approaches: one was to estimate an approximate angle of twist prior to determination of the deflection and the other was to do it in the reverse way. Numerical results reveal that the first approach yields less error than the second; however, the outcome obtained by the former was more cumbersome than the latter. Above all, both approaches provided feasible results and are useful for further applications dealing with the stability analysis of thin-walled beams.

References listed at the end of the paper:

ABSTRACT: A new nonlinear model based on the absolute nodal coordinate formulation (ANCF) and the nonlocal elasticity theory is proposed to investigate the single-layered graphene sheets (SLGSs) impacted by nanoparticles. The geometrical definition of SLGSs is described by using the ANCF thin plate element, and the strain energy is expressed by using the nonlocal theory. The Lennard–Jones pair potential is adopted to model the van der Waals (vdW) force between SLGSs and nanoparticles. The impact dynamics of the system is simulated in multibody framework by using the generalized-alpha numerical integration method. The impact response of the gold atom–SLGSs system is simulated to validate the performance of the proposed model. Three impact dynamic simulations are conducted to investigate the influence of nanoparticles on the impact dynamics of SLGSs. The results show that the coupling of SLGSs vibration and vdW force led to the amplitude inconsistency of Z-position for nanoparticles.

References listed at the end of the paper:


ABSTRACT: The thermo-electro-mechanical nonlinear vibration of circular cylindrical nanoshells on the Winkler–Pasternak foundation is investigated. The nanoshell is made of functionally graded piezoelectric material (FGPM), which is simulated by the nonlocal elasticity theory and Donnell’s non-linear shell theory. The Hamilton’s principle is employed to derive the non-linear governing equations and corresponding boundary conditions. Then, the Galerkin’s method is used to obtain the non-linear Duffing equation, to which an approximate analytical solution is obtained by the multiple scales method. The results reveal that the system exhibits hardening-spring behavior. External applied voltage and temperature change have significant effect on the non-linear vibration of the FGPM nanoshells. Moreover, the effect of power-law index on the non-linear vibration of the FGPM nanoshells depends on parameters such as the external applied voltage, temperature change and properties of the Winkler–Pasternak foundation.

References listed at the end of the paper:


This paper focuses on the aeroelastic vibration energy harvesting performance of a wing panel. A nonlinear mathematical model of fluid-structure-electric coupling field was established based on the aeroelastic vibration equation and piezoelectric equation. Numerical analysis was performed to explore the influences of the airflow velocity and the piezoelectric material structural parameters on both the dynamic response and the energy harvesting performance. A small experimental wind tunnel and several prototypes of energy harvesters of the wing panel were designed and fabricated. The experimental results show that the vibration amplitude and output power of the wing panel increase with the airflow velocity; the average output power first increases until it attains the maximum values, and then decreases with the increase of the dimensionless length \( \frac{L_p}{L_S} \) and the thickness of the piezoelectric patch. It shows that the theoretical and experimental results are in good agreement. The experimental optimal output power is 3mW at the airflow velocity of 12m/s, and the piezoelectric patch length, width and thickness of 40, 20 and 0.2mm, respectively. This work provides an effective theoretical and experimental basis for studying energy harvesting and vibration control of airfoil aircrafts.

ABSTRACT: The present paper concentrates on the active control of the static bending and dynamic response of a functionally graded piezoelectric material (FGPM) plate subjected to thermo-electro-mechanical loads. Using the first-order shear deformation theory and Hamilton’s principle, the equation of motion for the FGPM plate is deduced. Based on the smart properties of piezoelectric ceramic, the active control of the static bending and vibration of the FGPM plate is studied by the mechanical load feedback, velocity feedback and LQR control methods in thermal environment. The effects of load parameter, temperature, volume fraction index and feedback control gain on the static bending and dynamic response of the FGPM plate are examined in detail. The simulation results show that the present control method can largely improve both the static and dynamic stability of the FGPM plate.

References listed at the end of the paper:

17. K. Y. Lam and T. Y. Ng, Active control of composite plates with integrated piezoelectric sensors and actuators under various dynamic loading conditions, Smart Mater. Struct. 8(2) (1999) 223–237.

ABSTRACT: This paper investigates the lateral buckling of simply supported nonprismatic I-beams with axially varying materials by a novel finite element formulation. The material properties of the beam are assumed to vary continuously through the axis according to the volume fraction of the constituent materials based on an exponential or a power law. The torsion governing equilibrium equation of the simply supported beam with free warping is numerically solved by employing the power series approximation. To this end, all the mechanical properties and displacement components are expanded in terms of the power series to a known degree. Then the shape functions are obtained by representing the deformation shape of the axially functionally graded (AFG) web and/or flanges tapered thin-walled beam in a power series form. At the end, new 4x4 elastic and buckling stiffness matrices are exactly determined from the weak form expression of the governing equation. Three comprehensive examples each of axially nonhomogeneous and homogeneous tapered beams with doubly symmetric I-sections are presented to evaluate the effects of different parameters such as axial variation of material properties, tapering ratio and load height parameters on the lateral buckling strength of the beam. The numerical outcomes of this paper can serve as a benchmark for future studies on lateral-torsional critical loads of AFG beams with varying I-sections.

References listed at the end of the paper:

102. M. Şimşek, Bi-directional functionally graded materials (BDFGMs) for free and forced vibration of Timoshenko beams with various boundary conditions, Compos. Struct. 133 (2015) 968–978.

ABSTRACT: This paper presents a new attempt for geometric nonlinear and postbuckling analysis of structures using only elastic stiffness. This can be achieved not without reasons. Aside from a correct updating of the structural geometry in the incremental sense, there are two concerns for iterations: (i) The local strategy is that the element forces recovered in each iteration should not violate the rigid body rule, in order not to induce any fictitious forces. (ii) The global strategy is that the path-tracing scheme should be able to deal with multi critical points, such as limit and snap-back points. Both strategies will be explained via the mechanism of iterations, which seems not new, but can shed some new lights. The results obtained using only the elastic stiffness will be compared with the normal case including the geometric stiffness, with the level of approximation assessed by the general stiffness parameter (GSP). Through the study of a number of trusses, beams and shell structures, it is confirmed that the elastic stiffness alone can be used to solve the nonlinear and postbuckling responses of a wide range of structures, with only an increase in the number of iterations. This paper represents a limit application of the elastic stiffness to nonlinear structural analysis.

References listed at the end of the paper:


ABSTRACT: This paper presents the superharmonic and subharmonic resonances of spiral stiffened functionally graded (SSFG) cylindrical shells under harmonic excitation. The stiffeners are considered to be externally or internally added to the shell. Also, it is assumed that the material properties of the stiffeners are continuously graded in the thickness direction. In order to model the stiffeners, the smeared stiffener technique is used. Within the context of the classical plate theory of shells, the von Kármán nonlinear equations are derived for the shell and stiffeners based on Hooke’s law and the relations of stress-strain. Using Galerkin’s method, the equation of motion is discretized. The superharmonic and subharmonic resonances are analyzed by the method of multiple scales. The influence of the material parameters and various geometrical properties on the superharmonic and subharmonic resonances of SSFG cylindrical shells is investigated. Considering these results, the hardening nonlinearity behavior and jump value of cylindrical shell is less and more than others, when the angle of stiffeners is 60 degrees and zero degrees, respectively.

References listed at the end of the paper:

3. F. M. Li and G. Yao , 1/3 Subharmonic resonance of a nonlinear composite laminated cylindrical shell in subsonic air flow, Compos. Struct. 100 (2013) 249–256.
equations using the Hamilton's principle. The efficacy of the developed finite

ABSTRACT: In this work, the primary and secondary instability region analysis of rotating multi-walled carbon nanotube (MWCNT) reinforced non-uniform hybrid composite plates (CNT-FRP) under uniaxial periodic loads is performed. First-order shear deformation theory has been used to derive the kinetic and potential energy equations of the various configurations of non-uniform composite plates by including the effect of rotary inertia, shear deformation, varying centrifugal stiffness and non-uniformity along the transverse direction of the plate. The governing differential equations of motion are derived in the form of Mathieu–Hill equations using the Hamilton’s principle. The efficacy of the developed finite-element formulation has been
verified by comparing the natural frequencies of the rotating composite plates evaluated using the numerical simulation with the experimental results and available literature. This study also investigates the influence of the CNT vol%, CNT aspect ratio, angular rotation of plate and static load on the primary and secondary instability region of various non-uniform configurations of CNT-FRP hybrid composite plates. It was noticed that the primary and secondary regions of parametric instability of CNT-FRP hybrid composite plates shift upward when CNT vol% increases from 0 to 2%. It was further noticed that primary and secondary instability regions of various non-uniform configurations shift to the lower excitation frequency when MWCNT vol% increases beyond the saturation limit. It was observed that the effect of angular rotation and static load is significant on the primary and secondary regions of instability.

References listed at the end of the paper:
References listed at the end of the paper:


Vessel in free space under constrained volume condition. Three states of the toroidal pressure vessel surface...
comprising the initial unstrained surface, reference surface, and vibrating surface were considered in the energy functional of the toroidal pressure vessel system based on the principle of virtual work. For the reference surface, it was assumed that the toroidal pressure vessel has a circular cross-section and is subjected to uniform internal pressure. Nonlinear numerical solutions were obtained utilizing the FEM and a modified direct iteration technique, and compared with those generated by ABAQUS. More importantly, this study showed that the fundamental nonlinear natural frequency of a toroidal pressure vessel under the constrained volume condition was lower than that of the published results for an inflated toroidal membrane and shell.

References listed at the end of the paper:

21. H. L. Langhaar , Foundations of Practical Shell Analysis (Department of Theoretical and Applied Mechanics, University of Illinois at Urbana-Champaign, IL, 1964).


ABSTRACT: The vibration characteristics of piezolaminated plates under coupled electromechanical loading are investigated using the finite element method. Higher order shear deformation theory is adopted to incorporate the effect of shear in the formulation. In the finite element formulation, an isoperimetric eight-noded rectangular element is employed with linear through-the-thickness electric potential distribution. In the
parametric study, the influences of geometry and boundary conditions on the vibration characteristics of piezolaminated plates are evaluated. Numerical results are presented for the frequencies of simply supported, clamped plates fitted with piezoelectric patches at the top and bottom surfaces of the laminate. For this, a model simulating the effect of the electromechanical loading with control potential is developed. Studies are also performed for piezolaminated plates with various thickness-to-span ratios, along with convergence test. The effect of the provision of piezoelectric layers to improve the vibration response of plates is investigated. This analysis reveals that the electro-mechanical coupling can strengthen the plate’s resistance to vibration.

References listed at the end of the paper:

ABSTRACT: This paper aims to investigate the structural behavior of digitally fabricated thin-walled timber sections with edge connectivity provided by integral mechanical press-fit joints. Experimental, numerical, and analytical investigations have been developed to accurately characterize the press-fit section behavior and their failure modes. Plywood fiber orientation, material thickness, and connection tightness are considered as potential factors that may affect the performance of the press-fit jointing system. Experimental testing of square hollow sections (SHSs) under uniaxial compressive loading showed failure of sections through both conventional crushing and novel pop-off bifurcation failures. Pop-off buckling behaviors were shown to be governed by the integral joint transverse stiffness and its magnitude relative to a critical edge stiffness value. Columns with joint transverse stiffness value less than the critical edge stiffness value exhibited pop-off failures. These joint stiffness values were obtained from testing of unloaded joints and were used to obtain accurate predictions of column failure modes. Joint stiffness values for loaded joints were then predicted with an interpolation model mapping axial strain to a tighter connection tolerance and these were used to obtain accurate estimations for column failure load in most of the tested column types. Comparative investigations showed thin-walled sections with integral joints only to be capable of matching the compressive capacities of glued sections, for instances where crushing governed. Similarly, the weight-specific compressive capacity of timber sections was found to be comparable to thin-walled steel sections when crushing governs.

References listed at the end of the paper:


ABSTRACT: An integrated nonlinear couple stress-surface energy continuum model is developed to study the nonlinear vibration characteristics of size-dependent functionally graded nanobeams for the first time. The nanobeam theory is formulated based on the Timoshenko kinematics, augmented by von Kármán’s geometric nonlinearity. The modified couple stress and Gurtin–Murdoch surface elasticity theories are incorporated to capture the long-range interaction and surface energy, respectively. Unlike existing Timoshenko nanobeam models, the effects of surface elasticity, residual surface stress, surface mass density and Poisson’s ratio, in addition to bending and axial deformations, are incorporated in the newly developed model. A power law function is used to model the material distribution through the thickness of the beam, considering the gradation
of bulk and surface material parameters. A variational formulation of the nonlinear nonclassical governing equations and associated nonclassical boundary conditions is established by employing Hamilton’s principle. The generalized differential quadrature method is exploited in conjunction with either the Pseudo-arclength continuation or Runge-Kutta method to solve the problem with an exact implementation of the nonclassical boundary conditions. The formulation and solution procedure presented are verified by comparing the obtained results with available ones. Based on the parametric study, it is concluded that the nonclassical boundary conditions, material length scale parameter, residual surface stress, surface elasticity, bulk elasticity modulus, gradient index, nonlinear amplitude and thickness have important influences on the linear and nonlinear vibration responses of functionally graded Timoshenko nanobeams.

References listed at the end of the paper:
working condition of half filled tank are obtained. The results show acceleration and speed coupling are achieved between the implosion field (gas, liquid) and liquid storage tank. A new Bernoulli–Euler beam model incorporating microstructure and surface energy effects, Zeitschrift für angewandte Mathematik und Physik, 65 (2014) 393–404.


https://doi.org/10.1142/S1758825118500916


ABSTRACT: To deal with the effect of liquid storage on the distribution of implosion, a fluid–solid coupling model is built for the shared nodes of implosion in the liquid storage tank. The displacement compatibility and acceleration and speed coupling are achieved between the implosion field (gas, liquid) and liquid storage tank. First, using this model, the implosion-generated overpressure distribution and structural response under the working condition of half filled tank are obtained. The results show that the overpressure, displacement and
stress are high on the shell near the liquid level. Then, the effects of both the TNT equivalent and liquid level on implosion in the liquid storage tank are studied. As the TNT equivalent increases, the maximum overpressure, displacement and stress on the shell near the liquid level increase. Consequently, the maximum overpressure and displacement on the shell near the liquid level exceed those at the roof-to-shell connection of the tank. In contrast, as the liquid level increases, the maximum stress and displacement first increase near the shell. After reaching the peaks near half filled level, they begin to decrease. Only when the liquid reaches a certain level, it can have an attenuating effect on the overpressure at the bottom-to-shell connection. However, if the liquid level continues to rise beyond a certain threshold, the attenuating effect is no longer prominent.

References listed at the end of the paper:

22. J. B. Tian, Study on dynamic characteristics of pressure vessels with flat-wound steel ribbons subjected to explosion loading, PhD thesis, Taiyuan University of Technology, China (2007).

ABSTRACT: The modeling and analysis for mechanical response of nano-scale beams undergoing large displacements and rotations are presented. The beam element is modeled as a composite consisting of the bulk material and the surface material layer. Both Eringen nonlocal elasticity theory and Gurtin–Murdoch surface elasticity theory are adopted to formulate the moment–curvature relationship of the beam. In the formulation, the pre-existing residual stress within the bulk material, induced by the residual surface tension in the material layer, is also taken into account. The resulting moment-curvature relationship is then utilized together with Euler–Bernoulli beam theory and the elliptic integral technique to establish a set of exact algebraic equations governing the displacements and rotations at the ends of the beam. The linearized version of those equations is also established and used in the derivation of a closed-form solution of the buckling load of nano-beams under various end conditions. A discretization-free solution procedure based mainly upon Newton iterative scheme and a selected numerical quadrature is developed to solve a system of fully coupled nonlinear equations. It is demonstrated that the proposed technique yields highly accurate results comparable to the benchmark analytical solutions. In addition, the nonlocal and surface energy effects play a significant role on the predicted buckling load, post-buckling and bending responses of the nano-beam. In particular, the presence of those effects remarkably alters the overall stiffness of the beam and predicted solutions exhibit strong size-dependence when the characteristic length of the beam is comparable to the intrinsic length scale of the material surface.

References listed at the end of the paper:


ABSTRACT: In this work, a new method is used for the exact vibration analysis of plates with classical boundary conditions. Four classical edge conditions are included: C — clamped, S — Simply supported, F — free, and G — guided. For square plates, all the possibilities add up to 55 cases. The solutions for the natural frequencies of the plates are found in this paper using static analysis. Starting from the equations of motion of an isotropic rectangular thin plate supported on Winkler elastic foundation, with a positive or negative value, the solution for the vibration frequencies of the plate is equivalent to finding the values of the negative elastic foundation that will yield infinite deflection under a point load on the plate. The solution is composed of three parts, the sum of which satisfies exactly both the field equation and the boundary conditions. For zero force, the vibration frequencies are found up to the desired accuracy. Benchmark results of the first six normalized natural frequencies, of isotropic square plates, for all possible 55 combinations of classical boundary conditions are given, many for the first time.

References listed at the end of the paper:


ABSTRACT: This study deals with the dynamic instability problem of spherical shells composed of carbon nanotubes/fiber/polymer composite (CNTFPC) with delamination around a central cutout. A multiscale analysis using the Hewitt and Malherbe equation was performed to determine the carbon nanotube (CNT) weight ratios, thickness–radius ratios, thickness–length ratios, and delamination area ratios around the cutout. A delamination around a central cutout was modeled in two dimensions by introducing the continuity conditions of displacements at the delamination boundaries. The proposed approach has been verified through a comparison of the results obtained with previous ones. The parametric study showed the significance of a proper CNT ratio and curvature for better structural performance on the dynamic stability of delaminated CNTFPC spherical shells.

References listed at the end of the paper:


ABSTRACT: Steel tapered-I-columns are popular in modern buildings due to its material efficiency and the convenience in construction. For evaluating the flexural buckling strength of these columns, the current design methods with empirical and idealized assumptions are sometimes unreliable, especially for slender columns
with significant tapering ratios. To accurately calculate the flexural buckling resistance, this paper proposes a numerical framework for tapered-I-sections. The direct analysis method (DM) with the non-prismatic high-order beam-column elements considering the factors, including the second-order effects, the geometric imperfections, and the residual stresses is developed. A new shape-function representing the most critical initial out-of-straightness curve of a tapered member is adopted. An advanced non-prismatic beam-column element incorporating this imperfection shape-function named the curved tapered-three-hinges (TTH) element is derived. With the availability of the internal degree-of-freedoms, the one-element-per-member (OEPM) modeling method is permitted. Sequentially, a series of parametric studies using the proposed numerical method are conducted for generating the buckling curves for the non-prismatic columns with various tapered-stiffness ratios. The sophisticated finite-element method is adopted to verify the proposed numerical framework. Based on the proposed numerical approach, the design method in ANSI/AISC-360-16 is modified for tapered-I-section columns.

References listed at the end of the paper:
2. Y. D. Kim, Behavior and design of metal building frames using general prismatic and web-tapered steel I-section members (PhD dissertation), Georgia Institute of Technology, USA (2010).
23. CoPHK, Code of Practice for The Structural Use of Steel Building Department, Hong Kong SAR Government (2011).
31. E. Odar, F. Nishino and L. Tall, Residual Stresses in Welded Built-up T-1 Shapes (Fritz Engineering Laboratory, Department of Civil Engineering, Lehigh University, 1965).
ABSTRACT: Motivated by the lack of sufficient accuracy in investigation of nonlinear dynamics of graphene sheets (GS), nonlinear dynamic instability and frequency response of the pre-stressed single layered GS (SLGS) are investigated in the present paper. To achieve this aim, in the first step, SLGS embedded on a visco-Pasternak foundation is modeled while it is under an initial stress and subjected to a parametric axial force and magnetic field. Then, based on Eringen’s theory, nonlinear von Karman relations and Kelvin–Voigt model, the nonlinear governing equation of motion is derived. In the next step, Galerkin technique and multiple time scales method are employed to analyze and solve the equation of motion. Emphasizing the effect of parametric excitation, for considering the instability regions, bifurcation points are discussed. As a result, a parametric study is conducted to show the importance of damping coefficient and parametric excitation in dynamic instability of the system. Numerical examples are also treated which show various discontinuous bifurcations. Also, infinitely stable and unstable solutions are addressed.

References listed at the end of the paper:


ABSTRACT: This paper presents a two-variable refined plate theory for free vibration of functionally graded material (FGM) plates lying on viscoelastic Winkler–Pasternak foundations. The present work aims to examine the vibrations by a higher-order shear deformation theory including a new function of warping. The governing equations are derived from the principle of virtual displacements. Some illustrative examples are given in an attempt to solve the free vibration problem of a rectangular plate with various boundary conditions. The effects of damping on free vibrations, considering various parameters, are examined in detail. In the end, it is concluded that the present results with the new shear shape function of viscoelastic foundation are found to be in good agreement with other available results and the proposed method can easily be used to solve free vibration problems of the FGM plates.

References listed at the end of the paper:

References listed at the end of the paper:
11. M. D. O’Shea and R. Q. Bridge, Tests on circular thin-walled steel tubes filled with medium and high strength concrete, Department of Civil Engineering, Centre for Advanced Structural Engineering, University of Sydney (1997).
Shenghui Yi, Xiaqiao He and Jian Lu (Centre for Advanced Structural Materials, City University of Hong Kong Shenzhen Research Institute, 8 Yuexing 1st Road, Shenzhen Hi-Tech Industrial Park, Nanshan District, Shenzhen, P. R. China), “Experimental and Theoretical Investigation on Bistable Symmetric Shells Built by Locally Nanostructuring Isotropic Rectangular Plates”, International Journal of Structural Stability and Dynamics, Vol. 19, No. 11, 1950141, November 2019, https://doi.org/10.1142/S0219455419501414

ABSTRACT: A new bistable shell with two symmetric configurations is proposed by using the nanotechnology, surface mechanical attrition treatment (SMAT), to locally treat a rectangular region. The impacts from randomly fast moving balls during the process induce nanotwins and mesh material grains into nanoscale on originally flat plates, which largely increase the material’s yield strength and elastic deformation capacity. Also, the plastic deformations accumulated from thousands of impacts may stretch the plate under the constraint from the untreated region, while inducing internal compressive forces in the processed region. The experiments show that, when the accumulated plastic deformations are large enough, the locally nanostructured plate may buckle transversely by the internal forces to hold two different stable configurations, resulting in the bistable feature. An analytical model is developed to predict the stable configurations, which is numerically verified and experimentally validated. The parameters, including the SMAT region, plate dimensions, and SMAT process, to design the stable configurations of the bistable shells are systematically studied experimentally, analytically, and numerically.

References listed at the end of the paper:

Jiepeng Liu, Shu Huang, Jiang Li and Y. Frank Chen (School of Civil Engineering, Chongqing University, Chongqing 400045, P. R. China), “Vibration Behavior of Composite Slab with Precast Ribbed Panels due to Transient Impact”, International Journal of Structural Stability and Dynamics, Vol. 19, No. 12, 1950148, December 2019, https://doi.org/10.1142/S0219455419501487

ABSTRACT: Excessive floor vibrations due to human activities such as heel-drop and jumping can induce annoyance to occupants and cause a serious serviceability problem. Both field tests and finite element analysis were conducted to study the vibration behavior of the composite slab with precast ribbed panels (CSPRP), a relatively new floor system compared with the cast-in-place reinforced concrete (RC) slab. In addition, both heel-drop and jumping impacts were employed to generate the acceleration response of the floor, from which two important vibration characteristics of natural frequencies and damping ratios are obtained. A comparison of the vibration behavior of CSPRPs with RC slabs indicates that the former exhibits more satisfactory perceptibility in terms of vibration. Appropriate coefficients (i.e. $\beta_p=0.03$ and $\beta_p=0.14$) with the root-mean-square and peak accelerations subjected to heel-drop and jumping excitations are proposed for both CSPRPs and RC slabs. Lastly, an extensive parametric study considering different boundary conditions, floor types, and floor spans was carried out using the finite element method. It is recommended to use CSPRP under 3.5m span in order to keep the fundamental frequency above 3.0Hz.

References listed at the end of the paper:

ABSTRACT: Plates are applied to a wide array of structural applications of varying complexity. Each application requires rigorous analysis to determine the viability of the proposed model. One such application involves modeling a larger structure as a collection of smaller flat plates connected at the plate boundaries. Previous research into these types of structures has led to varying levels of accuracy. It has been dependent on the applications and assumptions involved. To improve the accuracy of these types of structures in a more general context, we propose expanding on current models of coupled plates by modeling the plates using Mindlin plate theory. We analyze the vibration of the improved model with general elastic boundary conditions, point supports and coupling conditions using the Fourier series method and finite element software. When the Fourier series method is applied directly, continuity issues arise at the plate coupling boundaries. To resolve these issues, the Fourier series solution of the vibration displacements is amended to include auxiliary functions. This improved coupled plate model is analyzed and numerically simulated for a variety of elastic boundary conditions and coupling conditions. The numerical results are produced using the Fourier series method and a finite element solution to demonstrate the validity of the improved coupled plate model.

References listed at the end of the paper:

Zhao Jing, Qin Sun, Ke Liang and Jianqiao Chen (The first three authors are from: Northwestern Polytechnical University, Xi’an 710072, Shaanxi, P. R. China), “Closed-Form Critical Buckling Load of Simply Supported Orthotropic Plates and Verification”, International Journal of Structural Stability and Dynamics, Vol. 19, No. 12, 1950157, December 2019, https://doi.org/10.1142/S0219455419501578

ABSTRACT: The buckling mode is important to determine the critical load of specially orthotropic rectangular plates under axial compression with simply supported boundary. However, in classical laminated plate theory (CLPT), the critical buckling mode can only be obtained by iterative or numerical methods. This paper derives the critical buckling mode mathematically and presents the critical buckling load in closed form. By taking advantage of the derived closed-form solution, it is convenient to investigate the effects of aspect ratio, load ratio, and fiber orientation on the buckling load, and the parameters affecting the buckling mode can be easily obtained. The first-order shear deformation theory (FSDT)-based finite element method is developed to verify the closed-form solution. The bending-torsional coupling effects are analyzed and discussed to assess the approximation of the buckling behavior of specially orthotropic plates to general laminates. The obtained finite element solutions of general laminates are compared with the closed-form solutions of specially orthotropic plates. The accuracy of approximation of the buckling behavior of specially orthotropic plates to the general laminates increases as the bending-torsional coupling coefficients decrease. The closed-form solution can be applied to laminates with small bending-torsional coupling coefficients.

References listed at the end of the paper:

ABSTRACT: This paper is concerned with the nonlinear vibration and dynamic response of carbon nanotube (CNT) reinforced composite truncated conical shells resting on elastic foundations in a thermal environment. The material properties of shells are assumed to be temperature-dependent and graded in the thickness direction according to various linear functions. The nonlinear equations of motion are expressed in the form of two-component deflection function and solved by the analytical method. Detailed studies for the influences of various types of distribution and volume fractions of CNTs, geometrical parameters, Winkler and Pasternak elastic foundations on the dynamic response and nonlinear vibration of CNT polymer composite truncated conical shells are examined and the comparison study is carried out to verify the accuracy and efficiency of the proposed method.

References listed at the end of the paper:


42. A. H. Sofiyev and E. Ozsancelbioglu, The free vibration of sandwich truncated conical shells containing functionally graded layers within the shear deformation theory, Compos. Part B: Eng. 120 (2017) 197–211.


ABSTRACT: In this paper, first a complete buckling experiment of the sandwich beams with the foam core is carried out, which includes the manufacturing of specimens and their experimental verification. Second, a refined sinusoidal zig-zag theory (RSZT) is established, which can describe the zig-zag effect during the in-plane compression of sandwich beam and accommodate the transverse shear free surface boundary conditions. Based on the established model combined with Hu–Washizu variational principle, a two-node beam element has been developed to address the buckling problem of the sandwich beams. Thus, the established beam element is able to accommodate interlaminar continuous conditions of transverse shear stress. Several examples have been investigated to validate the accuracy of the established method. The comparative analysis of the results including experimental data, the results acquired from three-dimensional finite element (3D-FEM) and
diverse models has been made. Comparative analysis shows that the accurate buckling loads can be acquired from the established model. Nevertheless, other models discarding the continuous conditions of transverse stresses among the adjacent layers largely overestimate the critical loads.

References listed at the end of the paper:
References listed at the end of the paper:

22. R. W. Ogden, Non-linear Elastic Deformations (Courier Corporation, 1997).


ABSTRACT: The present study focusses on buckling and post-buckling of graphene-reinforced laminated composite plates subjected to uniaxial and biaxial loadings. Poly-methyl-methacrylate (PMMA) is used for matrix. Depending on the type of graphene distribution in each layer, three patterns are considered for the plate cross-section. Graphene sheets are considered in both perfect and defective forms. Kinematics of the plate is modeled using the first shear deformation theory and for large deformation, von Karman nonlinearity is considered. Mechanical properties of each layer are evaluated using the molecular dynamics simulation. Besides, Halpin–Tsai and rule of mixtures are calibrated for graphene PMMA composite. Stability equations are solved based on the incremental-iterative type of Ritz method. In order to validate the solution procedure, comparison studies are conducted on isotropic plates. Numerical results are presented for four different types of boundary conditions. It is shown that, for all types of boundary condition, X-pattern provides higher buckling load. Furthermore, it is found that plates reinforced by defective graphene sheets with 5% vacancy provide lower buckling and post-buckling resistance with respect to those reinforced by pristine graphene.

References listed at the end of the paper:

ABSTRACT: This paper presents the moving element method (MEM) for dynamic analyses of functionally graded (FG) plates resting on Pasternak foundation under moving harmonic load. The Mindlin plate theory is used to model the FG plates. Macroscopic material properties of FG plates are assumed to continuously vary across the thickness direction by a simple power-law distribution. The governing equation of the FG plate is formulated in a coordinate system which moves along with the applied load. In addition, the method simply treats the moving load as “stationary” at the discretized node of plate to completely eliminate the update procedure of force vector due to the change of contact point with elements. To verify the accuracy of the computational paradigm, static and free vibration analyses of FG plates are examined first. Dynamic analyses of FG plates subjected to a moving harmonic load are then conducted to investigate the effects of various parameters such as volume fraction exponent, Young’s modulus, load velocity, foundation damping coefficient and load acceleration/deceleration on dynamic responses of the plate.

References listed at the end of the paper:

ABSTRACT: Exact solutions for the torsional bifurcation buckling of functionally graded (FG) multilayer graphene platelet reinforced composite (GPLRC) cylindrical shells are obtained. Five types of graphene platelets (GPLs) distributions are considered, and a slope factor is introduced to adjust the distribution profile of the GPLs. Within the framework of Donnell’s shell theory and with the aid symplectic mathematics, a set of lower-order Hamiltonian canonical equations are established and solved analytically. Consequently, the critical buckling loads and corresponding buckling mode shapes of the GPLRC shells are obtained. The effects of various factors, including the geometric parameters, boundary conditions and material properties on the torsional buckling behaviors are investigated and discussed in detail.

References listed at the end of the paper:

37. Y. Wang, C. Feng, Z. Zhao, F. Lu and J. Yang, Torsional buckling of graphene platelets (GPLs) reinforced functionally graded cylindrical shell with cutout, Compos. Struct. 197 (2018) 72–79.


ABSTRACT: In this paper, the dynamic stress and radial/lateral vibration of circular/annular discs made of fractional-order viscoelastic materials under nonuniform mechanical loads are investigated for the first time, utilizing the exact 3D theory of elasticity, rather than the plate theories. The governing equations of motion of the disc are derived based on the Kelvin–Voigt fractional viscoelastic model. To solve these equations, the spatial partial and the time ordinary derivatives are replaced by adequate central, backward or forward finite difference expressions. Then the resulting Caputo-type time-dependent system of the coupled integro-differential governing equations of the fractional-order is solved by a novel numerical procedure. Namely, a time-marching procedure is employed to extract the time histories of the responses, in the space-time domain for various time and spatial distributions. Finally, comprehensive sensitivity analyses and various 3D plots are presented and discussed. In this regard, effects of the fractional-order of the constitutive law, viscoelastic parameters, material rigidity, distribution and time variation patterns of the nonuniform distributed transverse loads, and boundary conditions on the distributions of the displacement and stress components are investigated.

References listed at the end of the paper:
ABSTRACT: According to Eurocode 3, the design of plated structures may be carried out using three different approaches: effective width method, reduced stress method, and finite element analysis (FEA). For the particular case of elements under compression, the effective width method makes use of the plate buckling slenderness to obtain the corresponding effective cross-sectional area. Since the effective width method was developed for uniform web and flange panels, Eurocode 3, and most design codes, has no specific provisions for the particular case of nonrectangular panels, stating that they may conservatively be treated as rectangular panels with this larger width. With the final objective of improving design rules for tapered members, this paper first presents finite element (FE) numerical results for the elastic buckling coefficient of trapezoidal plates under compression. Four cases are considered which correspond to different boundary conditions usually present in webs and flanges of steel profiles and rectangular hollow sections. Numerical results are used to propose approximate closed-form expressions that can be used to compute local buckling loads for trapezoidal plates in a direct way. Additionally, ultimate strength is obtained for a number of compressed trapezoidal plates using nonlinear geometric and material FEA with equivalent geometric imperfections. Contrary to the philosophy of Eurocode 3, results show that there is no clear correlation between buckling loads and ultimate strength.

References listed at the end of the paper:

Abbas Kamaloo, Mohsen Jabbari, Mehdi Yarmohammad Tooski and Mehrdad Javadi (Department of Mechanical Engineering, Faculty of Engineering, South Tehran Branch, Islamic Azad University, Dehaghi St, Nabard St, Pirozi St, Tehran, Iran), “Nonlinear Free Vibrations Analysis of Delaminated Composite Conical Shells”, International Journal of Structural Stability and Dynamics, Vol. 20, No. 1, 2050010, January 2020, https://doi.org/10.1142/S0219455420500108

ABSTRACT: This paper examines the nonlinear free vibration of laminated composite conical shells throughout the circumferential delamination. First, based on the energy method, the governing equation of motion for the shell was derived. To simplify the analysis, the nonlinear partial differential equations were reduced into a system of coupled ordinary differential equations using Galerkin’s method. Consequently, the results were obtained by the numerical methods. Finally, the effects of delamination, variations in the delamination length, conical shells characteristics, materials property and circumferential wave number on the nonlinear response of delaminated composite conical shells were examined. The results show that the presence of delamination leads to increase in the amplitude of oscillations for the shells. Besides, the increase in the delamination length and decrease of the circumferential wave number, number of layers, and half vertex angle of the cone and orthotropy bring about a decrease in the nonlinearity of delaminated composite conical shells. However, an increase of the middle surface radius of the shell leads to a reduction of the nonlinearity as well as an increase of the amplitude.

References listed at the end of the paper:
in auxetic honeycombs


Yin Fan, Y. Xiang and Hui-Shen Shen (First 2 authors are from: School of Engineering, Western Sydney University, Penrith, New South Wales, Australia), “Nonlinear Dynamics of Temperature-Dependent FG-GRC Laminated Beams Resting on Visco-Pasternak Foundations”, International Journal of Structural Stability and Dynamics, Vol. 20, No. 1, 2050012, January 2020, https://doi.org/10.1142/S0219455420500121

ABSTRACT: This paper studies the nonlinear dynamic responses of graphene-reinforced composite (GRC) beams in a thermal environment. It is assumed that a laminated beam rests on a Pasternak foundation with viscosity and consists of GRC layers with various volume fractions of graphene reinforcement to construct a functionally graded (FG) pattern along the transverse direction of the beam. An extended Halpin–Tsai model which is calibrated against the results from molecular dynamics (MD) simulations is used to evaluate the material properties of GRC layers. The mechanical model of the beam is on the establishment of a third-order shear deformation beam theory and includes the von-Kármán nonlinearity effect. The model also considers the foundation support and the temperature variation. The two-step perturbation technique is first applied to solve the beam motion equations and to derive the nonlinear dynamic load–deflection equation of the beam. Then a Runge–Kutta numerical method is applied and the solutions for this nonlinear equation are obtained. The influence of FG patterns, visco-elastic foundation, ambient temperature and applied load on transient response behaviors of simply supported FG-GRC laminated beams is revealed and examined in detail.

References listed at the end of the paper:


ABSTRACT: The investigation of hyperelastic responses of soft materials and structures is essential for understanding of the mechanical behaviors and for the design of soft systems. In this paper, by considering both the material and geometrical nonlinearities, a new neo-Hookean model for the hyperelastic beam is developed with focus on its nonlinear free vibration with large strain deformations. The neo-Hookean model is employed to capture the large strain deformation of the hyperelastic beam. The governing equations of the hyperelastic beam are derived by using Hamilton’s principle. To avoid expensive calculations for solving the nonlinear free vibrations of the hyperelastic beam, a simplified Taylor-series expansion model is proposed. The effects of two key system parameters, i.e. the initial displacement amplitude and the slenderness ratio, on the nonlinear free vibrations of the hyperelastic beam are numerically analyzed. The bifurcation diagrams, displacement time traces, phase portraits and power spectral diagrams are presented for the nonlinear free vibrations of the hyperelastic beam. For small initial displacement amplitudes, it is found that the hyperelastic beam will undergo limit cycle oscillations, depending on the initial amplitude employed. For initial displacement amplitudes large enough, interestingly, the free vibration of the hyperelastic beam will become quasi-periodic or chaotic, which were rarely reported for the free vibration of linearly elastic beams. Also observed is the traveling wave feature of oscillating shapes of the hyperelastic beam, indicating that higher-order modes of the beam are excited even for free vibrations. All these new features in the nonlinear free vibrations of hyperelastic beams indicate that the material and geometric nonlinearities play a great role in the dynamic analysis of hyperelastic beams.

References listed at the end of the paper:


ABSTRACT: A first attempt is made in this paper to explore new analytic shear buckling solution of clamped rectangular thin plates by a two-dimensional generalized finite integral transform method. The problem is classical but challenging due to the mathematical difficulty in handling the complex boundary value problem of the governing higher-order partial differential equation (PDE). Taking the vibrating beam functions as the integral kernels, and imposing the double transform, the problem comes down to solving a system of linear algebraic equations, thereby the analytic solution is obtained in a straightforward way. The present method is confirmed to be highly accurate with fast convergence, which agrees very well with both the finite element method (FEM) and energy method from the literature. The new analytic solution obtained may serve as a benchmark for validating other numerical and approximate methods.

References listed at the end of the paper:


2. K. Mercan and Ö. Civalek, Buckling analysis of Silicon carbide nanotubes (SiCNTs) with surface effect and nonlocal elasticity using the method of HDQ, Compos. Part B 114 (2017) 34–45.


ABSTRACT: The paper presents an analytical framework for the horizontal dynamic analysis of a large-diameter pipe pile subjected to combined loadings, in which the pipe pile is simulated by the Timoshenko beam theory. The derived solution allowed us to evaluate the effects of both the shear deformations and vertical loads on the horizontal dynamic performance of the pipe pile. The proposed solution provides appropriate estimates of complex impedances of large-diameter pipe piles, unlike the earlier solutions based on the Euler–Bernoulli beam theory for describing the pile behavior, which ignores the shear deformation of the pile. The results indicate that the Euler–Bernoulli theory overestimates the pipe pile’s horizontal impedance, while overestimating the effect of vertical loads on its horizontal performance.

References listed at the end of the paper:

REFERENCES LISTED AT THE END OF THE PAPER:

17. B. Byrne, R. McAdam, H. Burd et al., Monotonic laterally loaded pile testing in a stiff glacial clay till at Cowden, Géotechnique (2019) 1–40.

ABSTRACT: In this paper, the response of a bounded one-dimensional medium (strip) subjected to a thermal shock is investigated. The strip is made of a linear visco-elastic material, of which the time-dependency of the elastic modulus is described by the simple Kelvin–Voigt model. To obtain the displacement, stress and temperature within the strip, the Lord and Shulman theory of generalized thermo-elasticity containing a single relaxation time is used. Three coupled equations, namely, the equation of motion, the modified Fourier law and the second law of thermodynamics, are established in terms of the displacement, temperature and heat flux. It is worth noting that the second law of thermodynamics is not linearized and is kept in the nonlinear form. The equations derived are first represented in a dimensionless presentation. Then, they are discretized using the well-known generalized differential quadrature. To obtain the response of the strip in time, the Newmark time marching scheme is implemented. It should be mentioned that due to the nonlinear nature of the governing equations, the successive Picard algorithm is used. The results of the present study are compared with those available in the literature for an elastic strip. Besides, numerical results are given for a strip made of Kelvin–Voigt visco-elastic material. The effects of visco-elastic parameter, coupling parameter, thermal relaxation time and nonlinearity are discussed in numerical examples.
References listed at the end of the paper:


ABSTRACT: This work presents the nonlinear post-buckling behavior of carbon nanotubes (CNTs) reinforced sandwich composite annular spherical (AS) shells supported by elastic foundations in the thermal environment. This paper takes advantage of the sandwich-structured configuration with three layers: two nanocomposite face sheets and an isotropic core to analyze the static problem. Due to the precious properties, CNTs are applied to reinforce nanocomposite face sheets of AS shells. The governing equations of the nonlinear mechanical response of CNTs reinforced sandwich-structured composite (SSC) AS shells are achieved by using the classical shell theory (CST) and taking von Kármán’s geometrical nonlinearity into account. Applying Airy’s stress function and an approximate solution, we propose a form of stress function for CNTs reinforced SSC AS shells. The detailed effects of different types of CNTs’ reinforcement and volume fractions, geometrical parameters, core to face sheet thickness ratio, Winkler and Pasternak elastic foundations on the nonlinear mechanical post-buckling analysis are examined.

References listed at the end of the paper:

33. H. V. Tung, Nonlinear axisymmetric response of FGM shallow spherical shells with tangential edge constraints and resting on elastic foundations, Compos. Struct. 149 (2016) 231–238.
The buckling behavior of partially composite layered columns (PCLCs) under axial compressive load is significantly influenced by the slip at the interface of load carrying layers, which brings complexity to the analysis. In this paper, a matrix method based on the Hencky bar-chain model (HBM) is developed for the buckling analysis of PCLCs. The conventional assumption of HBM is modified to consider the interfacial slip properly. Three illustrative problems are presented to show the solving procedure of the HBM-based matrix method. The results are compared to those obtained through analytical formula or finite element method (FEM), and the applicability of the developed method in the buckling analysis of PCLCs with various sectional compositions and boundary conditions is validated. It is proved that the buckling load can be predicted accurately by the developed method. The method is easy to handle, highly adaptable and widely applicable, thus is a promising tool for the buckling analysis of PCLCs.

References listed at the end of the paper:


ABSTRACT: In this study, the combination of an expansion tube and a deformable rigid tube with axial splitting is developed as a new mechanism for use as an impact energy absorber. The impact absorbing structure consists of two circular tube forming dies, with each die allowing the tube to expand and to split. The latter is used to remove away radially the debris after expansion and splitting, so that the absorption process can continue without being obstructed by the debris itself. This paper presents the experimental and theoretical investigation of the combined expansion tube-axial splitting as an impact energy absorber. The experiment by the laboratory scale impact testing has been done with a variation of the parameters such as pipe thickness (\(t\)), angle of splitter (\(\theta\)), comparison of dies upgrading diameter (\(D_t\)) and inner pipe diameter (\(D_h\) (\(D_t/D_h\)). The theoretical investigation is carried out with a literature study related to the mechanics of material and theoretical studies from previous research studies. The final result of this paper, i.e. a new formula proposed to calculate the mean load, is reflective of the study of a combined expansion tube with axial splitting. The difference between the results of analytical calculation and experiments is 10.13%.

References listed at the end of the paper:
In this paper, the buckling response of laminated functionally-graded CNT-reinforced composite (FG-CNTRC) plate structure is predicted under various types of non-uniform edge compression loading. For the finite element (FE) discretization of the plate, a nine degree of freedom (DOFs)-type polynomial-based higher-order shear deformation theory (HSDT) is considered. The application of non-uniform edge load causes the in-plane stress distribution to be non-uniform. Hence, the in-plane stresses need to be evaluated prior to the buckling analysis. These in-plane stresses are calculated using the in-plane stress analysis method by FE approach or the in-plane elasticity approach. The differential equations are obtained by employing the Lagrange equation of motion and solved as a general eigenvalue problem, after the differential equations are converted into homogeneous equations by means of FE procedure. The accuracy and adaptability of the present model are validated by comparing the present result with the available literature. Further, the impact on the buckling response of the laminated FG-CNTRC plate is investigated by various parameters such as span thickness ratio, aspect ratio, various edge constraints, and different types of non-uniform edge load, CNT fiber gradation and temperature dependency material properties.

References listed at the end of the paper:

ABSTRACT: The paper presents simple computational algorithms for analyzing the lateral-torsional buckling of prismatic beams with rectangular cross-sections under bending action due to uniform and nonuniform loads by the Adomian decomposition method (ADM) and variational iteration method (VIM). Unlike the numerical techniques that lead to a discretization process, the proposed method allows us to derive the solution in terms of an analytical function for the problem considered. Although the governing equations of the problem appear as a system of two coupled variable coefficient ordinary differential equations, they reduce to a single equation for rectangular beams. The buckling loads for different loading conditions are computed, with the results for the simple beam compared with previous available results by the differential transformation method (DTM), variational iteration method (VIM) and finite element method (FEM) based on coupled governing equations. The results clearly show the efficiency and advantage of the present technique over those based on the coupled governing equations using the DTM and VIM in view of the number of terms required to obtain the convergent solution.

References listed at the end of the paper:

Identifying Buckling Resistance of Reinforced Concrete Columns During Inelastic Deformation

ABSTRACT: A simple solution method to identify buckling resistance of reinforced concrete (RC) columns during inelastic deformation is presented. Unlike conventional buckling solution methods, this proposed method predicts inelastic buckling loads of RC columns by directly solving the equilibrium differential equation under buckling. The method considers specific deflection configuration, end restraint conditions and inelastic material properties of the deformed column. In order to evaluate the reliability and accuracy of the proposed method, the results obtained from the purposed method are compared with the test results of eccentrically loaded RC columns. In addition, by using the proposed solution procedure, a parametric study is conducted to investigate the effects of critical RC column design parameters on column buckling behavior and resistance, including slenderness ratio, concrete strength, as well as longitudinal reinforcement and stirrup ratios. The results of the parametric study show that the proposed method is rational and can be adopted to effectively identify buckling resistance of RC columns subjected to inelastic damage, especially when load redistributions have occurred in the structure during progressive collapse.

References listed at the end of the paper:

1. R. M. Johns, Buckling of Bars, Plates and Shells (Bull Ridge, Virginia, USA, 2006).
6. ACI318-08, Building Code Requirements for Reinforced Concrete (American Concrete Institute, Detroit, 2008).
Struct. Stab. Dyn. \( \cdot \) Dynamic behaviors of sliding pipes can be classified into three types based on their motion. In sliding pipes, the free end is moving, and the pipe can display planar motions. In addition, the pipe can display planar motions, and then reduced to a set of ordinary differential equations by the Hamilton’s principle. A parametric study is performed to explore the transient vibration responses of the pipe for different values of flow velocity and sliding rate. Various dynamic behaviors are detected for the pipe in sliding and conveying fluid. The results show that 3-D oscillations of the pipe occur when the flow velocity exceeds a certain value, which can be affected by the sliding rate. For various flow velocities, the evolution of the dynamic characteristics of the sliding pipe can be classified into three typical types of motion. When the flow speed increases to high values, multi-type of 3-D motion consisting of three typical types occurs on the pipe. In addition, the pipe can display planar motions, transferring from one plane to the other. The result presented herein is helpful to understand the stabilities and dynamic behaviors of sliding-pipe systems used in aerial refueling applications.

References listed at the end of the paper:

46. T. Lundgren, P. Sethna and A. Bajaj, Stability boundaries for flow induced motions of tubes with an inclined terminal nozzle, J. Sound Vib. 64 (1979) 553–571.

Yang Lv (1), Zheng Zhao (1), Jia-Qi Lv (1), Nawawi Chouw (2) and Zhong-Xian Li (1)
ABSTRACT: The stress distribution of a steel wall is important in the determination of its shear capacity, e.g. under a wind load or an earthquake load. Since the wall has also to simultaneously carry the gravity load, the influence of this uniform vertical load on the stress distribution is relevant. For a simple-supported thick and square wall, a stress distribution in a cosine form was adequate. However, for an extremely thin wall, a cosine distribution is no longer valid, especially in the post-buckling condition. In this work a three-segment distribution is proposed, i.e. at both edge segments a cosine distribution from edge stress to buckling stress and in the middle segment a constant distribution of buckling stress. To evaluate the proposed distribution, a finite element model using the software ANSYS/LS-DYNA is developed. This model has been verified using the results obtained from own experiments and works done by others. The results show that the proposed stress distribution is able to describe the behavior of thin walls for different aspect ratios and slendernesses. The cosine distribution and the effective width model are also discussed.

References listed at the end of the paper:
This research presents a numerical approach to address the moving load problem of functionally graded (FG) beams with rotational elastic edge constraints, in which the regularized Dirac-delta function is used to describe a time-dependent moving load source. The governing partial differential equations of the system, derived in accordance with the classical Euler–Bernoulli beam theory, are approximated by the discrete singular convolution (DSC) method. The resulting set of algebraic equations can then be solved by the Newmark-$\beta$ integration scheme. Such a singular Dirac-delta formulation is also employed as the kernel function of the DSC method. In this work, the material properties of FG beams are assumed to be changed in the thickness direction. A convergence study is performed to validate the accuracy and reliability of the numerical results. In addition, the effects of moving load velocity and material distribution on the dynamic behavior of elastically restrained FG beams are also studied to serve as new benchmark solutions. By comparing with the available results in the existing literature, the present results show good agreement. More importantly, the major finding of this work indicates that the DSC regularized Dirac-delta approach is a good candidate for moving load problems, since the equally spaced grid system adopted in the DSC scheme can achieve a preferable representation of moving load sources.

References listed at the end of the paper:


ABSTRACT: Previous studies have shown that Eringen’s differential nonlocal model leads to some inconsistencies for both the Euler–Bernoulli and Timoshenko beams subjected to different boundary conditions. In this paper, the free vibration analysis of the Euler–Bernoulli and Timoshenko beams is performed theoretically using the stress-driven nonlocal integral model. The Fredholm-type integral constitutive equations of the first kind are transformed to Volterra integral equations of the first kind by simply adjusting the limit of integrals. Also, the general solutions to the deflection, bending moment and so on are derived by solving the integro-differential governing equations by the Laplace transformation, of which the unknown constants are determined by the boundary conditions and extra constraint equations related to the constitutive relationship. Then the characteristic equations for free vibration of the Euler–Bernoulli and Timoshenko beams are derived, from which the vibration frequency for different boundary conditions can be determined. The effects of nonlocal parameter and vibration order on the natural frequency of the Euler–Bernoulli and Timoshenko beams.
are investigated numerically. The results from the present model are validated against those existing in the literature, and demonstrated to be theoretically consistent.

References listed at the end of the paper:

89. C. Li, A nonlocal analytical approach for torsion of cylindrical nanostructures and the existence of higher-order stress and geometric boundaries, Compos. Struct. 118 (2014) 607–621.

Van Hai Luong, Xuan Vu Nguyen, Tan Ngoc Than Cao, Minh Thi Tran and Huu Phu Nguyen (The first author is from: Faculty of Civil Engineering, Ho Chi Minh City University of Technology (HCMUT), Ho Chi Minh

ABSTRACT: In this paper, hydroelastic behavior of a pontoon-type very large floating structure (VLFS) subjected to a moving single axle vehicle is computed using a novel numerical approach, in which the boundary element method (BEM) is firstly extended to cooperate with the moving element method (MEM), named the BEM–MEM. By utilizing this paradigm, the plate and fluid are discretized into “moving structural element” and “moving boundary element”, respectively, which are conceptual elements and “travel” with the moving vehicle. Thus, the proposed method can absolutely eliminate the need of keeping track the location of the “moving boundary element”, respectively, which are conceptual elements and “travel” with the moving vehicle. Furthermore, the governing equations of motion, moving element and fluid matrices of boundary element are formulated in a relative coordinate system traveling with the moving vehicle. Several examples are numerically conducted to illustrate the performance and ability of the BEM–MEM. Its obtained results are compared with those of the traditional finite element method for validation. The outcomes reveal that the proposed method is effective for the large-time behavior owing to the fact that it does not require a domain with the length greater than the horizontal displacement of the vehicle. The paper also discusses the effect of the liquid and structural parameters on responses of the vehicle and floating structure.

References listed at the end of the paper:
References listed at the end of the paper:


• 134. M. Şimşek, Bi-directional functionally graded materials (BDFGMs) for free and forced vibration of Timoshenko beams with various boundary conditions, Compos. Struct. 133 (2015) 968–978.


Huu-Tai Thai (1), Trung-Kien Nguyen (2), Seunghye Lee (3), Vipulkumar Ishvarbhai Patel (4) and Thuc P. Vo(5)
(1) Division of Construction Computation, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Vietnam
(2) Faculty of Civil Engineering, Ho Chi Minh City, University of Technology and Education, 1 Vo Van Ngan Street, Thu Duc District, Ho Chi Minh City, Vietnam
ABSTRACT: Structural steel frames exhibit significantly geometric and material nonlinearities which can be captured using the second-order inelastic analysis, also known as advanced analysis. Current specifications of most modern steel design codes, e.g., American code AISC360, European code EC3, Chinese code GB50017 and Australian code AS4100 permit the use of advanced analysis methods for the direct design of steel structures to avoid tedious member capacity checks. In the past three decades, a huge number of advanced analysis and modeling methods have been developed to predict the behavior of steel and composite frames. This paper presents a comprehensive review of their developments, which focus on beam-column elements with close attention to the way to capture geometric and material nonlinearity effects. A brief outline of analysis methods and analysis tools for frames was presented in the initial part of the paper. This was followed by a discussion on the development of displacement-based, force-based and mixed beam elements with distributed plasticity and concentrated plasticity models. The modeling of frames subjected to fire and explosion was also discussed. Finally, a review of the beam-column models for composite structures including concrete-filled steel tubular (CFST) columns, composite beams and composite frames was presented.

References listed at the end of the paper:

14. S. E. Kim, Practical advanced analysis for steel frame design, PhD thesis, Department of Civil and Environmental Engineering, Purdue University (1996).

60. T. Belytschko and L. W. Glaum, Applications of higher order corotational stretch theories to nonlinear finite element analysis, Comput. Struct. 10 (1979) 175–182.


118. E. M. Lui, Effects of connection flexibility and panel zone deformation on the behavior of plane steel frames, PhD thesis, Department of Civil Engineering, Purdue University (1985).


Jian Yang, Xu-Hao Huang and Hui-Shen Shen (School of Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, P. R. China), “Nonlinear Vibration of Temperature-Dependent FG-CNTRC Laminated Beams with Negative Poisson’s Ratio”, International Journal of Structural Stability and Dynamics, Vol. 20, No. 4, 2050043, April 2020, https://doi.org/10.1142/S0219455420500431
ABSTRACT: Laminated beams made of nanocomposite materials have been used in many industrial sectors. This paper reports a study on the vibration behavior of laminated beams when experiencing the large amplitude vibration. The beams are made of perfectly bonded carbon nanotube-reinforced composite (CNTRC) layers. The novel constructions of CNTRC laminated beams with out-of-plane maximum negative Poisson’s ratio (NPR) are proposed. The volume fraction of CNT may change across the beam thickness which results in a piece-wise pattern. The material properties of the CNTRC layers are temperature-dependent and can be estimated by the extended rule of mixture model. The beams are considered to rest on a two-parameter elastic foundation and under differential thermal environmental conditions. The higher order shear deformation beam theory is applied to derive the motion equations of the nonlinear vibration of FG-CNTRC laminated beams. These equations include the influencing factors such as the geometrical nonlinearity in the von Kármán sense, the thermal effects and the beam–foundation interaction. The nonlinear vibration solutions can be obtained by employing a two-step perturbation approach. The nonlinear vibration characteristics of FG-CNTRC laminated beams under different sets of loading conditions and thermal environmental conditions are discussed in detail through a series of parametric studies. Numerical results show that the NPR has a significant effect on the large amplitude vibration characteristics of CNTRC laminated beams.

References listed at the end of the paper:


and those with lateral bracings, columns resting on elastic foundations, inelastic columns, lateral restraints, shear deformation, and material nonlinearity are taken into account, and this, as a result, functions is chosen as an adaptive parameter and the exact buckled shape of each element is achieved when buckled shape via a simple iterative scheme. The bases of such solution space are constructed in an elementwise energy and the solution procedure follows the concept of Rayleigh–Ritz approximation. A crucial aspect of the proposed technique is to supply the adaptivity to the solution space allowing the accurate representation of the shear deformation to be treated. Results from an extensive numerical study have indicated that shear deformation and the solution procedure follows the concept of Rayleigh–Ritz approximation. A crucial aspect of the proposed technique is to supply the adaptivity to the solution space allowing the accurate representation of the shear deformation to be treated. Results from an extensive numerical study have indicated that shear deformation.
the proposed technique yields highly accurate buckling loads, comparable to the analytical and reference solutions, without the mesh refinement. In addition, a relatively low number of iterations is required to achieve the converged buckling load.

References listed at the end of the paper:

Xianzhong Wang, Yingying Zuo and Yongshui Lin (Wuhan University of Technology, Wuhan 430061, P. R. China), “Structural-Acoustic Modeling and Analysis of Carbon/Glass Fiber Hybrid Composite Laminates”, International Journal of Structural Stability and Dynamics, Vol. 20, No. 4, 2050048, April 2020, 
https://doi.org/10.1142/S0219455420500480

ABSTRACT: The vibration and acoustic behaviors of both glass fiber laminated plates and carbon/glass fiber hybrid laminated plates are investigated by numerical simulation. The free vibration, forced vibration and acoustic radiation of laminated plates including glass fiber laminates and carbon/glass fiber hybrid laminates in air and water are calculated by the coupled finite element and boundary element method and compared with the corresponding test results. It was demonstrated that results obtained by the coupled finite element and boundary element method are in good agreement with the experimental ones. The effects of dispersion, outer fiber types and fiber hybrid ratio on the vibration and sound radiation of the laminates plates are also discussed.

References listed at the end of the paper:


37. P. Seemaphokul, Buckling and vibration analysis of timoshenko beam-column on two-parameter elastic foundation, Master’s thesis, Department of Civil Engineering, Faculty of King Mongkut’s University of Technology Thonburi (2000).
51. Y. Notay, Convergence Analysis of Inexact Rayleigh Quotient Iterations, Technical Report, GANMN 01 02, Université Libre de Bruxelles, Brussels, Belgium (2001).

References listed at the end of the paper:

ABSTRACT: This paper deals with the nonlinear dynamic response of elastically supported stiffened plates with initial stresses under impact loads. A stiffened plate is assumed to be composed of a plate with some stiffeners, which are treated separately. The plate is modeled by the thin plate theory, whereas the stiffeners are considered as geometrically nonlinear Euler–Bernoulli beams. First, the equations of both the kinetic energies and strain energies of the plate and stiffeners are established. Then, the dynamic equilibrium equations for the stiffened plate are derived as the Lagrange’s equation of the functional. A parametric analysis is performed to evaluate how initial stresses, initial geometric imperfections, elastic supports, impact loads and configuration of stiffeners affect the time-history responses of the stiffened plates. Some useful nonlinear dynamic properties are obtained, which serve as references for engineering design and application.

References listed at the end of the paper:
ABSTRACT: Membranes have been popularly used in the fields of civil engineering and aerospace engineering. When wrinkled, a membrane loses its stiffness in the direction perpendicular to wrinkles and is more sensitive to wind loads. This paper numerically studied the wind-induced responses of a wrinkled membrane and their variations with respect to wind speed, wind direction, and wrinkling deformation. Based on the stability theory of plates and shells, the wrinkling deformation of a rectangular membrane under shear was obtained by post-buckling analysis. Then, by using the wind load derived from a wind tunnel test, the dynamic responses of the wrinkled membrane were numerically analyzed for different wind speeds, wind directions, and wrinkling deformations. The results indicate the following: (1) the displacement and extreme stresses of a membrane are gradually intensified with an increase in the wind speed; (2) the wind direction plays an important role in the displacement, but it has little effect on the stresses and (3) the displacement increases with the wrinkling deformation, and the extreme stresses are intensified with an increase in the pre-tension. This study on the wind-induced responses of a wrinkled membrane is helpful to the understanding of the complex behavior of a wrinkled membrane under wind loads while reducing the adverse effects of wrinkling deformation and ensuring the dynamic stability of membrane structures.

References listed at the end of the paper:


ABSTRACT: Foldable origami-based structures are a type of deployable structures that are increasingly applied in the space and building industries. When folded, the small size of such structures facilitates transportation and storage. Meanwhile, the properties of their larger deployed state may be of interest to different applications. A stable working condition is established by locking the structure in its deployed state, as in the process of deployment, the driving forces may generate a dynamic effect, thus leading to instability of the system. Hence,
the study of dynamic characteristics of such structures, including trajectory, duration, velocity, and acceleration is of paramount importance. In this paper, based on the general dynamic equation and Lagrange’s equations of the first kind, the finite element method is adopted to investigate the dynamic deployment of foldable plate structures in terms of the generalized nodal coordinates. The proposed geometric description of a quadrilateral plate element is based on a folding plate composed of refined triangular elements, which are used to approximate the real shells in the structure. Subsequently, a MATLAB framework is developed on the basis of the element using the Newmark integration and the Newton–Raphson iteration method to simulate the deployment process of the structure. Comparisons between MATLAB results and ADAMS results verify the reliability of the framework in analyzing the dynamic deployment of the foldable origami-based structures with sufficient accuracy.

References listed at the end of the paper:

ABSTRACT: The response of a long hollow cylindrical vessel made from a piezoelectric material is considered in the present investigation. The piezoelectric vessel is subjected to a thermal shock on one surface. The generalized piezo-thermo-elasticity formulation of Lord and Shulman is adopted which contains a single relaxation time to consider the finite speed of temperature wave propagation. The response of the cylinder is assumed to be axi-symmetric. Three coupled equations are established as the governing equations, which are the equation of motion, the energy equation and the Maxwell equation. These equations are transformed into the dimensionless ones. With the aid of the generalized differential algebraic equations, Nonlinear Dyn. 54(4) (2008) 283–296.


ABSTRACT: The response of a long hollow cylindrical vessel made from a piezoelectric material is considered in the present investigation. The piezoelectric vessel is subjected to a thermal shock on one surface. The generalized piezo-thermo-elasticity formulation of Lord and Shulman is adopted which contains a single relaxation time to consider the finite speed of temperature wave propagation. The response of the cylinder is assumed to be axi-symmetric. Three coupled equations are established as the governing equations, which are the equation of motion, the energy equation and the Maxwell equation. These equations are transformed into the dimensionless ones. With the aid of the generalized differential quadrature method, these equations are discretized in the radial direction. After that, with the aid of the Newmark time marching scheme, the temporal evolutions of the thermo-electro-elastic parameters are obtained. Novel numerical results are presented to obtain the response of the cylinder subjected to a thermal shock using the Lord and Shulman theory of thermoelasticity.

References listed at the end of the paper:

ABSTRACT: This paper concentrates on the work by Petrus van Musschenbroek published in 1729, constituting apparently the first study in the literature on column buckling. To understand the significance of Musschenbroek’s contribution, we provide the combined personal, historic and scientific contexts in which he carried out his studies; he was the first researcher to deal with the failure of compressed elements as a new phenomenon. Most unfortunately, his name is not currently known except for a small circle of historians of science, whereas engineering students at present are told that buckling should be associated with the name of Leonhard Euler. We fully share the idea of Benvenuto stating that “Musschenbroek’s experimental law is of considerable historical interest.” The contributions in his 1729 book are shown not only to include his experimental work but Musschenbroek also devised a design procedure for column buckling.

References listed at the end of the paper:


ABSTRACT: The nonlinear vibration of a hyperelastic moderately thick cylindrical shell with 2:1 internal resonance in a temperature field is investigated based on the third-order shear deformation theory. A radial harmonic excitation is applied to the shell. First, by employing the higher-order approximation for the curvature-related expansion, the displacement field of the moderately thick cylindrical shell with improved coefficients is derived. For the temperature field with gradient, the shear modulus of the shell is thickness dependent because of the temperature-dependent nature of the hyperelastic materials used. The graphical results manifest that the temperature gradient has a significant impact on the nonlinear vibration of the shell. In addition, the separation of the resonance peak caused by the variations of the structural parameter and temperature will result in a bubble shaped response curve for the shell.

References listed at the end of the paper:


ABSTRACT: In this paper, the sound radiation behaviors of the functionally graded porous (FGP) plate with arbitrary boundary conditions and resting on elastic foundation are studied by means of the modified Fourier series method. It is assumed that a total of three types of porosity distributions are considered in the present study. The material parameters are determined according to the porosity coefficient used to denote the size of pores in the plate. The governing equations of the FGP plate are derived by utilizing the Hamilton’s principle on the basis of the first-order deformation theory (FSDT). Each displacement component of the FGP plate is
expansion as the Fourier cosine series combined with auxiliary polynomial functions introduced to enhance the convergence rate of the series expansions. The acoustic response of the FGP plate due to a concentrated harmonic load is calculated by evaluating the Rayleigh integral. Good agreements are attained by comparing the present results with those in available literatures, which show the accuracy and versatility of the developed method in this paper. Finally, the influences of the porosity distribution type, porosity coefficient, boundary condition and elastic foundation on the sound radiation of the FGP plate are analyzed in detail.

References listed at the end of the paper:
ABSTRACT: This study attempts to propose innovative multi-layer cement-based composites to have high impact resistance which could be used for runway. In this paper, the performances of two innovative multi-layer composite runway pavements using asphalt concrete-high strength concrete-cement-treated aggregate and asphalt concrete-high strength concrete-cement mortar in surface-base-subbase layer were evaluated under impact loads. ABQAUS/Explicit software was used to simulate loading condition and nonlinear stabilized runway pavement layers characteristics. In addition, a detailed parametric study was also carried out to explore the effects of the selected materials and load-related parameters in changing the performance of multi-layer composites. The findings of the study will be helpful to introduce protective multi-layer composite runway pavement and consequently to reduce the maintenance work of runway pavement.

References listed at the end of the paper:


ABSTRACT: The in-plane vibrations of regular polygonal rings composed of rigid segments joined by torsional springs are studied for the first time. The nonlinear dynamical difference equations are formulated and solved by perturbation about the equilibrium state. As the number of segments increase, the frequencies, if aptly normalized, converge to the classical vibration frequencies of a continuous elastic ring. The vibration mode shapes are illustrated. The tiling of many identical polygons is discussed. Possible applications include the vibrations of space structures and graphene sheets.

References listed at the end of the paper:

ABSTRACT: The interaction between underground pipelines and soils is crucial to the design and maintenance of underground pipeline network systems. In this paper, the dynamic stiffness matrix in the frequency-domain of the buried pipeline is obtained by the improved scaled boundary finite element method (SBFEM) coupled with the finite element method (FEM) at the interface between the far and near fields. A new coordinate transformation together with a scaled line is introduced in the improved SBFEM. Combined with the mixed variable algorithm, the time-domain solution of the buried pipeline under dynamic loads is then obtained. The accuracy of the proposed algorithm was verified by numerical examples. A parametric study is performed to assess the influence of the anisotropic characteristics of the layered soils on the dynamic response of the pipeline, the result of which provides a reliable basis for engineering practice. The results show that these parameters have a significant impact on the pipeline. The understanding of this impact can contribute to the design, construction, and maintenance of the corresponding engineering projects.

ABSTRACT: In this paper, semi-analytical and analytical methods for the nonlinear static and dynamic buckling analyses of imperfect functionally graded porous (FGP) cylindrical shells subjected to axial compression are presented. The structure is embedded within a generalized nonlinear elastic foundation, treated as a two-parameter Winkler–Pasternak foundation augmented by a nonlinear cubic stiffness. The material property of the shell changes continuously through the thickness. Two types of FGP distributions, i.e. uniform porosity distribution (UPD) and nonuniform porosity distribution (NPD), are considered. By applying the Galerkin’s method to the von Kármán equations, the buckling of the shells was solved. The fourth-order Runge–Kutta method is utilized to obtain the responses of nonlinear dynamic buckling (NDB). The results obtained for some special cases are compared with those available elsewhere. The effects of various geometrical properties, material parameters and elastic foundation coefficients are investigated on the nonlinear static buckling (NSB) and dynamic buckling (DB) analyses of the shells. It was shown that various types of porosity, imperfection and the elastic foundation parameters have a strong effect on the buckling behaviors of the FGP cylindrical shells.

References listed at the end of the paper:

26. H. Huang and Q. Han, Nonlinear dynamic buckling of functionally graded cylindrical shells subjected to a time-dependent axial load, Compos. Struct. 92 (2010) 593–598.
ABSTRACT: In this study, we propose a novel and effective computational approach for free and forced vibration analyses of functionally graded (FG) porous plates with graphene platelets (GPLs) reinforcement under various loads. To this end, the outstanding features of isogeometric analysis (IGA) are first combined with the four-variable refined plate theory (RPT). The non-uniform rational B-splines (NURBS) are adopted to obtain the $C^1$-continuity essential to the RPT model. The various distributions of internal pores as well as GPLs with uniform or non-uniform properties along the plate’s thickness are investigated. The effective elastic properties of the material models are obtained by the Halpin–Tsai micromechanics model for Young’s modulus, the rule of mixture for Poisson’s ratio and mass density. The Newmark’s time integration scheme is implemented to obtain the solutions of the forced vibration problems. Numerical examples are carried out to investigate the effects of various key parameters such as porosity coefficient, GPL weight fraction, porosity distribution, as well as GPL dispersion pattern, on the behaviors of the plate structure.


References listed at the end of the paper:


ABSTRACT: The Refined Zigzag Theory (RZT) is a structural theory developed for the analysis of composite multilayer and sandwich beams. However, the accuracy of RZT for buckling analysis of sandwich beams has not been experimentally investigated, and for RZT and Timoshenko Beam Theory (TBT) the effect of the degree of heterogeneity on their accuracy requires further study. The aim of this work was to validate the use of the RZT for predicting the critical buckling loads of sandwich beams, even with highly heterogeneous material properties, and to assess the use of the TBT for the same application. Buckling experiments were conducted on five foam-core sandwich beams, which varied in geometry and included highly heterogeneous configurations. For each beam, two finite element (FE) models were analyzed using RZT- and TBT-beam FE models. The comparison between the numerical and the experimental results highlighted a major capability of RZT to correctly predict the critical buckling load for all the beams considered. The dependence of the TBT results on the beam characteristics was further investigated through a parametric analysis, which showed the dominant effect to be a close to linear relationship between the TBT error and the beam face-to-core thickness ratio. The work demonstrated the outstanding accuracy of the RZT predictions, including the superior capabilities with respect to TBT, and has application for rapid and accurate analysis of industrial structures.

ABSTRACT: In this paper, the lateral torsional buckling (LTB) behavior of multi-layered long-span laminated glass (LG) beams is investigated through full-scale model test and numerical simulation. In the test program, the LG beams consisting of up to four glass plies and spanning 5000mm are constructed and tested. The load-displacement curves and development of strain in glass plies are recorded, based on which the deformation and stress state of buckled LG beams are analyzed, and the strength checking criterion is provided. The test results are also used to determine the shape and amplitude of initial imperfection through statistical analysis and to validate a numerical model based on the finite element method (FEM). Parametric analysis based on the FEM model is then conducted to investigate influential factors on the LTB resistance of LG beams, among which the influence of shape and amplitude of initial imperfection is emphasized. For the LTB design of LG beams, the applicability of existing formula to determine the critical buckling moment through effective stiffnesses is evaluated for multi-layered LG beams with the test and numerical results. Finally, the design buckling curves adopting the Ayrton–Perry formula (APF) are proposed and validated for LG beams categorized with glass type and load duration.

References listed at the end of the paper:


ABSTRACT: Stability and dynamics of rotating coaxial cylindrical shells conveying incompressible and inviscid fluid are investigated. The interior shell is assumed to be flexible while the exterior cylinder is rigid. Using Sander’s–Koiter theory assumptions and following Hamilton’s principle, governing equations of motion are determined in their integral form. Employing the extended Galerkin method of solution, the integral equations of motion are projected to their equivalent system of algebraic equations. Fluid equations are fundamentally based on the linearized inviscid Navier–Stokes equations. Impermeability condition on the fluid and structure interface as well as the zero radial velocity component on the exterior shell give the coupled equations of motion governing the dynamics of fluid-loaded coaxial cylindrical shells. Using the coupled fluid–structural model, stability boundaries are determined for the rotating interior shell. Various parameter studies are conducted and effects of mass ratio, gap distance between the interior and exterior shells, boundary conditions of the interior shell, length to radius ratio on the stability margins are thoroughly investigated and reported.

References listed at the end of the paper:
32. Q. Han and F. Chu, Effects of rotation upon parametric instability of a cylindrical shell subjected to periodic axial loads, J. Sound Vib. 332(22) (2013) 5653–5661.
33. S. Sun, S. Chu and D. Cao, Vibration characteristics of thin rotating cylindrical shells with various boundary conditions, J. Sound Vib. 331(18) (2012) 4170–4186.


ABSTRACT: Considering both the nonlocal scale and material length scale effects, we investigate vibration and stability behaviors of functionally graded nanoplates with axial motion in order to model the two-dimensional nanobelt in nanoeengineering. The nonlocal strain gradient theory is applied and the differential nonlocal strain gradient constitutive relation is adopted. Using the physical neutral plane of a functionally graded thin plate, we derive the governing equation of motion for the functionally graded nanoplate with axial motion via Hamilton’s principle, where the kinematic characteristics are introduced into the dynamic behaviors. The governing equation is numerically solved using the Galerkin method. Effects of the nonlocal scale and material length scale parameters, axial velocity, gradient index, biaxial pre-tensions and aspect ratio are discussed. The results demonstrate that complex frequencies of the functionally graded nanoplate with axial motion decrease with an increase of axial velocity in the subcritical region, while the moving nanoplate experiences a divergent instability or flutter instability in the supercritical region. Natural frequency and critical speed decrease with the increase of the nonlocal scale parameter while increase with the increase of the material length scale parameter, reflecting the nonlocal softening and strain gradient hardening mechanisms, respectively. Besides, natural frequency and critical speed increase with the increase of the biaxial pre-tensions and aspect ratio, but decrease with the increase of the gradient index. In particular, the influences of the gradient index and size or weight of functionally graded nanoplates on the critical speed are explored.
References listed at the end of the paper:

2. S. Hales et al., 3D printed nanomaterial-based electronic, biomedical, and bioelectronic devices, Nanotechnology 31 (2020) 172001.

ABSTRACT: The damping characteristics of the composite thick-walled hollow shaft directly affect its amplitude of rotational vibration at low speeds and stability at high speeds. In this study, the shaft is made of carbon fiber reinforced plastic (CFRP) material. In order to study the damping characteristics of the composite hollow shaft, a 3D numerical damping model was established based on finite element method and strain energy expression. In this regard, both the contributions of in-plane and out-of-plane strain energy dissipation were studied. Then, the validity of 3D damping model in bending was verified by experiments. On this basis, the flexural damping characteristics of the thick-walled composite shaft were studied, and the effects of orientation angle and stacking sequences on the flexural damping were obtained.

References listed at the end of the paper:

ABSTRACT: Different kinds of membrane structures have been proposed for future space exploration and earth observation. However, due to the low stiffness, high flexibility, and low damping properties, membrane structures are likely to generate large-amplitude (compared to the thickness) vibrations, which may lead to the degradation of their working performance. In this work, the governing equations are established at first, taking into account the modal control force induced by the polyvinylidene fluoride (PVDF) actuator. The optimal vibration control of the membrane structure is explored subsequently. A square PVDF actuator is attached on the membrane to achieve the vibration suppression. The influence of actuator position and control gains on the vibration control performance are studied. The optimal criteria for actuator placement and energy allocation are developed. Several case studies are numerically simulated to demonstrate the validity of the proposed optimization criteria. The analytical results in this study can serve as guidelines for optimal vibration control of membrane structures. Additionally, the proposed optimization criteria can be applied to active control of different flexible structures.

References listed at the end of the article:


ABSTRACT: In this paper, the nonlinear free and forced vibrations analysis of in-plane bi-directional functionally graded (IBFG) rectangular plate with temperature-dependent properties is studied for the first time. For this purpose, with the aid of von Karman nonlinearity strain–displacement relations, the partial differential equations of motion are developed based on the first-order shear deformation theory (FSDT). Then, the nonlinear partial differential equations are transformed into the time-dependent nonlinear ordinary differential equations by applying the Galerkin method. The primary and super harmonic resonances are analyzed by the method of multiple scales (MMS). The material properties are assumed to be temperature-dependent and graded in the thickness direction according to the power-law distribution. The effects of some system parameters, such as vibration amplitude, volume fraction indexes, length-to-thickness ratio, temperature and aspect ratio on the nonlinear frequency and also frequency responses curve, are discussed in detail. To validate the analysis, the results of this paper are compared with the published data and good agreements are found.

References listed at the end of the paper:
17. M. Şimşek, Bi-directional functionally graded materials (BDFGMs) for free and forced vibration of Timoshenko beams with various boundary conditions, Compos. Struct. 133 (2015) 968–978.

ABSTRACT: This paper deals with analyzing free vibrations of the symmetric arch. The boundary conditions of the stress resultants are newly derived, which can be replaced by the conventional boundary conditions of the deflections. All solutions of the natural frequency with the mode shape, using the new boundary conditions, are the same as those of the conventional deflections. The boundary conditions mixed with new and conventional conditions act correctly to calculate natural frequencies. The mode shapes of the stress resultants using the new boundary conditions are reported in two types: symmetric and anti-symmetric modes.

References listed at the end of the paper:


ABSTRACT: Energy harvesting by wind turbines is of great concern in many countries/areas, yet its safety is inevitably related to the structural vibration of the turbine system. In this study, we present a complete linear analysis of structural vibrations for vertical axis wind turbines (VAWTs) based on Euler’s beam theory by Lagrangian mechanics. The un-deformed blade is assumed to be vertically straight. There are several findings from solving the resultant equations which represent four dimensions of deformation, involving motion: lateral bending-chordwise bending-axial torsion-axial extension (BBTE)
References listed at the end of the paper:
finding method. The mode shape function is then explicitly obtained. In particular, the natural frequencies of the angular speed, the dispersion relation of the 1 degree dominant factor in determining the natural frequencies of the as material damping geometrical and physical parameters such as blade length \( l \), chord length \( c \), radius \( R \) and angular speed \( \Omega \) as well as material damping \( \eta \). It is shown that among the four dimensions of deformation lateral bending is the dominant factor in determining the natural frequencies of the blade. In case the blade is rotating with a constant angular speed, the dispersion relation of the 1 degree-of-freedom (DOF) motion for lateral bending can be exactly derived that an implicit function of the natural, i.e. resonant frequencies has to be solved by a root-finding method. The mode shape function is then explicitly obtained. In particular, the natural frequencies of the 1-DOF motion for the rotating blade are shown to be conveniently approximated by simple analytical formulas.


ABSTRACT: In this part 2, we provide a detailed solution to the beam equations derived in Part 1 for a VAWT blade. The main results have been outlined in the abstract of Part 1 which includes the effects of various geometrical and physical parameters such as blade length \( l \), chord length \( c \), radius \( R \) and angular speed \( \Omega \) as well as material damping \( \eta \). It is shown that among the four dimensions of deformation lateral bending is the dominant factor in determining the natural frequencies of the blade. In case the blade is rotating with a constant angular speed, the dispersion relation of the 1 degree-of-freedom (DOF) motion for lateral bending can be exactly derived that an implicit function of the natural, i.e. resonant frequencies has to be solved by a root-finding method. The mode shape function is then explicitly obtained. In particular, the natural frequencies of the 1-DOF motion for the rotating blade are shown to be conveniently approximated by simple analytical formulas.
in terms of those for the stationary blade and the angular speed of rotation. The dependence of the natural frequencies on the chord length can also be approximated analytically by a ratio formula for given blade length to chord ratio. In addition, resonance maps of natural frequency plotted versus various parameters are provided to fully exploit the usefulness of the main results. Through a series of analysis of 2-DOF systems, we show the respective importance of the centrifugal force, coupling deformation and the Coriolis force in modifying the natural frequencies of the 1-DOF model rather than simply ignoring any of these effects.


ABSTRACT: An accurate buckling response analysis for functionally graded graphene platelet (GPL) reinforced piezoelectric cylindrical nanoshells subject to thermo-electro-mechanical loadings is presented by a rigorous symplectic expansion approach. Three types of GPL reinforced patterns are considered, and the modified Halpin–Tsai model is employed to determine their effective material properties. By using Eringen’s nonlocal stress theory and Reissner’s shell theory, new governing equations are established in the Hamiltonian form. Exact solutions are expanded into symplectic series and three possible forms are derived. A comparison with the existing study is presented to validate the solution and very good agreement is observed. The effects of material and geometrical properties of GPLs, electric voltage and temperature rise on critical buckling stresses are investigated and discussed in detail.

References listed at the end of the paper:
1. Stability to strength and damage accumulation, on the one hand, may change the failure mode of reticulated shells from dynamic instability to strength failure; on the other, may reduce the dynamic ultimate load obviously. This consideration should be taken into account when conducting nonlinear dynamic analysis of reticulated shells.

References listed at the end of the paper:
1. W. F. Chen and D. Han (eds.), Plasticity for Structural Engineers (Springer-Verlag, New York, 2012).

ABSTRACT: This study deals with a novel model of forced flexural vibrations in a transversely isotropic thermoelastic thin rectangular plate (TRP) due to time harmonic concentrated load. The mathematical model is prepared for the thin plate in a closed form with the application of Kirchhoff’s love plate theory for nonlocal generalized thermoelasticity with Green–Naghdi (GN)-III theory of thermoelasticity. The nonlocal thin plate has a nonlocal parameter to depict small-scale effect. The double finite Fourier transform technique has been used to find the expressions for lateral deflection, thermal moment and temperature distribution for simply supported (SS) thin rectangular plate in the transformed domain. The effect of classical thermoelasticity (CTE) theory of thermoelasticity and nonlocal parameters has been shown on the computed quantities. Few particular cases have also been deduced.
References listed at the end of the paper:

ABSTRACT: The thin plane plates are largely used in practice as single elements or as components of the thin-walled structures, and their behavior under compression is characterized by large post-buckling load-carrying capacity. Various semi-analytical solutions of the uniformly compressed simply supported plate with large deflections were formulated almost a century ago, mainly solving the fundamental equations governing the deformation of thin plates, or using classic energy methods. Due to several shortcomings, none of these solutions were introduced in the design codes of thin-walled members. This paper presents new semi-analytical solutions based on classic energy methods. The main innovation is brought by the considered displacement field which is far more accurate than the ones used by the previous formulations. The initial geometric imperfections are considered, and the proposed solutions are validated against numerical solutions and experimental data. The validation is also supported by a publicly available software application.

References listed at the end of the paper:

This paper deals with the lateral buckling behavior of an axially compressed beam interacting with the ground on which it is resting. Such a simple model is supposed to reproduce the same trends as observed during the lateral buckling of offshore pipelines on the seabed. In such practical analyses, the pipe-soil interaction relates the ground to the neutral axis of the pipeline. It is shown that, although such a constraint significantly affects the buckling behavior of the pipeline, it cannot reflect the torsional component of the buckling modes. However, this component is encountered in practice and may further modify the critical loads. Therefore, in this present preliminary study, the interaction between the beam in hand and the surrounding ground is modeled by a connection (a continuous distribution of lateral springs) related to the bottom line of the beam. In this way, the real contact between the soil and the bottom line of a pipe is mimicked, allowing for both flexural and torsional deformations in the buckling response. The problem is investigated analytically using an Euler–Bernoulli beam model with an isotropic linear elastic constitutive law and also an elastic interaction law. Original analytical solutions are derived and compared to numerical results obtained through finite element computations. In comparison with classical solutions (with the connection related to the neutral axis), new types of buckling modes may appear when considering torsional effects, depending on the boundary conditions, with generally much lower critical loads. These first results are certainly representative of some features of the global/localized lateral buckling of offshore pipelines, indicating that torsional effects should also be taken into account in such more comprehensive analyses.

References listed at the end of the paper:
ABSTRACT: This research aims to investigate the feasibility of using ambient vibration testing for system identification of an elevated water tank. To identify the natural dynamic properties, the experimental study is carried out on an elevated steel water tank located in Tehran. The tank is instrumented with a sensitive velocimeter sensor (microtremor), and the ambient velocity of the tank is recorded for 30min in three orthogonal axes. Employing the peak-picking method in the frequency domain, the fundamental frequency of the tank is determined as about 1.9Hz. Then, the numerical model of the tank is generated and calibrated based on the obtained data. In the primary modeling, the values of natural frequencies of the tank are in good agreement with the results of the ambient vibration data. This finding is judged to be reasonable considering no clear sign of corrosion in the steel material.

References listed at the end of the paper:

ABSTRACT: Investigated herein is the buckling of Euler–Bernoulli nano-beams made of bi-directional functionally graded material with the method of initial values in the frame of gradient elasticity. Since the transport matrix cannot be calculated analytically, the problem was examined with the help of an approximate transport matrix (matricant). This method can be easily applied with buckling analysis of arbitrary two-directional functionally graded Euler–Bernoulli nano-beams based on gradient elasticity theory. Basic equations and boundary conditions are derived by using the principle of minimum potential energy. The diagrams and tables of the solutions for different end conditions and various values of the parameters are given and the results are discussed.

References listed at the end of the paper:
40. I. G. Vardoulakis and J. Sulem, Bifurcation Analysis in Geomechanics (Taylor and Francis, 1995).

ABSTRACT: In this paper, the buckling characteristic of FGM plate considering the surface effect is studied based on general third-order plate theory and non-local theory. The surface effect of FGM plate is captured by the surface elasticity theory. The Kirchhoff hypothesis is released by employing parabolic variation of transverse shear strains. By using Navier solution technique, analytical solutions of buckling loads of FGM plate with surface effect are given, and detailed parametric studies are presented to show the relationship between surface effects and the plate thickness, power-law index, surface residual stress, surface moduli and non-local parameter. Furthermore, the surface effect on the buckling characteristic of FGM plate is also discussed.
References listed at the end of the paper:
governing equations about the axisymmetric state determine the critical temperature rise, a nonlinear eigenvalue problem is formulated by linearizing the physically neutral surface. It is shown that, when subjected to increasing temperature, the plate initially bends account. The governing equations are derived using the von Karman nonlinear plate theory and the concept of graded in the thickness direction and dependence of the material proper

ABSTRACT: The paper addresses the problem of asymmetric buckling of geometrically imperfect circular plates undergoing large axisymmetric deflections under thermal loading. The plate edge is assumed to be immovable in the radial direction and elastically restrained against bending rotation. The plate material is graded in the thickness direction and dependence of the material properties on temperature is taken into account. The governing equations are derived using the von Karman nonlinear plate theory and the concept of physically neutral surface. It is shown that, when subjected to increasing temperature, the plate initially bends into a figure of revolution and then buckles into asymmetric mode with local circumferential waves. To determine the critical temperature rise, a nonlinear eigenvalue problem is formulated by linearizing the governing equations about the axisymmetric state of equilibrium and solved using power-series expansions. The
effect of temperature-dependent material properties, rotational spring stiffness and initial geometric imperfection on the critical temperature rise and buckling mode shapes is studied.

References listed at the end of the paper:


ABSTRACT: The main objective of this paper is to validate a finite-element (FE) modeling protocol to simulate thin-walled members for static and dynamic analyses. Arbitrary-shaped cross-sections, including open, closed, and multicellular sections can be efficiently modeled for further advanced study. The framework is thoroughly validated and verified using the existing analytical and closed-form solutions, as well as experimental results available in literature. This work is motivated by the higher accuracy of the shell FE-based modeling to capture the local and global complex behaviors of thin-walled members with asymmetric sections. Higher computational expenses, however, are required for such sophisticated shell finite element models (SFEM). Accordingly, a framework hosted in MATLAB and implementing the python scripting technique in ABAQUS, is developed, which includes eigen buckling, static nonlinear, modal frequency and dynamic time-history analyses. For a more modeling convenience, various parameters are incorporated such as imperfections, residual stresses, material definitions, element choice, meshing control, and boundary conditions. Several examples are provided to illustrate the application of the proposed framework, and to prove the robustness and accuracy of the generated FE models. This paper concludes with the efficiency of implementing SFEMs for simulating thin-walled members; thereby, establishing a more accurate and advanced structural analysis.

References listed at the end of the paper:
36. B. W. Schafer and S. Adány, Buckling analysis of cold-formed steel members using CUFSM: Conventional and constrained finite strip methods, in Eighteenth Int. Specialty Conf. on Cold-Formed Steel Struct., 2006, Orlando, FL. Citeseer.
37. R. Ziemen and W. McGuire, MASTAN2 v5 (Bucknell University, Lewisburg, PA, USA, 2019).
42. N. S. Trahair, Flexural-Torsional Buckling of Structures (E & FN Spon, London, 1993).

ABSTRACT: The effects of different percentages of multiwall carbon nanotube (MWCNT) on natural frequencies of polymer composite plates of varying edge-to-thickness ratio, aspect ratio and boundary conditions at ambient temperature are investigated experimentally and numerically. Conventional hand lay-up technique is used to prepare the MWCNT polymer composite plates with different percentages of carbon nanotubes (CNTs) mixed to the polymer. The elastic properties are determined experimentally by conducting uniaxial tensile test in the universal testing machine INSTRON 8862 as per ASTM D-3039. A set of experiments were conducted for the natural frequencies of vibration of MWCNT composite plates using the Brue and Kjaer Fast Fourier Transform (FFT) analyzer with pulse platform. Detailed parametric studies are carried out to determine the effect of weight fraction of CNTs, aspect ratios, edge-to-thickness ratios and boundary conditions on the natural frequency of composite plates. Numerical solutions were obtained by the commercial finite element method (FEM) package ABAQUS. A simulation model is developed using geometrical and material properties determined experimentally from which the frequency responses are obtained. The simulation results are found to be consistent with the experimental ones. The results obtained showed an increase in elastic properties and natural frequencies up to 0.3 wt.% of MWCNT and decrease thereafter for all cases due to agglomeration of CNT in the polymer matrix. The morphology and dispersion of the CNTs in composites at micro level are investigated by using scanning electron microscopy (SEM) to further corroborate the behavior of specimens.

References listed at the end of the paper:

ABSTRACT: The size-dependent free vibration of microbeams submerged in fluid is presented in this paper based on the modified couple stress theory. Two different cross-section shapes of microbeams are considered, i.e. the circular cross-section and rectangular cross-section. This nonclassical microbeam model is introduced for capturing the size effect of microstructures. In this fluid and structure coupled system, the effect of hydrodynamic loading on microbeams can be expressed by the added mass method. By using Hamilton’s principle and differential quadrature (DQ) method, we can derive governing equations of microbeams in fluid, and then rewrite them in the discretized form. The frequencies and mode shapes for microbeams are determined by proposing an iterative method. Numerical examples are given to show the effect of fluid depth, fluid density, length scale parameter, slenderness ratio, boundary condition and cross-section shape on the vibration characteristics.

References listed at the end of the paper:

ABSTRACT: This study provides an overview on the effect of porosity on free vibrations and more importantly aeroelastic stability margins of cylindrical shells. A general formulation for cylindrical shells is first developed including the effects of shear deformation and rotary inertia along with Sander’s rigid body rotation modification. Two porosity distributions of even and uneven are considered for functionally graded shells. The most general form of power-law model which is known as four-parameter power-law is utilized to provide a clear understanding for the qualification of functionally graded material. A Ritz-based solution algorithm being capable of representing all combinations of symmetric and asymmetric boundary conditions by a penalty method is also introduced. In addition to the capability of satisfying all boundary conditions, the presented solution method is very fast in terms of convergence and computational effort. Various parametric studies are provided and practical results are reported.

References listed at the end of the paper:


37. V. H. Nam et al., Buckling and postbuckling of porous cylindrical shells with functionally graded composite coating under torsion in thermal environment, Thin-Walled Struct. 144 (2019) 106253.


This paper presents an analytical investigation on dynamic buckling of cylindrical shells with general thickness variations subjected to exponentially increasing external pressure. The asymptotic formulae for dynamic buckling loads considering general thickness variations are derived and expressed by geometry sizes of the shell and thickness variation functions. To validate the presented results, two specific non-axisymmetric thickness cases are discussed in detail. The critical dynamic buckling loads show a great agreement with the previous ones by other researchers for simple and axial thickness variation situations. Finally, example calculations and parametric discussion are performed, and influences of thickness variation types, speed of external pressure, and the power exponent of time on the critical dynamic buckling loads are discussed.

References listed at the end of the paper:
This paper aims at shedding new light on the elasto-plastic collapse of steel channel sections beams undergoing lateral-torsional (LT) buckling. This new insight is acquired using a two-node geometrically exact beam finite element developed by the author, which can handle large displacements, including torsion-related warping, Wagner effects, plasticity, residual stresses and arbitrary initial configurations (namely geometrical imperfections). Several cross-sections and loading/support conditions are analyzed. The results obtained show that the LT buckling behavior of channels is asymmetric, meaning that the direction of the geometric imperfection can influence significantly the strength of the beams. Moreover, it is demonstrated that the loading and support conditions play a major role, leading to a significant scatter of results which hinder the definition of a single buckling curve for design purposes.

Nevertheless, in all cases considered, the buckling strengths obtained fall significantly above those predicted by the current version of Eurocode 3.

References listed at the end of the paper:
28. V. Vlasov, Tonkostenye Sterjni (Fizmatgiz, Moscow, Russia, 1958).
33. MATLAB, Version 7.10.0 (R2010a) (The MathWorks Inc., Massachusetts, 2010).
38. N. Trahair, Flexural-Torsional Buckling of Structures (Taylor & Francis, 1993).
40. G. H. Handelman, Shear center for thin-walled open sections beyond the elastic limit, J. Aeronaut. Sci. 18(11) (1951) 749–754.
ABSTRACT: In this paper, the axial buckling of boron nitride nanotubes (BNNTs) is investigated by considering the effects of surface and electric field. To achieve this purpose, the surface elasticity theory is exploited and the results are compared with the molecular dynamic simulation in order to validate the accuracy of the applied theory. In the molecular dynamics simulation, the potential between boron and nitride atoms is considered as Tersoff type. The Timoshenko beam theory is adopted to model BNNT. Moreover, two types of zigzag and armchair BNNTs are considered. In this study, the effects of surface, electric field, length, and thickness of BNNT on the critical buckling load are investigated. According to the results, the critical load of zigzag BNNT depends on the electric field. However, the electric field would not affect the critical load of the armchair BNNT. It should be noted that the surface residual tension and surface Lamé’s constants of BNNT have considerable impact on the critical load of BNNT. For lower values of electric field and smaller dimensions of BNNT, the critical load would be more dependent on the surface effect regarding the results. Furthermore, as an efficient non-classical continuum mechanic approach, the surface elasticity theory can fill the potential gap between the classical continuum mechanic and molecular dynamics simulation.

References listed at the end of the paper:

17. A. Shariati et al., Extremely large oscillation and nonlinear frequency of a multi-scale hybrid disk resting on nonlinear elastic foundation, Thin-Walled Struct. 154 (2020) 106840.
54. S. Sahmani, M. Aghdam and M. Bahrami, Surface free energy effects on the postbuckling behavior of cylindrical shear deformable nanoshells under combined axial and radial compressions, Meccanica 52(6) (2016) 1329–1352.
ABSTRACT: The paper presents a solution to the dynamic response of three-layered, annular plates that are thermo-mechanically loaded. Time-dependent forces are considered to act on the facings of the plate. The thermal loading is defined by a flat, axisymmetric temperature field whose profile is expressed by the stationary or increase in time temperature differences between the plate edges. The cases of the plates loaded only thermally or mechanically have been examined. The problem has been solved analytically and numerically using the approximation methods: orthogonalization and finite difference. The selected reactions of an exemplar plate have been compared with the results obtained for the plate analyzed by the finite element method (FEM). The critical temperature differences and critical loads and corresponding dynamic buckling modes have been analyzed in detail. The numerous results presented for the dynamic responses have an important and practical meaning in the design process of plate structures subjected to complex thermo-mechanical loads.

References listed at the end of the paper:


ABSTRACT: This paper reports the most recent developments concerning Generalized Beam Theory (GBT) formulations, and corresponding finite element implementations, for steel-concrete composite beams. These formulations are able to perform the following types of analysis: (i) materially nonlinear analysis, to calculate the beam load-displacement response, up to collapse, including steel plasticity, concrete cracking/crushing and shear lag effects, (ii) bifurcation (linear stability) analysis, to obtain local/distortional bifurcation loads and buckling mode shapes of beams subjected to negative (hogging) bending, accounting for shear lag and concrete cracking effects and (iii) long-term service analysis including creep, cracking and arbitrary cross-section deformation (which includes shear lag) effects. The potential (computational efficiency and accuracy) of the proposed GBT-based finite elements is illustrated through several numerical examples. For comparison purposes, results obtained with standard finite strip and shell/brick finite element models are provided.

References listed at the end of the paper:
2. R. Schardt, Verallgemeinerte Technische Biegetheorie (Springer Verlag, Berlin, Germany, 1989) (in German).
8. L. Duan and J. Zhao, GBT deformation modes for thin-walled cross-sections with circular rounded corners, Thin-Walled Struct. 136 (2019) 64–89.

ABSTRACT: Medium-frequency (mid-frequency) vibration analysis of complex structures plays an important role in automotive, aerospace, mechanical, and civil engineering. Flexible beam structures modeled by the classical Euler–Bernoulli beam theory have been widely used in various engineering problems. A kinematic hypothesis made in the Euler–Bernoulli beam theory is that the plane sections of a beam normal to its neutral axis remain planes after the beam experiences bending deformation, which neglects shear deformation. However, previous investigations found out that the shear deformation of a beam (even with a large slenderness ratio) becomes noticeable in high-frequency vibrations. The Timoshenko beam theory, which describes both bending deformation and shear deformation, would naturally be more suitable for medium-frequency vibration analysis. Nevertheless, vibrations of Timoshenko beam structures in a medium frequency region have not been well studied in the literature. This paper presents a new method for mid-frequency vibration analysis of two-dimensional Timoshenko beam structures. The proposed method, which is called the augmented Distributed
Transfer Function Method (DTFM), models a Timoshenko beam structure by a spatial state-space formulation in the s-domain. The augmented DTFM determines the frequency response of a beam structure in an exact and analytical form, in any frequency region covering low, middle, or high frequencies. Meanwhile, the proposed method provides the local information of a beam structure, such as displacement, shear deformation, bending moment and shear force at any location, which otherwise would be very difficult with energy-based methods. The medium-frequency analysis by the augmented DTFM is validated in numerical examples, where the efficiency and accuracy of the proposed method is demonstrated. Also, the effects of shear deformation on the dynamic behaviors of a beam structure at medium frequencies are examined through comparison of the Timoshenko beam and Euler–Bernoulli beam theories.

References listed at the end of the paper:


ABSTRACT: Buckling loads of arches could be significantly affected by the assumptions made on the load behavior during buckling. For a funicular arch whose centerline coincides with the compression line, we may consider two types of load behaviors based on how the line of load action shifts during buckling. This paper presents the governing differential equations for the elastic in-plane buckling problem of funicular circular arches under uniform radial pressure based on the two different load behavior assumptions, as well as analytical and numerical methods for analysis. For the analytical method, buckling criteria of rotationally-restrained ended circular arches with an internal rotational spring are formulated by using the general solution of the governing differential equation. For the numerical method, the Hencky bar-chain model (HBM) and its simple matrix formulations for general funicular arches are established. The buckling loads and mode shapes of funicular
Two-dimensional reduction is extended to the 3D constitutive stiffness matrix. This was made possible through a two-step process in which the shear strain, lateral curvature, and twisting curvature are retained first. By


ABSTRACT: This study addresses the analytical treatment of a closed-form buckling equation for lateraltorsional stability of thin web composite cantilever beams under mid-height tip force. The beam is composed of random ply fiber orientations. Classical lamination theory is embedded into the Vlasov plate formulation to make up the framework of the analytical treatment. A closed-form solution is realized when an innovative dimensional reduction is extended to the 3D constitutive stiffness matrix. This was made possible through a two-step process in which the shear strain, lateral curvature, and twisting curvature are retained first. By

References listed at the end of the paper:
17. H. Hencky, Über die angenäherte Lösung von Stabilitätsproblemen im Raum mittels der elastischen Gelenkkette, Der Eisenbau 11 (1920) 437–452.
condensing the shear strain variable, effective lateral, torsional, and coupling stiffness terms were formulated. Applying the equilibrium conditions in the deformed configuration, two differential equations are obtained in terms of the lateral curvature and twisting angle. Eliminating the lateral curvature, the twisting angle differential equation with nonconstant coefficients is generated. This equation is solved using a hybrid numerical-analytical approach yielding an analytical buckling expression. Finite element results are generated to verify the accuracy of the buckling load predictions indicating very good correlation with the buckling equation results regardless of the random lamination applied.

References listed at the end of the paper:

24. H. Ahmadi, Lateral torsional buckling of anisotropic laminated composite beams subjected to various loading and boundary conditions, Dissertation, Kansas State University, Manhattan, KS (2017).

International Journal of Structural Stability and Dynamics, Vol. 20, No. 13, 2041016, December 2020,

Google the string: “International Journal of Applied Mechanics”, then click on the second entry, which is: “International Journal of Applied Mechanics (World Scientific)”

ABSTRACT: Buckling and vibration analysis of cantilever functionally graded (FG) beam that reinforced with carbon nanotube (CNT) is the purpose of this paper. The beam is graded in the thickness direction, and compressive axial force impressed the beam. The volume fractions of randomly oriented agglomerated single-walled CNTs (SWCNTs) are assumed to be graded in the thickness direction. To determine the effect of CNT agglomeration on the elastic properties of CNT-reinforced FG-beam, a two-parameter micromechanics model of agglomeration is employed. In this paper, an equivalent continuum model based on the Eshelby–Mori–Tanaka approach is obtained. The stability and motion equations are based on the two-dimensional elasticity theory and Hamilton’s principle. The generalized differential quadrature method (GDQM) that has high accuracy is used to discretize the equations of stability and motion and to implement the boundary conditions. To study the accuracy of the present analysis, a compression is carried out with a known data. Convergence rate, the influence of graded agglomerated CNTs, and the effect of axial forces exerted on the beam, on the natural frequencies of reinforced beam by randomly oriented agglomerated CNTs are investigated.

References listed at the end of the paper:
· 5. Y. An, L. Han and X. Zhao , Behaviour and design calculations on very slender thin-walled CFST columns, Thin-Walled Struct. 53 (2012) 161–175.
ABSTRACT: In this paper, an accurate and efficient method is presented for analyzing the dynamic response of two-dimensional (2D) periodic structures. The algebraic structure of the corresponding matrix exponential is analyzed and, based on its special structure, an accurate and efficient method for its computation is proposed. Accuracy is maintained using the precise integration method (PIM), and great efficiency is achieved in the computational effort using the periodic properties of the structure and the energy propagation features of the dynamic system. The proposed method is compared with the conventional Newmark and Runge–Kutta (R–K) methods, and it is shown to be accurate, efficient and extremely frugal in its memory requirements.

References listed at the end of the paper:

ABSTRACT: A family of hierarchical one-dimensional beam finite elements developed within a variables separation framework is presented. A Proper Generalized Decomposition (PGD) is used to divide the global three-dimensional problem into two coupled ones: one defined on the cross-section space (beam modeling kinematic approximation) and one belonging to the axis space (finite element solution). The displacements over the cross-section are approximated via a Unified Formulation (UF). A Lagrangian approximation is used along the beam axis. The resulting problems size is smaller than that of the classical equivalent finite element solution. The approach is, then, particularly attractive for higher-order beam models and refined axial meshes. The numerical investigations show that the proposed method yields accurate yet computationally affordable three-dimensional displacement and stress fields solutions.

References listed at the end of the paper:

It has been found that due to consideration of the sloshing effect, the frequency spectrum of the system can split into two parts in the case when the vibration frequencies of liquid differ from the vibration frequencies of an empty shell. Moreover, under harmonic excitation consideration of liquid sloshing leads to a more complicated amplitude-frequency curve characterized by displacement jumps.

References listed at the end of the paper:


Changchun 130026, P. R. China), “Analytical approximate prediction of thermal post
under earthquake loading)

ABSTRACT: This paper is concerned with thermal post-buckling of uniform isotropic beams with axially immovable spring-hinged ends. The ends of the beam with elastic rotational restraints represent the actual practical support conditions and the classical hinged and clamped conditions can be achieved as the limiting cases of the rotational spring stiffness. The governing differential–integral equation is solved by assuming suitable admissible function for lateral displacement and by employing the Galerkin method. A brief and explicit analytical approximate formulation is established to predict the thermal post-buckling behavior of the beam. The present analytical approximate expressions show excellent agreement with the corresponding numerical solutions based on the shooting method. This confirms the effectiveness and verifies the accuracy of the formulas established.

References listed at the end of the paper:

ABSTRACT: The present work is concerned with the dynamic behavior of a circular ring loaded between a wedge-shaped indenter and a rigid plate. First, an analytical model using the rigid-plastic theory is established. The effects of strain-hardening and strain-rate are incorporated. The history of displacement, velocity and reaction force of the wedge-shaped indenter and energy absorbed by the circular ring are obtained. Further, to verify the proposed analytical model, numerical simulations and experiments are performed and compared with the analytical predictions. It is found that the analytical solutions compare well with the numerical simulations and experiments. This study provides a better understanding of the energy dissipation behavior of circular rings.

References listed at the end of the paper:

ABSTRACT: In this paper, bending and free vibration analysis of carbon nanotubes reinforced composite (CNTRC) cylindrical shell is carried out using the three-dimensional theory of elasticity. The single-walled carbon nanotubes (SWCNT) reinforcement is either uniformly distributed (UD) or functionally graded (FG) in the thickness direction which, are specified as the cases [math] Effective material properties of CNTRC.
cylindrical shell are estimated according to the rule of mixture as well as considering theCNT efficiency parameters. An analytical solution is performed by using Fourier series along the axial coordinate together with state space technique along the radial coordinate for the simply supported CNTRC cylindrical shell. Moreover, for CNTRC cylindrical shell with other edges boundary conditions, a semi-analytical solution is accomplished by using differential quadrature method (DQM) along the axial coordinate and state space technique along the radial coordinate. Present approach is validated by comparing the numerical results with the available published results. Furthermore, effect of types of CNT distributions in the polymer matrix, volume fraction of CNT, edges boundary conditions and radial-to-thickness ratio on the bending and free vibration behavior of FG-CNTRC cylindrical shell are examined.

References listed at the end of the paper:

Xiang Xie, Hui Zheng and Haosen Yang (School of Mechanical Engineering, Shanghai Jiao Tong University, 800 Dongchuan Rd., Shanghai 200240, P. R. China), “Vibration analysis of laminated and stepped circular arches with arbitrary boundary conditions even full rings. The influences of shear deformation, inertia rotary and deepness term are considered in the theoretical model. The basic concept of the present approach is the expansion of the highest derivatives appearing in the governing equations instead of solution function itself by adopted basis functions. Then lower order derivatives and function itself are obtained by integration. The constants arising from the integrating process are determined by given boundary conditions. Due to the approximation process based on integration technique rather than conventional differentiation, it does not require the basis function to be differentiable or continuous, which makes the choice of basis functions quite freely. The robustness of the approach for the application of various basis functions is evaluated by using Haar wavelet and Chebyshev orthogonal polynomials. To test the convergence, efficiency and accuracy of the approach, the numerical results are compared with those previously published in literature. Very good agreement can be observed. A distinctive feature of the proposed approach is its unified applicability for arbitrary elastic-supported boundary conditions.

References listed at the end of the paper:


https://doi.org/10.1142/S1758825116500368
ABSTRACT: Elastic large deformation analysis based on the hybrid natural element method (HNEM) is presented in this paper. The natural neighbor interpolation is adopted to construct the shape functions for the HNEM. The incremental formulation of Hellinger–Reissner variational principle is used to derive discrete system of incremental equations under the total Lagrangian formulation. And the Newton-Raphson iteration is applied to solve these incremental equations. Compared with the natural element method (NEM), the HNEM can directly obtain nodal stresses of higher precision, which will bring advantage in the iteration process and improve computational efficiency in solving elastic large deformation problems. Some numerical examples demonstrate the validity of the HNEM for elastic large deformation problems.

References listed at the end of the paper:

ABSTRACT: It is well-known that rotating nanobeams can have different dynamic and stability responses to various types of loadings. In this research, attention is focused on studying the effects of magnetic field, surface energy and compressive axial load on the dynamic and the stability behavior of the nanobeam. For this purpose, it is assumed that the rotating nanobeam is located in the nonuniform magnetic field and subjected to compressive axial load. The nonlocal elasticity theory and the Gurtin–Murdock model are applied to consider the effects of inter atomic forces and surface energy effect on the vibration behavior of rotating nanobeam. The vibration frequencies and critical buckling loads of the nanobeam are computed by the differential quadrature method (DQM). Then, the numerical results are testified with those results are presented in the published works and a good correlation is obtained. Finally, the effects of angular velocity, magnetic field, boundary conditions, compressive axial load, small scale parameter and surface elastic constants on the dynamic and the stability behavior of the nanobeam are studied. The results show that the magnetic field, surface energy and the angular velocity have important roles in the dynamic and stability analysis of the nanobeams.

References listed at the end of the paper:
theories (HSDTs) of this gender, so deserves a lot of further research. (c) Transverse shear stresses results are described in the paper) appear to be of paramount importan

equations and boundary conditions are derived by employing the principle of virtual work. Th

than the first order shear deformation theory (FSDT) which as it is well

principal feature of this theory is that models the thick

analysis of functionally graded single

ABSTRACT: In th

advanced sandwich plates and shells”, International Journal of Applied Mechanics, Vol. 8, No. 4, 1650049,


ABSTRACT: In this paper, a simple and accurate sinusoidal trigonometric theory (STT) for the bending analysis of functionally graded single-layer and sandwich plates and shells is presented for the first time. The principal feature of this theory is that models the thickness stretching effect with only 4-unknowns, even less than the first order shear deformation theory (FSDT) which as it is well-known has 5-unknowns. The governing equations and boundary conditions are derived by employing the principle of virtual work. Then, a Navier-type closed-form solution is obtained for functionally graded plates and shells subjected to bi-sinusoidal load for simply supported boundary conditions. Consequently, numerical results of the present STT are compared with other refined theories, FSDT, and 3D solutions. Finally, it can be concluded that: (a) An accurate but simple 4-unknown STT with thickness stretching effect is developed for the first time. (b) Optimization procedure (described in the paper) appear to be of paramount importance for 4-unknown higher order shear deformation theories (HSDTs) of this gender, so deserves a lot of further research. (c) Transverse shear stresses results are sensitive to the theory and need carefully attention.

References listed at the end of the paper:


...
obtain a solution in the form of a double asymptotic series further summed using two-dimensional fractional rational approximations. Convergence of the approximations to the exact solution is proven.

References listed at the end of the paper:


Reza Ansari (University of Guilan, Rasht, Iran) and Raheb Gholami (Islamic Azad University Lahijan, Iran), “Size-dependent nonlinear vibrations of first-order shear deformable magneto-electro-thermo elastic nanoplates based on the nonlocal elasticity theory”, International Journal of Applied Mechanics, Vol. 8, No. 4, 1650053, June 2016, https://doi.org/10.1142/S1758822516500538

ABSTRACT: This paper deals with the size-dependent geometrically nonlinear free vibration of magneto-electro-thermo elastic (METE) nanoplates using the nonlocal elasticity theory. The mathematical formulation is developed based on the first-order shear deformation plate theory, von Kármán-type of kinematic nonlinearity and nonlocal elasticity theory. The influences of geometric nonlinearity, rotary inertia, transverse shear deformation, magneto-electro-thermal loading and nonlocal parameter are considered. First, the generalized differential quadrature (GDQ) method is utilized to reduce the nonlinear partial differential equations to a system of time-dependent nonlinear ordinary differential equations. Afterwards, the numerical Galerkin method, periodic time differential operators and pseudo-arc length continuation algorithm are employed to compute the nonlinear frequency versus the amplitude for the METE nanoplates. The presented methodology enables one to describe the large-amplitude vibration characteristics of METE nanoplates with various sets of boundary conditions. A detailed parametric study is carried out to analyze the important parameters such as the
nondimensional nonlocal parameter, external electric potential, external magnetic potential, temperature change, length-to-thickness ratio, aspect ratio and various edge conditions on the nonlinear free vibration characteristics of METE nanoplate results in decreasing the natural frequency, a remarkable increasing effect on the hardening behavior and subsequently increasing the nonlinear-to-linear frequency ratio.

References listed at the end of the paper:

considering surface effects and nonlocal elasticity theory.

An exact closed-form analytical solution is presented to solve the thermo-elasto-plastic problem of thick-walled spherical vessels made of functionally graded materials (FGMs). Assuming that the inner surface is exposed to a uniform heat flux, and that the outer surface is exposed to an airstream. The heat conduction equation for the one-dimensional problem in spherical coordinates is used to obtain temperature distribution in the sphere. Material properties are graded in the thickness direction according to a power law distribution, whereas the Poisson’s ratio is kept constant. The Poisson’s ratio due to slight variations in engineering materials is assumed constant. The plastic model is based on von Mises yield criterion and its associated flow rules under the assumption of perfectly plastic material behavior. For various values of inhomogeneity constant, the so-obtained solution is then used to study the distribution of limit heat flux, displacement and stresses versus the radial direction. Moreover, the effect of increasing the heat flux and pressure on the propagation of the plastic zone are investigated. Furthermore, the effect of change in Poisson’s ratio on the value of the critical material parameter is demonstrated. The present study is also validated by comparing the numerical results for thick elasto-plastic spherical shells available in the literature. To the best of the authors’ knowledge, in previous studies, exact thermo-elasto-plastic behavior of FGM thick-walled spherical pressure vessels has not been investigated.

References listed at the end of the paper:

Zeinab Mazarei, Mohammad Zamani Nejad and Amin Hadi (First author is from: Mechanical Engineering Department, Yasouj University, P. O. Box 75914-353, Yasouj, Iran), “Thermo-Elasto-Plastic analysis of thick-walled spherical pressure vessels made of functionally graded materials”, International Journal of Applied Mechanics, Vol. 8, No. 4, 1650054, June 2016, https://doi.org/10.1142/S175882511650054X

ABSTRACT: An exact closed-form analytical solution is presented to solve the thermo-elasto-plastic problem of thick-walled spherical vessels made of functionally graded materials (FGMs). Assuming that the inner surface is exposed to a uniform heat flux, and that the outer surface is exposed to an airstream. The heat conduction equation for the one-dimensional problem in spherical coordinates is used to obtain temperature distribution in the sphere. Material properties are graded in the thickness direction according to a power law distribution, whereas the Poisson’s ratio is kept constant. The Poisson’s ratio due to slight variations in engineering materials is assumed constant. The plastic model is based on von Mises yield criterion and its associated flow rules under the assumption of perfectly plastic material behavior. For various values of inhomogeneity constant, the so-obtained solution is then used to study the distribution of limit heat flux, displacement and stresses versus the radial direction. Moreover, the effect of increasing the heat flux and pressure on the propagation of the plastic zone are investigated. Furthermore, the effect of change in Poisson’s ratio on the value of the critical material parameter is demonstrated. The present study is also validated by comparing the numerical results for thick elasto-plastic spherical shells available in the literature. To the best of the authors’ knowledge, in previous studies, exact thermo-elasto-plastic behavior of FGM thick-walled spherical pressure vessels has not been investigated.

References listed at the end of the paper:


ABSTRACT: Modal analysis of rotating tapered cantilevered Timoshenko beams undergoing in-plane vibration is investigated. The coupling effect of axial motion and transverse motion is considered. The Kane dynamic method is applied to deriving the governing eigenvalue equations. The displacement and rotational angle components are approximately described by the products of Chebyshev polynomials and corresponding boundary functions. Chebyshev polynomials guarantee the numerical robustness while the boundary functions guarantee the satisfaction of the geometric boundary conditions. The excellent convergence of the present solution is exhibited. The results are compared with those available in literature, good agreement is observed. The parametric studies on modal characteristics are presented in detail. The tuned rotational speed is examined and the eigenvalue loci veering phenomenon along with the corresponding mode shapes is investigated.

References listed at the end of the paper:


ABSTRACT: When blood flows in vessel curved portion, the presence of curvature generates a centrifugal force that acts in the same manner as a compressive load. Therefore, blood flow velocity has an important effect on the stability of vessels. In this study, the blood vessel is simulated as a flexible beam conveying fluid on Euler–Bernoulli beam theory, and various boundary conditions are represented for the modeled vessels. Then, analytical and numerical methods are deployed to extract desired parameters. The effects of blood flow, hematocrit and stiffness of surrounding tissues on the buckling critical pressure are investigated. The results show that the mentioned parameters have considerable effects on blood vessels stability. Several numerical findings illustrate a reduction in critical buckling pressure with increasing hematocrit and blood flow velocity. In addition, the size of red blood cell has a significant effect on critical buckling pressure in low hematocrits. As increasing red blood cell diameter decreases critical buckling pressure. Furthermore, because of blood viscosity, the non-uniformity effects of the blood flow on blood vessels stability are investigated by considering a modification factor. These results improve our understanding of blood vessels instability.

References listed at the end of the paper:


ABSTRACT: The present work investigates the effects of the curvature terms in the three-dimensional (3D) equilibrium equations used for the free vibration analysis of functionally graded material (FGM) structures. The 3D equilibrium equations have been written in general orthogonal curvilinear coordinates which are valid for spherical shells. They automatically degenerate in those for cylindrical shells and plates considering one of the
two radii of curvature and both radii of curvature equal to infinite, respectively. The approximation of curvature terms in the 3D equilibrium equations has been evaluated by means of frequency analyses. Results obtained via 3D equilibrium equations with exact geometry have been compared with those calculated via 3D equilibrium equations written with the approximation of the curvature terms. The effects of the curvature approximations depend on the thickness and curvature of the structures, on the materials, lamination sequences and FGM laws, on the frequency orders and vibration modes. The resulting system of second order partial differential equations has been reduced into a system of first order partial differential equations redoubling the variables. Therefore, the exponential matrix method has been employed using a layer wise approach. The final 3D equations have been solved in exact form considering harmonic displacement components and simply supported structures. The approximation of the curvature terms has been introduced in the 3D equilibrium shell equations. For numerical reasons, interlaminar continuity conditions and the top and bottom boundary and loading conditions have been written including the exact geometry. The introduction of curvature approximations only in the equilibrium equations is sufficient to obtain an exhaustive qualitative analysis of the importance of curvature terms in the free vibration problems for FGM structures.

References listed at the end of the paper:

Yue Ding, Xin-Rui Niu and Gang-Feng Wang (First author is from: Department of Engineering Mechanics, SVL, Xi’an Jiaotong University, Xi’an 710049, P. R. China), “Compression of hyperelastic cells at finite deformation with surface energy,” International Journal of Applied Mechanics, Vol. 8, No. 6, 1650080, September 2016, https://doi.org/10.1142/S1758825116500800

ABSTRACT: In this paper, the compression of an isolated cell by two rigid indenters is analyzed. The neo-Hookean model is employed to characterize the hyperelastic behavior of biological cells. Owing to the greatly increased ratio between surface energy density and elastic modulus, surface energy plays important roles in the mechanical performance of biological cells. Using the dimensional analysis method and a finite element approach incorporating surface energy, we study the elastic compression of hyperelastic cells at finite deformation and give the explicit relations of contact radius and indent depth depending on compressive load. Our results reveal that surface energy obviously influences both the local deformation and the overall responses of hyperelastic cells at finite deformation. The obtained results are useful to determine the elastic properties of biological cells from indent-depth curves accurately.

References listed at the end of the paper:


ABSTRACT: In this paper, we present a theoretical and finite element framework for the inhomogeneous swelling of fiber-reinforced anisotropic hydrogels and investigate the effects of their orientations and moduli on the swelling behaviors of hydrogel bilayers. The effects of fibers on swelling are incorporated into the constitutive equations by introducing the corresponding energy contribution, expressed as the invariants related to the deformation of fibers, into the Flory–Rehner model. Unified constitutive equations and corresponding tangent moduli for anisotropic hydrogels reinforced with two families of fibers are deduced. A nonlinear finite element procedure is developed to simulate the inhomogeneous steady anisotropic swelling, where the chemical potential is prescribed in an incremental way. The accuracy and effectiveness of the numerical procedure are demonstrated by the anisotropic swelling of hydrogel blocks with one or two families of fibers. Based on the numerical procedure, many kinds of swelling configurations for hydrogel bilayers with different fiber orientations and modulus coefficients can be obtained, ranging from pure bending, twisting or saddle-like to combinations of them, which provide systematic guidance for the design of anisotropic-hydrogel based bilayers.

References listed at the end of the paper:


ABSTRACT: When exposed to a solvent, a gel bilayer beam can bend due to different swelling abilities of the two layers. In this work, an analytical model is derived to obtain the curvature of the bilayer beam. The model is further linearized to obtain an explicit expression for the curvature. The finite element model is used to verify the above analytical solutions. The results show the curvature predicted by the analytical model is in excellent agreement with the finite element results. The linear model predicts a smaller curvature at large swelling ratio. These results suggest the analytical models can provide a design metric for self-folding 3D structures.

References listed at the end of the paper:
Chenbo Fu, Yiwei Xu, Fan Xu and Yongzhong Huo (First author is from: Institute of Mechanics and Computational Engineering, Department of Aeronautics and Astronautics, Fudan University, 220 Handan Road, Shanghai 200433, P. R. China), “Light-induced bending and buckling of large-deflected liquid crystalline polymer plates”, International Journal of Applied Mechanics, Vol. 8, No. 7, 1640007, October 2016, https://doi.org/10.1142/S175882511640007X

ABSTRACT: Cross-linked liquid crystalline polymers (LCPs) are smart materials for large light-activated variation or bend to transfer luminous energy into mechanical energy. We study the light-induced behavior of homeotropic nematic network polymer plates. The perturbation method is applied to find approximate solutions under uniform illumination and compared with finite element simulations. Moreover, situations of nonuniform laser illumination are investigated. Unlike single solution obtained from small displacement assumption, multiple solutions within Föppl–von Kármán nonlinear geometry framework are found in the post-buckling regime and the effect of various boundary conditions is discussed. The nonuniform bending moment generated by the inhomogeneous light-induced strain, membrane force and boundary effects lead to the unconventional nonsymmetric buckling behavior that is rarely observed under traditional mechanical or thermal loading.

References listed at the end of the paper:

ABSTRACT: In this paper, post-buckling analysis of an edge cracked cantilever column subjected to non-follower axial compression loads are studied by using the total Lagrangian Timoshenko column element approximation. The cross-section of the column is circular. The cracked column is modeled as an assembly of two sub-column connected through a massless elastic rotational spring. In the case of columns subjected to compression loads, load rise causes compressible forces end therefore buckling and post-buckling phenomena occurs. It is known that post-buckling problems are geometrically nonlinear problems. The considered highly non-linear problem is solved considering full geometric nonlinearity by using incremental displacement-based finite element method in conjunction with Newton–Raphson iteration method. There is no restriction on the magnitudes of deflections and rotations in contradistinction to von-Karman strain–displacement relations of the column. The columns considered in numerical examples are made of lower-carbon steel. In the study, the effect of the cracks on the deflections, rotational angles, post-buckling configuration and Cauchy stresses of the columns are illustrated in detail in post-buckling case. The difference between cracked case and intact case is investigated in detail.

References listed at the end of the paper:


and nonlinear temperature distributions through the plate thickness are taken into account. A hybrid and trigonometric hyperbolic shear strain shape functions are introduced in normalized and non-normalized form in the mathematical model. The obtained results are compared with the classical polynomial ones for several order of expansion. Interesting approximations with 3D solution are shown for low and high order of expansion.

References listed at the end of the paper:


ABSTRACT: The present paper deals with the study of nonlinear vibration of a functionally graded cantilever micro-beam imposed on a bias DC voltage and superimposed on a sinusoidal heat source. The governing equation of motion is derived extremizing the Lagrange’s equation and Hamilton’s principal under the assumption of Euler–Bernoulli beam theory. The thermo-elastic equation is obtained utilizing the first law of thermodynamics under the assumption of the classical Fourier heat conduction model. Due to the displacement dependency of the electrostatic force and time variability of the heat source, the governing differential equations of the system are nonlinear implicitly parametrically electro-thermo-elastic coupled equations. To evaluate the dynamic response of the micro-beam, the coupled equations are discretized applying a Galerkin-based reduced order model and then integrated numerically by the Runge–Kutta method. By solving the equations, the stable and unstable regions at different bias DC voltages are identified. By picking some special points from these regions and depicting the time history and phase portrait diagrams, their behaviors are investigated in detail. In addition to the classical dynamic pull-in, in which a homoclinic orbit separates stable periodic orbits from the unbounded solutions, a new kind of dynamic pull-in is presented, which separates unstable solutions, due to parametric resonance response, from unbounded rapidly growing solutions owing to the existence of saddle and singular fixed points in the system.

References listed at the end of the paper:


ABSTRACT: In this paper, arbitrary boundary conditions including classical and elastic ones are considered in analyzing the vibration and damping characteristics of the sandwich conical shells and annular plates using a simple and efficient modified Fourier solution. The displacement field is expressed as the linear combination of a standard Fourier series and several supplementary terms. The addition of these terms make the Fourier series expansion applicable to any boundary conditions, and the Fourier series expansions improved drastically regarding its accuracy and convergence. Instead of adopting conventional differentiation procedure, a Rayleigh–Ritz technique based on the energy function is conducted which leads to a set of algebraic equations. Then natural frequencies and loss factors can be obtained by solving the algebraic equations. Accuracy and reliability of the current method are checked by comparing the present results with the existing solutions. Influences of some vital parameters on the free vibration and damping performance of sandwich shells and plates are discussed. The detailed effect of restraints from different directions on the frequencies and loss factors is investigated. So, the method can provide a guide to design sandwich structures with desired vibration characteristic and well damping performance by reasonably adjusting the boundary condition. Some new numerical results are presented for future validation of various approximate/numerical methods.

References listed at the end of the paper:
A general Fourier solution for the vibration analysis of composite laminated structure elements of revolution with general elastic restraints,” Composites Structures 109, 150–168.


Curved structures are common shapes used in practical engineering. In this paper, the large deflection behavior of a curved elastic nanobeam with rectangular cross-section under static bending is investigated. Surface stresses in the curved nanobeam are considered as an external load and derived on the basis of the general Young–Laplace equation. The governing equations for the large deflection of the curved nanobeam with surface effect are established. By using the shooting method, the boundary value problem is solved numerically. Some numerical examples are given for cantilever, simply supported, and fixed–fixed nanobeams with positive and negative residual surface stresses. It is found that nanobeams in the presence of surface effect may be stiffer or more flexible, which is related to the residual surface stress, initial curvature of the nanobeam, the externally applied load, and boundary conditions. For nanobeams with smaller cross-sectional sizes, the height of the nanobeam can affect the deflection of the nanobeam considerably and the influence of the width of the nanobeam is negligible. The findings in the present investigation are helpful in understanding the mechanical behavior of curved nanobeams with surface effects.

References listed at the end of the paper:
Yan Qing Wang and Jean W. Zu (First author is from: Department of Mechanics, Northeastern University, Shenyang 110819, P. R. China), “Instability of viscoelastic plates with longitudinally variable speed and immersed in ideal liquid”, *Int. J. Appl. Mechanics* **09**(1), 1750005 (2017) [38 pages], January 2017 [https://doi.org/10.1142/S1758825117500053](https://doi.org/10.1142/S1758825117500053)

**ABSTRACT:** The instability of longitudinally variable speed viscoelastic plates in contact with ideal liquid is studied for the first time. The effect of free surface waves is taken into account in the present study. The viscoelasticity is considered by using the Kelvin–Voigt viscoelastic constitutive relations. The classical theory of thin plate is utilized to derive the governing equation of variable speed plates. The fluid is assumed to be incompressible, inviscid and irrotational. Additionally, the velocity potential and Bernoulli’s equation are utilized to describe the fluid pressure acting on the vibrating plates. The fluid effect on the vibrational plates is described as the added mass of the plates which can be formulated by the kinematic boundary conditions at the structure–fluid interfaces. Parametric instability is analyzed by directly applying the method of multiple scales to the governing partial-differential equations and boundary conditions. The unstable boundaries are derived from the solvability conditions and the Routh–Hurwitz criterion for principal parametric, sum-type and difference-type combination resonances. Based on the numerical simulation, the effects of some key parameters on the unstable boundaries are illustrated in the excitation frequency and excitation amplitude plane in detail.

**References listed at the end of the paper:**

Atteshamuddin S. Sayyad and Yuwaraj M. Ghugal (First author is from: Department of Civil Engineering, SRES’s Sanjivani College of Engineering, Savitribai Phule Pune University, Kopargaon-423601, Maharashtra, India), “A unified shear deformation theory for the bending of isotropic functionally graded, laminated and sandwich beams and plates,” Int. J. Appl. Mechanics 09(1), 1750007 (2017) [36 pages], January 2017 https://doi.org/10.1142/S1758825117500077

ABSTRACT: In this paper, a displacement-based unified shear deformation theory is developed for the analysis of shear deformable advanced composite beams and plates. The theory is developed with the inclusion of parabolic (PSDT), trigonometric (TSDT), hyperbolic (HSDT) and exponential (ESDT) shape functions in terms of thickness coordinate to account for the effect of transverse shear deformation. The in-plane displacements consider the combined effect of bending rotation and shear rotation. The use of parabolic shape function in the present theory leads to the Reddy’s theory, but trigonometric, hyperbolic and exponential functions are first time used in the present displacement field. The present theory is accounted for an accurate distribution of transverse shear stresses through the thickness of plate, therefore, it does not require problem dependent shear correction factor. Governing equations and associated boundary conditions of the theory are derived from the principle of virtual work. Navier type closed-form solutions are obtained for simply supported boundary conditions. To verify the global response of the present theory it is applied for the bending of both one-dimensional (beams) and two-dimensional (plates) functionally graded, laminated composite and sandwich structures. The present results are compared with exact elasticity solution and other higher order shear deformation theories to verify the accuracy and efficiency of the present theory.

References listed at the end of the paper:

CUF approach, differential geometry and differential quadrature method for shells with variable radii of curvature using layerwise theories of Elastic Plates (Academia, Prague).


Mohammed Sobhy and Ahmed F. Radwan (First author is from: Department of Mathematics and Statistics, Faculty of Science, King Faisal University, P. O. Box 400, Hofuf 31982, Saudi Arabia), “A new quasi 3D nonlocal plate theory for vibration and buckling of FGM nanoplates”, *Int. J. Appl. Mechanics* **09**(1), 1750008 (2017) [29 pages], January 2017
https://doi.org/10.1142/S1758825117500089

**ABSTRACT:** This paper presents the analyses of free vibration and buckling of functionally graded (FG) nanoplates in thermal environment by using a new quasi-3D nonlocal hyperbolic plate theory in which both shear and normal strains are included. The nonlocal equations of motion for the present problem are derived from Hamilton’s principle. For simply-supported boundary conditions, Navier’s approach is utilized to solve the motion equations. Eringen’s nonlocal theory is employed to capture the effect of the nonlocal parameter on natural frequency and buckling of the FGM nanoplates. Numerical results of the present formulation are compared with those predicted by other theories available in the open literature to explain the accuracy of the suggested theory that contains the shear deformation and thickness stretching. Other numerical examples are also presented to show the influences of the nonlocal coefficient, power law index and geometrical parameters on the vibration and buckling load of FGM nanoplates.

**References listed at the end of the paper:**


Mohammad Zamani Nejad, Tahereh Taghizadeh, Saeed Jafari Mehrabadi and Saeed Herasati (First author is from: Mechanical Engineering Department, Yasouj University, P. O. Box 75914–353, Yasouj, Iran), “Elastic

https://doi.org/10.1142/S1758825117500119

**ABSTRACT:** This paper investigates the deflection and stress behavior of composite plates reinforced by single-walled carbon nanotubes (SWCNTs) with piezoelectric layers which are under transverse mechanical load. Two kinds of carbon nanotube-reinforced composite (CNTRC) plates, namely uniformly distributed (UD) and functionally graded (FG) along the plate thickness, are considered. The extended rule of mixture approach is used to estimate the effective material properties. The governing equations are derived using the Hamilton approach based on the first-order shear deformation plate theory (FSDT) and third-order shear deformation plate theory (TSDT). In addition, the Navier technique is employed to obtain the deflection and stress response of the nanocomposite plates. The results of present work are also compared with those available in the literature and show good agreement. The effects of applied force, volume fraction of CNT, distribution of CNT, thickness of piezoelectric layer, thickness to width ratio and aspect ratio on the static behavior are studied. In previous studies, deflection and stress analysis of nanocomposite plate with piezoelectric layers based on third-order shear deformation plate theory has not investigated.

**References listed at the end of the paper:**
Yu Wang and Guangyu Shi (Department of Mechanics, Tianjin University, 135 Yaguan Road, Tianjin 300354, P. R. China), “Simple and accurate eight-node and six-node solid-shell elements with explicit element stiffness matrix based on quasi-conforming element technique”, International Journal of Applied Mechanics, Vol. 9, No. 1, 1750012, January 2017, https://doi.org/10.1142/S1758825117500120

ABSTRACT: Based on the quasi-conforming (QC) element technique, accurate and reliable eight-node and six-node solid-shell elements are presented in this paper. These QC solid-shell elements can alleviate shear and Poisson thickness locking by appropriately interpolating the strain fields over the element domain, and they are completely free from hourglass modes by ensuring the rank sufficiency of the element stiffness matrix a priori. Furthermore, the element stiffness matrices of the present elements are evaluated explicitly rather than resorting to the numerical integration, which leads to a high computational efficiency. The QC solid-shell elements with the properly interpolated element strain fields can rigorously pass both membrane and bending patch tests. The popular benchmark problems are used to evaluate the performance of the QC solid-shell elements. The numerical results show that the present QC solid-shell elements yield not only accurate displacements but also good stress results for all the stress components. Particularly, the present QC solid-shell elements are capable of giving quite accurate results even with very coarse mesh.

References listed at the end of the paper:


ABSTRACT: The modal synthesis method is frequently used for the analysis of large structures composed of multiple parts concerning dynamic aspects. In this paper, we extended the modal synthesis method under the isogeometric analysis framework. The isogeometric Kirchhoff--Love shell elements are used for the analysis of the substructures, the Craig--Bampton method is used for the modal synthesis and the bending-strip method is used for the substructures coupling. We give examples on the modal analysis and the harmonic response analysis. The results show the effectiveness of the method.

References listed at the end of the paper:


Zhen Lei, Frederic Gillot, and Louis Jezequel (First author is from: Key Laboratory for Road Construction Technology and Equipment, Chang’an University, Xi’an 710064, P. R. China), “Modal synthesis with the isogeometric Kirchhoff-Love shell elements”, *Int. J. Appl. Mechanics* **09**(2), 1750017 (2017) [19 pages], March 2017

https://doi.org/10.1142/S175882511750017X
Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, Vol. 229, pp. 1

Embedded DWCNT conveying fluid under magnetic field with slip conditions considerati


Ali Ghorbanpour Arani and Elham Haghiparast (Faculty of Mechanical Engineering, Institute of Nanoscience & Nanotechnology, University of Kashan, Kashan, Iran), “Size-dependent vibration of axially moving viscoelastic micro-plates based on sinusoidal shear deformation theory”, Int. J. Appl. Mechanics 09(2), 1750026 (2017) [20 pages], March 2017

https://doi.org/10.1142/S1758825117500260

ABSTRACT: In the present research, vibration and instability of axially moving viscoelastic micro-plate is investigated. Sinusoidal shear deformation theory (SSDT) is utilized due to its accuracy of polynomial functions than other plate theories. Based on Kelvin’s model, the viscoelastic structural properties of micro-plate are taken into consideration. The modified couple stress theory (MCST) is employed because of its capability to interpret the size effect. Using Hamilton’s principle, equations of motion are obtained and solved by hybrid analytical–numerical solution at different boundary conditions. Influences of various parameters such as size effect, axially moving speed, viscoelastic structural damping coefficient, thickness and aspect ratio on the vibration characteristics of moving viscoelastic micro-plate are discussed in detail. The results indicated that the critical speed of moving micro-plate is strongly dependent on the aspect ratio, therefore, the low aspect ratio should be considered for optimum design of this kind of moving micro-devices. The results of this investigation can be used in design and manufacturing of axially moving systems at the micro-scale such as micro-magnetic tapes.

References listed at the end of the paper:


Sha Zhou, Tian-Jun Yu, Xiao-Dong Yang and Wei Zhang (First author is from: Beijing Key Laboratory of Nonlinear Vibrations and Strength of Mechanical Structures, College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, P. R. China), “Global dynamics of pipes conveying pulsating fluid in the supercritical regime”, Int. J. Appl. Mechanics 09(2), 1750029 (2017) [22 pages], March 2017

https://doi.org/10.1142/S1758825117500296

ABSTRACT: Global dynamics of supercritical pipes conveying pulsating fluid considering superharmonic resonance of the second mode with 1:2 internal resonance are investigated. The governing partial differential equations in the supercritical regime are obtained based on the nontrivial equilibrium configuration of the pipes conveying fluid and then transformed into a discretized nonlinear gyroscopic system via assumed modes and Galerkin’s method. The method of multiple scales and canonical transformation are applied to reduce the equations of motion to the near-integrable Hamiltonian standard form. The energy-phase method is employed to demonstrate the existence of chaotic dynamics by identifying the existence of multi-pulse jumping orbits in the perturbed phase space. The global solutions are subsequently interpreted in terms of the physical motion of such gyroscopic system. Two types of nonlinear normal modal motion and the chaotic pattern conversion between the locked simple bidirectional traveling wave motion and the complex bidirectional traveling wave motion are discussed.

References listed at the end of the paper:


Yaghouh Tadi Beni and Fahimeh Mehralian (Faculty of engineering, Shahrekord University, Shahrekord, Iran), “Size-dependent torsional buckling of carbon nano-peapods based on the modified couple stress theory”, Int. J. Appl. Mechanics 09(2), 1750030 (2017) [30 pages], March 2017
https://doi.org/10.1142/S1758825117500302

ABSTRACT: Using the modified couple stress theory and the shell model, this paper investigates the torsional instability of carbon nano peapods (CNPs), which are the hybrid structures made by inserting C_{60} fullerenes into CNT. Based on the modified couple stress theory as a higher order elasticity theory and using the first-order shear deformation shell theory, the equilibrium equations are derived through the principle of the minimum potential energy. The critical torsional moment is determined for the (10,10) CNT and the C_{60}(10,10) CNP, and compared with that of MD simulations in the literature. Then, the increase in critical torsional moment is represented with the increase in the length scale parameter in both (10,10) CNT and C_{60}(10,10) CNP based on the modified couple stress theory. Besides, by comparing the critical torsional moment in the C_{60}(10,10) CNP and the (10,10) CNT, 100 percent increase in buckling resistance due to the presence of C_{60} fullerene is exhibited as well. In addition, the CNP surrounding is modeled as Pasternak foundation, and the effects of Pasternak stiffness are shown on the critical torsional moment.

References listed at the end of the paper:


https://doi.org/10.1142/S1758825117500326

ABSTRACT: A hybrid nanotube (HNT) is fabricated by coating carbon nanotubes (CNTs) with a concentric coating layer. Vibration of the HNTs is of great interest due to its potential applications in nano-resonators, nanosensors/actuators and nanogenerators. In particular, it is expected that the super stiff but very light CNTs would largely up-shift the vibration frequency and improve the performance of the achieved nanodevices. On the other hand, the hybrid structures may lead to the defects at the CNT-coating layer interface, which would down-shift the frequency and impair the integrity of the HNT. This paper aims to examine these issues by using a multiple-beam model for the pristine HNTs and a finite element model for the defective ones. The frequencies are obtained for the first five modes of the HNTs reinforced by a single-wall or a multi-wall CNT. It was shown that the strengthening effect of the CNTs is substantial for the high frequency vibrations of the HNTs with a thin coating layer. In this case, the inverse effect of the interfacial defects can also be observed.

References listed at the end of the paper:


Dengbao Xiao and Guiping Zhao (State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace, Xi’an Jiaotong University, Xi’An 710049, P. R. China), “Influence of gradient metallic cellular core on the indentation response of sandwich panels,” International Journal of Applied Mechanics, Vol. 9, No. 3, 1750035, April 2017, https://doi.org/10.1142/S1758825117500351

ABSTRACT: The characteristics of gradient metallic cellular materials vary along its thickness direction. Under quasi-static compression, the crushing stress of gradient cellular materials cannot be simplified as a constant before the cellular materials are all crushed. To calculate the crushing stress of gradient metallic cellular material, a new formula associate with strain hardening for gradient cellular materials is presented. Subsequently, an analytical model is developed to investigate the plastic indentation response of the sandwich panel with gradient metallic cellular core. Finite element (FE) simulation is carried out in order to verify the analytical results. Finally, the influences of gradient cellular cores with equivalent mass, in which two types of gradients: linear mass density and linear plateau stress distributions are considered, on the response of sandwich panels are further investigated. And the results show that the plastic energy due to compressive deformation of the gradient cellular core with the linear mass density is larger than that of the gradient cellular core with linear plateau stress under the same indentation.

References listed at the end of the paper:


ABSTRACT: Large-deflection bending of fully clamped slender metal foam-filled rectangular tubes is investigated theoretically, experimentally and numerically. A plastic yield criterion for the foam-filled rectangular tube is proposed. Considering the filled foam strength effect and the interaction of bending and stretching, an analytical solution is proposed to predict the structural response of the foam-filled rectangular tubes transversely loaded by a flat punch. Clamped bending tests of aluminium alloy foam-filled rectangular tubes are conducted. The analytical model captures experimental results reasonably. Numerical calculations are carried out to predict the large-deflection behavior of the foam-filled tubes, and good agreement is achieved between the analytical solutions and numerical results. The effects of wall thickness of tube, punch size and filled foam strength are discussed in detail. It is demonstrated that the present analytical model can reasonably predict the post-yield behavior of the foam-filled rectangular tube.
References listed at the end of the paper:


Kulmani Mehur, Subrata Kumar Panda, and Bhumesh Kumar Patle (First author is from: National Institute of Technology, Rourkela, Odisha 769008, India), “Thermoelastic vibration and flexural behavior of FG-CNT

**ABSTRACT:** The free vibration and flexural behavior of functionally graded carbon nanotube reinforced composite curved panel is investigated under uniform and linear thermal environment. The carbon nanotube reinforced composite curved panel has been modeled mathematically based on the higher-order shear deformation theory. The nanotube properties are assumed to be depended on the temperature and graded in the thickness direction using different grading rules. The governing equations for the static and vibration analysis of the functionally graded carbon nanotube reinforced composite panel are obtained using the variational method. Further, isoparametric finite element steps are implemented for the discretization of the governing equation and solved numerically via a specialized computer code developed in MATLAB environment. The rate of convergence and the validity of the presently developed numerical model have been checked. Finally, the effect of different geometrical and material parameters (thickness ratios, support conditions, volume fractions, thermal load, aspect ratios, and type of grading) on the free vibration and flexural behavior of functionally graded carbon nanotube reinforced composite are examined and discussed detail under thermal environment.

**References listed at the end of the paper:**
ABSTRACT: This paper focuses on the dynamic behavior of composite anisogrid lattice conical shells. Lattice composite conical shell consists of composite helical and circumferential ribs and thin outer skin. The free vibration analysis of anisogrid composite lattice conical shell is presented. A smeared method is employed to calculate the variable coefficients of stiffness of conical shell and more close to the realistic applications. The lattice part of conical shell is modeled as a beam, so in addition to the axial loads, ribs endure shear loads and bending moments. The first-order shear deformation shell theory is used to account for the effects of transverse shear deformations and rotary inertia. The current results are verified with 3D finite element model of conical shell by ANSYS Software and those reported in the literature. Some special cases as influences of geometric parameters of lattice part of shell, effects of boundary conditions and circumferential wave number on natural frequencies of the shell are discussed. It was concluded that employment of the smear method could be recommended for determining the coefficients of stiffness of the composite lattice conical shells with outer skin. Also increasing the vertex angle of cone increases the natural frequencies of conical shell.

References listed at the end of the paper:


Hu Ding, Minghui Zhu, Zhen Zhang, Ye-Wei Zhang and Li-Qun Chen (First author is from: Shanghai Institute of Applied Mathematics and Mechanics, Shanghai Key Laboratory of Mechanics in Energy Engineering, Shanghai University, Shanghai 200072, P. R. China), “Free vibration of a rotating ring on an elastic foundation”, International Journal of Applied Mechanics, Vol. 9, No. 4, 1750051, June 2017, https://doi.org/10.1142/S175882511750051X

ABSTRACT: In the present paper, free vibration of a rotating ring supported by an elastic foundation is studied by analytical method, finite element (FE) simulation and experiment. By adopting the ring analogy of Timoshenko beam theory, the nonlinear vibration of the rotating ring on an elastic foundation is modeled based on Hamilton’s principle. Radial and tangential deformation are considered. By solving the generalized eigenvalue problem, natural frequencies and flexural modes are obtained. Furthermore, the Euler–Bernoulli (E–B) theory is also employed to investigate the free vibration. For determining the necessity of the Timoshenko theory, the flexural vibration frequencies from two theories are compared. Specifically, the effects of the radius and the radial height (the thickness) of the ring on the difference between the two models are studied. In order to confirm the analytical results, finite element analysis and experiments on three test specimens are used to verify the natural frequency and flexural mode predictions. Overall, this work shows the necessity of the Timoshenko theory for studying free vibration of an elastic ring.

References listed at the end of the paper:

ABSTRACT: This paper aims to investigate the postbuckling behavior of piezoelectric microbeams (PMBs) using a modified couple stress theory (MCST) and a Euler–Bernoulli–von Kármán beam model. The critical buckling force, voltage and the deformation amplitude were calculated for the buckling of the axially compressed microbeams with a clamp–clamp boundary condition. It is found that the stiffness of microbeams considering the MCST is higher than that given by the classical model when the feature size decreases to the microscale. Moreover, the microscale size effect has a strong influence on the critical buckling loads and the amplitude of postbuckling deformation. This study brings an improved understanding of the postbuckling behavior of PMBs, and offers useful guidance for the design of piezobeam-based sensors, actuators and stretchable microelectronics.

References listed at the end of the paper:
Yan Qing Wang and Jean W. Zu (First author is from: Department of Mechanics, Northeastern University, Shenyang 110819, P. R. China), “Nonlinear dynamics of functionally graded material plates under dynamic liquid load and with longitudinal speed,” International Journal of Applied Mechanics, Vol. 9, No. 4, 1750054, June 2017. This paper investigates the dynamics of functionally graded material (FGM) plates under dynamic liquid load and with longitudinal speed. The liquid is assumed to be ideal so that it is incompressible, inviscid and irrotational. Based on the D’Alembert’s principle, the mathematical model of the system is developed by taking into account geometrical and material nonlinearities as well as velocity potential and Bernoulli’s equation. The Galerkin method is employed to discretize the partial differential governing equation to a series of ordinary differential ones, which are then analyzed via the use of the method of harmonic balance. Analytical results are compared with numerical ones to validate the present method. The stability of the steady-state response is examined by means of the perturbation technique. Linear analysis of the system shows the possible appearance of internal resonance, and nonlinear frequency-response curves demonstrate strong hardening-spring property of the system. A modal interaction behavior through 1:1 internal resonance is detected; the behavior can happen in a wide domain of constituent volume fraction, which is a unique phenomenon in moving FGM plates compared with their metallic counterparts. Furthermore, results show the modal interaction can be easily evoked in the moving FGM plate under dynamic liquid load, even while the plate is subjected to minimal exciting force or large damping. In addition, influence of the plate location on nonlinear dynamics of the system is examined; results show the dynamic response of the plate will change considerably when the plate is near the container wall.

References listed at the end of the paper:


https://doi.org/10.1142/S1758825117500557

ABSTRACT: In this paper, discrete shear gap method (DSG)-based central point of the three-node triangular element (CP-DSG3) is presented for both linear and geometrically nonlinear analysis of plates and shells. A fictitious central point is introduced as the base point of the DSG to overcome the anisotropy of the formerly
proposed formulation. In the CP-DSG3, the discrete shear gap at each field node is deduced using rotations of all three nodes in local coordinate system, which makes it an isotropic triangular plate and shell element. At the same time, the CP-DSG3 inherits the advantages of shear-locking-free from the DSG. Moreover, a series of numerical examples consisting of standard patch test, linear and geometrically nonlinear problems have been investigated and the results demonstrate the excellent performance and accuracy of the proposed CP-DSG3.

References listed at the end of the paper:

https://doi.org/10.1142/S1758825117500569

ABSTRACT: Flexoelectricity, a spontaneous polarization in linear response to strain gradients or non-uniform deformation, is believed to contribute to the size-dependent electromechanical coupling of piezoelectric materials at the nanoscale. In the current work, the flexoelectric effect upon the static bending behaviors of a cantilevered piezoelectric nanoplate (PNP) is studied. Based on the Kirchhoff plate model and the extended linear piezoelectric theory, the non-conventional governing equations and the boundary conditions of the PNP under both mechanical and electrical loads are derived with the incorporation of the flexoelectric effect. Finite difference method (FDM) is performed to get the numerical solution for the electrostatic fields of the plate. Simulation results show that the flexoelectric effect is more prominent for the thinner plates with smaller thickness. It is also found that the flexoelectric effect upon the electrostatic responses of the clamped PNP is also sensitive to some other factors, including the boundary conditions, the plate geometric ratio, and the applied mechanical and electrical loads. This work aims to provide an increased understanding of the size-dependent electromechanical coupling properties of a piezoelectric plate structure.

References listed at the end of the paper:
The absorption capacity of origami crash box. The complete diamond mode could be successfully triggered, which

https://doi.org/10.1142/S1758825117500661

ABSTRACT: The origami crash box has been recognized as an efficient energy absorption device. In this paper, quasi-static axial compression tests and numerical simulations are carried out to investigate the energy absorption capacity of origami crash box. The complete diamond mode could be successfully triggered, which
indicates that this collapse mode is insensitive to geometric imperfection when the tube is subjected to quasi-static loading. And the results confirm that axially compressed tubes with longer modules \( (d/r=60) \) renders higher mean crushing force than those with short modules \( (d/r=40) \). Moreover, in order to figure out the energy dissipation percentage of each region in origami crash box, the plastic deformation of shells in two representative regions is measured and analyzed by utilizing electrical measurement and noncontact optical measurement. The results reveal that about 10% of total energy is absorbed by those shells, which is large enough to affect the prediction accuracy of expressions deduced by super folding element theory.

References listed at the end of the paper:


ABSTRACT: The static instability of functionally graded carbon nanotube-reinforced composite (FG-CNTRC) beam in the presence of the material and geometrical uncertainties is investigated. By utilizing the extended rule of mixture, the mechanical properties of nanocomposite beam are estimated, and critical buckling loads are obtained by the use of Galerkin’s method. To take propagation of uncertain variables into account, a nonprobabilistic approach is employed. The suggested model is justified by a great agreement between the obtained results and available data in the literature. The most prominent uncertain variables are distinguished based on a sensitivity analysis. Furthermore, the influence of volume fraction of the carbon nanotube on the upper and lower bounds of uncertain buckling load and uncertainty propagation percent of FG-CNTRC beam is examined.

References listed at the end of the paper:


https://doi.org/10.1142/S1758825117500727.

ABSTRACT: The study of the dynamic behavior of a membrane in contact with a fluid is interesting due to the numerous applications in technology. The vibro-acoustic behavior of a circular membrane in a cylindrical container or a membrane drum filled with a nonviscous fluid is analyzed. A boundary element method is used and the acoustic pressure over the boundary is calculated employing the Kirchhoff’s integral equation and that with the equation of motion of the membrane, the natural frequencies of vibration are obtained. Furthermore, the effect of the drum height, drum radius, membrane material density, tension parameter and fluid density on the frequencies are evaluated, as well as the variation of the fluid mass coefficient with the wave number. Validation of the method is made comparing the results with those obtained by other authors and theories.

References listed at the end of the paper:


ABSTRACT: The purpose of this study is to investigate the thermal effects on the free vibration of functionally graded (FG) porous deep beams. Mechanical properties of the FG deep beam are temperature-dependent and vary across the height direction with different porosity models. The governing equations problem is obtained by using the Hamilton’s principle. In the solution of the problem, plane piecewise solid continua model and finite element method are used. The effects of porosity parameters, material distribution, porosity models and temperature rising on the vibration characteristics are presented and discussed with porosity effects for FG deep beams.

References listed at the end of the paper:

of Applied Mechanics 40(03), 1250026.


ABSTRACT: This paper studies stress distribution in a single-walled carbon nanotube (SWCNT) under internal pressure with various chirality. Strain gradient theory is used to capture the size-dependent behavior of the SWCNT. Minimum total potential energy principle is successfully applied to derive the governing differential equation and its associated boundary conditions. Due to complexity of the governing differential equation and boundary conditions, numerical scheme is used to solve the problem. Comparing the results based on strain gradient theory and that of classical elasticity shows a major difference between these two methods. However, a
close examination of the results indicates that both theories predict the same trend for variations in the radial displacement along the SWCNT radius. Numerical results also indicate that the proposed model can lead into the classical elasticity model, provided the material length scale parameters are taken to be zero. Additionally, for plane strain condition, the radial displacements predicted by strain gradient theory are lower than those predicted by classical elasticity theory. Moreover, numerical results show that in a SWCNT, the non-dimensional radial and circumferential stresses along the wall thickness of the SWCNT increase as the radius is increased. The opposite behavior is true for non-dimensional high-order stresses.

References listed at the end of the paper:
ABSTRACT: A wavelet-decomposed Rayleigh–Ritz model for 2D plate vibration analyses is proposed in this work. For an elastically-supported rectangular plate under Love–Kirchhoff theory, 2D Daubechies wavelet scale functions are used as the admissible functions for analyzing the flexural displacement in an extremely large frequency range. For constructing the mass and stiffness matrices of the system, the 2D wavelet connection coefficients are deduced. It is shown that by inheriting the versatility of the Rayleigh–Ritz approach and the superior fitting ability of the wavelets, the proposed method allows reaching very high frequencies. Validations are carried out in terms of both eigen-frequencies and the forced vibration responses for cases which allow analytical solutions. Effects of the wavelet parameters on the calculation accuracy and convergence are also studied.

References listed at the end of the paper:


ABSTRACT: This paper presents an adaptive continuation method for buckling topology optimization of continuum structures considering buckling constraints, "International Journal of Applied Mechanics 9(5), 792–806.

Rule, an effective scheme is developed for determining th optimization process, a rule is established to determine the appropriate penalization parameter values. Using this investigation on the effect of the penalization parameter on design evolution during the

Based on an investigation on the effect of the penalization parameter on design evolution during the optimization process, a rule is established to determine the appropriate penalization parameter values. Using this rule, an effective scheme is developed for determining the penalization parameter values such that the buckling constraints are appropriately considered throughout the optimization process. Numerical examples are presented to illustrate the effectiveness of the proposed method.

References listed at the end of the paper:


Conjunction with APCOM'04

Numerical Methods in Engineering

· Circular plate by reduced order finite element analysis

· Structural Optimization

· Design method

· Density elements in topology optimization with large deformation

· Multidisciplinary Optimization

· Optimization method

· 157

Chinese Journal of Theoretical and Applied Mechanics

· Multiple eigenfrequencies and frequency gaps

· Constraint circuit analog absorber core

· Mechanics Sinica

· Journal of Applied Mechanics

· Engineering

·...
ABSTRACT: Both functionally graded materials (FGMs) and fluid-conveying pipes have wide applications in engineering communities. In this paper, the transverse vibration and stability of multi-span viscoelastic FGM pipes conveying fluid are investigated. Volume fraction laws including power law, sigmoid law and exponential law are introduced to describe the variations of material properties in FGM pipes. A hybrid method which combines reverberation-ray matrix method and wave propagation method is developed to calculate the natural frequencies, and the results determined by present method are compared with the existing results in literature. Then, a comparative study is performed to investigate the effects of fluid velocity, volume fraction laws and internal damping on transverse vibration and stability of the FGM pipes conveying fluid. The results demonstrate that the present method has high precision in dynamic analysis of multi-span pipes conveying fluid. It is also found that natural frequencies of FGM pipes can be adjusted by devising the volume fractions laws. This particular feature can be tailored to fulfill the special applications in engineering.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: In this paper, forced vibration responses of functionally graded (FG) nanobeams are presented for modified couple stress theory (MCST) with damping effect. The FG nanobeam is excited by a transverse triangular force impulse modulated by a harmonic motion. Mechanical properties of FG beam depends on the position. The Kelvin–Voigt model is considered in the damping effect. In solution of the dynamic problem, finite element method is used within Timoshenko beam theory. The obtained system of differential equations is reduced to a linear algebraic equation system and solved in the time domain by using Newmark average acceleration method. Influences of the geometry and material parameters on forced vibration responses of FG nanobeams are examined and discussed.

References listed at the end of the paper:
in asymmetric composite beams with structural discontinuities


The effects of thermal environment, including uniform, linear and nonlinear temperature distribution across the shell thickness. Governing equations are derived based on the Donnell’s thin shell theory. Material properties of the FGM are assumed to be variable through the shell thickness according to a power law function. Discretization of the obtained governing equations is performed using the Galerkin’s method. An averaging method and the Runge–Kutta method are applied to obtain the frequency–amplitude relation and time–deflection relation, respectively. Comprehensive numerical results are given for investigating the effects of thermo-mechanical loads, material and geometrical properties and nonlinear elastic foundation parameters on nonlinear dynamic characteristics of the functionally graded cylindrical shells (FGCSs). Present formulations are validated by comparing the results with the published data for some specific cases. References listed at the end of the paper:

Employing an efficient numerical strategy, the nonlinear forced vibration analysis of composite cylindrical shells reinforced with single-walled carbon nanotubes (CNTs) is carried out. It is assumed that the distribution of CNTs along the thickness direction of the shell is uniform or functionally graded and the temperature dependency of the material properties is accounted. The governing equations are presented based on the first-order shear deformation theory along with von-Karman nonlinear strain-displacement relations. The vectorized form of energy functional is derived and directly discretized using numerical differential and integral operators. By the use of variational differential quadrature (VDQ) method, discretized nonlinear governing equations are obtained. Then, the time periodic differential operators are applied to perform the discretization procedure in time domain. Finally, the pseudo-arc length continuation method is employed to solve the nonlinear governing equations and trace the frequency response curve of the nanocomposite cylindrical shell. A comparison study is first presented to verify the efficiency and validity of the proposed numerical method. Comprehensive numerical results are then given to investigate the effects of the involved factors on the nonlinear forced vibration characteristics of the structure. The results show that the changes of fundamental vibrational mode shape have considerable effects on the frequency response curves of composite cylindrical shells reinforced with CNTs.

References listed at the end of the paper:
Feng Liang, Xiao-Dong Yang, Ying-Jing Qian and Wei Zhang (First author is from: College of Mechanical Engineering and Applied Electronics, Beijing University of Technology, Beijing 100124, P. R. China), “Free vibration analysis of pipes conveying fluid based on linear and nonlinear complex modes approach”, International Journal of Applied Mechanics, Vol. 9, No. 8, 1750112, December 2017, https://doi.org/10.1142/S1758825117501125

ABSTRACT: In this paper, linear and nonlinear complex modes are used to analyze the free vibration of pipes conveying fluid involving the gyroscopic properties of the system. The natural frequencies, complex mode functions and time domain responses of the admissible mode functions based on discretized model are obtained using the invariant manifold method and compared with those of the continuous model. A good agreement has been achieved if the admissible mode functions for the static beams are adopted. The energy contributions of different admissible modes to the modal motions are also studied which explores the gyroscopic coupling variation among the admissible modes for different fluid velocities. Nonlinear complex modes are constructed for the nonlinear case and the morphology of the modal motions is demonstrated for different initial energy to show the contribution of the nonlinear terms. ‘Traveling waves’ are found for the transverse vibrations of the pipes conveying fluid due to the gyroscopic effects, contrary to the “standing waves” found for the pipes without moving fluid.

References listed at the end of the paper:


ABSTRACT: The transient response of a circular nanoplate subjected to the normal impact by a nanosphere (e.g., Co) is investigated theoretically. The nanoplate is modeled by the Kirchhoff thin plate theory. Gurtin–Murdock’s theory is employed to account for the surface effects of the nanoplate with surface elasticity and surface residual stress. The van der Waals interaction between the nanosphere and the nanoplate is also taken into account. The governing equations for the vibration of the nanoplate impinged by a rigid nanoplate are established by using the Hamilton’s principle. The displacement field in the circular nanoplate is obtained by using the Fourier–Bessel expansion method. We reveal some physical mechanisms in the nanoimpact problem that are different from those in macroscopic impact problems, and surface effects have pronounced influences on the dynamic responses of a plate when its thickness shrinks to a few nanometers.

References listed at the end of the paper:

panels under transverse loading · matrix composites · pyramidal truss cores · with carbon fiber pyramidal truss cores · cores in three References listed at the end of the paper: the collapse of the sandwich structure. cracking occurred in struts sequentially. Finally, delamination took place at junctions and struts and it triggered the collapse of the sandwich structure.

References listed at the end of the paper:


Yanfei Chen, Shigang Ai, Rujie He, Kai Wei and Daining Fang (First author is from: College of Civil Engineering and Transportation, South China University of Technology, Guangzhou 510640, P. R. China), “A study on the compressive performance of C/SiC lattice sandwich panel at high temperature”, International Journal of Applied Mechanics, Vol. 9, No. 8, 1750120, December 2017, https://doi.org/10.1142/S1758825117501204

ABSTRACT: In this study, the mechanical properties and failure behaviors of a C/SiC lattice sandwich panel were investigated by numerical simulation approach. On the bases of Hashin’s criteria, a novel failure criterion for 2D C/SiC textile composite was proposed. An UMAT subroutine based on Abaqus code was constructed to demonstrate the fracture mechanism of the C/SiC composite, in which fiber fracture and buckling, matrix failure and the laminate delamination were considered. Out-of-plane compressive experiments of the C/SiC lattice sandwich panels at room temperature were performed to give verifications of the numerical programmer. Based on the simulation method proposed, the mechanical properties and failure features of the C/SiC lattice sandwich panels at high temperatures were studied. It was found that the junction between struts and the panels of the core firstly damaged due to fiber rupture and matrix cracking. Then fiber tensile fracture and matrix cracking occurred in struts sequentially. Finally, delamination took place at junctions and struts and it triggered the collapse of the sandwich structure.

References listed at the end of the paper:

vibration frequencies and the negative stiffness. Consequently, determining the natural frequencies becomes a

species of a beam subjected to a given concentrated force and subsequently deduce the possible infinite deflection when

specifically, the basic governing equation for beams with harmonic loadings and resting on an elastic

foundation is solved and the solution is used directly to yield the beam free vibration solutions. In the free

vibration analysis, the natural frequency can be a real number or an imaginary number while in the static

analysis, the foundation stiffness can be either positive or negative. We show that one can solve the deflection

of a beam subjected to a given concentrated force and subsequently deduce the possible infinite deflection when

the stiffness becomes zero or negative. In such cases, there exists an equivalent relationship between the free

vibration frequencies and the negative stiffness. Consequently, determining the natural frequencies becomes a

C.W. Lim and Zhenyu Chen (Department of Architecture and Civil Engineering, City University of Hong

Kong, Kowloon, Hong Kong SAR, P. R. China), “A new static analysis approach for free vibration of beams”,

International Journal of Applied Mechanics, Vol. 10, No. 1, 1850004, January 2018,

https://doi.org/10.1142/S1758825118500047

ABSTRACT: This study deals with a new method for the free vibration analysis of beams under different

boundary conditions. We show that it is possible to apply a static approach for solving free vibration systems,

i.e., we obtain natural frequencies for free vibration of beams by analyzing static beam bending problems.

Specifically, the basic governing equation for beams with harmonic loadings and resting on an elastic

foundation is solved and the solutions are used directly to yield the beam free vibration solutions. In the free

vibration analysis, the natural frequency can be a real number or an imaginary number while in the static

analysis, the foundation stiffness can be either positive or negative. We show that one can solve the deflection

of a beam subjected to a given concentrated force and subsequently deduce the possible infinite deflection when

the stiffness becomes zero or negative. In such cases, there exists an equivalent relationship between the free

vibration frequencies and the negative stiffness. Consequently, determining the natural frequencies becomes a

problem of determining an appropriate negative foundation elastic constant. In general, the numerical vibration solutions can be obtained by analyzing the relationship between loadings and frequencies. For comparison, a comparison with the classical free vibration solutions is presented and excellent agreement is illustrated. We further show that this static approach for free vibration solutions has a clear edge over the classical free vibration approach in computational beam vibration solutions. Very accurate and convergent numerical solutions can be obtained using a very simple numerical solution method. This static approach for free vibration problems can be extended for plate, shell and other structural systems.

References listed at the end of the paper:


ABSTRACT: This paper deals with the free vibration of a skew functionally graded material (FGM) plate in the thermal environment. A higher-order shear deformation theory (HOSDT) is employed to develop a finite
element model of the plate. The material properties are assumed to be temperature-dependent and are graded along the thickness direction as per simple power law distribution in terms of volume fraction of metal and ceramic constituent phases. The model is based on an eight-noded isoparametric element with seven degrees of freedom (DOFs) per node. The general displacement equation provides Co continuity. The transverse shear strain undergoes parabolic variation through the thickness of the plate. The governing equations are derived using the Hamilton’s principle. The obtained results are compared with the published results to determine the accuracy of the method. The effects of various parameters like aspect ratio, side-thickness ratio, volume fraction index, boundary conditions and skew angle on the natural frequencies are investigated.

References listed at the end of the paper:

ABSTRACT: In this study, a novel multi-objective hybrid algorithm (MHGH, multi-objective HPSO-GA hybrid algorithm) is developed by crossing the heuristic particle swarm optimization (HPSO) algorithm with a genetic algorithm (GA) based on the concept of Pareto optimality. To demonstrate the effectiveness of the MHGH, the optimizations of four unconstrained mathematical functions and four constrained truss structural problems are tested and compared to the results using several other classic algorithms. The results show that the MHGH improves the convergence rate and precision of the particle swarm optimization (PSO) and increases its robustness.

References listed at the end of the paper:

ABSTRACT: When soft cellular structures are compressed axially beyond critical limits, elastic instabilities of applied axial load. This paper numerically and experimentally explores the effect of friction on the buckling behavior of the cellular structures, which have been widely investigated, the effect of the friction on the structural response has not yet been explored. In this paper, we develop a simple theoretical model for the buckling of holey column with holes. Meanwhile, we also numerically and experimentally explore the effect of friction on the buckling behavior of the cellular structures. We find out that friction could prevent conventional, global Euler buckling for holey column, which tends to choose the pattern switching mode, and our study also provides future perspectives for mechanics of buckling or optimal design for the cellular structures.

References listed at the end of the paper:

ABSTRACT: The aim of the present study is to investigate thermo-mechanical buckling response of skew functionally graded laminated plates (FGLP) with initial geometric imperfections. The formulation has been performed using Reddy’s higher order shear deformation theory (HSDT) with the Co continuous displacement field. A nine-noded isoparametric element has been employed to discretize the domain of the plate. Variational principle has been used to derive the governing differential equation of the problem. Several examples with various comparison and parametric studies have been shown to prove the efficiency and effectiveness of the present formulation. The numerical results have been highlighted with different system parameters and boundary conditions.

References listed at the end of the paper:


ABSTRACT: Interaction of an oscillating membrane with a fluid is important because the wide variety of technological applications. A boundary element method has been employed for the analysis of a vibrating rectangular membrane in contact with a compressible fluid at rest. The deformation modes of the membrane correspond to the vacuum case. For the calculation of the pressure jump over the membrane, the Helmholtz’s integral equation for the fluid pressure is employed taking into account the fluid-membrane interface boundary condition. Considering the membrane equation and applying a collocation method, the natural frequencies of the interacting system are obtained. The influence of various parameters such as aspect ratio, fluid density and membrane dimension on these frequencies is evaluated. Furthermore, the influence of the wave number on the fluid mass coefficient and the acoustic damping ratio are evaluated. The validity of the method is deduced when comparing the results obtained by other authors and theories.

References listed at the end of the paper:


ABSTRACT: A novel higher order coupled finite-boundary element scheme is presented for the computation of the thermoacoustic responses of the layered panel structure under the harmonic excitation. The thermally prestressed vibrating composite panel model is derived mathematically using the higher-order shear deformation mid-plane kinematics. The eigen frequencies and the corresponding vibrational mode shapes are computed via the finite element method using Hamilton’s principle. Similarly, the surrounding medium is modeled via Helmholtz wave equations and solved numerically using the boundary element steps for the computation of the acoustic responses. The frequency and sound radiation output are computed numerically by means of an own computer code prepared in MATLAB environment. To avoid excess thermal loading during analysis, the
critical buckling temperature of the composite panel structure is obtained and the range of thermal loading is selected accordingly. The model accuracy is demonstrated through the proper comparison studies of different structural responses (critical buckling temperature, natural frequency and radiated sound power level) of the curved composite panel with the available benchmark solutions. The reliability and the usefulness of the proposed novel scheme have been revealed by solving several numerical illustrations for different lamination schemes, panel geometries including the geometrical parameters.

References listed at the end of the paper:
Penetration of flat-ended cylindrical projectiles into thin laminated composite plates was investigated analytically and experimentally. An analytical modeling was carried out for thin laminated composite plates by developing a new function for deflection by computing Von Karman nonlinear strains and by using the principle of energy balance. During the perforation process, different regions were considered for the plate, such as fracture region, elastic deformation region, delamination region, and undeformed region. The energy absorbed by each region was measured in small time intervals. To validate this model, the ballistic experiment is performed on the thin laminated composite plate near and beyond ballistic limit velocity. The samples were made from plain woven glass/epoxy using a hand lay-up method. In addition to the initial velocity, the residual velocity of the projectile was also measured using two parallel laser curtains. A
comparison drawn between analytical and experimental results demonstrated a good consistency in the residual velocity of the projectile. Finally, the distribution of strains along the plate thickness direction over time, the different amounts of absorbed energy of the failure modes, delamination radius, and energy are assessed at near and beyond ballistic limit velocity.

References listed at the end of the paper:


ABSTRACT: Swirling flows in conical pipe can be found in a number of industrial processes, such as hydrocyclone, separator and rotating machinery. It has been found that wall oscillations can reduce the drag in water channel and pipe flows, but there is no study of a swirling flow combined with a vibrating wall in conical pipes, though there are many applications of such combination in engineering processes. A two-dimensional particle image velocimetry (PIV) is used to measure the swirling flow field in a water conical pipe subjected to a periodic vibrating wall for a Reynolds number 3800. The flow velocity statistics are studied under different Reynolds number 3800. The flow velocity statistics are studied under different

References listed at the end of the paper:


ABSTRACT: This paper deals with the vibration characteristics and nonlinear aeroelastic response of the functionally graded (FG) multilayer composite plate reinforced with graphene nanoplatelets (GPLs) subjected to plane excitations and applied voltage. The different GPL nanofillers distribution patterns across the thickness order shear deformation theory, the motion equations of the FG plate system considering the von Kármán nonlinear aerelastic behavior and quasi-periodic motion can be observed. Reference.
Vibration analysis of thick functionally graded rectangular plates: Explicit 3D elasticity solutions


ABSTRACT: Based on classical small deflection plate theory, the governing equation of functionally graded (FG) plates in thermal environment is derived by using Hamilton’s principle. Closed-form analytical solutions are obtained via separation-of-variable method for free vibration of rectangular FG thin plates with simply supported, clamped and guided edges, especially for the plates with two adjacent clamped edges in thermal environment. The normal modes and frequencies are in an elegant and explicit closed form. Comprehensive numerical comparison and results in dimensionless form validate the present method and reveal a few physical phenomena.

References listed at the end of the paper:

Structures · foundation · classical boundary conditions · International Journal of Applied Mechanics · Composite Structures · theory · Mechanical Engineering Science · plates · techniques and solution methods · functionally graded plates with elastic restraints · recent literature with some numerical results · graded plates resting on Winkler · environment · vibration of FGM plates under initial thermal stresses · Free vibration analysis of FGM plates under initial thermal stresses · Malekzadeh, P. and Beni, A. A. [2010] “Free vibration of functionally graded arbitrary straight-sided quadrilateral plates in thermal environment,” Composite Structures 92(11), 2758–2767.


ABSTRACT: The problem about the indentation of the rigid spherical stamp into the cylindrical specimen was considered. The material of the specimen was assumed to be weakly compressible. The formulation of the problem was performed for the case of finite deformations. The method of construction of the constitutive relations in terms of logarithmic strain tensor for elastic media and the variant of the algorithm to take into account the variation of the contact zone were proposed. The expansion of Hencky tensor and its time derivative into the series in powers of Cauchy strain tensor was used to calculate correctly the components of these tensors. Within the indentation problem, we used the model of nonlinear elastic material which provides the best agreement between numerical solution and experimental data among other used types of constitutive relations including various elastic and hypoelastic models.

References listed at the end of the paper:


Raheb Gholami and Reza Ansari (First author is from: Department of Mechanical Engineering, Lahijan Branch, Islamic Azad University, P.O. Box 1616, Lahijan, Iran), “Imperfection sensitivity of post-buckling behavior and vibration response in pre- and post-buckled regions of nanoscale plates considering surface effects”, International Journal of Applied Mechanics, Vol. 10, No. 3, 1850027, April 2018, https://doi.org/10.1142/S1758825118500278

ABSTRACT: This paper aims to investigate the imperfection sensitivity of the post-buckling behavior and the free vibration response under pre- and post-buckling of nanoplates with various edge supports in the thermal environment. Formulation is based on the higher-order shear deformation plate theory, von Kármán kinematic hypothesis including an initial geometrical imperfection and Gurtin–Murdoch surface stress elasticity theory. The discretized nonlinear coupled in-plane and out-of-plane equations of motion are simultaneously obtained using the variational differential quadrature (VDQ) method and Hamilton’s principle. To this end, the displacement vector and nonlinear strain–displacement relations corresponding to the bulk and surface layers are matrixed. Also, the variations of potential strain energies, kinetic energies and external work are obtained in matrix form. Then, the VDQ method is employed to discretize the obtained energy functional on space domain. By Hamilton’s principle, the discretized quadratic form of nonlinear governing equations is derived. The resulting equations are solved employing the pseudo-arc-length technique for the post-buckling problem. Moreover, considering a time-dependent small disturbance around the buckled configuration, the vibrational characteristics of pre- and post-buckled nanoplates are determined. The influences of initial imperfection, thickness, surface residual stress and temperature rise are examined in the numerical results.

References listed at the end of the paper:
ABSTRACT: The higher-order kinematic theory in conjunction with Green–Lagrange strain field has been incorporated to compute the nonlinear frequency parameter of the curved (single/doubly) graded (functionally) sandwich panel structure numerically via finite element technique. The current sandwich panel model is derived assuming the functionally graded carbon nanotube face sheets and isotropic (epoxy) core. The current mathematical model is generic in nature, i.e., the grading configurations of the face sheets and sandwich construction including the different geometrical shapes can be achieved easily. The governing equation of the sandwich structure is obtained and the subsequent weak form derived with the help of the isoparametric finite element method. The nonlinear solutions are computed via an original computer code using a robust numerical method (direct iterative method). The consistency and the accuracy of the current finite element solutions are established by executing different types of numerical examples. Also, the concurrence of current numerical solution is established by comparing the results with the available benchmark solutions. Finally, the effect of various design parameters on the nonlinear natural frequency values have been computed under the uniform temperature environment and the inferences provided in detail.

References listed at the end of the paper:


References listed at the end of the paper:


Sina Jalili and A.R. Daneshmehr (School of Mechanical Engineering, University of Tehran, North Amirabad, Tehran, Iran), “Statistical analysis of nonlinear response of rectangular cracked plate subject to chaotic

ABSTRACT: The presence of part-through cracks with limited length is one of the prevalent defects in plate structures. The vibrational response of plates can be used to investigate the effect of crack presence. In this paper the modified line spring method (MLSM) is used to develop a nonlinear multi degree of freedom model of part-through cracked rectangular plate. After a convergence study in time series domain, tuning of the chaotic signal is conducted in two steps: (i) crossing of the Lyapunov exponents’ spectrums for the nonlinear model of the plate and the chaotic signal which assures the effectiveness of the model filter on the Lyapunov dimension of chaotic signal and (ii) varying the tuning parameter of chaotic signal to find a span in which tangible sensitivity in statistical parameters can be observed. Standard deviation, skewness and kurtosis are proposed as features to analyze the time series response of cracked plate. Damage characteristics such as: length, angle, location and depth of crack are considered as parameters to be varied in order to scrutinize the response of plates. Results show that by implementation of a tuned chaotic interrogator signal, tangible sensitivity and also near to monotonic behavior of statistical parameters versus damage characteristics are achievable.

References listed at the end of the paper:
Chi Wei Ong, Choon Hwai Yap, Foad Kabinejadian, Yen Ngoc Nguyen, Fangsen Cui, Kian Jon Chua, Pei Ho and Hwa Liang Leo (First author is from: Biofluid Mechanics Research Laboratory, Department of Biomedical Engineering, National University of Singapore, Singapore), “Association of hemodynamic behavior in the thoracic aortic aneurysm to the intraluminal thrombus prediction: A two-way fluid structure coupling investigation”, International Journal of Applied Mechanics, Vol. 10, No. 4, 1850035, May 2018, https://doi.org/10.1142/S1758825118500357

ABSTRACT: Clotting of blood elements or intraluminal thrombus (ILT) is known to develop within aortic aneurysm sacs, and is clinically associated with the dilation and rupturing of aneurysms. However, the underlying factors that generate ILT are still unclear. We hypothesize that ILT can form under the influence of unfavorable hemodynamic patterns. This paper presents evidence for one such type of flow dynamics that could give rise to ILT within the aneurysm sac. Image-based patient-specific fluid–structure-interaction modeling of three cases of thoracic aortic aneurysms was performed, using retrospective CT images to investigate the formation of ILT as a result of local hemodynamic of aneurysm. This study showed that the formation of the ILT was associated with a vortex observed near the aortic narrowing, upstream of the aneurysm sac. This vortex could subject the blood elements to elevated stresses before directing them into the sac. The recirculation flow within the aneurysm sac may trap these activated blood elements, thus, leading to the formation of ILT during early diastole. One primary cause for ILT, as indicated in this study, could be attributed to the sharp curvature at the aortic narrowing (or isthmus) that gives rise to the vortex. Our study also showed that the size and location of the aneurysm have a direct impact on the duration and location of the vortex, which could influence the formation of the ILT.

References listed at the end of the paper:


ABSTRACT: Low-velocity impact of elasto-plastic functionally graded material (FGM) plates is first investigated in this paper based on Mori–Tanaka model to underline micromechanics and locally determine the effective FGM properties and self-consistent method of Suquet for the homogenization of the stress-field. The elasto-plastic behavior of the particle reinforced metal matrix FGM plate is assumed to follow Ludwik hardening law. An incremental formulation of the elasto-plastic constitutive relation is developed to predict the tangent operator. The homogenization formulation and numerical algorithms are implemented into ABAQUS/Standard via a user material subroutine (UMAT) and USDFLD subroutine. The effect of the power-law index on low-velocity impact parameters like contact force, deflection, permanent indentation, velocity distribution and the kinetic energy are examined using the proposed method. With the aim of demonstrating the accuracy and efficiency of the present method, current numerical results are compared to experimental and theoretical results from the literature and show very good agreement.

References listed at the end of the paper:

- Huang, H., Zhang, Y. and Han, Q. [2017] “ Inelastic buckling of FGM cylindrical shells subjected to combined axial and torsional loads,” International Journal of Structural Stability and Dynamics 17(9), 1771010.
directional materials distribution can significantly change the critical flow velocity, nonlocal parameter, and mode order on the dynamics and stability. It is shown that the two different boundary conditions.


ABSTRACT: In the paper, a novel model of fluid-conveying nanotubes made of bi-directionally functionally graded materials is presented for investigating the dynamic behaviors and stability. For the first time, the material properties of the nanotubes along both radical and axial directions are under consideration. Based on Euler–Bernoulli beam and Eringen’s nonlocal elasticity theories, the governing equation of the nanotubes and associated boundary conditions are developed using Hamilton’s principle. Differential quadrature method (DQM) is applied for discretizing the equation to determine the numerical solutions of the nanotubes with different boundary conditions. Numerical examples are presented to examine the effects of the material gradation, nonlocal parameter, and mode order on the dynamics and stability. It is shown that the two-directional materials distribution can significantly change the critical flow velocity, fundamental frequencies
and stability. Comparing with traditional one-directional distribution, such 2D is more flexible to tune overall dynamic behaviors, this may provide new avenues for smart pipes.

References listed at the end of the paper:


ABSTRACT: Abnormal iris movement (floppy iris syndrome) during intraocular surgery is associated with an increased risk of intraoperative complications. We have previously investigated this scenario with respect to intracameral air in corneal endothelial transplantation, and described the concept of iris buckling. As a number of clinical interventions are recommended for addressing floppy iris syndrome, we wished to evaluate the impact of intracameral phenylephrine on iris buckling and so refine our mathematical model. We considered the stability of an iris structure under a uniform pressure loading. We performed mathematical and computational simulations to demonstrate iris buckling, and then altered the parameters to assess the impact of phenylephrine on the model. We elucidated a number of buckled iris configurations which become unstable as the intraocular pressure increased, for transversely isotropic iris material properties, and identified a positive correlation between the critical pressure and the iris stiffness. A mechanical analysis with a dilated pupil (mimicking phenylephrine use) was also conducted, and demonstrated a significant increase in the critical pressure required to induce iris buckling. We have shown that iris buckling can arise at lower pressures when the iris stiffness is reduced, as in floppy iris syndrome. The use of phenylephrine was shown to prevent iris movement (buckling) by increasing the required critical pressures. This refined model demonstrates the positive effectiveness of phenylephrine in the management of floppy iris syndrome and gives evidence to the clinical practice of using this as a preventative measure.

References listed at the end of the paper:
Intracameral phenylephrine 1.5% for prophylaxis against intraoperative floppy iris syndrome: Prospective, randomized fellow e

buckling intracameral forces causing pupil block due to air bubble use in descemet's stripping endothelial keratoplasty: The mechanics and Refractive Surgery dispersion syndrome and in normal eyes

anatomical risk factors

Journal of Biomechanics

glaucoma progression: Results from the early manifest glaucoma trial

patients on tamsulosin

Mathematical Medicine and Biology

Narendran, N., Jaycock, K., Allen, D.

Liebmann, J. M., Tello, C., Chew, S.


ABSTRACT: This paper presents triply coupled vibrations and instability analysis of thin-walled columns having a non-symmetrical open cross-section. Vlasov’s theory is used to derive the governing differential equations for coupled flexural and torsional vibrations. A numerical method is presented to determine the exact natural frequencies and corresponding mode shapes in terms of real functions. Employing Galerkin’s method, the coupled partial differential equations are reduced to a set of coupled Mathieu type equations. Following Bolotin’s method, the principal instability regions of thin-walled column with a non-symmetrical cross-section having various boundary conditions are determined. Numerical examples are presented to examine the effect of different boundary conditions, aspect ratios, static and dynamic load factors on principal instability regions. The study of response and corresponding phase plot in stable and unstable regions are carried out to identify the dynamic instability behavior.

References listed at the end of the paper:


ABSTRACT: Static and free vibration multiscale analysis of fuzzy-fiber-reinforced composite (FFRC) beam is investigated using a three-dimensional micromechanical model together with two-dimensional elasticity macromechanical theory. In the hybrid nanocomposite, aligned carbon nanotubes (CNTs) are radially grown on the circumferential surfaces of carbon fibers. Influence of the carbon fiber orientation, volume fraction and arrangement; CNT volume fraction and interphase region characteristics on the FFRC beam deflection and natural frequencies are studied. Good agreements are reported for the presented results compared with available experiments and the other modeling strategies at both micro and macro levels. The results reveal that the FFRCs properties are strongly dependent on the carbon fiber off-axis angle. By increasing the off-axis angle from 0° to 90°, the FFRC beam deflection sharply increases up to 50° fiber angle and then its value decreases. It is shown that the growth of CNTs on the carbon fiber surface leads to the highest decrease in the beam deflection for 90°-coupon. Also, increasing the interphase thickness decreases the beam deflection and increases the natural frequencies, especially for 90°-coupon. Moreover, the increasing the interphase Young’s modulus gives maximum 1.74% increase in the natural frequencies.

References listed at the end of the paper:

ABSTRACT: The analysis of impact response for metal–ceramic functionally graded materials is important for the design of advanced impact resistance structures in aerospace, nuclear and mechanical industries. Here, we propose a dislocation-based continuum model to analyze elasto-plastic deformation of metal–ceramic functionally graded plates under low-velocity impact. The dislocation-based continuum model explicitly accounts for strengthening effects due to geometrically necessary dislocations and plastic strain gradient in impact analysis of metal–ceramic functionally graded plates by combining Taylor dislocation model and Tamura–Tomota–Ozawa (TTO) model. In the dislocation-based model, we describe the effective linear elastic properties of the metal–ceramic functionally graded plates based on the Mori–Tanaka scheme. We show from finite element simulations that particle-size-dependent elasto-plastic properties play important roles in determining the impact behavior of metal–ceramic functionally graded plates and provide a good prediction of diameters of after-impact impression compared to experiments on SiC/Al functionally graded circular plates. References listed at the end of the paper:

of a ductile Al
metal interfaces. 1. Model description and geometrical effects

Mechanics

fracture in aluminum alloy composite via an extended conventional theory of mechanism

matrix composites

instrumented indentation

foundation subject to noncentral low velocity impact in thermal field

Metallurgica

·

functionally graded materials

·

beams

1121

·

57

·

on functionally graded circular plates

approach

·

impact

CNTRC l

Solids and Structures

·

Composites Science and Technology

·

Formulation and parameter identification

Yang, J., Cady, C., Hu, M. S., Zok, F., Mehrabian, R. and Evans, A. G.

Williamson, R. L., Rabin, B. H. and Drake, J. T.

Taylor, G. I.

Tamura, I., Tomota, Y. and Ozawa, H.

Talha, M. and Singh, B. N.

Qu, S., Siegmund, T., Huang, Y., Wu, P. D., Zhang, F. and Hwang, K. C.

Nan, C. W. and Clarke, D. R.

Mori, T. and Tanaka, K.

Kocks, U. F.

Kiani, Y., Sadighi, M.

Joshi, S. P. and Ramesh, K. T.

Gunes, R., Aydin, M., Apalak, M. K. and Reddy, J. N.


ABSTRACT: This paper addresses the transverse vibration of a nematic elastomer (NE) beam embedded in soft viscoelastic surroundings with the aim to clarify a new dissipation mechanism caused by dynamic soft elasticity of this soft material. Based on the viscoelasticity theory of NEs in low-frequency limit and the Timoshenko beam theory, the governing equation of motion is derived by using the Hamilton principle and energy method, and is solved by the complex modal analysis method. The dependence of vibration property on the intrinsic parameters of NEs (director rotation time, rubber relaxation time, anisotropic parameter) and foundation (spring, shear and damping constants) are discussed in detail. The results show that dynamic soft elasticity leads to anomalous anisotropy of energy transfer and attenuation. The relative stiffer foundation would restrain the rubber dissipation of viscoelastic beams, but has less influence on the director rotation dissipation, which is particular for NE beams. This study would provide a useful guidance in the dynamic design of NE apparatus embedded in soft viscous media.

References listed at the end of the paper:


ABSTRACT: In this research, we analyze size-dependent bending and vibration of microbeams made of porous metal foams. The porous microbeam model is developed based on the sinusoidal beam theory and the modified strain gradient theory. Hamilton’s principle is employed to obtain the governing equations and boundary conditions of the porous microbeam. Analytical solutions are presented for deflections and natural frequencies of the porous microbeam by using Navier’s method. The influences of the porosity distribution, the porosity coefficient, the slenderness ratio, and the microbeam thickness are clarified on the static bending and free vibration of porous microbeams. These findings can be applied to the design of metal foam microstructures in engineering.

References listed at the end of the paper:


Chunping Xiang, Qinghua Qin, Fangfang Wang, Xuehui Yu, Mingshi Wang, Jianxun Zhang and T.J. Wang
(First author is from: Department of Engineering Mechanics, State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace Engineering, Xi’an Jiaotong University, Xi’an 710049, P. R. China), “Impulsive response of rectangular metal sandwich plate with a graded foam core”, International Journal of Applied Mechanics, Vol. 10, No. 6, 1850064, July 2018, https://doi.org/10.1142/S1758825118500643

ABSTRACT: An analytical study considering inhomogeneous core compression is conducted to investigate the impulsive response of fully clamped rectangular metal sandwich plate with a graded foam (GF) core. The dynamic compressive properties of GF under impulsive loading are theoretically modeled antecedently. The approximate analytical predictions are achieved for the impulsive response of rectangular sandwich plate with a linear strength distributed GF core along the thickness by using the relevant loci of a new yield criterion. The analytical predictions agree well with the finite element (FE) results and indicate that the sandwich plates with negative gradient design outperform their uniform counterparts in impulsive resistance. The present study provides an insight into understanding the blast resistance of the sandwich structures with inhomogeneous cores.

References listed at the end of the paper:


ABSTRACT: In this paper, an elastic–plastic analytical method is proposed to predict the cyclic deformation of the fully clamped square plates made of elastic–perfectly plastic material under repeated quasi–static uniform pressure. The whole process can be divided into the loading and unloading phases. The loading phase is formulated as three separate regimes: the elastic regime, the mixed elastic–plastic regime and the fully plastic regime. Unloading from a status in each phase is modeled as an elastic process. The total and elastic strain energies are characterized by the loading and unloading paths together with the displacement profiles, respectively. It is theoretically revealed that the elastic strain energy and the structural stiffness of the plate increase with the increasing transverse deflection. In addition, the effect of material elasticity is highlighted in the scenario of repeated loadings. The theoretical results are validated against the numerical simulations conducted by the commercial software ABAQUS. It is shown that the proposed elastic–plastic theoretical
model has reasonable accuracy and can be employed to predict pressure–deflection relationship for this class of problems.

References listed at the end of the paper:


**ABSTRACT:** In the present paper, the vibration behavior of a buckled functionally graded (FG) microplate lying on a nonlinear elastic foundation is studied. The modified couple stress theory is utilized to capture the size effect of the FG microplate, and the Mindlin plate theory with the von Karman’s geometric nonlinearity is adopted to describe its deflection behavior. Based on these assumptions and Hamilton’s principle, the governing equations and associated boundary conditions are derived for the FG microplate. By linearizing the governing equations around a pre-buckling/post-buckling state, linear perturbation equations are obtained. After substituting the pre-buckling/post-buckling deformation and assumed vibration mode into the linear perturbation equations and applying the Galerkin method, an eigenvalue problem is obtained, from which the free vibration frequency of the FG microplate around its pre-buckling/post-buckling state can be determined analytically. Based on the obtained closed-form solutions, numerical examples are also presented to investigate
the effects of the material length scale parameter to thickness ratio, the power law index, and the stiffness of the elastic foundation on the vibration behavior of the buckled FG microplate.

References listed at the end of the paper:

Jian-Xun Zhang, Yang Ye, Qing-Hua Qin and T.J. Wang (First author is from: State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace Engineering, Xi’an Jiaotong University, Xi’an 710049, P. R. China), “Dynamic compressive response of sinusoidal corrugated core sandwich plates”, International Journal of Applied Mechanics, Vol. 10, No. 7, 1850075, August 2018, https://doi.org/10.1142/S1758825118500758

ABSTRACT: In this paper, the dynamic compressive response of metal sinusoidal corrugated core sandwich plates is investigated. The analytical model for the reaction forces of top and bottom face sheets subjected to constant velocity are developed. Finite element (FE) method is carried out to predict the dynamic collapse of metal sinusoidal corrugated cores. Several collapse modes of cores are found in terms of different impact velocity and relative core density. The analytical predications are compared with numerical results, and the analytical model captures numerical results for reaction forces reasonably. The collapse mechanism maps are constructed for sinusoidal corrugated cores with elastic-perfectly plastic material and strain hardening plastic material. The effect of strain rate sensitive on the collapse response is discussed. It is demonstrated that the strain hardening of the metal material increases the dominant deformation mode of the collapse mechanism maps.

References listed at the end of the paper:

Drill strings are one of the most significant rotor components employed in oil and gas exploitation. In this paper, an improved dynamical model of drill-string-like pipes conveying fluid is developed by taking into account the axial spin, fluid–structure interaction (FSI), damping as well as curvature and inertia.
nonlinearities. The partial differential equations of motion are derived by two sequential Euler angles and the Hamilton principle and then directly handled by the multiple scales method. The nonlinear amplitudes, frequencies and whirling mode shapes are all investigated towards various system parameters to display the nonlinear dynamical characteristics of such a special rotor system coupled with FSI. It is revealed that the nonlinear amplitudes and frequencies are explicitly dependent on the spinning speed, while the flowing fluid mainly contributes to the linear frequencies, and consequently influences the nonlinear amplitudes and frequencies. The FSI effect and axial spin can both improve the forward procession mode and suppress the backward one, while both procession modes will be suppressed by the viscoelastic damping. The pipe will ultimately present a forward as well as decayed whirling motion for the fundamental mode.

References listed at the end of the paper:
Mohammed Sobhy and Ashraf M. Zenkour (First author is from: Department of Mathematics and Statistics, Faculty of Science, King Faisal University, P. O. Box 400, Hofuf 31982, Saudi Arabia), “Nonlocal thermal and mechanical buckling of nonlinear orthotropic viscoelastic nanoplates embedded in a visco-Pasternak medium”, International Journal of Applied Mechanics, Vol. 10, No. 8, 1850086, September 2018, https://doi.org/10.1142/S1758825118500862

ABSTRACT: This paper discusses the thermal and mechanical buckling of simply supported and clamped orthotropic viscoelastic graphene sheets (nanoplates) embedded in a visco-Pasternak elastic medium. For this purpose, the nonlocal continuum mechanical model is employed with two-variable plate theory. The material of the present nanoplate is assumed to be orthotropic and viscoelastic. The modified nonlinear Kelvin–Voigt viscoelastic model is utilized to formulate the constitutive relations depending on the viscoelastic structural damping coefficient. Moreover, the visco-Pasternak elastic medium is composed of both viscoelastic and shear layers. The viscoelastic layer includes a set of dashpots and elastic springs connected in parallel. In accordance with the two-variable theory, two governing equations are derived via Hamilton’s principle. These equations are analytically solved for various boundary conditions to obtain the explicit solution for critical buckling temperature and buckling load. The present buckling load and buckling temperature both are compared well with the published ones in the literature. In addition, various numerical studies are thoroughly carried out, concentrating on the influences of the plate geometric, nonlocal parameter, structural damping coefficient, elastic foundation parameters, foundation damping parameter and boundary conditions on the critical buckling load and temperature of the nanoplates. The results show that the involvement of the viscosity of the nanoplate and viscoelastic foundation enhances the strength of the nanoplates and therefore increases the resistance of them to external loads.

References listed at the end of the paper:


**ABSTRACT:** A unified formulation for thermo-mechanical vibration analysis of size-dependent Timoshenko micro-beams comprised of functionally graded materials (FGMs) with general restraints is presented. The size effect is considered by incorporating the modified strain gradient theory into Timoshenko beam theory. The thermal and mechanical properties of FGMs are related to temperature and are assumed as continuous variation along the thickness. The Mori–Tanaka estimate is used for calculation of the material properties of FGM micro-beam. The formulation is deduced on the basis of the variational principle combined with penalty function method. The displacements and rotation of the FGM micro-beam are uniformly expanded by a modified Fourier series composed of traditional cosine series and some appropriate supplementary functions. Several comparisons of the present solutions with those from existing literature confirm the validity of the current formulation. In addition, a parametric study is given to demonstrate the influence of length scale parameters, gradient indices, end restraints and temperature changes on vibration characteristic of functionally graded micro-beam.

References listed at the end of the paper:


ABSTRACT: To improve the energy absorption capacity of thin-walled tubular structures and simultaneously reduce their initial peak force (IPF), hierarchical hexagonal tapered tube (HHTT) is proposed combining the advantages of the hierarchical hexagonal tube (HHT) and the tapered tube (TT), for HHTTs can greatly improve the mean crushing force (MCF) while TTs can reduce the IPF. Crushing behaviors of HHTTs under quasi-static compression are investigated through numerical simulations and theoretical analyses. According to the folding modes, a theory to predict the MCF of the HHTT is proposed. According to the research, it is found that the combination of hierarchy and tapering improves the MCF of the tubular structure and the crushing force efficiency (CFE), defined by the ratio of the MCF to the IPF. It is also found that increasing the tapered angle, the wall thickness and the cell number of the lattice wall can effectively improve the CFE of the HHTT.

References listed at the end of the paper:


ABSTRACT: In this paper, the vibration suppression mechanism of a nonlinear fluid-pipe under harmonic foundation excitation is studied for the first time. The fluid pipe is simply supported under harmonic foundation excitation. The complexification-averaging method combined with the arc-length continuation method is used to predict the response of the system. The analytical solution is supported by the numerical result. The trend of interaction between liquid speed and NES parameters are investigated by comparison of parameters optimization. It is especially pointed out that the change of stiffness has a very complicated influence on the response. The parameters optimization is investigated at the resonance frequency. It is noted that the liquid speed has an important effect on the vibration suppression of the fluid pipe. Besides, the system is evaluated from the point of view of energy. The distribution of the input energy is calculated and the instantaneous transaction of the energy is examined by considering the energy transaction measure (ETM). The numerical simulations demonstrate that the target energy transfer (TET) leads to a very efficient vibration suppression.

References listed at the end of the paper:


ABSTRACT: The objective of this paper is to investigate the large deflection of a slender functionally graded beam under the transverse loading. Firstly, by modeling the functionally graded beam as a layered structure with graded yield strength, a unified yield criterion for a functionally graded metallic beam is established. Based on the proposed yielding criteria, analytical solutions (AS) for the large deflections of fully clamped functionally graded beams subjected to transverse loading are formulated. Comparisons between the present solutions with numerical results are made and good agreements are found. The effects of gradient profile and gradient intensity factor on the large deflections of functionally graded beams are discussed in detail. The reliability of the present analytical model is demonstrated, and the larger the gradient variation ratio near the loading surface is, the more accurate the layer-graded beam model will be.

References listed at the end of the paper:

ABSTRACT: We report on the structural stability of ideal (defect-free) and structurally and morphologically degenerate carbon nanotubes and nanotube junction systems under axial loading based on the finite element method. We estimated the values for critical buckling load for uncapped and capped single-walled carbon nanotubes (SWCNTs) and linear and angle-adjointed SWCNT heterojunctions in ideal and structurally degenerate systems containing single-, double-, triple-, pinhole- and pentagon–heptagon (i.e., 5–7) structural defects and also containing a substitutional nitrogen (N) atom inclusion under compressive loading. Absolute atomic vacancy (defect) concentration in studied SWCNTs models was assumed to be nil for ideal systems, and was up to 3.0 at.% for structurally and morphologically degenerate systems. It was found that all types of structural defects and the morphological N-defect had reduced the load carrying capacity and mechanical strength in all SWCNT systems studied. The SWCNT models containing physically large vacant sites, such as triple- and pinhole-defects, displayed significantly lower critical load values compared to the systems that contained only a single-, double- or triple-vacancies. In addition, we found that capped SWCNTs performed marginally better in critical load carrying capacity compared to uncapped SWCNT systems. Furthermore, majority of the investigated structures displayed reduced load in SWCNTs with narrower tube widths, proportional to the size and the type of the defect investigated. The effects of chirality, such as zigzag- versus armchair-type, on the structural stability of the investigated SWCNT models were also investigated.

References listed at the end of the paper:

- Sadegh Imani Yengejeh, Andreas Oechsner, Seyed Alieh Kazemi and Maksym Rybachuk (First author is from: Centre for Clean Environment and Energy, School of Environment and Science, Griffith University, Gold Coast Campus, Southport 4222, Australia), “Numerical analysis of the structural stability of ideal (defect-free) and structurally and morphologically degenerated homogeneous, linearly- and angle-adjointed nanotubes and cylindrical fullerences under axial loading using finite element method”, International Journal of Applied Mechanics, Vol. 10, No. 9, 1850100, September 2018, https://doi.org/10.1142/S1758825118501004
Gradients in the nanobeam and a large flexoelectric response will occur. By assuming that the material truncated pyramids depend on shape geometry, dimension and aspect ratio of the strain gradients induced electric polarization in nonpiezoelectric dielectrics with irregular shapes (i.e., truncated pyramids) depend on shape geometry, dimension and aspect ratio of the structures. In this work, a novel asymmetric piezoelectric nanobeam based on functionally graded (FG) nanomaterial is modeled and the flexoelectricity in such a designed structure is theoretically examined. Since the material properties of FG nanomaterial vary along a certain direction, it is expected that such an inhomogeneity will result in large strain gradients in the nanobeam and a large flexoelectric response will occur. By assuming that the material


ABSTRACT: Flexoelectricity refers to the linear coupling between the strain gradient and the electric polarization at micro/nanometer scale and exists in all dielectrics. Flexoelectricity exhibits strong size-dependence, which can be remarkably enhanced by size reduction. Flexoelectricity is also shape-associated and the strain gradients induced electric polarization in nonpiezoelectric dielectrics with irregular shapes (i.e., truncated pyramids) depend on shape geometry, dimension and aspect ratio of the structures. In this work, a novel asymmetric piezoelectric nanobeam based on functionally graded (FG) nanomaterial is modeled and the flexoelectricity in such a designed structure is theoretically examined. Since the material properties of FG nanomaterial vary along a certain direction, it is expected that such an inhomogeneity will result in large strain gradients in the nanobeam and a large flexoelectric response will occur. By assuming that the material

properties of FG nanomaterial obey a power volume fraction distribution, we derive a six-order governing equation based on modified couple stress elasticity theory, and closed-form solutions are obtained. Results indicate that the flexoelectricity has a significant influence on the electromechanical responses in FG piezoelectric nanobeams. The results obtained from the current work may help explain the extremely large flexoelectric coefficients observed in some classes of materials with irregular shapes.

References listed at the end of the paper:

evaluated on the basis of the Leaderman viscoelastic model. Then, extended for viscoelastic materials. The viscous component of the nonclassical and classical stress tensors are

ABSTRACT:


ABSTRACT: In this study, the nonstationary oscillation, secondary resonance and nonlinear dynamic behavior of viscoelastic nanoplates with linear damping are investigated based on the modified strain gradient theory extended for viscoelastic materials. The viscous component of the nonclassical and classical stress tensors are evaluated on the basis of the Leaderman viscoelastic model. Then, incorporating the size-dependent potential
energy, kinetic energy and an external excitation force work, the governing equations of the oscillations are obtained based on the Hamilton’s principle. The governing formula is obtained as a nonlinear second-order integro-differential partial equation. This size-dependent viscoelastic formula is solved using analytical Harmonic balance method (HBM) and the fourth-order Runge–Kutta technique after applying the expansion theory. Additionally, the stability of the steady-state response is examined by means of HBM. Then, the secondary resonance conditions due to the super-harmonic motion are determined by performing frequency response, force response, Poincare map and phase portrait analyses. In addition, the nonstationary transient vibration of viscoelastic nanosystem is analyzed by performing Hilbert–Huang transform.

References listed at the end of the paper:


Kemal Arslan and Recep Gunes (Department of Mechanical Engineering, Erciyes University, Kayseri 38039, Turkey), “Low-velocity flexural impact analyses of functionally graded sandwich beams using finite element...
ABSTRACT: A comparative numerical investigation on low-velocity impact response of a metal/ceramic functionally graded sandwich beam (FGSB) is performed by the commercial finite element (FE) software, LS-DYNA®. The mechanical properties of the FG core are represented by a power-law depending on the volume fractions of the constituents. The effective elastic properties and elastoplastic behavior of the FG core are defined by Mori–Tanaka method and TTO (Tamura–Tomota–Ozawa) model, respectively. The effects of number of layers, compositional gradient, impact energy, and impact side are investigated. The simulation results indicated that both number of layers and compositional gradient have almost no effect on the kinetic energy history. In other respects, the compositional gradient exhibits a considerable effect, and the number of layers has a minor effect on the contact force history. Increasing impact energy does not have a considerable effect in terms of number of layers whereas it exhibits a significant effect in terms of compositional gradient on the percentage difference between the peak contact forces. Finally, the impact side does not influence the contact force history for all number of layers and compositional gradients.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: In the present work, the chaotic wave motions and the chaotic dynamic responses are investigated for a four-edge simply supported piezoelectric composite laminated rectangular thin plate subjected to the transverse and the in-plane excitations. Based on the reductive perturbation method, the complicated partial differential nonlinear governing equation of motion for the piezoelectric composite laminated rectangular thin plate subjected to the transverse and the in-plane excitations is transformed into an equivalent and solvable nonlinear wave equation. The heteroclinic orbit and resonant torus are obtained for the unperturbed nonlinear wave equation. The topological structures of the unperturbed and the perturbed nonlinear wave equations are investigated on the fast and the slow manifolds. The persistence of the heteroclinic orbit is studied for the perturbed nonlinear wave equation through the Melnikov method. The geometric analysis is utilized to prove that the heteroclinic orbit goes back to the stable manifold of the saddle point on the slow manifold under the perturbations. The existence of the homoclinic orbit is confirmed for the perturbed nonlinear wave equation by the first and the second measures. When the homoclinic orbit is broken, the chaotic motions occur in the Smale horseshoe sense for the piezoelectric composite laminated rectangular thin plate subjected to the transverse and the in-plane excitations. Numerical simulations are finished to study the influence of the damping coefficient on the propagation properties of the piezoelectric composite laminated rectangular thin plate subjected to the transverse and the in-plane excitations. Both theoretical study and numerical simulation results indicate the existence of the chaotic wave motions and the chaotic dynamic responses of the piezoelectric composite laminated rectangular thin plate subjected to the transverse and the in-plane excitations.

References listed at the end of the paper:


· Hao, Y.-X., Yang, S. W., Zhang, W., Yao, M. H. and Wang, A. W. [2018] “Flutter of high-dimension nonlinear system for a FGM truncated conical shell,” Mechanics of Advanced Materials and Structures 25, 47–61.


· Li, Y. [1999] “Homoclinic tubes in nonlinear Schrödinger equation under Hamiltonian perturbations,” Progress of Theoretical Physics 101, 559–577.


· Li, Y. [2004a] “Persistent homoclinic orbits for nonlinear Schrödinger equation under singular perturbation,” Dynamics of Partial Differential Equations 1, 87–123.

· Li, Y. [2004b] “Existence of chaos for nonlinear Schrödinger equation under singular perturbation,” Dynamics of Partial Differential Equations 1, 225–237.


ABSTRACT: In the present study, the natural frequency of finite element modeled geometrically imperfect shear deformable functionally gradient sandwich arches in thermal environment has been studied. The formulation is based on the higher-order shear deformation theory. The upper layer of the sandwich arch is considered to be ceramics, whereas the lower layer is made of metal. The core of the sandwich arch is made of gradient materials. The material properties of the sandwich arches are varying continuously in the thickness direction only by a simple power-law distribution in terms of volume fractions of the constituents. Comparison and convergence studies have been performed to validate the present formulation with the limited available literature. Parametric studies have been performed to study the effect of various influencing parameters on the
frequency of the FG sandwich arches, i.e., volume fraction index, thickness-to-length ratio, imperfection amplitude, and opening angle. New results are presented which can be treated as benchmark solutions for future researches.

References listed at the end of the paper:


Zihao Yang and Dan He (Key Laboratory of Liaoning Province for Composite Structural Analysis of Aerocraft and Simulation, Shenyang Aerospace University, Shenyang 110136, P. R. China), “Vibration and buckling of functionally graded sandwich micro-plates based on a new size-dependent model”, International Journal of Applied Mechanics, Vol. 11, No. 1, 1950004, 2019, https://doi.org/10.1142/S1758825119500042

ABSTRACT: Within the framework of re-modified couple stress theory, the Refined Zigzag Theory is added to the vibration and buckling analysis of sandwich micro-plates embedding functionally graded layers. The disparity between the scale effects along two orthogonal directions is considered through two orthogonal material length scale parameters (MLSPs). Meanwhile, the solutions of natural frequencies and buckling loads show an improved predictive capability through comparing the results with exact and quasi-3D solutions. Two types of functionally graded sandwich micro-plates with simply supported boundary conditions are taken as the illustrative examples, namely, an isotropic functionally grade sandwich micro-plate with a power law and an orthotropic one with an exponential law. The numerical results indicate that the present model can capture the varying scale effects along two orthogonal directions, particularly when the geometric size of the micro-plates is comparable to the MLSPs. When microscopic isotropy is observed, the present model can also make accurate predictions on those kinds of micro-structures by setting the two orthogonal MLSPs equal to each other. In addition, the scale effects are less obvious as the functionally graded sandwich micro-plate is getting thinner and harder; the grading index also has an influence on the scale effects, but this influence is simultaneously depending on the side-to-thickness ratio of the micro-plate.

References listed at the end of the paper:


Alireza Shaterzadeh, Kamran Foroutan and Habib Ahmadi (Faculty of Mechanical Engineering, Shahrood University of Technology, P. O. Box 316, Shahrood, Iran), “Nonlinear static and dynamic thermal buckling analysis of spiral stiffened functionally graded cylindrical shells with elastic foundation”, International Journal of Applied Mechanics, Vol. 11, No. 1, 1950005, 2019, https://doi.org/10.1142/S1758825119500054

ABSTRACT: In this paper, an analytical method is used to study the nonlinear static and dynamic thermal buckling analysis of imperfect spiral stiffened functionally graded (SSFG) cylindrical shells. The SSFG cylindrical shell is surrounded by a linear and nonlinear elastic foundation. The proposed linear model is based on the two-parameter elastic foundation (Winkler and Pasternak). A three-parameter elastic foundation with hardening/softening cubic nonlinearity is used for nonlinear model. The material properties are temperature dependent and assumed to be continuously graded in the thickness direction. Also, for thermal buckling analysis, the uniform and linear temperature distribution in thickness direction is considered. The SSFG cylindrical shells are considered with various angles for spiral stiffeners. The strain-displacement relations are obtained based on the von Kármán nonlinear equations and the classical plate theory of shells. The smeared stiffener technique and the Galerkin method are applied to solve the nonlinear problem. In order to find the nonlinear dynamic thermal buckling responses, the fourth-order Runge–Kutta method is used. To validate the results, comparisons are made with those available in literature and good agreements are shown. The effects of various geometrical and material parameters are investigated on the nonlinear static and dynamic thermal buckling response of SSFG cylindrical shells.

References listed at the end of the paper:


Huang, H. and Han, Q. [2010c] “Nonlinear dynamic buckling of functionally graded cylindrical shells subjected to a time-dependent axial load,” Composite Structures 92, 593–598.


ABSTRACT: The main goal in this paper is to make analysis of post-buckling of laminated composite beams under hygrothermal effect. In solution of problem, finite element method is utilized with the first shear beam theory. Total Lagrangian approach is used nonlinear kinematic relations. It is known that post-buckling problems are geometrically nonlinear problems. In nonlinear solution of problem, the Newton–Raphson method is used based on incremental displacement. The novelty in this study is to investigate the hygrothermal post-buckling analysis of laminated composite beams by using total Lagrangian nonlinear approach. The influences of temperature, moisture, fiber orientation angles, stacking sequence of laminas on post-buckling responses of composite laminated beam are illustrated and examined in numerical results. The results show that fiber orientation angles, stacking sequence of laminas play an important role in hygrothermal post-buckling responses of laminated beams. Also, comparison studies are performed with special results of published paper.

References listed at the end of the paper:


Structures under buckling and wrinkle

laminated beams under hygrothermal conditions

· resting on two

formulation for hygro

Engineering Software

· Composite Materials

· elastic foundations

unsymmetrically laminated composite beams on nonlinear elastic foundation

method

foundations

67

·


Li, Z. M. and Qiao, P. [2015a], “Buckling and postbuckling behavior of shear deformable anisotropic laminated beams with initial geometric imperfections subjected to axial compression,” Engineering Structures 85, 277–292.


ABSTRACT: The strain formulation approach improves accuracy and removes complications, such as shear parasitic errors and sensitivity to mesh distortions. For analyzing plane stress and strain problems, two new strain-based triangular elements are proposed. Both compatibility and equilibrium conditions are imposed to these elements. Contrary to the quadrilateral shape, triangular element facilitates proper meshing of various geometries. To formulate these elements, the linear strain field is assumed. The first element is a five-node triangular element, in which each node has two degrees of freedom. In the second one, which is a four-node element, drilling degrees of freedom are added to improve applicability of the element for bending problems. Various numerical examples and patch tests verify high accuracy and efficiency of the suggested elements in comparison with the other existing plane elements.

References listed at the end of the paper:


Mohammad Rezaiee-Pajand, Nima Gharaei-Moghadam and Mohammadreza Ramezani (Department of Civil Engineering, School of Engineering, Ferdowsi University of Mashhad, Mashhad, Khorasan Razavi, Iran), “Two triangular membrane elements based on strain”, International Journal of Applied Mechanics, Vol. 11, No. 1, 1950010, 2019, [https://doi.org/10.1142/S1758825119500108](https://doi.org/10.1142/S1758825119500108)

ABSTRACT: The strain formulation approach improves accuracy and removes complications, such as shear parasitic errors and sensitivity to mesh distortions. For analyzing plane stress and strain problems, two new strain-based triangular elements are proposed. Both compatibility and equilibrium conditions are imposed to these elements. Contrary to the quadrilateral shape, triangular element facilitates proper meshing of various geometries. To formulate these elements, the linear strain field is assumed. The first element is a five-node triangular element, in which each node has two degrees of freedom. In the second one, which is a four-node element, drilling degrees of freedom are added to improve applicability of the element for bending problems. Various numerical examples and patch tests verify high accuracy and efficiency of the suggested elements in comparison with the other existing plane elements.

References listed at the end of the paper:


ABSTRACT: This paper introduces a novel approach for small-scale effects on nonlinear free-field vibration of a nano-disk using nonlocal elasticity theory. The formulation of a nano-disk is based on the nonlinear model of von Kármán strain in polar coordinates and classical plate theory. To analyze the nonlinear geometric and small-scale effects, the differential equation based on nonlocal elasticity theory was extracted from Hamilton principle, while the inertial and shear-stress effects were neglected. The equation of motion was discretized using the Galerkin method on selecting an appropriate function based on the boundary condition used for the nano-disk. Due to presence of nonlinear terms, the homotopy method was used in conjunction with the perturbation method (HPM) to ease up the solution and completely solve the problem. For further comparison,
the nonlinear equations were solved by the fourth-order Runge–Kutta method, the solution of which was compared with that of HPM. Excellent agreements in results were observed between the two methods, indicating that the latter method can simplify the solution, and hence, can be applied to nonlinear nano-disk problems to seek their solution with a high accuracy.

References listed at the end of the paper:

ABSTRACT: Stiff thin films supported by pressure sensitive ductile solids are an ubiquitous architecture appearing in a wide range of applications. The film rupture and delamination of films are important reliability issues of such an architecture. In this study, we investigate the synergistic effects of plastic deformation of substrates and fracture properties of film/substrate interface on the delamination of films. The focus of this study is on the interplay between the debonding of the interface and the plastic deformation of substrates. Finite deformation analyses are carried out for a stiff film deposited on a soft substrate with the substrate subjected to stretching. The fracture process of film/substrate interface is represented by a cohesive zone model, and the substrate is modeled as an elastic–plastic solid with pressure sensitive and plastically dilatant plastic flow. It is found that increasing the degree of pressure sensitivity of substrate can generate large plastic deformation, promoting crack tip blunting and thereby retarding delamination of film/substrate interface. Whereas, the increase in the degree of plastic dilatancy of substrate gives rise to the limited plastic deformation and leads to poor resistance to interface delamination. The strain hardening of substrate also affects the film/substrate debonding; the substrate with weakly post-yield strain hardening behavior contributes to enhanced resistance to interface delamination. It is further identified that the fracture properties of interface play an important role in activating plastic deformation of substrates. The film/substrate interface with high stiffness, large cohesive strength and high toughness enables the substrate to undergo significant plastic deformation, which suppresses the film/substrate delamination.

References listed at the end of the paper:

REFERENCES LISTED AT THE END OF THE PAPER:


ABSTRACT: The wrinkling instability of a stiff film adhering to a pre-strained inhomogeneous bi-layer substrate consisting of a homogeneous substrate and a graded coating is investigated in the present paper. The critical strain, wavelength and amplitude of the film/inhomogeneous substrate system are calculated numerically and analyzed comprehensively. Compared with the numerical result, a theoretical model is introduced to approximately predict the wrinkling responses of the system. The influence of various geometric and material parameters on the wrinkling behavior is mainly focused. The wrinkling responses are found to be highly related to the graded laws and the thickness of the inhomogeneous coating as well as the Poisson’s ratio. What is more, a proper choice of graded properties of a substrate can improve the wrinkling response of a film/substrate system. The present finding should be very meaningful to guide the design of various stretchable and flexible electronics.

References listed at the end of the paper:


ABSTRACT: The flexural vibration and damping performances of a bio-based sandwich structure with auxetic core are investigated in this paper. The material studied is made up of an auxetic core and two skins. Each of the skins and core are made up of a polylactic acid reinforced with flax fibers. The whole sandwich structure was manufactured using a three-dimensional (3D) printing technique. Experimental analysis was used to evaluate the damping properties of this material. The skins, the core and the whole sandwich structure were tested experimentally in a clamp-free configuration. In addition, a finite element model was developed to evaluate the loss factors and natural frequencies regarding different cases. The influence of the relative core densities and thicknesses on the dynamic stiffness and loss factors were measured and discussed. The results obtained from the experiment and the numerical analysis were in a close agreement.

References listed at the end of the paper:

In this paper, the in-plane free vibration analysis of the functionally graded rotating disks with variable thickness is presented utilizing DQM. It is assumed that the rotational velocity of the disk is constant and the thickness and material properties including modulus of elasticity and density vary along the radial coordinate. The distribution of the forward and backward traveling waves versus the angular velocity is demonstrated for several modal circles and nodal diameters with respect to the fixed and rotating coordinate systems. After presenting the accuracy and convergence of the numerical method, the derived formulation and the solution method are validated by comparing the results with those obtained in the literature for simple rotating disks. Furthermore, the critical speed of the rotating disk is introduced and obtained for different modes. Finally, the effects of the functionally graded index (describes the distribution of material properties) and geometric shape of the disks (thickness profile and radius ratio) on the natural frequencies and critical speed.
of the disk are presented. It is observed that as the number of nodal diameter increases, the critical speed of the disk consequently decreases and reaches to an asymptotic value. This value is independent of the geometric characteristics of the disk.

References listed at the end of the paper:
ABSTRACT: This paper clarified kinematic aspects of motion of axially moving beams undergoing large-amplitude vibration. The kinematics was formulated in the mixed Eulerian–Lagrangian framework. Based on the kinematic analysis, the governing equations of nonlinear vibration were derived from the extended Hamilton principle and the higher-order shear beam theory. The derivation considered the effects of material parameters on the beam deformation. The proposed governing equations were compared with a few previous governing equations. The comparisons show that proposed equations are with higher precision. Besides, the proposed equations can be viewed as the asymptotic governing equations of Lagrange’s equations of motion for large displacement. Finally, the corresponding boundary conditions and the comparison between the presented model equation and classical model equation were provided.

References listed at the end of the paper:


Yuanbin Wang, Hu Ding and Li-Qun Chen (First author is from: Department of Mathematics, ShaoXing University, 312000 ShaoXing, Zhejiang, P. R. China), “Kinematic aspects in modeling large-amplitude vibration of axially moving beams,” International Journal of Applied Mechanics, Vol. 11, No. 2, 1950021, 2019, https://doi.org/10.1142/S1758825119500212


ABSTRACT: First time, an analytical solution based on three-dimensional (3D) piezoelectricity is developed for the free vibration analysis of Levy-type piezolaminated plates using 3D extended Kantorovich method (EKM). Extended Hamilton principle (which is extended from elastic to piezoelectric case) is further extended to the dynamic version of mixed form containing contributions from the electrical terms. Multi-term multi-field extended Kantorovich method in conjunction with Fourier series (along y-direction) is employed to obtain two sets of first-order homogeneous ordinary differential equations (8n along x- and z-axes). A robust algorithm is designed (Fortran Code) to extract the natural frequencies and mode shapes of Levy-type piezolaminated plates. The accuracy and efficacy of this technique are verified thoroughly by comparing it with the existing results in the literature and with the 3D finite element (FE) solutions. Numerical results are presented for single-layer piezoelectric and smart sandwich plates considering five different boundary support conditions, three aspect
ratios (length to thickness ratio) and electric open and close circuit conditions. The present results shall be used as a benchmark to assess various two-dimensional (2D) and 3D numerical solutions (e.g., FEM, DQM, etc.).

References listed at the end of the paper:

Abaqus/CAE user manual [2013], Version 6.13-1, Dassault Systèmes Simulia Corp., Providence, RI, USA.


ABSTRACT: This paper presents the influence of various random system parameters on dynamics response of imperfection sensitive higher order shear deformable functionally graded material (FGM) plates. Young’s moduli, Poisson’s ratio and volume fraction index are considered as random system parameters. The material properties of the FGM plates are assumed to vary along the thickness direction using simple power-law distribution in terms of the volume fraction of the constituents. The plate kinematics is based on Reddy’s higher order shear deformation theory. Finite element method (FEM) is employed in conjunction with first-order perturbation technique (FOP) and Newmark integration scheme to explore the influence of different system parameters, like volume fraction indices, aspect ratio, material uncertainties, and imperfection amplitude on the dynamic responses of the FGM plates.

References listed at the end of the paper:


Installing flexible layer is one kind of supporting techniques to deal with the large deformation in tunnels excavated in viscoelastic rocks. The role of flexible layer is to absorb rock deformation due to rock rheology. For further understanding the effect of flexible layer on mechanical behavior of tunnels, a three-layered model is established to study the mechanical behavior of tunnel where flexible layer is installed between surrounding rock and primary support. Visco-elastic analytical solutions for displacements and interaction forces in the rock/flexible layer interface and in the flexible layer/primary support interface are provided. Numerical calculation by use of finite element software Abaqus is carried out to verify the effectiveness and reliability of theoretical analysis. It could be found that flexible layer has a good ability to absorb rock deformation. Compared with rigid support structure, pressure and displacement of primary support in tunnels employing flexible layer could achieve a good improvement. This improvement is dramatically affected by the thickness and deformability of reserved flexible layer.

References listed at the end of the paper:


ABSTRACT: The present investigation deals with the assessment of parametric resonance behavior of new aircraft material, i.e., woven fiber metal laminated (FML) plates subjected to in-plane static and harmonic loading using finite element (FE) technique and Bolotin’s method. In this analysis, a four-node isoparametric element with five degrees of freedom per node is adopted. Based on the first-order Reissner–Mindlin theory, the parametric instability of FML plate subjected to in-plane harmonic loading is examined. A MATLAB code is developed for the parametric study on the dynamic stability of FML plates. The reliability of present formulation is checked by comparing numerical results obtained from present FE analysis with the published researches in the field. The influences of several factors, viz. static load factor, aspect ratio, length-to-thickness ratio, number of layers, ply orientation and boundary conditions on the dynamic instability regions are discussed. Significant variations of these factors on dynamic instability zones of FML plates are observed. The instability zones can be used as guidelines for the prediction of the dynamic behavior of FML plates.

References listed at the end of the paper:


ABSTRACT: Dynamic response analysis plays an important role for the structural design. For engineering structures, there exist model inaccuracies and structural parameters uncertainties. Consequently, it is necessary to express these uncertain parameters as interval variables and introduce the interval finite element method (IFEM), in which the elements in stiffness matrix, mass matrix and damping matrix are all the function of interval parameters. The dependence of interval parameters leads to overestimation of dynamic response analysis. In order to reduce the overestimation of IFEM, the element-based subinterval perturbation for static analysis is applied to dynamic response analysis. According to the interval range, the interval parameters are divided into different subintervals. With permutation and combination of each subinterval, the upper and lower bounds of displacement response are obtained. Because of the large number of degrees of freedom and uncertain parameters, the Laplace transform is used to evaluate the dynamic response for avoiding to frequently solve the interval finite element linear equations. The numerical examples illustrate the validity and feasibility of the proposed method.

References listed at the end of the paper:


ABSTRACT: This paper investigates size-dependent vibration of graphene platelet (GPL) reinforced circular cylindrical polymeric microshells. The microshells are composed of multilayers with GPL fillers uniformly dispersed in each individual layer, but GPL weight fraction changes layer-by-layer along the thickness direction. The effective Young’s modulus is predicted by the modified Halpin–Tsai model, while effective Poisson’s ratio and mass density are determined by the rule of mixture. Four different patterns of GPL dispersion are considered to achieve the functionally graded property of the microshells. Based on Love’s thin shell theory and the modified couple stress theory, the governing equations are derived by using Hamilton’s principle. Then, the Navier and Galerkin methods are utilized to solve natural frequencies of GPL reinforced polymeric (GPLRP) microshells. A parametric study is conducted, with a particular focus on the effects of the GPL distribution pattern, the weight fraction, the geometries of the GPL and the microshells, as well as the total number of layers of the microshells.

References listed at the end of the paper:


ABSTRACT: A novel nonlinear model of single-layered graphene sheets (SLGSs) subject to large deformation is proposed using the absolute nodal coordinate formulation (ANCF) and the nonlocal elasticity theory. The geometrical definition of SLGSs is described by ANCF thin plate element while the strain energy is expressed by nonlocal theory. Then, the formulation of elastic force and the Jacobian of the elastic force is derived. We verify the proposed model by comparing the results with other published results and conduct corresponding numerical case study to clarify the influence of boundary conditions (BCs), nonlocal parameters, side length and aspect ratio. Large deformation problem of SLGSs with several BCs and different loading modes are simulated to study the mechanical nonlinearity of the SLGSs.

References listed at the end of the paper:


ABSTRACT: In this paper, coupled axial and torsional large deformation of an incompressible isotropic functionally graded nonlinearly elastic solid cylinder is investigated. Utilizing stretch-based constitutive models, where the deformation tensor is non-diagonal, is complex. Hence, an analytical approach is presented for combined extension and torsion of functionally graded hyperelastic cylinder. Also, finite element analysis is carried out to verify the proposed analytical solutions. The Ogden model is employed to predict the mechanical behavior of hyperelastic materials whose material parameters are function of radius in an exponential fashion. Both finite element and analytical results are in good agreement and reveal that for positive values of exponential power in material variation function, stress decreases and the rate of stress variation intensifies near the outer surface. A transition point for the hoop stress is identified, where the distribution plots regardless of the value of stretch or twist, intersect and the hoop stress alternates from compressive to tensile. For the Ogden model, the torsion induced force is always compressive which means the total axial force starts from being tensile and then eventually becomes compressive i.e., the cylinder always tends to elongate on twisting.


ABSTRACT: Through the Timoshenko beam theory (TBT), the 3D dynamics of a rotary functional gradient (FG) cantilever beam are investigated. Material capabilities alter continuously throughout the thickness obeying the power law. It is assumed that the Poisson’s ratio does not change. Based on the von Kármán nonlinearity, the governing equation is determined through the Hamilton principle, which includes the Coriolis effects. The couplings among the axial, flapwise and chordwise deformations caused by the usage of the functionally graded materials (FGMs) are revealed. Chebyshev polynomials are utilized to construct trial functions of deformations in the Rayleigh–Ritz method. The centrifugal strengthening effect caused by the rotational motion is described through the nonlinear axial shortening deformations derived from transverse deformations. The influences of the dimensionless angular velocity, FG index and slenderness ratio on vibration characteristics are studied. It is proved that the FG index significantly affects the dynamic response of deformation. For high-frequency external excitation cases, selection of Chebyshev polynomials as trial functions is more stable and effective than other polynomials.


ABSTRACT: A new analytical approach to investigate the nonlinear buckling and postbuckling of the sandwich functionally graded circular cylindrical shells reinforced by ring and stringer or spiral stiffeners subjected to external pressure is presented in this paper. By employing the Donnell shell theory, the geometrical nonlinearity in Von Kármán sense and developed Lekhnitskii’s smeared stiffener technique, the governing equations of sandwich functionally graded circular cylindrical shells are derived. Resulting equations are solved by applying the Galerkin method to obtain the explicit expression of critical buckling external pressure load and postbuckling load–deflection curve. Effects of spiral stiffeners, thermal environment, external pressure, and geometrical parameters on nonlinear buckling behavior of sandwich functionally graded circular cylindrical shells are shown in numerical results.

References listed at the end of the paper:


Huang, H. and Han, Q. [2010a] “Nonlinear buckling of functionally graded cylindrical shells subjected to time-dependent axial load,” Composite Structures 92(2), 593–598.


Huang, H. and Han, Q. [2010c] “Research on nonlinear postbuckling of functionally graded cylindrical shells under radial loads,” Composite Structures 92(6), 1352–1357.


ABSTRACT: Cruciform structures have desirable energy absorption capacity. However, the engineering application is limited by the difficulties in the manufacturing process. In this paper, a kirigami approach is introduced to simplify the manufacturing process. Based on the kirigami strategy, a structure referred to as a discontinuous kirigami cruciform sandwich panel (DKC), is investigated to validate the mechanical performance in energy absorption. Experiments and numerical simulations were carried out to investigate the impact resistance of DKC under four levels of impact energy and the energy−absorption performance is evaluated by comparing to a typical energy−absorption device, pyramidal truss sandwich panel (PT). In order to reduce the initial impact force and the displacement of the bottom surface on the protected objective, the DKC is further optimized by introducing an additional cutout at the opposite end in each component plate. With the new design, the displacement of the bottom surface on the sandwich structure is reduced by 13.9%, together with a decrease of impact peak force and an increase of energy absorption.

References listed at the end of the paper:
James, S. and Jonghwan, S. [2012] “Core material effect on wave number and vibrational damping characteristics in carbon fiber sandwich composites,” Composites Science and Technology 72(13), 1493–1499.
ABSTRACT: This paper presents a parametric study on aeroelastic stability analysis of multi-layered functionally graded carbon nanotubes reinforced composite (FG-CNTRC) cylindrical panels subjected to a yawed supersonic flow. The panel is considered to be composed of different layers reinforced by carbon nanotubes arranged in different directions with various patterns and different volume fractions. Reddy’s third-order shear deformation theory (TSDT) is employed to model the structure and external pressure is estimated based on the linear supersonic piston theory. The set of governing equations and boundary conditions are derived using Hamilton’s principle and are solved numerically using generalized differential quadrature method (GDQM). Convergence and accuracy of the presented solution are confirmed and effect of volume fraction, distributions and orientation of carbon nanotubes (CNTs), yaw angle and geometrical parameters of the panel on the flutter boundaries are investigated. Results of this paper can be considered as a useful tool in design and analysis of supersonic airplanes and missiles.

References listed at the end of the paper:


ABSTRACT: This paper presents a parametric study on aeroelastic stability analysis of multi-layered functionally graded carbon nanotubes reinforced composite (FG-CNTRC) cylindrical panels subjected to a yawed supersonic flow. The panel is considered to be composed of different layers reinforced by carbon nanotubes arranged in different directions with various patterns and different volume fractions. Reddy’s third-order shear deformation theory (TSDT) is employed to model the structure and external pressure is estimated based on the linear supersonic piston theory. The set of governing equations and boundary conditions are derived using Hamilton’s principle and are solved numerically using generalized differential quadrature method (GDQM). Convergence and accuracy of the presented solution are confirmed and effect of volume fraction, distributions and orientation of carbon nanotubes (CNTs), yaw angle and geometrical parameters of the panel on the flutter boundaries are investigated. Results of this paper can be considered as a useful tool in design and analysis of supersonic airplanes and missiles.

References listed at the end of the paper:


ABSTRACT: In this paper, the geometrical nonlinear vibrations of a rectangular plate have been investigated experimentally and numerically. The experiment was conducted on a thin rectangular plate. The plate was excited close to the first fundamental natural frequency. The time history of velocities of the central point has been measured by using a laser vibrometer. While the numerical investigation has been carried using the Finite Element Method (FEM), the numerical results are validated by analytical and experimental results. In order to develop and test the extraction procedure of the bifurcation plot of a dynamical system, a chaotic pendulum has been analyzed. Then, the same successful code has been used again for the experimental dynamics of the investigated plate. The plate has been forced with a sinusoidal input at a gradually stepped and increased amplitude. For every step, the phase portrait is determined, and then processed to extract the bifurcation map. The resulted map has shown successfully the linear range where the classical plate theory is adequate, and the boundary at which the transition to nonlinearity has occurred. The bifurcation has occurred when the lateral amplitude has reached 50% of the plate thickness.

References listed at the end of the paper:


Mousa Rezaee and Naser Sharafkhani (Department of Mechanical Engineering, University of Tabriz, Tabriz, Iran), “Nonlinear Dynamic Analysis of an Electrostatically Actuated Cylindrical Micro-Beam Subjected to
ABSTRACT: This work investigates the nonlinear dynamic behavior of an electrostatically actuated clamped-clamped cylindrical micro-beam subjected to vortex induced vibrations (VIV). Lift and drag forces are the two basic flow-induced factors affecting the dynamics of the micro-beam under fluid flow which are neglected in micro-structures immersed in stationary fluids. The electrostatically actuated micro-beam is modelled using Timoshenko beam theory and the impact of the fluid cross-flow is accounted for by considering its resultant force elements comprising inertia, lift and drag force vectors. In addition, the size dependency effect on the nonlinear dynamics of the micro-beam is studied based on the Modified Couple Stress Theory (MCST). The governing nonlinear equations are solved using the Galerkin and step-by-step linearization method to evaluate the response of the coupled structure to a combined voltage excitation plus fluid flow. Response of the micro-beam to different input voltages in the presence of fluid velocities are investigated and it is shown that the range and intensity of the lock-in regime is effectively controlled by the input voltage and fluid-to-beam density ratio.

References listed at the end of the paper:

ABSTRACT: A nonlocal strain gradient theory (NSGT) is utilized to investigate the thermal buckling, free vibration and wave propagation in smart piezoelectromagnetic nanoplates in hygrothermal environments embedded in an elastic substrate. The main advantage of the NSGT over other continuum theories is that it contains both nonlocal parameter and material length scale parameter. The elastic substrate is modeled as Pasternak foundation model. According to the NSGT and the sinusoidal two-variable shear deformation plate theory, the governing equations of motion are derived involving the material parameters and hygrothermo-electromagnetic effects. The present solutions are checked through comparisons with those presented in the literature. Numerical results show the impacts of the nonlocal and gradient parameters, side-to-thickness ratio, hygrothermo-electromagnetic loads and substrate stiffness on the thermal buckling, frequencies and wave propagation in the smart nanoplates.

References listed at the end of the paper:


ABSTRACT: In this study, the vibration of functionally graded porous truncated conical shell reinforced with graphene platelets (GPLs) is investigated. The GPLs nanofillers and pores are considered to be uniform and nonuniform throughout the thickness direction. Using Hamilton’s principle, the governing equations are derived based on Love’s first approximation theory. The generalized differential quadrature method is applied to solve the governing equations of motion and to obtain the natural frequencies of the shells for various boundary conditions. Applying the Halpin–Tsai model and the rule of mixture, the effective elastic modulus, the Poisson’s ratio and the density of nanocomposite shell reinforced with GPLs are computed. The effects of porosity coefficients, distribution patterns of porosity, GPL weight fraction, geometry and size of GPLs, semi-
vertex angle as well as boundary conditions on the natural frequency of the system are analyzed. It was observed in the results that the shells with symmetric porosity distribution reinforced by graphene platelet pattern A predict the highest natural frequencies. Furthermore, it was found that the natural frequencies of nanocomposite conical shell can be decreased by increasing the porosity coefficient. Besides, the geometry and size of GPLs as well as weight fraction of GPLs have significant effects on the natural frequencies.

References listed at the end of the paper:

- Duc, N. D., Cong, P. H., Tuan, N. D., Tran, P. and Van Thanh, N. J. [2017] “Thermal and mechanical stability of functionally graded carbon nanotubes (FG CNT)-reinforced composite truncated conical shells surrounded by the elastic foundations,” Thin-Walled Structures 115, 300–310.
Then, by using both Floquet technology and Bolotin’s method, a linear analysis is

ABSTRACT: The size-dependent stability mechanism and nonlinear dynamics of a nano-scale beam under an axial time-dependent load are theoretically studied based on nonlocal strain gradient theory. First, with the consideration of geometric nonlinearity of the nanobeam, the equation of motion is derived with the aid of Hamilton’s principle. Then, by using both Floquet technology and Bolotin’s method, a linear analysis is
employed to investigate the size-dependent stability mechanism of the nanobeam for pinned-pinned boundary conditions. It is demonstrated that the results obtained based on the Floquet technology and Bolotin’s method agree well with each other in most cases. Furthermore, the analytical expressions for stability boundaries of the nanobeam system are derived. It is found that when the size-dependent nanobeam system is reduced to a classical one, the obtained expressions for stability boundaries are in good agreement with previous experimental results. Finally, the nonlinear responses of the nanobeam are presented in the form of time traces, bifurcation diagrams and phase portraits. It is shown that the axially excited nanobeam always undergoes a limit cycle oscillation. For all results regarding stability boundaries and nonlinear responses, the size-dependent effects are found to be significant.

References listed at the end of the paper:


ABSTRACT: Free vibrational and bending behavior of functionally graded graphene platelet reinforced composite (FG-GPLRC) circular and annular plate with various boundary conditions is studied using the differential quadrature method (DQM). The weight fraction differs gradually across the thickness direction. Effective elasticity modulus of the nanocomposite has been estimated by the modified Halpin–Tsai model. Using equations of motion in the framework of the elasticity theory and constitutive relation, the state-space first-order differential equation along the thickness direction is derived. A semi-analytical solution is carried out based on the application of DQM along the radial direction and the state-space technique across the thickness of the plate. The present approach is validated by comparing the numerical results with those reported in the literature. Effect of graphene platelets (GPLs) weight fraction, different GPL distribution patterns, thickness-to-radius and outer-to-inner radius ratios and edge boundary conditions on the static and vibrational behavior of GPLs reinforced composite circular/annular plates are examined. The results implied that GPLs can improve the composite strength against different loading and GPLs could have an extraordinary reinforcing influence on the static and vibrational behavior of the circular/annular plates.

References listed at the end of the paper:

ABSTRACT: This paper presents the second-order statistics of hygro-thermo-electrically-induced progressive failure in terms of first-ply failure load (FPFL) and last-ply failure load (LPFL) analysis for laminated composite material plate (LCMP) under out of plane mechanical loading with random system properties. Basic governing equation of nonlinear progressive failure analysis is based on shear deformation theory (higher order) with von-Karman nonlinear kinematics using Newton’s Raphson approach through Tsai–Wu failure criteria.

The random input variables are assumed as uncorrelated type and are evaluated using second-order perturbation method (SOPT). Laminated composite plate with elliptical cutouts are subjected to uniformly distributed, point and hydrostatic load. The effect of boundary conditions, temperature variation, moisture content and voltage variations by utilizing piezo-electric layer position and various cutout shapes on the mean and corresponding covariance (COV) of FPFL and LPFL load are evaluated. Convergence of numerical analysis is performed, and results are validated with those available in literatures to check the efficiency of present methodology. It is observed that the presence of elliptical hole always causes an increase in the failure load of plates subjected to bending, even further increase for LPFL due to the reduction of stresses.

References listed at the end of the paper:


ABSTRACT: A semi-analytical method is presented to investigate time-dependent thermo-elastic creep behavior and life assessment of thick truncated conical shells with variable thickness subjected to internal pressure and thermal load. Based on the first-order shear deformation theory (FSDT), equilibrium equations and boundary conditions are derived using the minimum total potential energy principle. To the best of the researcher’s knowledge, in previous studies, thermo-elastic creep analysis of conical shell with variable thickness based on the FSĐT has not been investigated. Norton’s law is assumed as the material creep constitutive model. The multilayered method is proposed to solve the resulting equations, which yields an accurate solution. Subsequently, the stresses at different creep times can be obtained by means of an iterative approach. Using Robinson’s linear life fraction damage rule, the creep damages of conical shells are determined and Larson–Miller parameter (LMP) is employed for assessing the remaining life. The results of the proposed approach are validated with those of the finite element method (FEM) and good agreement was found. The results indicate that the present analysis is accurate and computationally efficient.


ABSTRACT: The free vibration analysis of sandwich micro-beam (SMB) which is subjected to electrical field is investigated by adopting the Euler–Bernoulli beam theory (EBBT) and modified strain gradient theory (MSGT). SMB is made of three layers, including a functionally graded (FG) porous core and two flexoelectric face-sheets. The porosities are assumed to be distributed over the beam thickness based on the two distribution functions. Also, due to the electric properties of flexoelectric materials, face-sheets of SMB are subjected to the external electric field. The modified Silica Aerogel foundation model is employed to consider the effects of elastic foundation on SMB. The size-dependent governing equations of motion are derived using Hamilton’s principle and solved by Navier’s solution method for a case of simply supported SMB. The effects of various parameters, such as length to thickness ratio, porosity index, flexoelectric loadings (the load applied to the flexoelectric face-sheets caused by external electric field), small scale parameter and foundation parameters on dimensionless frequency of SMB, are assessed. The results of this work can be used for optimum design and control of micro-electro-mechanical devices.

References listed at the end of the paper:
Fundamental frequency analysis of functionally graded beams by using different higher-order beam theories,” Nuclear Engineering and Design 240, 697–705.


Abstract: Vibration problems of pipelines made of composite materials conveying pulsating flow of gas and fluid are investigated in the paper. A dynamic model of motion of pipelines conveying pulsating fluid flow supported by a Hetenyi’s base is developed taking into account the viscosity properties of the structure material, axial forces, internal pressure and Winkler’s viscoelastic base. To describe the processes of viscoelastic material strain, the Boltzmann–Volterra integral model with weakly singular hereditary kernels is used. Using the Bubnov–Galerkin method, the problem is reduced to the study of a system of ordinary integro-differential equations (IDE). A computational algorithm is developed based on the elimination of the features of IDE with weakly singular kernels, followed by the use of quadrature formulas. The effect of rheological parameters of the pipeline material, flow rate and base parameters on the vibration of a viscoelastic pipeline conveying pulsating fluid is analyzed. The convergence analysis of the approximate solution of the Bubnov–Galerkin method is carried out. It was revealed that the viscosity parameters of the material and the pipeline base lead to a significant change in the critical flow rate. It was stated that an increase in excitation coefficient of pulsating flow and the parameter of internal pressure leads to a decrease in the critical flow rate. It is shown that an increase in the singularity parameter, the Winkler base parameter, the rigidity parameter of the continuous base layer and the Reynolds number increases the critical flow rate.

References listed at the end of the paper:

References


nearly perfect spherical shells and may be helpful to obtain more accurate buckling analyses. This finding may give better understandings to the differences between theoretical and experimental results for the Willis equations, which explicitly contain the stress gradients at previous loading step. It can be shown that the fluid under thermal loading may FEM are about 10% lower than the values from classical FEM. This discrepancy is customarily attributed to initial geometrical imperfections, and the impact of inhomogeneously distributed stresses during loading process is usually ignored. In order to investigate the effect of this ignored factor, the buckling loads of several spherical shells are analyzed by the geometrically nonlinear finite element method (FEM) based on the Willis-form equations, which explicitly contain the stress gradients at previous loading step. It can be shown that the buckling loads from the Willis-form FEM are about 10% lower than the values from classical FEM. This finding may give better understandings to the differences between theoretical and experimental results for nearly perfect spherical shells and may be helpful to obtain more accurate buckling loads for shells with initial geometrical imperfections.

References listed at the end of the paper:


In this paper, nonlinear dynamic buckling of laminated composite cylindrical panels subjected to in-plane impulsive compressive load is studied along with the failure analysis. Balanced and symmetric angle-ply laminated composite curved panels are considered. Convergence study is performed, and results are validated with the results from the existing literature, and then the dynamic buckling loads are calculated. The failure index of laminated composite curved panels is also calculated to check the precedence of first ply failure load over nonlinear dynamic buckling load. The effect of aspect ratio, loading function, and radius of curvature is studied. The analysis is carried out using finite element method. It is observed that the first ply failure for balanced and symmetric angle-ply laminated composite curved panels occurs after the panel has buckled due to dynamic impulse loads.

References listed at the end of the paper:


ABSTRACT: In this paper, nonlinear dynamic buckling of laminated composite cylindrical panels subjected to in-plane impulsive compressive load is studied along with the failure analysis. Balanced and symmetric angle-ply laminated composite curved panels are considered. Convergence study is performed, and results are validated with the results from the existing literature, and then the dynamic buckling loads are calculated. The failure index of laminated composite curved panels is also calculated to check the precedence of first ply failure load over nonlinear dynamic buckling load. The effect of aspect ratio, loading function, and radius of curvature is studied. The analysis is carried out using finite element method. It is observed that the first ply failure for balanced and symmetric angle-ply laminated composite curved panels occurs after the panel has buckled due to dynamic impulse loads.
ABSTRACT: The aeroelastic flutter analysis of thick porous plates surrounded with piezoelectric layers in supersonic flow is studied. In order to aeroelastic analysis of the thick porous-cellular plate, Reddy’s third-order shear deformation plate theory and first-order piston theory are used. Furthermore, the plate is composed of two face piezoelectric layers and three functionally graded porous distributions core. Applying the extended Hamilton’s principle and Maxwell’s equation, the governing equations of motion are obtained. The partial differential governing equations are transformed into a set of ordinary differential equations by applying Galerkin’s approach. The effects of porosity coefficient, porosity distributions, piezoelectric layers, geometric dimensions, electrical and mechanical boundary conditions on the flutter aerodynamic pressure and natural frequencies of porous-cellular plates are investigated.

References listed at the end of the paper:


ABSTRACT: Due to the interesting properties such as light weight and high deformation ability, dielectric elastomer (DE) resonators can be good alternatives for conventional silicon resonant beams used in micro-electro-mechanical systems (MEMS). This paper proposes a modeling in which a pre-stretched clamped-clamped DE-based microbeam oscillating above the ground substrate is subjected to an external electrostatic pressure. Using a DE-based beam affects the total rigidity of the system, which may lead to an anticipated saddle-node or pitchfork bifurcation. Hence, the present study tries to analyze the effects of DE properties on changing the stability regime of DE-based microbeams under electrostatic actuation. The stability of the system has been investigated using an eigen-value form of the problem. The effects of DE properties including pre-stress, relative permittivity and voltage value across the electrodes on pull-in or divergence instability as well as the frequency response of the system have been investigated. Moreover, the critical values of the DE voltage as a booster of instability occurrence have been obtained in either the presence or absence of the direct current (DC) voltage. It has been found that the pre-stress and appropriate DE permittivity can provide a needed magnitude of the DE actuating voltage to alter the resonance frequency and stability positions of the structure.

References listed at the end of the paper:


Salamat Ullah, Jinghui Zhang and Yang Zhong (First author is from: Faculty of Infrastructure Engineering, Dalian University of Technology, No. 2 Linggong Road, Ganjingzi District, Dalian City, Liaoning Province, 116024, P. R. China), “New Analytical Solutions of Buckling Problem of Rotationally-Restrained Rectangular Thin Plates”, International Journal of Applied Mechanics, Vol. 11, No. 10, 1950101, 2019, https://doi.org/10.1142/S1758825119501011

ABSTRACT: A double finite sine integral transform method is employed to analyze the buckling problem of rectangular thin plate with rotationally-restrained boundary condition. The method provides more reasonable
and theoretical procedure than conventional inverse/semi-inverse methods through eliminating the need to preselect the deflection function. Unlike the methods based on Fourier series, the finite integral transform directly solves the governing equation, which automatically involves the boundary conditions. In the solution procedure, after performing integral transformation the title problem is converted to solve a fully regular infinite system of linear algebraic equations with the unknowns determined by satisfying associated boundary conditions. Then, through some mathematical manipulation the analytical buckling solution is elegantly achieved in a straightforward procedure. Various edge flexibilities are investigated through selecting the rotational fixity factor, including simply supported and clamped edges as limiting situations. Finally, comprehensive analytical results obtained in this paper illuminate the validity of the proposed method by comparing with the existing literature as well as the finite element method using (ABAQUS) software.

References listed at the end of the paper:


ABSTRACT: This is the first research on the vibration and buckling analysis of a graphene nanoplatelet composite (GPLRC) microdisk in the framework of a numerical based generalized differential quadrature method (GDQM). The stresses and strains are obtained using the higher-order shear deformable theory (HOSDT). Rule of the mixture is employed to obtain varying mass density, thermal expansion, and Poisson’s ratio, while the module of elasticity is computed by modified Halpin–Tsai model. Governing equations and boundary conditions of the GPLRC microdisk are obtained by implementing Extended Hamilton’s principle. The results show that outer to inner ratios of the radius ($R_i/R_o$), ratios of length scale and nonlocal to thickness ($\beta/h$ and $\mu/h$), and GPL weight fraction ($\delta_{GPL}$) have a significant influence on the frequency and buckling characteristics of the GPLRC microdisk. Another necessary consequence is that by increasing the value of the $R_i/R_o$, the distribution of the displacement field extends from radial to tangent direction, especially in the lower mode numbers, this phenomenon appears much more remarkable. A useful suggestion of this research is that, for designing the GPLRC microdisk at the low value of the $R_i/R_o$, more attention should be paid to the $\delta_{GPL}$ and $R_i/R_o$, simultaneously.

References listed at the end of the paper:


propagation problems
strip method
Chen, Q. and Qiao, P.
York, Tokyo).
Bradford, M. A. and Azhari, M.
Enginee
Belytschko, T., Lu, Y. Y. and Gu, L.
1559.
Belinha, J.
References listed at the end of the paper:
effectiveness of this work.
reduces the analysis time, and the essential boundary conditions are easily enforced in FS sub
ed for free vibration analysis of thin plates. This method is very easy to
complex geometry, and FS method is used for the remaining domains. The use of the FS method considerably
finite strip (FS) method is presented for free vibration analysis of thin plates. This method is very easy to

ABSTRACT: In this paper, a coupling of improved element-free Galerkin (IEFG) method and semi-analytical
finite strip (FS) method is presented for free vibration analysis of thin plates. This method is very easy to
implement and has advantages of both IEFG and FS methods, so that IEFG method is used in sub-domain with
complex geometry, and FS method is used for the remaining domains. The use of the FS method considerably
reduces the analysis time, and the essential boundary conditions are easily enforced in FS sub-domain. In the
IEFG method, the shape function does not have the Kronecker delta function property. Therefore, Lagrange
multipliers method is used to satisfy the boundary conditions. Finally, five examples are presented to show the
effectiveness of this work.

References listed at the end of the paper:


ABSTRACT: In this paper, the improved complex variable element-free Galerkin (ICVEFG) method is proposed for solving the bending problem of thin plate on elastic foundations. In the ICVEFG method, the approximation function regarding the deflection of thin plate is formed with the improved complex moving least-squares (ICVMLS) approximation, the discrete equation is obtained from Galerkin weak form of bending problem of thin plate on different elastic foundations, and essential boundary conditions are considered based on penalty method. As the ICVMLS approximation is based on the complex variable theory, it can obtain the shape function quickly with high precision. Three sample problems are used to discuss the advantages of the ICVEFG method, and the numerical results show that the ICVEFG method presented in this paper has a fast convergence speed and great computational accuracy.

References listed at the end of the paper:


ABSTRACT: In this study, axisymmetric elastic deformation analysis of rotating disks with variable thickness is conducted using an improved Adomian decomposition method (IADM). Variation of thickness is assumed as hyperbolic and different variations are employed for each case considered. Several analytical approximate solutions in different orders are obtained for radial stress, tangential stress, radial displacement and are compared with exact solutions. Results show that IADM can effectively be used in the deformation analysis of rotating variable thickness disks providing the solution as an analytical continuous function in the solution domain.

References listed at the end of the paper:

ABSTRACT: In this research, the nonlinear free vibrations analysis of functionally graded (FG) rectangular plate which simply supported all edges are investigated analytically using modified Lindstedt–Poincare (MLP) method for the first time. For this purpose, with the aid of von Karman nonlinearity strain–displacement relations, the partial differential equations of motion are developed based on first-order shear deformation theory (FSDT). Afterward, by applying Galerkin method, the nonlinear partial differential equations are transformed into the time-dependent nonlinear ordinary differential equations. The nonlinear equation of motion is then solved analytically by MLP method to determine the nonlinear frequencies of the FG rectangular plate. The material properties are assumed to be graded through the direction of plate thickness according to power law distribution. The effects of some system parameters such as vibration amplitude, volume fraction index and aspect ratio on the nonlinear to linear frequency ratio are discussed in detail. To validate the analysis, the results of this paper are compared with both the published data and numerical method, and good agreements are found.

References listed at the end of the paper:


Ying Liu and Peng Zhou (Department of Mechanics, Beijing Jiaotong University, Beijing 100044, P. R. China),

ABSTRACT: In this work, a surface-reinforced sandwich configuration with variable material layer is proposed to improve the plastic performance of sandwich structures in limited-space with the least cost, which is promoted by hierarchy of human bone with multi-stiff layers outside the cellular core. First, a generalized yielding criterion and an analytical model for the large deflection of the fully clamped surface-reinforced sandwich beams under transverse loading are developed. Then, the comparison between finite element (FE) simulations and experimental results for surface-reinforced sandwich beams with varied geometric and physical properties of each material layers is presented, which verifies the accuracy of the theoretical solutions. Finally, the coordinated design of the surface-reinforced sandwich beam in limited-space is investigated and the synergistic effects of each material layer on the load carrying and energy absorption ability of the structure are discussed in detail. The results given in this paper provide theoretical guidance in plastic design of sandwich structures with multi-cover sheets as well as the selection of the face-sheet, the core and the reinforced skin.

References listed at the end of the paper:


Atteshamuddin S. Sayyad (1) and Yuvaraj M. Ghugal (2)

(1) Department of Civil Engineering, SRES’S Sanjivani College of Engineering, Savitribai Phule Pune University, Kopargaon-423601, Maharashtra, India

(2) Department of Applied Mechanics, Government College of Engineering, Karad-415124, Maharashtra, India


ABSTRACT: In this study, a theoretical unification of twenty-one nonlocal beam theories are presented by using a unified nonlocal beam theory. The small-scale effect is considered based on the nonlocal differential constitutive relations of Eringen. The present unified theory satisfies traction free boundary conditions at the top and bottom surface of the nanobeam and hence avoids the need of shearing correction factor. Hamilton’s principle is employed to derive the equations of motion. The present unified nonlocal formulation is applied for the bending, buckling and free vibration analysis of functionally graded (FG) nanobeams. The elastic properties of FG material vary continuously by gradually changing the volume fraction of the constituent materials in the thickness direction. Closed-form analytical solutions are obtained by using Navier’s solution technique. Non-

dimensional displacements, stresses, natural frequencies and critical buckling loads for FG nanobeams are presented. The numerical results presented in this study can be served as a benchmark for future research. References listed at the end of the paper:


ABSTRACT: The aim of the present study was to introduce new crushing mechanisms in terms of crushing modes for estimating the crushing force and absorbed energy of polygonal thin walled metal sections subjected to axial progressive collapse. For this purpose, two models were developed. The first model, which has been extensively used before and named as “plastic hinge model” (PHM), was modified based on new crushing modes; and as the second, a novel model was introduced by the authors named as “induced curvature model” (ICM). The latter model was considered to be more realistic than the former due to consideration of metal sheet curvatures during progressive folding process, as well as including the hardening effect of the material during plastic deformation. All possible crushing modes for a typical polygonal section were considered and discussed by combining different crushing modes of the corner elements. New expressions for the absorbed energies and crushing force were presented based on the resulting crushing modes. To evaluate the validity and efficiency of the proposed models, a detailed FE simulation was conducted using LS-DYNA. Comparison of FEM, PHM and ICM results showed the superiority of the ICM over PHM.

References listed at the end of the paper:


Winter, G. and Pian, R. J. I. [1946] Crushing Strength of Thin Steel Webs: Engineering Experiment Station, Bulletin No. 35 (Cornell University, New York).


ABSTRACT: This is the first research on the thermal buckling analysis of graphene nanoplatelets reinforced composite (GPLRC) doubly curved open cylindrical micropanel in the framework of numerical-based two-dimensional generalized differential quadrature method (2D-GDQM). Additionally, the small-scale effects are analyzed based on nonlocal strain gradient theory (NSGT). The stresses and strains are obtained using the high-order shear deformable theory (HOSDT). The rule of mixture is employed to obtain varying thermal expansion, and Poisson’s ratio, while module of elasticity is computed by modified Halpin–Tsai model. In addition, nonlinear temperature changes along the GPLRC micropanel’s thickness direction. Governing equations and boundary conditions of the GPLRC doubly curved open cylindrical micropanel are obtained by implementing the extended Hamilton’s principle. Besides, for the validation of the results, the results of current model are compared to the results acquired from analytical method. The results show that GPL weight function (\(\gamma_{GPL}\)), the ratio of shell curvatures (\(R_{1}/R_{2}\)), NSG parameters, and geometric parameters have a significant influence on the thermal buckling characteristics of the GPLRC doubly curved open cylindrical micropanel.

References listed at the end of the paper:


https://doi.org/10.1080/15376494.2019.1672337


https://doi.org/10.1080/15397734.2019.1662310


https://doi.org/10.1080/15397734.2019.1701490


https://doi.org/10.1080/15397734.2019.1697932


ABSTRACT: In this paper, we present an efficient finite element framework for modeling the finite deformations of slender magneto-active elastomers (MAE) under applied magnetic fields or currents. For the convenience of numerical modeling, magnetic field is defined at fixed spatial coordinates in the background space rather than in the elastic MAEs using material coordinates. The magnetic field will vary with free or localized currents while the spatial distribution of the magnetic field will evolve with the motion or deformation of the MAE materials, which is actuated by the surface or body forces induced by external magnetic fields or
equivalent currents. A staggered strategy and a Riks method are introduced to solve the strongly coupled governing equations of the magnetic field and displacement field using finite element method. The mesh distortion along the interfaces between MAE domain and free-space domain is resolved by considering concurrent deformation of the mesh in these two domains. A few 2D numerical examples demonstrate the validity and efficiency of the developed model for simulating large deformation of MAE with non-uniform spatial magnetic field under different actuation sources such as free currents, magnetization or external magnetic field. This framework offers a new solution strategy for modeling mechano-magneto problems of MAEs and will help rational design and analysis of MAE-based actuators and soft robotics in the future.

References listed at the end of the paper:
Mohammed Sobhy (Department of Mathematics and Statistics, Faculty of Science, King Faisal University, P. O. Box 400, Hofuf 31982, Saudi Arabia and Department of Mathematics, Faculty of Science, Kafrelsheikh University, Kafrelsheikh 33516, Egypt), “Size-Dependent Hygro-Thermal Buckling of Porous FGM Sandwich Microplates and Microbeams Using a Novel Four-Variable Shear Deformation Theory”, International Journal of Applied Mechanics, Vol. 12, No. 2, 2050017, March 2020, https://doi.org/10.1142/S1758825120500179

ABSTRACT: Based on a new shear deformation theory and the modified couple stress theory, in this paper, the hygro-thermal buckling of porous FGM sandwich microplates and microbeams is investigated. Unlike the classical elasticity theory, the present model involves a material length scale parameter, and, thereby, can capture the small size effect. The four-variable shear deformation theory with a new shape function is utilized to derive the governing stability equations for the microplates and microbeams from the principle of virtual work. The present microstructures are composed of three layers and subjected to hygro-thermal conditions. The core is assumed to be fully homogeneous and isotropic material. While, the face layers are made from porous functionally graded materials that vary only in the thickness direction. The governing equations are solved analytically to obtain the thermal buckling of FGM sandwich microplates and microbeams under humidity effects. The temperature rise and moisture concentration are graded uniformly, linearly or nonlinearly through the thickness. Comparison studies are made between the present results and those available in the literature to check the validity of the obtained formulations and results. Moreover, the effects played by the length scale parameter, power-law exponent, moisture concentration, core thickness and other parameters on the thermal buckling of microplates and microbeams are all investigated.

References listed at the end of the paper:


ABSTRACT: The influence of a multi-layer core on the blast response of composite sandwich cylinders under internal explosive loading was investigated. Experiments were conducted first to obtain the fundamental deformation and failure patterns of composite cylinders with uniform, double-layer, and triple-layer profile cores. They were compared with the finite element model for prediction with good agreement. The mechanisms of energy absorption and deformation of a composite sandwich were explored by parametric analysis. Experimental results indicated that compaction wave in a double-layer core was initiated from the inner face sheet and then propagated to the outer face sheet when the gradient was positive; however, the core densification started at the inner surfaces of both layers and propagated to the outer face sheet together. The maximum radial deflection decreased with increasing face sheet thickness or decreasing blast loading. The percentage of energy absorbed by the core increased with decreasing face sheet thickness or increasing blast loading. This study revealed a possibility to reduce the maximum deflection (same structural mass and same energy absorption) for the sandwich cylinders by using a proper core distribution.

References listed at the end of the paper:
ABSTRACT: The first research on the buckling and free vibration analysis of functionally graded cellular rods under impact. This study uses Kirigami approach and welding technology to design sandwich panels subjected to blast loading. The energy absorption behavior of cruciforms designed by Kirigami approach is investigated. The high velocity impact mitigation with gradient cellular solids is discussed. The analytical solutions for large deflections of functionally graded beams based on layer-graded beam model is obtained.
kinematics on the basis of HSDT makes the results closer to real condition. Numerical results are compared with those published in the literature to examine the accuracy and validity of the applied approach. A comprehensive parametric study is accomplished to reveal the influence of stiffness of the substrate, patterns of temperature rise, temperature gradient, axial load, weight fraction and distribution patterns of GPLs, outer radius to inner radius ratio, inner radius to thickness ratio of the plate and geometric dimensions of GPLs on the response of the structure. This study provides essential information to engineers seeking innovative ways to promote the composite structures in a practical way.

References listed at the end of the paper:
Part C: Journal of Mechanical Engineering Science

Spinning cantilever cylindrical 3D elastic foundations in thermal environments

Cylindrical shells in thermal environments

Thermomechanical loading by finite element method

Multi-axial material heterogeneities based on curved B

Stress analysis of temperature dependent FG multilayer GPLRC composite nanostructures strung on elastic foundation

Nanoshell in thermal environment based on the nonlocal strain gradient theory

America.

Reinforced porous composite cylindrical shell

Improved whale optimization algorithm

Optimization problems on quantum dolphin swarm algorithm

Wavelet transform and an improved deep learning algorithm

Characteristics of the GPL reinforcement composite nanostructures

Hygrothermal field

Flat plates

Multiaxial material heterogeneities based on curved B


Shokrgozar, A., Safarpour, H. and Habibi, M. [2019] “Influence of system parameters on buckling and frequency analysis of a spinning cantilever cylindrical 3D shell coupled with piezoelectric actuator,” Proceeding...


**ABSTRACT:** This paper presents a solution for static torsion in a microtube made of bi-directional functionally graded materials (BDFGMs). The material properties are assumed to vary according to the arbitrary function along radius and length of microtube. As for the torque effect of the axial magnetic field, the well-known Maxwell’s relation is used. Couple stress theory is employed to study the influence of small-scale on static torsion of microtube. The Navier equation and boundary conditions of the size-dependent BDFGM microtube were derived by the minimum potential energy. These equations were solved by employing the generalized differential quadrature method (GDQM). Comparison between the results of this work with the analytical method for static torsion of microtube made of one direction FG material reveals the accuracy of this study. Finally, numerical results are presented to study the small-scale effect and heterogeneity constants on the static torsion of the bi-directional functionally graded microtube.

**References listed at the end of the paper:**


Abbas Barati (1), Mohsen Mahdavi (2) Adeli and Amin Hadi (3)

(1) Department of Mechanical Engineering, University of Guilan, Rasht, Iran
(2) Department of Mechanical Engineering, Soussegerd Branch, Islamic Azad University, Soussegerd, Iran
(3) School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran

Nejad, M. Z., Hadi, A. and Rastgoo, A. [2016] “Buckling analysis of arbitrary two-directionally functionally graded Euler–Bernoulli nano-

ABSTRACT: Non-Pneumatic Tires with honeycomb structure have complex design and their mechanical behavior is influenced by their geometry. As a result, deep understanding of the effect of various design parameters is very important for design optimization. In this numerical analysis, the effect of a wide range of internal geometrical parameters on the tire’s weight and mechanical behavior was quantified. For this purpose, a parametric finite element model was designed and subjected to vertical loading to assess its maximum stress, contact pressure, maximum vertical displacement and energy absorbed during loading. The analysis indicated that vertical stiffness is strongly affected by the density, thickness and internal angles of the honeycomb cells. The internal angles of the honeycomb also appeared capable of changing the tire’s vertical stiffness without changing its weight, which is associated with the tire’s fuel efficiency and dynamic properties. A decrease in cell length or an increase in cell density was capable of significantly reducing the internal stresses. Proper tuning of cell thickness or cell length could also significantly reduce the magnitude of contact pressure developed by producing a more even distribution of loading between the tread and the internal angles of the honeycomb cells.

References listed at the end of the paper:


ABSTRACT: Free vibration of coupled system including clamped-free thin circular plate with hole submerged in three-dimensional cylindrical container filled with inviscid, irrotational and compressible fluid is investigated in this work. Numerical approach based on the finite element method (FEM) is performed using the Comsol Multiphysics software, in order to analyze qualitatively the vibration characteristics of the plate. Plate modeling is based on Kirchhoff–Love plate theory. Velocity potential is deployed to describe the fluid motion since the small oscillations induced by the plate vibration is considered. Bernoulli’s equation together with potential theory is applied to get the fluid pressure on the free surface of the plate. To prove the reliability of the present numerical solution, a comparison is made with the results in the literature, which shows a very good agreement. Then, different parameters effect including fluid density, fluid height, free surface wave, hole radius and hole eccentricity on the natural frequencies of the coupled system is discussed in detail. Some three-dimensional mode shapes of the submerged plate are illustrated. Furthermore, the obtained results can serve as benchmark solutions for the vibration control, parameter identification and damage detection of plate.

References listed at the end of the paper:


ABSTRACT: A nonlocal Peridynamic Differential Operator (PDDO) is presented for static analysis of laminated composite plates based on the First-order Shear Deformation Theory (FSDT). The equilibrium equations and boundary conditions of the FSDT were derived from the principle of virtual work. The local spatial derivatives in these equations were replaced with their nonlocal PD forms. The continuous transverse shear stresses were achieved by integrating the stress equilibrium equations through the thickness of the plate. This approach was validated against an existing analytical solution by considering a simply supported laminated composite plate under uniformly distributed sinusoidal load for different aspect ratios. The performance of this formulation was investigated by comparing through-the-thickness stress variations against the analytical solutions.

References listed at the end of the paper:


ABSTRACT: In this paper, flutter and divergence instabilities of functionally graded plates and shells by radial basis functions, Engineering Analysis with Boundary Elements 51, 1550059.

The effects of graphene nanoplatelets distributions, graphene nanoplatelets weight fraction, geometry of graphene nanoplatelets, porosity coefficient and porosity distributions on the flutter and divergence instabilities of the system are studied. The results show that the plate strip with symmetric distribution pattern (stiffness in the surface areas) and GPLs pattern A predict the highest stable area. The flutter and divergence regions decrease as the porosity coefficient increases. Besides, the critical aerodynamic loads increase by adding a small amount of GPL to the matrix.

References listed at the end of the paper:


ABSTRACT: For the first time, a two-dimensional (2D) piezoelasticity-based analytical solution is developed for free vibration analysis of axially functionally graded (AFG) beams integrated with piezoelectric layers and subjected to arbitrary supported boundary conditions. The material properties of the elastic layers are considered to vary linearly along the axial ($x$) direction of the beam. Modified Hamiltons principle is applied to derive the weak form of coupled governing equations in which, stresses, displacements and electric field variables act as primary variables. Further, the extended Kantorovich method is employed to reduce the governing equation into sets of ordinary differential equations (ODEs) along the axial ($x$) and thickness ($z$) directions. The ODEs along the $z$-direction have constant coefficients, whereas the ODEs along $x$-direction have variable coefficients. These sets of ODEs are solved analytically, which ensures the same order of accuracy for all the variables by satisfying the boundary and continuity conditions in exact pointwise manner. New benchmark numerical results are presented for a single layer AFG beam and AFG beams integrated with piezoelectric layers. The influence of the axial gradation, aspect ratio and boundary conditions on the natural frequencies of the beam are also investigated. These numerical results can be used for assessing 1D beam theories and numerical techniques.

References listed at the end of the paper:


---

**References**

- [Differential transformation and quadrature methods](#)
- [Rajasekaran, S.](#)
- [Applied Mechanics](#)
- [Nemat](#)
- [Structures](#)
- [Li, X. F., Kang, Y. A. and Wu, J. X.](#)
- [11Kumari, P. and Behera, S](#)
- [Kumar, S. and Pueh Lee, H.](#)
- [Calim, F. F.](#)
- [Applied Mathematics and Mechanics](#)
- [Cozum, M.](#)
- [Elishakoff, I. and Candan, S.](#)
- [Fang, J. and Zhou, D.](#)
- [Ghazaryan, D., Burlayenko, V. N., Avetisyan, A. and Bhaskar, A.](#)
- [Huang, R., Zheng, S., Liu, Z. and Ng, T. Y.](#)
- [Huang, Y. and Li, X. F.](#)
- [Huang, Y. and Rong, H. W.](#)
- [Hwang, H. Y., Lee, J. W., Yang, J., Shul, C. W. and Kim, E.](#)
- [Kapuria, S., Dumir, P. and Ahmed, A.](#)
- [Karamanli, A.](#)
- [Kojima, M.](#)
- [Kumar, S., Mitra, A. and Roy, H.](#)
- [Kumari, P. and Behera, S.](#)
- [Li, S., Hu, J., Zhao, C. and Xie, L.](#)
- [Li, X. F., Kang, Y. A. and Wu, J. X.](#)
- [Mahmoud, M.](#)
- [Nemat–Alla, M., Ahmed, K. I. and Hassab–Allah, I.](#)
- [Nikolić, A.](#)
- [Rajasekaran, S.](#)


ABSTRACT: The propagation of surface waves of symmetric and anti-symmetric families is investigated in a generalized thermoelastic plate. Frequency equations of such surface waves are derived and deduced for the cases of long compressional, flexural and Rayleigh waves. The existence of two modes of vibration is discussed. Numerically and analytically, the phase speeds and attenuations of these waves are computed for a particular model to show the effect of specific heat.

References listed at the end of the paper:


ABSTRACT: Since lightweight and energy-absorbing materials have an effective role in occupant safety during accidents, the use of hybrid aluminum–composite tubes and their optimum designs are of great importance in the crashworthiness. In this study, finite element simulation and multi-objective optimization of a hybrid aluminum–composite tube are performed under axial crushing to investigate the effect of metal volume fraction (MVF) on the objective functions, the specific energy absorption and the peak force. Besides, the effects of annealing and tempering of ductile aluminum alloys (Al-6061) as the base metal of hybrid tubes are investigated. The optimum values of the objective functions are obtained at \( \text{MVF} = 0.5 \) (the same thickness of aluminum and composite). Also, annealing of ductile aluminum alloys has a negative effect on the objective functions. As a guideline for the design of fiber metal laminates under crushing, it is suggested to use tempered Al-6061 and increase the thickness of composite material so that \( \text{MVF} < 0.5 \).

References listed at the end of the paper:


Zhigang Liu


ABSTRACT: Rijke tube is a benchmark model widely used in thermo-aoustic community. As an alternative to existing modeling methods, this work proposes a modified Fourier series solution for modal characteristic analyses of a one dimensional (1D) thermo-acoustic system. The proposed modeling framework allows the consideration of arbitrary impedance boundaries owing to the special feature of the Fourier expansion series enriched by boundary smoothing polynomial terms. Thermo-acoustic Helmholtz governing equation coupled with a first-order heat release model is discretized through Galerkin procedure. Thermo-acoustic modal parameters are obtained by solving a standard quartic matrix characteristic equation, different from conventionally used root searching based on a transcendental equation. Numerical examples are presented to validate the proposed model through comparisons with results reported in the literature. Influences of boundary impedance are analyzed. Results reveal a quantitative relationship between the thermo-acoustic instability and heat source position with respect to the acoustic mode shapes. Results also show the existence of a sensitive zone, in which the thermo-acoustic modal behavior of the impedance-ended (IE) tube shows drastic changes with the boundary impedance. Meanwhile, a stable zone can be achieved upon a proper setting of the boundary impedance through suitable combination of the real and imaginary parts of the impedance.

References listed at the end of the paper:


ABSTRACT: In this research contribution, the static behavior and failure mechanisms are developed for a three-dimensional (3D) printed dogbone, auxetic structure and sandwich composite using acoustic emissions (AEs). The skins, core and whole sandwich are manufactured using the same bio-based material which is polylactic acid reinforced with micro-flax fibers. Tensile tests are conducted on the skins and the core while bending tests are conducted on the sandwich composite. Those tests are carried out on four different auxetic densities in order to investigate their effect on the mechanical and damage properties of the materials. To monitor the invisible damage and damage propagation, a highly sensitive AE testing method is used. It is found that the sandwich with high core density displays advanced mechanical properties in terms of bending stiffness, shear stiffness, facing bending stress and core shear stress. In addition, the AE data points during testing present an amplitude range of 40–85dB that characterizes visible and invisible damage up to failure.

References listed at the end of the paper:


ABSTRACT: This paper is devoted to superharmonic and subharmonic behavior investigation of imperfect functionally graded (FG) cylindrical shells with external FG spiral stiffeners under large amplitude excitations. The structure is embedded within a generalized nonlinear viscoelastic foundation, which is composed of a two-parameter Winkler–Pasternak foundation augmented by a Kelvin–Voigt viscoelastic model with a nonlinear cubic stiffness, to account for the vibration hardening/softening phenomena and damping considerations. The von Kármán strain-displacement kinematic nonlinearity is employed in the constitutive laws of the shell and stiffeners. The external spiral stiffeners of the cylindrical shell are modeled according to the smeared stiffener technique. The coupled governing equations are solved by using Galerkin’s method in conjunction with the stress function concept. The multiple scales method is utilized to detect the subharmonic and superharmonic resonances and the frequency–amplitude relations of the 1/3 and 1/2 subharmonic and 3/1 and 2/1 superharmonic resonances of the system. Finally, the influences of the stiffeners helical angles, foundation type, coefficient of the nonlinear elastic foundation, material distribution, and excitation amplitude on the system resonances are investigated comprehensively.

References listed at the end of the paper:


An axial or longitudinal magnetic field which is also exposed to both the hygroscopic as well as thermal and acts like classical beam approach but with considering shear deformations. The

ABSTRACT: In this study, vibration analysis of single-walled carbon nanotube (SWCNT) has been carried out by using a refined beam theory, namely one variable shear deformation beam theory. This approach has one variable lesser than a contractual shear deformation theory such as first-order shear deformation theory (FSDT) and acts like classical beam approach but with considering shear deformations. The SWCNT has been placed in an axial or longitudinal magnetic field which is also exposed to both the hygroscopic as well as thermal

environments. The thermal environment is considered as nonlinear thermal stress field based on the Murnaghan’s model whereas the hygroscopic environment is assumed as a linear stress field. The size effect of the SWCNT has been captured by both the nonlocal and gradient parameters by employing the Nonlocal Strain Gradient Theory (NSGT). Governing equation of motion of the proposed model has been developed by utilizing the extended Hamilton’s principle and the non-dimensional frequency parameters have been computed by incorporating the Navier’s approach for Hinged–Hinged (HH) boundary condition. The proposed model is validated with the existing model in special cases, by comparing the non-dimensional frequency parameters, displaying an excellent agreement. Further, a parametric study has been conducted to analyze the impact of nonlocal parameter, gradient parameter, thermal environment, hygroscopic environment, and magnetic field intensity on the non-dimensional frequency parameters. Also, results for some other theories like Classical Elasticity Theory (CET), Nonlocal Elasticity Theory (NET), and Strain Gradient Theory (SGT) have been presented along with the NSGT.

References listed at the end of the paper:


ABSTRACT: This paper studies the dynamic viscoelastic response of functionally graded (FG) thick 2D cantilever and simply supported beams under dynamic pulse load, for the first time. A point load applied at a specific spatial point is described as a time-pulse sinusoidal load. Two-dimensional plane-stress constitutive equation is exploited to describe the local stress–strain relation through the beam. The gradation of material is depicted by generalized power law function through the layer thickness across beam thickness. The Kelvin–Voigt viscoelastic model is proposed to describe material damping of structure. Lagrange’s equation is employed to derive governing motion equation. A finite element method (FEM) is exploited to discretize the spatial domain of 2D beam structure by using 12-node 2D plane element. Numerical Newmark implicit time integration method is proposed to solve the equation of motion incrementally and get the response of beam structure. Two types of boundary conditions are considered in the numerical examples. In numerical results, effects of stacking sequence, geometry parameters and material gradation index and viscoelasticity coefficients on the displacement-time response of layered functionally graded viscoelastic deep beams for different boundary conditions.

References listed at the end of the paper:


In this paper, free and forced vibrations of nanocomposite beams reinforced by 3D graphene are studied. Different distributions of 3D-GrF in the beam thickness direction are considered. In accordance with the rule of mixture, the effective Young’s modulus, Poisson’s ratio and mass density of the 3D-GrF reinforced beams are predicted. Based on the Timoshenko beam theory, the governing equation of the 3D-GrF reinforced beam is derived by using the Lagrange equation. The natural frequencies and dynamic responses of the 3D-GrF reinforced beam are solved by the Ritz method and the Newmark-β method, respectively. Results show that the foam coefficient, the 3D-GrF distribution, the slenderness ratio and the 3D-GrF mass fraction play important roles on free and forced vibration characteristics of the 3D-GrF reinforced beams.

References listed at the end of the paper:


ABSTRACT: This paper experimentally investigates the behavior of sandwich beam with auxetic core subjected to low-velocity impact loading. Two types of sandwich beams with different topologies of auxetic cellular cores were produced. Furthermore, a test procedure involving a cylindrical impactor was developed, and a parametric study was designed and performed. The results revealed that, at the same level of impact energy, the peak load decreased by increasing the re-entrant angle compared to the conventional sample. This is due to the negative Poisson’s ratio effect of structure that makes unit cells be strengthened. The results showed that once the core structure changed from the conventional to auxetic, the energy level leading to the best performance due to the highest amount of failure energy. Finally, the results showed that the auxetic core structure changed from the conventional to auxetic, the energy level leading to damage to the structure increased so that it was escalated by a factor of 2 in the auxetic sample compared to the conventional sample. This is due to the negative Poisson’s ratio effect of structure that makes unit cells be drawn into the projectile impact area and, in turn, the structure is strengthened.

References listed at the end of the paper:
ABSTRACT: In this paper, an analytical solution for functionally graded sandwich plate adhesively bonded by viscoelastic interlayer is proposed to research its time-dependent behavior. The Kirchhoff plate theory is
employed to describe the mechanical property of each gradient layer with elastic modulus defined as the arbitrary function through the thickness direction. The standard linear solid model is applied to simulate the viscoelasticity of the interlayer with considering the strain memory effect. By the use of the vibrational method and the Laplace transformation, the solutions of stresses and displacements are solved analytically. The validation study indicates that the present solution is correct and more effective than the finite element solution because of the fine mesh both in the geometric shape and the time step. In addition, the influences of the geometry and material parameters on the time-dependent behavior of the sandwich plate are investigated in detail.

References listed at the end of the paper:

ABSTRACT: In this paper, the novel model of fluid-conveying imperfect pipe supported at both ends is established by considering the geometric imperfection and the geometric nonlinearity induced by mid-plane stretching. The integral-partial differential equation is discretized by the Galerkin method and solved by a fourth-order Runge–Kutta integration algorithm. Compared with the supercritical pitchfork bifurcation of the perfect pipe conveying fluid, the results show that the cusp bifurcation occurs in the imperfect pipe when increasing the flow velocity. Excellent agreement is observed between the numerical results and the analytical results. The two stable asymmetry bifurcation branches bring interesting phenomena in the post-buckling state. The global nonlinear dynamic behaviors of the imperfect pipe are studied by establishing the bifurcation diagrams. The influence of the geometric imperfection amplitude on the nonlinear response is leading to cusp bifurcation comparing with pitchfork bifurcation of the perfect pipe. When pulsation frequency is set as the bifurcation parameter, there are clear nonresonance ranges, low energy resonance ranges and high energy resonance ranges. In the high energy resonance ranges, the first mode vibration coexisting with the subharmonic resonance and combination resonance occurs. As the mean flow velocity and pulsation amplitude are set as bifurcation parameters, the vibration of the imperfect pipe becomes more and more complicated. The vibration exhibits far richer dynamic behaviors including periodic, multi-periodic, quasi-periodic, and chaotic motions. The viscoelastic damping can effectively suppress the vibration response and transfer the high energy resonance to the low energy resonance state. The improved model and corresponding results provide useful information for further understanding the dynamic behaviors of fluid-conveying pipe with geometric imperfections.

References listed at the end of the paper:


ABSTRACT: Smart control and dynamic investigation of a graphene nanoplatelets reinforced composite (GPLRC) cylindrical shell surrounded by a piezoelectric layer as actuator and sensor based on a numerical solution method called generalized differential quadrature method (GDQM) are presented for the first time. The strains and stresses can be determined via the first-order shear deformable theory (FSDT). For accessing to various mass densities, thermal expansion as well as Poisson ratio, the rule of mixture is applied, although a modified Halpin–Tsai theory is used for obtaining the module of elasticity. The external voltage is applied to the sensor layer, while a proportional-derivative (PD) controller has been utilized for controlling the output of sensor. GPLRCs boundary conditions are derived through governing equations of the cylindrical shell using an energy method known as Hamilton’s principle. The outcomes show that the PD controller, viscoelastic foundation, slenderness factor (L/R), external voltage and graphene nanoplatelets (GPLs) weight fraction have a considerable impact on the amplitude, and vibration behavior of a GPLRC cylindrical shell. As an applicable
result in related industries, the parameter and consideration of the PD controller have a positive effect on the static and dynamic behaviors of the structure.

References listed at the end of the paper:
Yun Xing, Yi Han, Hua Liu and Jialing Yang, “Surface Effects on Large Deflection of Nanobeams Subjected to a Follower Load”, International Journal of Applied Mechanics, Vol. 12, No. 6, 2050067, July 2020, https://doi.org/10.1142/S1758825120500672

ABSTRACT: As a basic element of the micro/nanodevices, nanobeams have remarkable physical properties and have attracted considerable attention in the previous studies. However, previous publications did not study the large deformation problem of nanobeams under follower loading when the surface effect becomes significant and especially for the influence of surface effect on mechanical behaviors of the nanobeams under follower loading remains unclear. In this paper, we investigated the large deformation behavior of nanobeams subjected to follower loads in consideration of the surface effects. The mechanical model of large deflection of extensible cantilever nanobeams under follower loading is presented in combination with the surface elasticity and residual surface stress, and then a MATLAB program of shooting method with a technique for determining the initial value was developed to solve the problems. The results indicate that the surface effects have an important influence on the large deflection of nanobeams under follower loading: when the surface residual stress is positive, the maximums of displacement in horizontal and vertical directions and the rotation angle of the free end become lager, but the corresponding follower force related to those maximums becomes smaller. When the residual surface stress is negative, the results are the opposite. In addition, the influence of the cross-sectional dimension of the nanobeams under follower loading on surface effects was discussed. This work is beneficial to understand the mechanism of large deformation of nanobeams with surface effects subjected to follower loads, and can also provide inspirations to design advanced nanomaterials and nanoscaled devices. Reference listed at the end of the paper:


ABSTRACT: The free vibration frequency responses of the laminated composite structure with a cut-out of variable shapes (square/circular/elliptical), position (center/eccentric) and orientation (parallel/inclined) are investigated for the first time in this research including geometrical shapes. The eigenvalues are obtained computationally for the cut-out borne structure via a linear isoparametric finite element model of the composite structure in association with cubic-order of displacement kinematics. Also, a coupled code is prepared in MATLAB environment by joining the higher-order formulation and the simulation model (ABAQUS) to achieve the generic form to investigate the influential cut-out parameter (shape, size and position) on their eigenvalues. Further, a series of experimentations are carried out using the cut-out borne composite panel and compared with the computational frequency, including the experimental properties. Finally, the key behavior is surveyed through different kinds of numerical examples for various design constraint parameters including the cut-out relevant factors (shape, position and orientation) to show the subsequent inclusiveness of the proposed model.

References listed at the end of the paper:


ABSTRACT: An efficient finite element model based on three nodded element has been developed for the vibration analysis of sandwich arches with graded metallic cellular (GMC) core. The present formulation is based on the higher-order shear deformation theory and orthogonal curvilinear coordinate axes. The arch consists of two isotropic face sheets and a GMC core layer. The internal pores in the core layer follow the different types of distributions. The material properties of the GMC core layer of the sandwich arches vary in the thickness direction as a function in terms of porosity coefficient and mass density. Three types of porosity distributions have been considered to accomplish the vibration responses of sandwich arches. The present formulation is validated with limited results available in the literature. Few new results are computed and the effects of different influencing parameters such as porosity coefficient (α), porosity distribution type, the thickness-to-length ratio (h/L), boundary conditions and opening angle (θ) on the free vibration characteristics of sandwich arches with the GMC core are observed. The present finite element model gives better convergence and more accurate results than a conventional two nodded element-based finite element model.

References listed at the end of the paper:


ABSTRACT: This paper deals with the nonlinear large deflection torsional buckling of functionally graded carbon nanotube (CNT) orthogonally reinforced composite cylindrical shells surrounded by Pasternák’s elastic foundations with the thermal effect. The shell is made by two layers where the polymeric matrix is reinforced by the CNTs in longitudinal and circumferential directions for outer and inner layers, respectively. The stability equation system is obtained by combining the Donnell’s shell theory, von Kármán nonlinearity terms, the circumferential condition in average sense and three-state solution form of deflection. The critical torsional buckling load, postbuckling load-deflection and the load-end shortening expressions are obtained by applying the Galerkin procedure. The effects of temperature change, foundation parameters, geometrical properties and CNT distribution law on the nonlinear behavior of cylindrical shell are numerically predicted. Especially, the effect of orthogonal reinforcement in comparison with longitudinal and circumferential reinforcement on the torsional buckling behavior of shells is observed.

References listed at the end of the paper:


ABSTRACT: High importance of fluid-conveying structures in multifarious engineering applications arises the necessity of enhancing the mechanical characteristics of these systems in an effective way. Accordingly, this paper is concerned with vibration performance of functionally graded graphene-platelets reinforced composite (FG-GPLRC) fluid-conveying viscoelastic cylindrical shell surrounded by two-parameter elastic substrate and exposed to temperature gradient and axial load within the context of refined higher order shear deformation theory (RHSDT) including trapezoidal shape factor. Generalized differential quadrature method (GDQM) is employed to solve differential equations of motion for different cases of boundary conditions. The fourth-order Runge–Kutta technique is utilized to determine the time response of the system. Validity of the results is verified through comparison with those presented in the published articles. Comprehensive parametric analysis is performed to reveal the impact of fluid-flow velocity, distribution patterns of GPL, different forms of applied temperature gradient, different boundary conditions, viscoelasticity coefficient, geometrical dimensions of the shell as well as graphene-sheets on the vibration of the system. The numerical results demonstrate that negative influence of applying compressive axial load and rising temperature gradient on the vibrational response of the system can be alleviated when the system is exposed to sinusoidal form of temperature rise with proper power-index.

References listed at the end of the paper:


Employing Hamilton’s principle, the equations of motion are obtained and solved by the semi-matrix. The governing equations are derived based on sinusoidal shear. Moving plate are considered for both ideal and viscous fluid. Halpin–Tsai model is utilized to determine the material properties of two-phase composite consist of uniformly distributed and randomly oriented carbon nanotubes (CNTs) through the PmPV (poly{m-phenylenediyvinylene-co-[(2,5-dioctoxy-p-phenylene)vinylene]}) matrix. The governing equations are derived based on sinusoidal shear deformation plate theory (SSDT) which is more accurate than the conventional theories, and significantly, it does not require a shear correction factor. Employing Hamilton’s principle, the equations of motion are obtained and solved by the semi-analytical.

**ABSTRACT:** This research presents a theoretical investigation to analyze vibration of axially moving sandwich plate floating on fluid. This plate is composed of balsa wood core and two nanocomposite face sheets where the three layers vibrated as an integrated sandwich. The fluid–structure interaction (FSI) effects on the stability of moving plate are considered for both ideal and viscous fluid. Halpin–Tsai model is utilized to determine the material properties of two-phase composites consist of uniformly distributed and randomly oriented carbon nanotubes (CNTs) through the PmPV (poly{m-phenylenediyvinylene-co-[(2,5-dioctoxy-p-phenylene)vinylene]}) matrix. The governing equations are derived based on sinusoidal shear deformation plate theory (SSDT) which is more accurate than the conventional theories, and significantly, it does not require a shear correction factor.
method. Results indicated that the dimensionless frequencies of moving sandwich plate decrease rapidly with increasing the water level and they are almost independent of fluid level when it is higher than 50% of the plate length. The results of this investigation can be used in design and manufacturing of marine vessels and aircrafts.

References listed at the end of the paper:


ABSTRACT: Buckling problems of plates with interfaces caused by step changes in thickness, internal line supports and line hinges under uni-axial and bi-axial in-plane compressive loads are solved by using the matched interface and boundary (MIB) method. In view of buckling problems of plates, new MIB algorithms and their interpolation formulations are developed to deal with various interfaces. A number of examples are taken to examine the accuracy and convergence of the present algorithms. Numerical results are compared with the existing solutions to validate the applicability of these algorithms to the title problems. Numerical analysis
shows that on the whole, MIB and its interpolation formulation are equivalent, and they are highly accurate and efficient approaches for buckling analysis of plates with various interfaces.

References listed at the end of the paper:


Feng, H. S. and Zhao, S. [2020] “FFT-based high order central difference schemes for the three-dimensional Poisson equation with various types of boundary conditions,” Journal of Computational Physics 410, 109391.


ABSTRACT: Due to strong nonlinear, unsteady characteristics and the fluid–structure interaction effect, vibration analysis of blades under the excitation of the airflow is still one of the technical difficulties. In this paper, the accurate subsonic aerodynamic force is obtained through numerical simulation, and the aerodynamic coupling model of the rotary blade is established. The distribution of the aerodynamic force of the compressor blade under the unsteady airflow is focused on. The blade is modeled as presetting a presetting pre-twisted rotary cantilever plate. Dynamic frequencies of the plate, calculated by Chebyshev–Ritz method, are compared with frequencies calculated using the finite element method (FEM). Effects of different parameters on natural frequencies of the rotary plate are discussed. Based on von-Karman nonlinear geometric relation and the first-order shear deformation theory, nonlinear dynamic equations of the pre-twisted rotary plate under the combination of the centrifugal force and the aerodynamic are derived by utilizing Hamilton’s principle. Second-order ordinary differential equations are derived by applying the Galerkin method. Analytical solution of the dynamic deformation of the plate is presented and is compared with that produced by FEM. Results indicate the accuracy of the explicit presentation of the aerodynamic of the low-pressure compressor blade. Effects of the rotor speed, the thickness, the pre-twisted angle and the presetting angle on vibration characteristics of the warping blade are studied. Mode shape shift and frequency loci veering are discussed.

References listed at the end of the paper:


ABSTRACT: Thermal buckling of graphene platelets (GPLs) reinforced sandwich functionally graded porous (SWFGP) plate with temperature-dependent (TD) properties is investigated. The studied plate is composed of two homogeneous face layers and one functionally graded porous core. Two types of porosity distribution with uniformly distributed GPL reinforcement are included. Based on the first-order shear deformation plate theory, Hamilton principle and Galerkin procedure are employed to build the analytical framework. Uniform, linear, and nonlinear thermal loads along the thickness direction are considered. Subsequently, an iterative procedure is introduced to find out the critical buckling temperature of the plate with the temperature dependence considered. Verifications are conducted to demonstrate the accuracy of the proposed method. Several parametric analyses are investigated in detail where the effects of porosity, GPL weight fraction, geometric configuration, and the boundary condition on the thermal buckling of the plates are discussed.

References listed at the end of the paper:


ABSTRACT: Bending of bidirectional functionally graded nanobeams under mechanical loads and magnetic force was investigated. The nanobeam is assumed to be resting on the Winkler–Pasternak foundation. Eringen’s nonlocal elasticity theory and Timoshenko beam model are utilized to describe the mechanical behavior of the nanobeam. Material properties of the functionally graded beam are assumed to vary in the thickness and length of the nanobeam. Hamilton’s principle is employed to derive the governing equation and related boundary conditions. These equations are solved using the generalized differential quadrature method. The obtained results are compared with the results presented in other studies, to ensure the validity and versatility of this method. This comparison shows a good agreement between the results. Results are presented and discussed for different values of functionally graded materials indices, different aspect ratios, and different boundary conditions. The effect of the magnetic field and elastic foundation on buckling load has also been studied. The difference in nanobeam behavior for different values of the size-effect parameter is clearly shown.

References listed at the end of the paper:


International Journal of Applied Mechanics, Vol. 12, No. 8, 2050093, September 2020,


ABSTRACT: Energy absorption structures are widely used in many scenarios. Thin-walled members have been heavily employed to absorb impact energy. This paper presents a novel, Ron Resch origami pattern inspired energy absorption structure. Experimental characterization and numerical simulations were conducted to study the energy absorption of this structure. The results show a new collapse mode in terms of energy absorption featuring multiple plastic hinge lines, which lead to the peak force reduction and larger effective stroke, as compared with the classical honeycomb structure. Overall, the Ron Resch origami-inspired structure and the classical honeycomb structure are quite complementary as energy absorption structures.

References listed at the end of the paper:

ABSTRACT: Wrinkles in layered neo-Hookean structures were recently formulated as a Hamiltonian system by taking the thickness direction as a pseudo-time variable. This enabled an efficient and accurate numerical method to solve the eigenvalue problem for onset wrinkles. Here, we show that wrinkles in graded elastic layers can also be described as a time-varying Hamiltonian system. The connection between wrinkles and the Hamiltonian system is established through an energy method. Within the Hamiltonian framework, the eigenvalue problem of predicting wrinkles is defined by a series of ordinary differential equations with varying Hamiltonian coefficients. By modifying the boundary conditions at the top surface, the eigenvalue problem can be efficiently and accurately solved with numerical solvers of boundary value problems. We demonstrated the accuracy of the symplectic analysis by comparing the theoretically predicted displacement eigenfunctions, critical strains, and wavelengths of wrinkles in two typical graded structures with finite element simulations.

References listed at the end of the paper:

ABSTRACT: The competition between the structural rigidity and the van der Waals interactions may lead to collapsing of aligned nanotubes, and the resulting changes of both configurations and properties promise the applications of nanotubes in nano-composites and nano-electronics. In this paper, a finite-deformation model is applied to study the adhesion of parallel multiwall nanotubes with both partial and full collapsing, in which the noncontact adhesion energy is analytically determined. The analytical solutions of both configurations and energies of collapsed nanotubes are consistent with the molecular dynamics (MD) results, demonstrating the effectiveness of the finite-deformation model. To study the critical conditions of generating the partially and fully collapsed multiwall nanotubes, our analytical model gives the predictions for both the geometry and energy-related critical diameters, which are helpful for the stability analysis and design of nanotube-based devices.

References listed at the end of the paper:

A non-field within the surrounding environment due to the shock and the shell structural response. Simulations involve structural response of a single unstiffened cylindrical shell to dynamic pressure loading and (2) the fluid within the dynamic system mechanics advanced simulation (DYSMAS) code, to explicitly model the (1) loading of hydrostatic pressure alone. Simulations are combined hydrostatic and dynamic pressure loading within a tubular environment as compared to the traditional environment, ASME Journal of Applied Mechanics, Vol. 86, No. 2, 021008, Paper No: JAM-18-1549, February 2019, doi: 10.1115/1.4042046

ABSTRACT: This paper details a numerical study of the dynamic stability of a cylindrical shell structure under combined hydrostatic and dynamic pressure loading within a tubular environment as compared to the traditional loading of hydrostatic pressure alone. Simulations are executed using a coupled Eulerian–Lagrangian scheme, within the dynamic system mechanics advanced simulation (DYSMAS) code, to explicitly model the (1) structural response of a single unstiffened cylindrical shell to dynamic pressure loading and (2) the fluid flow field within the surrounding environment due to the shock and the shell structural response. Simulations involve a non-pressure-compensated aluminum 6061-T6 cylindrical structure with a length-to-diameter ratio, L/D, equal
to 9.6. This structure is 31.8 mm (1.25-in) in outer diameter and is concentrically and longitudinally centered within the outer tube, which has an inner diameter of 177.8 mm (7.00-in) and total internal length of 2.13 m (84-in). Simulations are run at four hydrostatic tank pressures, which are categorized by percentage of measured critical collapse pressure, \( P_c \), of the shell structure: 66% \( P_c \), 80% \( P_c \), 85% \( P_c \), and 90% \( P_c \). For each case, the shell structure is subjected to shock loading created by the detonation of a commercial blasting cap at a given standoff to the structure within the confining tube. Simulated pressure histories are compared to experimental pressure data at gage locations. The simulations and corresponding experiments produce the same overall result for three of four cases (i.e., survive: 66% \( P_c \) or implode: 85% \( P_c \) and 90% \( P_c \)). For the 80% \( P_c \) case, the overall result differs between simulation and experiment in that the specimen in the experiment survives but the simulated cylinder implodes. However, the discrepancy between the overall experimental result and corresponding simulation is not deemed a failure for the 80% \( P_c \) case; instead, this signifies a transitional case for the dynamic stability of the shell structure (i.e., collapse is sensitive to small deviations from assumed conditions in this regime).

References listed at the end of the paper:


ABSTRACT: The nonlinear extremely large-amplitude oscillation of a cantilever subject to motion constraints is examined for the first time. In order to be able to model the large-amplitude oscillations accurately, the equation governing the cantilever centerline rotation is derived. This allows for analyzing motions of very large amplitude even when tip angle is larger than π/2. The Euler–Bernoulli beam theory is employed along with the centerline inextensibility assumption, which results in nonlinear inertial terms in the equation of motion. The motion constraint is modeled as a spring with a large stiffness coefficient. The presence of a gap between the motion constraint and the cantilever causes major difficulties in modeling and numerical simulations, and results in a nonsmooth resonance response. The final form of the equation of motion is discretized via the Galerkin technique, while keeping the trigonometric functions intact to ensure accurate results even at large-amplitude oscillations. Numerical simulations are conducted via a continuation technique, examining the effect of various system parameters. It is shown that the presence of the motion constraints widens the resonance frequency band effectively which is particularly important for energy harvesting applications.

References listed at the end of the paper:
ABSTRACT: The deployment dynamics of a simplified solar sail quadrant consisting of two Euler–Bernoulli beams and a flexible membrane are studied. Upon prescribing the in-plane motion and modeling the tension field based on linearly increasing stresses assumed on the attached boundaries, the coupled equations of motion that describe the system’s transverse deflections are obtained. Based on these equations and their boundary conditions (BCs), deployment stability is studied by deriving simplified analytic expressions for the rate of change of system energy. It is shown that uniform extension and retraction result in decreasing and increasing energy, respectively. The motion equations are discretized using expansions in terms of “time-varying quasi-modes” (snapshots of the modes of a cantilevered beam and a clamped membrane), and the integrals needed for the resulting system matrices are rendered time-invariant via a coordinate transformation. Numerical simulation results are provided to illustrate a sample deployment and validate the analytic energy rate expressions.

References listed at the end of the paper:

In this paper, we study the wrinkling instability of two layers embedded in a homogeneous matrix, and characterize the wrinkling of the two layers as a function of the layer spacing and the shear moduli ratio between the two materials. When the layers are stiffer than the surrounding matrix, stiffness contrast largely determines the stability behavior of the system. When the layers are softer than the surrounding matrix, stiffness contrast and layer spacing interact to determine critical threshold strain and wavelength, and result in striking discontinuities in wavelength between regimes. When the layers are close to each other, the system has a strong preference for the symmetric wrinkling mode, but as the distance between the two layers increases, the anti-symmetric mode may emerge.

References listed at the end of the paper:

We theoretically study the electromechanical behaviors of a laminated thin-film piezoelectric semiconductor (PS) composite plate with flexural deformation. The nonlinear equations for drift currents of electrons and holes are linearized for a small carrier concentration perturbation. Following the structural theory systemized by R. D. Mindlin, a system of two-dimensional (2D) equations for the laminated thin-film PS plate, including the lowest order coupled extensional and flexural motion, are presented by expanding the displacement, potential, and the incremental concentration of electrons and holes as power series of the plate thickness. Based on the derived 2D equations, the analytical expressions of the electromechanical fields and distribution of electrons in the thin-film PS plate with an n-type ZnO layer subjected to a static bending are presented. The numerical results show that the electromechanical behaviors and piezotronic effects can be effectively controlled by the external applied force and initial concentration of carriers. The derived 2D equations and numerical results in this paper are helpful for developing piezotronic devices.

References listed at the end of the paper:


ABSTRACT: Emerging stretchable piezoelectric devices have added exciting sensing and energy harvesting capabilities to wearable and implantable soft electronics. As conventional piezoelectric materials are intrinsically stiff and some are even brittle, out-of-plane wrinkled or buckled structures and in-plane serpentine ribbons have been introduced to enhance their compliance and stretchability. Among those stretchable
structures, in-plane piezoelectric serpentine ribbons (PSRs) are preferred on account of their manufacturability and low profiles. To elucidate the trade-off between compliance and sensitivity of PSRs of various shapes, we herein report a theoretical framework by combining the piezoelectric plate theory with our previously developed elasticity solutions for passive serpentine ribbons without piezoelectric property. The electric displacement field and the output voltage of a freestanding but nonbuckling PSR under uniaxial stretch can be analytically solved under linear assumptions. Our analytical solutions were validated by finite element modeling (FEM) and experiments using polyvinylidene fluoride (PVDF)-based PSR. In addition to freestanding PSRs, PSRs sandwiched by polymer layers were also investigated by FEM and experiments. We found that thicker and stiffer polymers reduce the stretchability but enhance the voltage output of PSRs. When the matrix is much softer than the piezoelectric material, our analytical solutions to a freestanding PSR are also applicable to the sandwiched ones.

References listed at the end of the paper:
are linearized for a small carrier concentration perturbation. Following the structural theory systemized by R. D. 

We theoretically study the electromechanical behaviors of a laminated thin-film piezoelectric semiconductor (PS) composite plate with flexural deformation. The nonlinear equations for drift currents of electrons and holes are linearized for a small carrier concentration perturbation. Following the structural theory systemized by R. D.
Mindlin, a system of two-dimensional (2D) equations for the laminated thin-film PS plate, including the lowest order coupled extensional and flexural motion, are presented by expanding the displacement, potential, and the incremental concentration of electrons and holes as power series of the plate thickness. Based on the derived 2D equations, the analytical expressions of the electromechanical fields and distribution of electrons in the thin-film PS plate with an n-type ZnO layer subjected to a static bending are presented. The numerical results show that the electromechanical behaviors and piezotronic effects can be effectively controlled by the external applied force and initial concentration of carriers. The derived 2D equations and numerical results in this paper are helpful for developing piezotronic devices.

References listed at the end of the paper:

ABSTRACT: Emerging stretchable piezoelectric devices have added exciting sensing and energy harvesting capabilities to wearable and implantable soft electronics. As conventional piezoelectric materials are intrinsically stiff and some are even brittle, out-of-plane wrinkled or buckled structures and in-plane serpentine ribbons have been introduced to enhance their compliance and stretchability. Among those stretchable structures, in-plane piezoelectric serpentine ribbons (PSRs) are preferred on account of their manufacturability and low profiles. To elucidate the trade-off between compliance and sensitivity of PSRs of various shapes, we herein report a theoretical framework by combining the piezoelectric plate theory with our previously developed elasticity solutions for passive serpentine ribbons without piezoelectric property. The electric displacement field and the output voltage of a freestanding but nonbuckling PSR under uniaxial stretch can be analytically solved under linear assumptions. Our analytical solutions were validated by finite element modeling (FEM) and experiments using polyvinylidene fluoride (PVDF)-based PSR. In addition to freestanding PSRs, PSRs sandwiched by polymer layers were also investigated by FEM and experiments. We found that thicker and stiffer polymers reduce the stretchability but enhance the voltage output of PSRs. When the matrix is much softer than the piezoelectric material, our analytical solutions to a freestanding PSR are also applicable to the sandwiched ones.

References listed at the end of the paper:
The results obtained from the analytical derivations are confirmed using finite element analysis (FEA). Supports reduce the top values of all pairs of critical loads compared to the case of symmetric elastic supports. Critical loads are very sensitive to the degree of asymmetry in equilibria, resulting in the appearance of more limit points. The analytical solutions are also derived to directly numerically using typical path following controls only with prior knowledge of location of these paths. A small occurrence of small asymmetry exists in the elastic supports, the equilibria of the arch may abruptly split and lead to the bifurcation of remote unconnected equilibria. Such unconnected equilibria can be obtained experimentally or numerically using typical path following controls only with prior knowledge of location of these paths. A small asymmetry in the elastic supports may also make a secondary branch shrink into points connecting surrounding equilibria, resulting in the appearance of more limit points. The analytical solutions are also derived to directly calculate critical loads. We find that the magnitude of the stiffness of symmetric elastic supports has no influence on limits loads and bifurcation loads at branching into secondary paths with symmetric configurations, but greatly affect the bifurcation loads of secondary paths with asymmetric configurations. All critical loads are very sensitive to the degree of asymmetry in the elastic supports. The asymmetry in the supports reduces the top values of all pairs of critical loads compared to the case of symmetric elastic supports. The results obtained from the analytical derivations are confirmed using finite element analysis (FEA).
ABSTRACT: Wrinkling is a common phenomenon in natural and engineering film structures. The wrinkles influence the geometry and dynamic response of these structures. In this work, we investigate the wrinkling of a stretched thin film containing engineered microstructures and its derived functionality on controlling the propagation of bending waves. The underlying mechanism is revealed and the effect of wrinkles on the bandgap of bending waves is systematically evaluated via numerical simulations based on the Bloch wave theory. We show that wrinkles with a customized wavelength can be triggered in the microstructured film due to the mismatched deformation in the film. The bandgap of the wrinkled film can be finely tuned via applied stretching, resulting in the controllable propagation of bending waves in thin films. Our work provides fundamental insights into wave propagation in wrinkled films and potential applications for dynamic control of the wave propagation in engineering film structures.

Xia Ding, Yuchen Zhao, Dong Yan and Kai Zhang (School of Aerospace Engineering, Beijing Institute of Technology, Beijing 100081, China), Controllable propagation of bending waves in wrinkled films*, ASME Journal of Applied Mechanics, Vol. 86, No. 6, 061005, Paper No: JAM-18-1695, 2019, doi: 10.1115/1.4043073

ABSTRACT: Wrinkling is a common phenomenon in natural and engineering film structures. The wrinkles influence the geometry and dynamic response of these structures. In this work, we investigate the wrinkling of a stretched thin film containing engineered microstructures and its derived functionality on controlling the propagation of bending waves. The underlying mechanism is revealed and the effect of wrinkles on the bandgap of bending waves is systematically evaluated via numerical simulations based on the Bloch wave theory. We show that wrinkles with a customized wavelength can be triggered in the microstructured film due to the mismatched deformation in the film. The bandgap of the wrinkled film can be finely tuned via applied stretching, resulting in the controllable propagation of bending waves in thin films. Our work provides fundamental insights into wave propagation in wrinkled films and potential applications for dynamic control of the wave propagation in engineering film structures.

References listed at the end of the paper:

ABSTRACT: In this study, a new geometrically exact nonlinear model is developed for accurate analysis of buckling and postbuckling behavior of beams, for the first time. Three-dimensional nonlinear finite element analysis is conducted to verify the validity of the developed model even at very large postbuckling amplitudes. It is shown that the model commonly used in the literature for buckling analysis significantly underestimates the postbuckling amplitude. The proposed model is developed on the basis of the beam theory of Euler–Bernoulli, along with the assumption of centerline inextensibility, while taking into account the effect of initial imperfection. The Kelvin–Voigt model is utilized to model internal energy dissipation. To ensure accurate predictions in the postbuckling regime, the nonlinear terms in the equation of motion are kept exact with respect to the transverse motion, resulting in a geometrically exact model. It is shown that even a fifth-order truncated nonlinear model does not yield accurate results, highlighting the significant importance of keeping the terms exact with respect to the transverse motion. Using the verified geometrically exact model, the possibility of dynamic buckling is studied in detail. It is shown that dynamic buckling could occur at axial load variation amplitudes as small as 2.3% of the critical static buckling load.

References listed at the end of the paper:
Curved shell structures are known for their excellent load-carrying capability and are commonly used in thin-walled constructions. Although theoretically able to withstand greater buckling loads than flat structures, shell structures are notoriously sensitive to imperfections owing to their postbuckling behavior often being governed by subcritical bifurcations. Thus, shell structures often buckle at significantly lower loads than those predicted numerically and the ensuing dynamic snap to another equilibrium can lead to permanent damage. Furthermore, the strong sensitivity to initial imperfections, as well as their stochastic nature, limits the predictive capability of current stability analyses. Our objective here is to convert the subcritical nature of the buckling event to a supercritical one, thereby improving the reliability of numerical predictions and mitigating the possibility of catastrophic failure. We explore the elastically nonlinear postbuckling response of axially compressed cylindrical panels using numerical continuation techniques. These analyses show that axially compressed panels exhibit a highly nonlinear and complex postbuckling behavior with many entangled postbuckled equilibrium curves. We unveil isolated regions of stable equilibria in otherwise unstable postbuckled regimes, which often possess greater load-carrying capacity. By modifying the initial geometry of the panel in a targeted—rather than stochastic—and imperceptible manner, the postbuckling behavior of these shells can be tailored without a significant increase in mass. These findings provide new insight into the buckling and postbuckling behavior of shell structures and opportunities for modifying and controlling their postbuckling response for enhanced efficiency and functionality.

References listed at the end of the paper:


References listed at the end of the paper:


ABSTRACT: This paper introduces a method for calculating the deformation displacement of the origami mechanism. The bearing capacity of each face can be analyzed by the relationship between the stress and displacement, which can provide a reference for the origami design. The Miura origami mechanism unit is
considered. First, the folding angle of each crease is solved based on the geometric characteristics. The deforming form of the creases is then analyzed, and the bending moment acting on the paper surface is solved. Based on the geometric characteristics and stress forms, the paper surface is modeled as a sheet. Based on the bending theory of a thin plate with small deflection, the complex external load forms are decomposed by Levy's method and the superposition principle, and the expression of the deflection curve during the folding process is obtained. According to the stress and bending moment equations, the relationship between the bending moment and displacement is obtained. Finally, through an application example, the maximum deflection of the paper surface is calculated by MATLAB, and the deflection diagram of the deformed paper surface is drawn, which verifies the expression of the deflection curve.

References listed at the end of the paper:


ABSTRACT: This paper presents a new energy dissipation system composed of multistable cosine-curved domes (CDD) connected in series. The system exhibits multiple consecutive snap-through and snap-back buckling behavior with a hysteretic response. The response of the CDDs is within the elastic regime and hence the system's original configuration is fully recoverable. Numerical studies and experimental tests were conducted on the geometric properties of the individual CDD units and their number in the system to examine the force–displacement and energy dissipation characteristics. Finite element analysis (FEA) was performed to simulate the response of the system to develop a multilinear analytical model for the hysteretic response that
considers the nonlinear behavior of the system. The model was used to study the energy dissipation characteristics of the system. Experimental tests on 3D printed specimens were conducted to analyze the system and validate numerical results. Results show that the energy dissipation mainly depends on the number and the apex height-to-thickness ratio of the CCD units. The developed multilinear analytical model yields conservative yet accurate values for the dissipated energy of the system. The proposed system offered reliable high energy dissipation with a maximum loss factor value of 0.14 for a monostable (self-recoverable) system and higher for a bistable system.

References listed at the end of the paper:


ABSTRACT: Polymer matrix composites have high strengths in tension. However, their compressive strengths are much lower than their tensile strengths due to their weak fiber/matrix interfacial shear strengths. We
recently developed a new approach to fabricate composites by over wrapping individual carbon fibers or fiber tows with a carbon nanotube sheet and subsequently impregnate them into a matrix to enhance the interfacial shear strengths without degrading the tensile strengths of the carbon fibers. In this study, a theoretical analysis is conducted to identify the appropriate thickness of the nanocomposite interphase region formed by carbon nanotubes embedded in a matrix. Fibers are modeled as an anisotropic elastic material, and the nanocomposite interphase region and the matrix are considered as isotropic. A microbuckling problem is solved for the unidirectional composite under compression. The analytical solution is compared with finite element simulations for verification. It is determined that the critical load at the onset of buckling is lower in an anisotropic carbon fiber composite than in an isotropic fiber composite due to lower transverse properties in the fibers. An optimal thickness for nanocomposite interphase region is determined, and this finding provides a guidance for the manufacture of composites using aligned carbon nanotubes as fillers in the nanocomposite interphase region.

References listed at the end of the paper: Cannot cut and paste them.

Hamed Farokhi (1) and Mergen H. Ghayesh (2)
(1) Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne NE1 8ST, UK
(2) School of Mechanical Engineering, University of Adelaide, Adelaide, South Australia 5005, Australia
ABSTRACT: This paper investigates the nonlinear static response as well as nonlinear forced dynamics of a clamped–clamped beam actuated by piezoelectric patches partially covering the beam from both sides. This study is the first to develop a high-dimensional nonlinear model for such a piezoelectric-beam configuration. The nonlinear dynamical resonance characteristics of the electromechanical system are examined under simultaneous DC and AC piezoelectric actuations, while highlighting the effects of modal energy transfer and internal resonances. A multiphysics coupled model of the beam-piezoelectric system is proposed based on the nonlinear beam theory of Bernoulli–Euler and the piezoelectric constitutive equations. The discretized model of the system is obtained with the help of the Galerkin weighted residual technique while retaining 32 degrees-of-freedom. Three-dimensional finite element analysis is conducted as well in the static regime to validate the developed model and numerical simulation. It is shown that the response of the system in the nonlinear resonant region is strongly affected by a three-to-one internal resonance.
References listed at the end of the paper: Cannot cut and paste them.

ABSTRACT: Negative Poisson’s ratio materials, or auxetics, have drawn attention for the past 30 years. The auxetic effect could lead to improved mechanical properties such as acoustic damping, indentation resistance, or crashworthiness. In this work, two 3D auxetic lattices are introduced. Auxeticity is achieved by design through pre-buckling of the lattice struts. The influence of geometrical parameters on the effective elastic properties is investigated using computational homogenization method with periodic boundary conditions. Effective Young’s modulus is 3D mapped to reveal anisotropy and identify spatial orientations of interest. The effective Poisson ratio is computed for various geometric configurations to characterize auxeticity. Finally, the influence of effective elastic properties on energy dissipation under compression is explored for elastoplastic lattices with different loading directions, using finite element simulations. Results suggest that loading 3D auxetic lattices along their stiffest direction maximizes their crashworthiness.
References listed at the end of the paper: Cannot cut and paste them.

ABSTRACT: Two-dimensional hexachiral lattices belong to the family of honeycomb-like mechanical metamaterials such as triangular, hexagonal, and kagome lattices. The common feature of this family of beam-based metamaterials is their six-fold rotational symmetry which guarantees their (transversely-) isotropic elastic response. In the case of hexachiral lattices, a single geometric parameter may be introduced to control the degree of chirality such that the elastic Poisson's ratio can be adjusted between 0.33 and -0.8. Detailed finite element simulations are performed to establish the structure–property relationships for hexachiral lattices for relative densities ranging from 1% to 45%. It is shown that both the Young's and shear moduli are always lower for hexachiral structures than for optimal lattices (triangular and kagome). This result is in line with the general understanding that stretching-dominated architectures outperform bending-dominated architectures. The same conclusions may be drawn from the comparison of the tensile yield strength. However, hexachiral structures provide a lower degree of plastic anisotropy than stretching-dominated lattices. Furthermore, special hexachiral configurations have been identified that exhibit a slightly higher shear yield strength than triangular and kagome lattices, thereby presenting an example of bending-dominated architectures outperforming stretching-dominated architectures of equal mass. Tensile specimens have been additively manufactured from a tough PLA polymer and tested to partially validate the simulation results.

References listed at the end of the paper:  (Cannot cut and paste them)


ABSTRACT: Mechanical metamaterials are artificial composites with tunable advanced mechanical properties. Particularly, interesting types of mechanical metamaterials are flexible metamaterials, which harness internal rotations and instabilities to exhibit programable deformations. However, to date, such materials have mostly been considered using nearly purely elastic constituents such as neo-Hookean rubbers. Here, we experimentally explore the mechanical snap-through response of metamaterials that are made of constituents that exhibit large viscoelastic relaxation effects, encountered in the vast majority of rubbers, in particular, in 3D printed rubbers. We show that they exhibit a very strong sensitivity to the loading rate. In particular, the mechanical instability is strongly affected beyond a certain loading rate. We rationalize our findings with a compliant mechanism model augmented with viscoelastic interactions, which qualitatively captures well the reported behavior, suggesting that the sensitivity to the loading rate stems from the nonlinear and inhomogeneous deformation rate, provoked by internal rotations. Our findings bring a novel understanding of metamaterials in the dynamical regime and open up avenues for the use of metamaterials for dynamical shape-changing as well as vibration and impact damping applications.

References listed at the end of the paper:  (Cannot cut and paste them)


ABSTRACT: The mechanics of phase transforming cellular materials (PXCMs) with three different chiral honeycomb architectures, viz., hexachiral, tetra-anti-chiral, and tetra-chiral, are investigated under quasi-static loading/unloading. Each PXCM comprises interconnected unit cells consisting of tape springs rigidly affixed to circular nodes that can rotate and/or translate. The phase change is associated with snap-through instability due to bending of the tape springs and corresponds to sudden changes in the geometry of the unit cells from one stable configuration to another stable (or metastable) configuration during loading/unloading. When compared with similar chiral materials with flat ligaments, the chiral PXCMs exhibit a significantly higher energy dissipation in quasi-static experiments. The hexachiral PXCM was selected for detailed parametric analysis with finite element simulations including 21 models constructed to investigate the effects of PXCM geometry on phase change and energy dissipation. An analytical formalism is developed to predict the minimum compressive load required to induce phase transformation and snap-through. The formalism predictions are
ABSTRACT: We present a weak form implementation of the nonlinear axisymmetric shell equations. This implementation is suitable to study the nonlinear deformations of axisymmetric shells, with the capability of considering a general mid-surface shape, non-homogeneous (axisymmetric) mechanical properties and thickness variations. Moreover, given that the weak balance equations are arrived to naturally, any external load that can be expressed in terms of an energy potential can, therefore, be easily included and modeled. We validate our approach with existing results from the literature, in a variety of settings, including buckling of imperfect spherical shells, indentation of spherical and ellipsoidal shells, and geometry-induced rigidity (GIR) of pressurized ellipsoidal shells. Whereas the fundamental basis of our approach is classic and well established, from a methodological viewpoint, we hope that this brief note will be of both technical and pedagogical value to the growing and dynamic community that is revisiting these canonical but still challenging class of problems in shell mechanics.

References listed at the end of the paper: (Cannot cut and paste them)


ABSTRACT: The “carpenter’s measuring tape” is a thin spring-steel strip, preformed to a curved cross section of radius R, which is straight when being used for measuring. Under bending moments, it forms a localized hinge, in which the transverse curvature is suppressed, and the longitudinal radius r is approximately equal to R. Rimrott made a simple strain energy analysis of the hinge region for isotropic material, which predicted that r=R. Both experimental observations and finite element computations show that $\xi=r/R>1$, where the value of $\xi$ exceeds unity by up to 15%, depending on whether the tape is bent in “equal-sense” or “opposite-sense” curvature; $\xi$ varies linearly with Poisson’s ratio in both cases. We make a minor change to Rimrott’s analysis by introducing a boundary layer, in order better to satisfy the physical conditions at the free edges; this successfully accounts for the observed behavior of the tape. [DOI: 10.1115/1.4045006]

References listed at the end of the papers:


Yunfeng Shi, Bo Wang, Hao Wu, Bin Wang, Changzhi Liu, Rui Li (First author is from: International Research Center for Computational Mechanics, Dalian University of Technology, Dalian, Liaoning 116024, China), “A Theoretical and

**ABSTRACT:** To ensure both adequate axial load-bearing capacity and radial vulnerability of a circumferentially notched thin cylindrical shell is one of the major challenges in designing some crucial aerospace structures such as the pyrotechnic separation devices. The most favorable design for such a shell is to optimize the notch geometry such that zero stress at the notch root is realized, which enhances the axial strength without impacting the notch failure during separation. However, few studies have focused on such extreme stress concentration-free designs of a single-side notch on a shell because the asymmetrical structure under common eccentric loading brings much difficulty for theoretical analysis, while numerical approaches can hardly meet the requirements of highly efficient rapid optimal designs. In this paper, a theoretical and experimental study toward extreme stress concentration-free designs of single-side-notched thin cylindrical shells is presented. The general stress concentration factors (SCFs) for single-side-notched shells with arbitrary depths are obtained based on the theory of notch stresses, which are well validated by the refined finite element modeling. An important finding reveals that, for a common notched shell in aerospace vehicles, the stress at the notch root approaches zero when a specific ratio of load eccentricity to minimum section width is attained. Comprehensive experiments for specially designed notched specimens confirm the theoretical finding. The present study provides an effective approach to analyzing single-side-notched structures and yields an explicit quantitative guideline for the optimal design of circumferentially notched thin cylindrical shells.


**ABSTRACT:** An infinitely long elastic plate/layer is under uniaxial compression with its long dimension held by adhesion to a flat rigid base without friction. A prescribed length of the plate/layer is free of adhesion. This configuration is similar to a pre-stressed elastic film for which buckling of an unbonded section is a necessary, but not sufficient, condition for delamination. For that configuration, buckling occurs at the Euler buckling load of a fixed–fixed plate. Although the present study does not include friction or tangential interface stresses, the onset of buckling should be similar for these two cases. For the case of an elastic plate, a cohesive zone is used and it is found that the fixed–fixed buckling load is not attained except for extremely large values of a cohesive zone parameter. For realistic values, the buckling load is about half of that value. For the situation of an elastic layer with adhesion (without a cohesive zone), the buckling load approaches the fixed–fixed value only for very large values of the ratio of the unbonded length to the thickness.

References listed at the end of the paper:

(Cannot easily cut and paste them)

Zhengang Yan, Baolin Wang, Kaifa Wang, Shiwei Zhao, Shupeng Li, Yonggang Huang and Heling Wang (First author is from: School of Science, Harbin Institute of Technology, Shenzhen, China and Departments of Civil and Environmental Engineering, Mechanical Engineering, and Materials Science and Engineering, Center for Bio-Integrated Electronics, Northwestern University, Evanston, IL, USA), “Cellular Substrate to Facilitate Global Buckling of Serpentine Structures”, *J. Appl. Mech.* February 2020, 87(2): 024501, https://doi.org/10.1115/1.4045282

**ABSTRACT:** Three-dimensional (3D) serpentine mesostructures assembled by mechanics-guided, deterministic 3D assembly have potential applications in energy harvesting, mechanical sensing, and soft robotics. One limitation is that the serpentine structures are required to have sufficient bending stiffness such that they can overcome the adhesion with the underlying substrate to fully buckle into the 3D shape (global buckling). This note introduces the use of cellular substrate in place of conventional homogeneous substrate to reduce the adhesion energy and therefore ease the above limitation. A theoretical model based on energetic analysis suggests that cellular substrates significantly enlarge the design space of global buckling. Numerical examples show that the enlarged design space enables 3D serpentine structures with reduced maximum strains and resonant frequencies, which offers more possibilities for their potential applications.

References listed at the end of the paper:

(Cannot easily cut and paste them)

ABSTRACT: Bistable compliant elements offer excellent advantages in many applications ranging from high precision sensing to energy harvesting. The essential nonlinear mechanics of such elements are strongly coupled with their buckling mode, geometric parameters, and loading conditions. The force–displacement plot of bistable curved beams could contain a displacement limit point, which cannot be well modeled by the commonly used smooth cubic function and would cause operational problems due to incorrect predictions of the bistability. In this technical brief, the nonlinear bistable mechanics of a compliant curved beam with both ends fixed is analyzed based on the large deflection finite element theory. By using the multistep displacement loading method, the deformation behaviors and their transition from symmetric to asymmetric modes are numerically studied, which provides insights into the force–displacement curve and the multiple snapping pathways. Furthermore, the influences of the structure parameters on bistable mechanics are analyzed, and a quality factor for identifying the occurrence of displacement limit points is introduced for different loading conditions. Finally, a method for achieving a single smooth snapping pathway is proposed, providing a theoretical basis to the design and control of the bistable compliant structures.

Zheng Xu, Zhichao Fan, Yanyang Zi, Yihui Zhang and Yonggang Huang (First author is from: Manufacturing and Systems Engineering, School of Mechanical Engineering, Xi’an Jiaotong University, Xi’an, China and AML, Department of Engineering Mechanics, Tsinghua University, Beijing, China), “An Inverse Design Method of Buckling-Guided Assembly for Ribbon-Type 3D Structures”, J. Appl. Mech. March 2020, 87(3): 031004, https://doi.org/10.1115/1.4045367

ABSTRACT: Mechanically guided three-dimensional (3D) assembly based on the controlled buckling of pre-designed 2D thin-film precursors provides deterministic routes to complex 3D mesostructures in diverse functional materials, with access to a broad range of material types and length scales. Existing mechanics studies on this topic mainly focus on the forward problem that aims at predicting the configurations of assembled 3D structures, especially ribbon-shaped structures, given the configuration of initial 2D precursor and loading magnitude. The inverse design problem that maps the target 3D structure onto an unknown 2D precursor in the context of a prescribed loading method is essential for practical applications, but remains a challenge. This paper proposes a systematic optimization method to solve the inverse design of ribbon-type 3D geometries assembled through the buckling-guided approach. In addition to the torsional angle of the cross section, this method introduces the non-uniform width distribution of the initial ribbon structure and the loading mode as additional design variables, which can significantly enhance the optimization accuracy for reproducing the desired 3D centroid line of the target ribbon. Extension of this method allows the inverse design of entire 3D ribbon configurations with specific geometries, taking into account both the centroid line and the torsion for the cross section. Computational and experimental studies over a variety of elaborate examples, encompassing both the single-ribbon and ribbon-framework structures, demonstrate the effectiveness and applicability of the developed method.

References listed at the end of the paper:


ABSTRACT: Carbon micro/nanolattice materials, defined as three-dimensional (3D) architected metamaterials made of micro/nanoscale carbon constituents, have demonstrated exceptional mechanical properties, including ultrahigh specific strength, stiffness, and extensive deformability through experiments and simulations. The ductility of these carbon micro/nanolattices is also important for robust performance. In this work, we present a novel design of using reversible snap-through instability to engineer energy dissipation in 3D graphene nanolattices. Inspired by the shell structure of flexible straws, we construct a type of graphene counterpart via topological design and demonstrate its associated snap-through instability through molecular dynamics (MD) simulations. One-dimensional (1D) straw-like carbon nanotube (SCNT) and 3D graphene nanolattices are constructed from a unit cell. These graphene nanolattices possess multiple stable states and are elastically reconfigurable. A theoretical model of the 1D bi-stable element chain is adopted to understand the collective deformation behavior of the nanolattice. Reversible pseudoplastic behavior with a finite hysteresis loop is predicted and further validated via MD. Enhanced by these novel energy dissipation mechanisms, the 3D graphene nanolattices show good tolerance of crack-like flaws and is predicted to approach a specific energy dissipation of 233 kJ/kg in a loading cycle with no permanent damage (one order higher than the energy absorbed by carbon steel at failure, 16 kJ/kg). This study provides a novel mechanism for 3D carbon nanolattice to dissipate energy with no accumulative damage and improve resistance to fracture, broadening the promising application of 3D carbon in energy absorption and programmable materials.

References listed at the end of the paper:


Buckling Thresholds for Pre-Loaded Spherical Shells Subject to Localized Blasts”, *J. Appl. Mech.* March 2020, 87(3): 031013. [https://doi.org/10.1115/1.4045588](https://doi.org/10.1115/1.4045588)

ABSTRACT: This paper investigates the robustness against localized impacts of elastic spherical shells pre-loaded under uniform external pressure. We subjected a pre-loaded spherical shell that is clamped at its equator to axisymmetric blast-like impacts applied to its polar region. The resulting axisymmetric dynamic response is computed for increasing amplitudes of the blast. Both perfect shells and shells with axisymmetric geometric imperfections are analyzed. The impact energy threshold causing buckling is identified and compared with the energy barrier that exists between the buckled and unbuckled static equilibrium states of the energy landscape associated with the pre-loaded pressure. The extent to which the impact energy of the threshold blast exceeds the energy barrier depends on the details of its shape and width. Targeted blasts that approximately replicate the size and shape of the energy barrier buckling mode defined in the paper have an energy threshold that is only modestly larger than the energy barrier. An extensive study is carried out for more realistic Gaussian-shaped blasts revealing that the buckling threshold energy for these blasts is typically in the range of at least 10–40% above the energy barrier, depending on the pressure pre-load and the blast width. The energy discrepancy between the buckling threshold and energy barrier is due to elastic waves spreading outward from the impact and dissipation associated with the numerical integration scheme. Buckling is confined to the vicinity of the pole such that, if the shell is not shallow, the buckling thresholds are not strongly dependent on the location of the clamping boundary, as illustrated for a shell clamped halfway between the pole and the equator.

References listed at the end of the paper:

ABSTRACT: Hard magnetic soft materials (HMSMs) manufactured by embedding hard magnetic particles in soft materials belong to a new type of soft active materials. The abilities of fast and complicated transformations of hard-magnetic soft structures provide a promising technology for soft robotics, flexible electronics, and biomedical devices. It is significant to investigate the mechanical behaviors of hard-magnetic soft structures for their better applications. In this work, a hard-magnetic soft beam under an external magnetic field is theoretically modeled and the exact solutions for its mechanical responses are presented. First, the governing equations and boundary conditions are derived based on the principle of minimum potential energy. To solve the derived governing equations analytically, a new polynomial fitting model for hyperelastic materials is proposed for the hard-magnetic soft beam. Then, the exact solutions of a cantilevered hard-magnetic soft beam
actuated by a uniform magnetic field in any direction are obtained. The newly derived exact solutions are further verified by comparing current results with those from recent simulations and experiments. For large bending angles up to 90 deg and extreme bending angle up to 180 deg, quite consistent agreement among exact solutions, numerical simulations, and experimental observations can be achieved. Finally, using our theoretical model, the deformation of the hard-magnetic soft beam actuated by magnetic fields in an arbitrary direction with non-zero magnetic declination is explored. When the magnetic actuation is increased from a small level gradually, the hard-magnetic soft beam deflects and it would undergo small, large, and extreme bending deformations in sequence. It is very interesting that, when the magnetic actuation is sufficiently large, the hard-magnetic soft beam is stretched and its centerline tends to align with the external magnetic field direction, implying that the hard-magnetic soft beam undergoes a uniaxial tension. The theoretical modeling and exact solutions for hard-magnetic soft beams are expected to be useful in the analysis and design of soft materials and structures.


ABSTRACT: The presence of imperfections significantly reduces the load carrying capacity of thin cylindrical shells due to the high sensitivity of thin shells to imperfections. To nullify this unfavorable characteristic, thin cylindrical shells are designed using a conservative knockdown factor method, which was developed by NASA in the late 1960s. Almost all the design codes, explicitly or implicitly, follow this approach. Recently, a new approach has emerged to significantly reduce the sensitivity of thin cylindrical shells. In this approach, wavy cross sections are used instead of circular cross sections for creating thin cylinders. Past studies have demonstrated the effectiveness of wavy cylinders to reduce imperfection sensitivity of thin cylinders under axial compression assuming linear elastic material behavior. These studies used eigenmode imperfections which do not represent realistic imperfections found in cylinders. In this paper, using a realistic dimple-like imperfection, new insights are presented into the response of wavy cylinders under uniform axial compression and bending. Furthermore, the effectiveness of the wavy cylinders to reduce imperfection sensitivity under bending load is investigated assuming a plastic Ramberg–Osgood material model. The effect of wave parameters, e.g., the amplitude and the number of waves, is also explored. This study reveals that wavy thin cylinders are insensitive to imperfections under bending in the inelastic range of the material. It is also found that the wave parameters play a decisive role in the response of thin wavy cylinders to imperfections under bending.


ABSTRACT: The buoyancy control mechanism is critical for undersea robots to achieve effective vertical motion. However, current buoyancy control mechanisms are associated with problems such as complex design, bulky structure, noisy operation, and slow response. Inspired by the swim bladder of natural fish, we develop an artificial swim bladder, using dual membranes of the dielectric elastomer, which exhibit interesting attributes, including fast response, light weight, silent operation, especially large volume change. Both the experiments and theoretical simulations are conducted to analyze the performance of this artificial swim bladder, and they quantitatively agree with each other. This artificial swim bladder of dual membranes is capable of large voltage-induced volume change, 112% larger than the conventional single-membrane design. Consequently, this soft actuator can generate a buoyancy force of 0.49 N. This artificial swim bladder demonstrates effective up-and-down motion in water, due to its large reversible volume change. Future work includes adding horizontal-motion and turning capabilities to the existing robotic structure, so that the soft robotic fish can achieve successful navigation in undersea environments.

ABSTRACT: Island-bridge structures incorporated with kirigami membranes emerge as a novel design strategy for flexible/stretchable electronics, taking advantages of large stretchability, high-surface filling ratio and low resistance. However, it is hard to determine the mechanical properties of this design due to its complex geometries and nonlinear deformation configuration, thereby limiting its further applications. In this paper, we present a model for the postbuckling behavior of kirigami membranes through a combination of theoretical modeling, finite element analysis, and experiments. Scaling laws for elastic stretchability are developed, showing good agreement with numerical results and experimental images. Investigations on the critical height of post array are conducted to ensure the boundary condition of the kirigami membranes in the analytical model. These results can serve as design guidelines for kirigami structures and facilitate their applications in flexible/stretchable electronics.


ABSTRACT: We present a combined experimental and analytical approach to study the formation of creases in tightly folded Kapton polyimide films. In the experiments, we have developed a robust procedure to create creases with repeatable residual fold angle by compressing initially bent coupons. We then use it to explore the influence of different control parameters, such as the force applied, and the time the film is being pressed. The experimental results are compared with a simplified one-dimensional elastica model, as well as a high fidelity finite element model; both models take into account the elasto-plastic behavior of the film. The models are able to predict the force required to create the crease, as well as the trend in the residual angle of the fold once the force is removed. We non-dimensionalize our results to rationalize the effect of plasticity, and we find robust scalings that extend our findings to other geometries and material properties.


ABSTRACT: We present a simple model for geophysical systems involving sources of deformation, such as magmatic intrusions, subglacial lakes, and the subsurface storage of CO. We consider the idealized system of a uniform elastic layer overlying a localized region of constant pressure that is surrounded by a Winkler foundation composed of springs. We investigate the effect of source depth and foundation stiffness on the resulting displacement profiles at both the surface and the level of the source. The system is characterized by three key features: the maximum uplift, the maximum subsidence, and the distance to the point of zero displacement. For each of these, we determine asymptotic scaling behavior in the limits of a thin/thick layer and a soft/stiff foundation and form composite curves that allow specific parameter values to be determined from field data. Both two-dimensional and axisymmetric pressure patches are considered, and in the thin-layer limit we derive analytical solutions.


ABSTRACT: The geometrically exact nonlinear deflection of a beamshell is considered here as an extension of the formulation derived by Libai and Simmonds (1998, The Nonlinear Theory of Elastic Shells, Cambridge University Press, Cambridge, UK) to include deformation through the thickness of the beam, as might arise from transverse squeezing loads. In particular, this effect can lead to receding contact for a uniform beamshell resting on a smooth, flat, rigid surface; traditional shell theory cannot adequately such behavior. The formulation is developed from the weak form of the local equations for linear momentum balance, weighted by an appropriate tensor. Different choices for this tensor lead to both the traditional shell equations corresponding to linear and angular momentum balance, as well as the additional higher-order representation for the squeezing deformation. In addition, conjugate strains for the shell forces are derived from the deformation power, as presented by Libai and Simmonds. Finally, the predictions from this approach are compared against predictions from the finite element code abaqus for a uniform beam subject to transverse applied loads. The current
geometrically exact shell model correctly predicts the transverse shell force through the thickness of the beamshell and is able to describe problems that admit receding contact.


**ABSTRACT:** This paper presents a method to simultaneously predict the elastic modulus, axial load, and boundary conditions of a nanoelectromechanical system (NEMS) beam from a minimum of two measured natural frequencies. The proposed method addresses the challenges of the inverse problem at the nano scale, which include high natural frequencies, small geometric beam dimensions, and measurements limited to natural frequencies. The method utilizes a finite element model of an Euler–Bernoulli beam under axial loading to predict the response of the beam with axial loading and flexible boundary conditions. By expressing the finite element model in terms of dimensionless beam parameters, the proposed method may be applied to nano scale beams while maintaining numerical stability of the finite element equation of motion. With the stabilized finite element model, the NEMS beam properties are predicted by iterating through values of dimensionless beam parameters until the normalized error between predicted and measured natural frequencies is minimized. A key feature of the proposed method is the simultaneous prediction of the elastic modulus during the iterative search, resulting in a reduction of the search space and significant computational savings. Additionally, the proposed method readily accommodates an arbitrary number of measured natural frequencies without the reformulation of procedures and analyses. Numerical examples are presented to illustrate the proposed method’s ability to predict the elastic modulus, axial load, and boundary conditions. The proposed method is applied to experimental measurements of a NEMS beam, where the normalized error between predicted and measured natural frequencies is reduced below 0.001.

Shiwei Zhao, Feng Zhu, Zhengang Yan, Daochun Li, Jinwu Xiang, Yonggang Huang and Haiwen Luan (First author is from: School of Aeronautic Science and Engineering, Beihang University, Beijing, China and Departments of Mechanical Engineering, Civil and Environmental Engineering, Materials Science and Engineering, Center for Bio-Integrated Electronics, Northwestern University, Evanston, IL, USA), “A Nonlinear Mechanics Model of Zigzag Cellular Substrates for Stretchable Electronics”, *J. Appl. Mech.* June 2020, 87(6): 061006, https://doi.org/10.1115/1.4046662

**ABSTRACT:** The use of cellular elastomer substrates not only reduces its restriction on natural diffusion or convection of biofluids in the realm of stretchable electronics but also enhances the stretchability of the electronic systems. An analytical model of “zigzag” cellular substrates under finite deformation is established and validated in this paper. The deformed shape, nonlinear stress–strain curve, and Poisson’s ratio–strain curve of the cellular elastomer substrate calculated using the reported analytical model agree well with those from finite element analysis (FEA). Results show that lower restriction on the natural motion of human skin could be achieved by the proposed zigzag cellular substrates compared with the previously reported hexagonal cellular substrates, manifesting another leap toward mechanically “invisible” wearable, stretchable electronic systems.


**ABSTRACT:** The present work aims to examine the metamaterial vibrational behavior of circular few-layer graphene sheets under layerwise tension forces. For this objective, a simplified three-membrane model is developed to simulate flexural vibration of tensioned circular few-layer graphene sheets, in which tensioned top and bottom layers are modeled as two elastic membranes while all less-tensioned or tension-free inner layers together are treated as a single membrane, and the three membranes are coupled through the van der Waals interaction between adjacent layers. Our results show that when the two outermost layers are highly tensioned but the inner layers are free of tension, circular few-layer graphene sheets exhibit negative effective mass within a certain terahertz frequency range. Moreover, such few-layer graphene sheets with negative effective mass demonstrate remarkable vibration isolation and vibration suppression. This research broadens our perspectives
for designing and analyzing graphene-based metamaterials and resonators and could find potential application in nanoelectromechanical systems.


ABSTRACT: Flexible structures carrying moving subsystems are found in various engineering applications. Periodic passage of subsystems over a supporting structure can induce parametric resonance, causing vibration with ever-increasing amplitude in the structure. Instead of its engineering implications, parametric excitation of a structure with sequentially passing oscillators has not been well addressed. The dynamic stability in such a moving-oscillator problem, due to viscoelastic coupling between the supporting structure and moving oscillators, is different from that in a moving-mass problem. In this paper, parametric resonance of coupled structure-moving oscillator systems is thoroughly examined, and a new stability analysis method is proposed. In the development, a set of sequential state equations is first derived, leading to a model for structures carrying a sequence of moving oscillators. Through the introduction of a mapping matrix, a set of stability criteria on parametric resonance is then established. Being of analytical form, these criteria can accurately and efficiently predict the dynamic stability of a coupled structure-moving oscillator system. In addition, by the spectral radius of the mapping matrix, the global stability of a coupled system can be conveniently investigated in a parameter space. The system model and stability criteria are illustrated and validated in numerical examples.

Peng Feng (1), Jianghong Yuan (1), Yin Huang (2) and Xiangyu Li (1)
(1) School of Mechanics and Engineering, Southwest Jiaotong University, Chengdu 610031, Sichuan, China
(2) Materials Science and Engineering, Southwest Jiaotong University, Chengdu 610031, Sichuan, China

ABSTRACT: Serpentine interconnects, as an integral part of island-bridge layouts, enable extremely large reversible deformation under the action of mechanical loads and are thus widely used in the emerging new field of stretchable electronics. In this paper, the lateral-torsional buckling is analytically studied for a simplified S-shaped serpentine structure that consists of five straight components rigidly connected at point joints. Simple analytic scaling laws between the dimensionless critical buckling load and the aspect ratio of the serpentine structure are newly derived and uniformly expressed in terms of generalized hypergeometric series for various types of boundary conditions, which can serve as the benchmark of numerical simulations. These scaling laws, fully verified by finite element analysis, may well capture the implied connection between stretching- and compression-induced buckling, the strong dependence of buckling modes on end conditions, and the monotonic/asymptotic properties of the critical load with respect to the aspect ratio of serpentine structures. References listed at the end of the paper.
(Cannot cut and paste them)

Claire Lestringant (1) and Dennis M. Kochmann (2)
(1) Structures Research Group, Department of Engineering, University of Cambridge, Cambridge CB3 0FA, UK
(2) Mechanics & Materials, Department of Mechanical and Process Engineering, ETH Zürich, 8092 Zürich, Switzerland

ABSTRACT: We demonstrate how a geometrically exact formulation of discrete slender beams can be generalized for the efficient simulation of complex networks of flexible beams by introducing rigid connections through special junction elements. The numerical framework, which is based on discrete differential geometry of framed curves in a time-discrete setting for time- and history-dependent constitutive models, is applicable to elastic and inelastic beams undergoing large rotations with and without natural curvature and actuation. Especially, the latter two aspects make our approach a versatile and efficient alternative to higher-dimensional
considering box and T-bar tensegrities. Representative examples are provided to demonstrate the effectiveness of the design method. Reinforcement approaches include increasing the areas of the members and increasing the prestress in the structures to prevent buckling. The buckling force of the structure is determined by comparing the external force and the critical global buckling force. If the critical global buckling force is larger than the external force, the dominant failure is global buckling of the tensegrity, where it loses stability without undergoing local failure at its individual members. The formulation and numerical approach to determine the critical global buckling forces and mode shapes of tensegrities with arbitrary shape and topology are presented. In this work, a novel efficient method for designing lightweight tensegrities under local and global failure constraints is proposed. Different from previously reported nanobeams based flexoelectric energy harvesters, the flexoelectric membrane, the polarization direction around its center is opposite in sign to that far away from the center. To avoid the cancelation of the electric output, electrodes coated to upper and lower surfaces of the flexoelectric membrane are respectively divided into two parts according to the sign of bending curvatures. Based on Hamilton’s principle and Ohm’s law, we obtain governing equations for the circular membrane-based flexoelectric energy harvester. A generalized assumed-modes method is employed for solving the system, so that the performance of the flexoelectric energy harvester can be studied in detail. We analyze the effects of the thickness \( h \), radius \( r \), and their ratio on the energy harvesting performance. Specifically, we show that, by selecting appropriate \( h \) and \( r \), it is possible to design an energy harvester with both high energy conversion efficiency and low working frequency. At last, through numerical simulations, we further study the optimization ratio for which the electrodes should be divided.


ABSTRACT: This study presents a new analytical model for nonlinear dynamics of a discrete rectangular membrane that is subjected to external harmonic force. It has recently been shown that the corresponding autonomous system admits a series of nonlinear normal modes. In this paper, we describe stationary and non-stationary dynamics on a single mode manifold. We suggest a simple formula for the amplitude-frequency response in both conservative and non-conservative cases and present an analytical expression (in parametric space) for thresholds for all possible bifurcations. Theoretical results obtained through asymptotic approach are confirmed by the experimental data. Experiments on the shaking table show that amplitude-frequency response to external force in a real system matches our theory. Substantial hysteresis is observed in the regimes with increasing and decreasing frequency of external force. The obtained results may be used in designing nonlinear energy sinks.


ABSTRACT: Tensegrities are prestressable trusses that have been proven to support various load distributions with minimum mass. This article presents a novel efficient method for designing lightweight tensegrities under local and global failure constraints. Local failure includes buckling and material yielding of individual members in the tensegrity. Global failure refers to global buckling of the tensegrity, where it loses stability without undergoing local failure at its individual members. The formulation and numerical approach to determine the critical global buckling forces and mode shapes of tensegrities with arbitrary shape and topology are first provided. Next, the design method considering local and global failure is presented, which starts with the local sizing of the member areas of the given tensegrity for the prevention of local failure. The method then determines the dominant failure mode by comparing the external forces and the critical global buckling force of the locally sized structure. If the critical global buckling force is larger than the external force, the dominant mode is a local failure and the locally sized design is returned as the minimum mass design. Conversely, if global failure is the dominant mode, different global reinforcement approaches are applied to raise the critical buckling force of the structure until it matches the external force, preventing global buckling. These reinforcement approaches include increasing the areas of the members and increasing the prestress in the tensegrity. Representative examples are provided to demonstrate the effectiveness of the design method considering box and T-bar tensegrities.
ABSTRACT: A buckled beam with shallow rise under lateral constraint is considered. The initial rise results from a prescrib ed end displacement. The beam is modeled as inextensible, and analytical solutions of the equilibria are obtained from a constrained energy minimization problem. For simplicity, the results are derived for the archetypal beam with pinned ends. It is found that there are an infinite number of zero lateral-load equilibria, each corresponding to an Euler buckling mode. A numerical model is used to verify the accuracy of the results. Numerical analysis was carried out, using generalized Eigen value analysis and non-linear analysis using a modified-Riks technique with various material models to correlate with the experimental observations. Non-linear elasto-plastic analysis with a perfectly elastic-plastic material model agrees well with the experimental observations. A comparison of experimental results with that of the numerical study indicates that material plasticity has a major effect on critical buckling pressure.


ABSTRACT: Previously, the buckling behavior of several conical and spherical shells have been studied with great rigor. In this paper, snap-through buckling behavior for metallic dished shells under uniform external pressure is investigated. These shells are geometrically complex since they consist of a shallow conical frustum with a flat closed top. Such shells find many engineering applications, for instance as actuator elements in control components in cryogenic engines. Currently, no clear guidelines exist for design performance evaluation of such peculiar shells. This paper aims to establish a valid FE methodology for snap-through buckling and post-buckling analysis of such shells using abaqus in tandem with experiments. A parametric study is carried out to understand the effect of geometrical parameters and imperfection sensitivity of these shells to snap-through buckling. Moreover, experiments were carried out using 3D Digital Image Correlation (3D-DIC) for measuring whole-field deflection and strains. Numerical analysis was carried out, using generalized Eigen value analysis and non-linear analysis using a modified-Riks technique with various material models to correlate with the experimental observations. Non-linear elasto-plastic analysis with a perfectly elastic-plastic material model agrees well with the experimental observations. A comparison of experimental results with that of the numerical study indicates that material plasticity has a major effect on critical buckling pressure.


ABSTRACT: This paper describes a primarily experimental study in which a nonlinear structural component (a slender, mechanically buckled panel) is subject to probing. That is, equilibrium configurations are explored when a specific location on the panel is subject to the application of a (variable) displacement constraint and characterized by a corresponding probe force. This probe force (in this study located at the center of the rectangular panels) is measured using a load cell and the resulting shape(s), taken up by the panel, measured using digital image correlation (DIC). Although the probe is only applied at a single location, this arrangement supplies considerable information about the changing equilibrium landscape including revealing co-existing equilibrium configurations using large perturbations and associated hysteretic phenomena. In addition, monitoring the probing force, and specifically when it drops to zero, provides a window into “free” equilibria that would otherwise be unstable and unobservable. Finally, it is shown that the probed equilibrium configurations provide the “landscape” within which any dynamically induced trajectories evolve including snap-through oscillations.


ABSTRACT: A buckled beam with shallow rise under lateral constraint is considered. The initial rise results from a prescribed end displacement. The beam is modeled as inextensible, and analytical solutions of the equilibria are obtained from a constrained energy minimization problem. For simplicity, the results are derived for the archetypal beam with pinned ends. It is found that there are an infinite number of zero lateral-load equilibria, each corresponding to an Euler buckling mode. A numerical model is used to verify the accuracy of the model and also to explore the effects of extensibility.


ABSTRACT: The energy absorption properties of all-metallic corrugated sandwich cylindrical shells (CSCSs) subjected to axial compression loading were investigated by the method combining experiments, finite element (FE) simulations, and theoretical analysis. CSCS specimens manufactured using two different methods, i.e.,
high-speed wire-cut electric discharge machining (HSWEDM) and extrusion, were tested under axial compression. While specimens fabricated separately by HSWEDM and extrusion both exhibited a stable crushing behavior, the extruded ones were much more applicable as lightweight energy absorbers because of their good energy absorption capacity, repeatability, and low cost. The numerically simulated force–displacement curve and the corresponding deformation morphologies of the CSCS compared well with those obtained from experiments. The specific folding deformation mode was revealed from both experiments and simulations. Subsequently, based upon the mode of folding deformation, a theoretical model was established to predict the mean crushing force of the CSCS construction. It was demonstrated that CSCSs with more corrugated units, smaller value of t/t and W/R, could dissipate more impact energy. Such sandwich cylindrical shells exhibited better energy absorption than monolithic cylindrical shells, with an increase of at least 30%. Ultimately, the dynamic effect under the impact load was further evaluated. The dynamic amplification coefficient of CSCS decreased with the increase of the wall thickness.


ABSTRACT: We consider how the bending stiffness of a multilayer graphene sheet relies on its bending geometry, including the in-plane length L and the curvature κ. We use an interlayer shear model to characterize the periodic interlayer tractions due to the lattice structure. The bending stiffness for the sheet bent along a cylindrical surface is extracted via an energetic consideration. Our discussion mainly focuses on trilayer sheets, particularly the complex geometry-dependency of their interlayer stress transfer behavior and the overall bending stiffness. We find that L and κ dominate the bending stiffness, respectively, in different stable regions. These results show good quantitative agreement with recent experiments where the stiffness was found to be a non-monotonic function of the bending angle (i.e., Lκ). Besides, for a given in-plane length, the trilayer graphene in the flat state (κ → 0) is found to have the maximum bending stiffness. According to our analytical solution to the flat state, the bending stiffness of trilayer graphene sheet can vary by two orders of magnitude. Furthermore, once multilayer graphene sheets are bent along a cylindrical surface with small curvature, the sheets perform similar characteristics. Though the discussion mainly focuses on the trilayer graphene, the theoretical framework presented here can be readily extended for various van der Waals materials beyond graphene of arbitrary layer numbers.


ABSTRACT: Arranging inertar arrays in designing metamaterials can achieve low-frequency vibration suppression even with a small configuration mass. In this work, we investigate flexural wave bandgap properties of an elastic metamaterial plate with periodic arrays of inertar-based dynamic vibration absorbers (IDVAs). By extending the plane wave expansion (PWE) method, the inertar elastic metamaterial plate is explicitly formulated in which the interactions of the attached IDVAs and the host plate are considered. Due to the additional degree-of-freedom induced by each IDVA, multiple band gaps are obtained. Along the ΓX direction, the inertar elastic metamaterial plate exhibits two locally resonant (LR) band gaps and one Bragg (BG) band gap. In contrast, along the ΓM direction, two adjacent LR band gaps are obtained. Detailed parametric analyses are conducted to investigate the relationships between the flexural wave bandgap properties and the structural inertar parameters. With a dissipative mechanism added to the IDVAs, extremely wide band gaps in different directions can be further generated. Finally, by adopting an effective added mass technique in the finite element method, displacement transmission and vibration modes of a finite inertar elastic metamaterial plate are obtained. Our investigation indicates that the proposed inertar elastic metamaterial plate has extra-wide low-frequency flexural band gaps and therefore has potential applications in engineering vibration prohibition.

ABSTRACT: Composites comprising a high-volume fraction of stiff reinforcements within a compliant matrix are commonly found in natural materials. The disparate properties of the constituent materials endow resilience to the composite, and here we report an investigation into some of the mechanisms at play. We report experiments and simulations of a prototype laminated composite system comprising silicon layers separated by polymer interlayers, where the only failure mechanism is the tensile fracture of the brittle silicon. Two failure modes are observed for such composites loaded in three-point bending: failure under the central roller in (i) the top ply (in contact with the roller) or (ii) the bottom ply (free surface). The former mode is benign with the beam retaining load carrying capacity, whereas the latter leads to catastrophic beam failure. Finite element (FE) simulations confirm this transition in failure mode and inform the development of a reduced order model. Good agreement is shown between measurements, FE simulations, and reduced order predictions, capturing the effects of material and geometric properties on the flexural rigidity, first ply failure mode, and failure load. A failure mechanism map for this system is reported that can be used to inform the design of such laminated composites.


ABSTRACT: Departures of the geometry of the middle surface of a thin shell from the perfect shape have long been regarded as the most deleterious imperfections responsible for reducing a shell’s buckling capacity. Here, systematic simulations are conducted for both spherical and cylindrical metal shells whereby, in the first step, dimple-shaped dents are created by indenting a perfect shell into the plastic range. Then, in the second step, buckling of the dented shell is analyzed, under external pressure for the spherical shells and in axial compression for the cylindrical shells. Three distinct buckling analyses are carried out: (1) elastic buckling accounting only for the geometry of the dent, (2) elastic buckling accounting for both dent geometry and residual stresses, and (3) a full elastic–plastic buckling analysis accounting for both the dent geometry and residual stresses. The analyses reveal the relative importance of the geometry and the residual stress associated with the dent, and they also provide a clear indicator of whether plasticity is important in establishing the buckling load of the dented shells.


ABSTRACT: Based on their shape-shifting capabilities, soft active materials have enabled new possibilities for the engineering of sensing and actuation devices. While the relation between active strains and emergent equilibrium shapes has been fully characterized, the transient morphing of thin structures is a rather unexplored topic. Here, we focus on polymer gel plates and derive a reduced linear model to study their time-dependent response to changes in the fluid environment. We show that independent control of stretching and bending deformations in stress-free conditions allows to realize spherical shapes with prescribed geometry of the mid-plane. Furthermore, we demonstrate that tensile (compressive) membrane stresses delay (accelerate) swelling-induced shape transitions compared to the stress-free evolution. We believe that these effects should be considered for the accurate design of smart systems and may contribute to explain the complexity of natural shapes.


ABSTRACT: Numerous natural and synthetic systems can be modeled as clusters of interacting cantilever beams. However, a closed-form mathematical model capable of representing the mechanics of multiple interacting cantilever beams undergoing large deflections has yet to be presented. In this work, a pioneering mathematical model of the force–deflection response of multiple, inline, interacting (i.e., contacting) cantilever
beams is presented. The model enables the determination of the force–deflection response of a system of interacting cantilever beams and is predicated upon the “Pseudo Rigid Body Model” concept. The model was validated through data triangulation experiments which included both physical and computational studies. An analysis of the mathematical model indicates it is most accurate with deflections less than 50 deg. In the future, the model may be used in high throughput phenotyping applications for investigating stalk lodging and estimating the flexural rigidity of crop stems. The model can also be used to gain intuition and aid in the design of synthetic systems composed of multiple cantilever beams. 

ASME Journal of Applied Mechanics, 041005, ASME Paper No. JAM-20-1515, Vol. 88, No. 4, April 2021,


Yuelong Yu, Yingzheng Liu and Xavcier Amandolese (First author is from: School of Mechanical Engineering, Gas Turbine Research Institute, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, China), “A review on fluid-induced flag vibrations”, ASME Applied Mechanics Reviews, Vol. 71, No. 1, 010801, Paper No. AMR-18-1077, January 2019, doi: 10.1115/1.4042446

ABSTRACT: Fluid-induced flag vibrations provide unattended, efficient, low-cost, and scalable solutions for energy harvesting to power distributed wireless sensor nodes, heat transfer enhancement in channel flow, and mixing enhancement in process industries. This review surveys three generic configurations, the inverted flag, the standard flag, and the forced flag, i.e., an inverted or standard flag located downstream of a bluff body. Their instability boundaries, vibration dynamics, and vortex dynamics are compared in a unified framework to elucidate their common and distinct features and provide insights into the design of vibrating flags for various applications. Some common features are also identified and analyzed for describing the interaction between multiple flags, three-dimensional (3D) effects, and Reynolds number effects. The suggestions are intended to guide future research directions.

References listed at the end of the paper:


(No appropriate reviews through July 2019)

ABSTRACT: Extreme events, such as rogue waves, earthquakes, and stock market crashes, occur spontaneously in many dynamical systems. Because of their usually adverse consequences, quantification, prediction, and mitigation of extreme events are highly desirable. Here, we review several aspects of extreme events in phenomena described by high-dimensional, chaotic dynamical systems. We especially focus on two pressing aspects of the problem: (i) mechanisms underlying the formation of extreme events and (ii) real-time prediction of extreme events. For each aspect, we explore methods relying on models, data, or both. We discuss the strengths and limitations of each approach as well as possible future research directions.

References listed at the end of the paper: (Cannot cut and paste them)


(No appropriate articles in the November issue: 71(6))


ABSTRACT: Thin-walled beams made of laminated composite materials are increasingly used in any engineering branch where structural weight is one of the major aspects in the design process of load bearing structures. Quite naturally, when composite materials are being employed, analysis methods are required that adequately take effects such as material anisotropy, coupling effects, and shear deformations into account which are inherent to this class of materials. This paper aims to provide an overview of engineering analysis methods concerning the buckling and post-buckling behavior of thin-walled composite laminated beams, covering topics such as exact and closed-form analytical approximate solutions as well as semi-analytical and numerical methods wherein a distinction is made between local and global buckling of beam structures, and the interaction of global and local buckling modes. This paper also covers an overview of experimental investigations as well as of design optimization studies and closes with an outlook on future investigations.

References listed at the end of the paper:
Committee for Aeronautics, Washington, DC, Report No. 3781.


[34] Jones, R. M., 2006, Buckling of Bars, Plates and Shells, Bull Ridge Publishing, Blackburg, VA.


Performance of GBT-Based Structural Analyses,” Thin-Walled Struct., 92, pp. 29–47.


334 Zhang, Y., and Matthews, F. L., 1984, “Postbuckling Behaviour of Anisotropic Laminated Plates Under Pure Shear and Shear...
Mingxiang Ling (1), Larry L. Howell (2), Junyi Cao (3) and Guimin Chen (4)

(1) Institute of Systems Engineering, China Academy of Engineering Physics, Mianyang, China
(2) Department of Mechanical Engineering, Brigham Young University, Provo, Utah, USA and Department of Mechanical Engineering, Brigham Young University, Provo, Utah, USA
(3) Manufacturing Systems Engineering, Xi’an Jiaotong University, Xi’an, China
(4) Intelligent Robots, Xi’an Jiaotong University, Xi’an, China


ABSTRACT: Flexure-based compliant mechanisms are becoming increasingly promising in precision engineering, robotics, and other applications due to the excellent advantages of no friction, no backlash, no wear, and minimal requirement of assembly. Because compliant mechanisms have inherent coupling of kinematic-mechanical behaviors with large deflections and/or complex serial-parallel configurations, the kinetostatic and dynamic analyses are challenging in comparison to their rigid-body counterparts. To address these challenges, a variety of techniques have been reported in a growing stream of publications. This paper surveys and compares the conceptual ideas, key advances, and applicable scopes, and open problems of the state-of-the-art kinetostatic and dynamic modeling methods for compliant mechanisms in terms of small and large deflections. Future challenges are discussed and new opportunities for extended study are highlighted as well. The presented review provides a guide on how to select suitable modeling approaches for those engaged in the field of compliant mechanisms.

References listed at the end of the paper (Hard to cut-and-paste; somewhat off-topic; therefore left in somewhat rough form):


Materials, and the obtained strain energy release rate of a crack was validated by re

of an existing crack in composite laminates. The developed analytical method was implemented in isotropic

ABSTRACT: The present paper explores different techniques for increasing flexural performance of composite


Google the string: “Journal of Composite Materials”, then click on the third entry, which is: “Journal of Composite Materials – All Issues – SAGE Journals


https://doi.org/10.1177/0021998318780206

ABSTRACT: The present paper explores different techniques for increasing flexural performance of composite sandwich panels made of hand-layup glass fiber reinforced polymer skins and low density closed cell polyurethane foam core. An experimental program compares the performance of simple panels face to the use of transversal and longitudinal internal glass fiber reinforced polymer ribs and the installation of a strain hardening cementitious base composite top layer over the panels. Based on the experimental results, finite element models are also developed to simulate the flexural behavior of tested panels and conducted an in depth analysis of the techniques studied. Obtained experimental and numerical results show that the use of internal glass fiber reinforced polymer ribs (especially in longitudinal direction) along with the use of strain hardening cementitious base composite significantly and effectively increases the flexural performance of sandwich panels. The high stiffness to weight ratio capacity of the panels attained by applying the proposed method enables its use in rehabilitation of historical places. Furthermore, the proposed techniques could be helpful for strengthening available composite sandwich panels.


https://doi.org/10.1177/0021998318785952

ABSTRACT: An energy method based on beam theory is proposed to determine the strain energy release rate of an existing crack in composite laminates. The developed analytical method was implemented in isotropic materials, and the obtained strain energy release rate of a crack was validated by reference results and finite
element solutions. The general behavior of crack growth on the left or right crack tip was evaluated, and basic trends leading to crack propagation to one side of the crack were established. A correction factor was introduced to improve the accuracy of the strain energy release rate for small cracks. The singularity at the crack tip caused by dissimilar materials was investigated and was found that the inclusion of the singularity effect could increase the accuracy for small cracks. The calculated strain energy release rate of a crack in a composite beam has been verified by comparing with a finite element model.


ABSTRACT: Composite structures are often cured in an autoclave to acquire the required space grade quality. Now the industry is focusing on the out of autoclave manufacturing method which leads to more voids inside laminate with respect to those manufactured in the autoclave. In the present work, the influence of voids on microcrack formation under thermal cycling and environmental conditions was analyzed. Thermal cycle experiments were performed using liquid nitrogen and oven, followed by microscopic observation of the polished cross-section of the 90° layered plies. Cracks were monitored, counted, and measured with respect to void and void free areas. Void content was characterized using microscopic and ImageJ software was used. It was observed that the microcracks will be formed both around the voids and in void free areas. As the number of thermal cycle increases, the number of microcrack around the voids increases much faster than compared to the void free areas. Also it was observed that most of microcracks were propagated in the transverse direction. Interlaminar shear strength was measured. Results indicate that interlaminar shear strength reduces as the number of cycle rises due to the increase in the microcrack density. Finite element method was used to simulate the process. The micro, meso, and macro model were created with respect to original samples voids and positions to calculate the stress distribution and its concentration. Good agreement between experiment and simulation was observed.


ABSTRACT: Stitched sandwich becomes popular in structural application owing to its better performance in the transverse direction with respect to classical sandwich structure and relatively low-cost additional stitching process. The identification of its elastic properties is essential for offering a tailored structure for specific applications. A non-destructive identification method based on vibration test is proposed to obtain these parameters. The number of parameters is firstly reduced by a sensibility analysis. The retained parameters are identified by minimizing the cost function which indicates the gap between measured frequencies from vibration test and calculated frequencies from a finite element model. This method is applied to a stitched sandwich panel and its elastic properties are successfully identified.


ABSTRACT: In this study, the static and dynamic responses of bi-stable hybrid composite laminates [0/AL/90], and [0/AL/90], were scrutinized, and their behavior was compared to bi-stable pure composite laminates including [0/90], and [0/90]. The work consisted of an analytical study that was validated experimentally. An analytical method based on Hamilton’s principle was developed to investigate the static and vibration characteristics of the laminates. Experimentally, curvatures and out-of-plane-displacement, and snap-through load were measured using a quasi-static loading on a universal testing machine. Further experimental analysis was performed to characterize the damping viscous ratio, natural frequency, and critical base excitation that cause the snapping between the two different stable shapes. The results show that the hybridization of bi-stable pure composite laminates has the potential to increase the stable curvatures and enhance the static load-carrying capability up to five times when compared to a pure bi-stable composite laminate of the same thickness. It was
also observed that the hybridization of bi-stable pure composite laminates may result in a dramatic change in the dynamic response. The natural frequencies of bi-stable hybrid composite laminates are increased in comparison with bi-stable pure composite laminates. The critical base excitation required for snapping has increased significantly for the hybrid composite laminate. The qualitative and quantitative comparisons between the analytical and experimental results were very promising and they agreed well.


ABSTRACT: The effect of different weight percentages (wt.%) of MWCNTs includes 0, 0.17, 0.34 and 0.51% on the mechanical and low-velocity impact properties are presented on the example of the pure epoxy and epoxy/fiberglass composites beams. A sonication technique is used to disperse MWCNTs in the epoxy network and the nanocomposite beams are fabricated using hand lay-up technique. In tensile tests, the value of Young’s modulus, tensile strength and strain at break are reported. In the low-velocity impact tests on the MWCNTs/fiberglass/epoxy, the time-history response of contact force, displacement and velocity of the impactor and indentation and displacement of the beam are measured and presented. The results show that compared to pure epoxy, Young’s modulus and tensile strength of epoxy/MWCNTs are increased 21.98% and 58.32% at 0.34 wt.% of CNTs, respectively, and raised 1.05 and 1.17 times at 0.17 wt.% of CNTs for the epoxy/fiberglass/MWCNTs, respectively. It is observed that the excellent improvement in the impact properties is achieved for 0.34 wt.% of CNTs. A series of polynomial formulations as a function of wt.% of CNTs are proposed to calculate the Young’s modulus, peak contact force and maximum beam deflection at the impact position.


ABSTRACT: This work deals with post-impact residual mechanical behavior of composite plates made with glass fiber cloth and two different thermosetting resins (epoxy and polyester). It is well known that damages induced by multiple impacts greatly reduce the residual properties. How are the residual strength or stiffness affected by the impacts? How does impact energy and number of impacts contribute to the degradation of mechanical properties? What kind of supports induces more damages and consequently a larger reduction in residual properties? These are some questions that we attempt to clarify in this paper. To investigate and assess the effect of the energy level and number of impacts on the total induced damage and residual properties, impact fatigue tests were carried out at selected energy range of: 3 J, 4 J, 5 J, and 6 J. Then, coupons containing the damaged area are cut out, in order to estimate the tensile, compressive, and shear residual properties, particularly residual strength. The energy level and number of impacts are major factors influencing the loss of stiffness and strength. However, stiffness is more affected than strength by the repeated impacts. A clear decrease of compressive residual strength with the number of impacts for the two fixture conditions (clamped on two opposite sides and a circular clamp) is demonstrated. The drop in the case of the circular clamping is more visible, confirming a greater extent of damages. A three-parameter damage model is proposed and applied, with some conclusions are withdrawn in this investigation.


ABSTRACT: This study was focused on the effect of carbon nanotubes on the impact resistance and damage evolution in laminate carbon nanotubes/epoxy composites under an impact loading. The composite panels were made from carbon fibers and carbon nanotubes randomly distributed into epoxy resin. The amount of carbon nanotubes dispersion was varied up to 4% by weight. Taylor impact tests were carried out to obtain the impact response of specimens with dimensions of 70×70×4 mm. A projectile manufactured from a high strength and
hardened steel with a diameter of 20 mm and 1.5 kg of mass was launched by a compressed gas gun within the velocity of 3 m/s, 7 m/s and 12 m/s. For the experimental test, three velocity levels were used: 3 m/s for the elastic deformation, 7 m/s for the penetration of the impactor and 12 m/s for the perforation of panels. Deformation histories and damage modes in specimens were recorded during the impact test using a high-speed camera. Processing of carbon nanotubes dispersed in laminates, testing, damage, and key findings is reported. It is observed that the impact resistance of laminates reinforced with a random distribution of carbon nanotubes increases up to 15.6% at high-strain rate compared with that of 0% of carbon nanotubes. It is also observed that the resistance to damage initiation and evolution increases with the addition of carbon nanotubes concentration.


ABSTRACT: This paper addresses the effects of different stacking sequences and seawater on the buckling behavior of hybrid composite plates. For the buckling tests, 12-layered hybrid composite plates were produced using different combinations of carbon, E-glass and aramid fibers, with an epoxy resin system as the matrix (Araldite LY1564/Aradur 3486). The hybrid composite plates were designed at the symmetric orientation angles of [(0/90)], [(30/−60)], [(45/−45)], and an anti-symmetric orientation angle of [(0/90)]. The hybrid composite samples were divided into groups and were subjected to buckling tests after being kept in different settings for varying periods of time (room temperature for 90 days, Black Sea water for 90 days, Mediterranean Sea water for 90 days, Mediterranean Sea water for 150 days). In light of the data obtained from the tests, the buckling behaviors of the layered hybrid composite plates were examined. The highest critical buckling load occurred in the carbon/aramid/glass (CAG) hybrid samples with the stacking sequence of [(0/90)], whereas the lowest critical buckling load occurred in the carbon/aramid/glass (CAG) hybrid samples with the stacking sequence of [(45/−45)]. It was observed that the critical buckling loads of the samples immersed in seawater decreased when compared to the critical buckling loads of the samples kept at room temperature. It was also found that the critical buckling loads of the hybrid samples immersed in the Mediterranean Sea water, which has high salinity, were lower than the critical buckling loads of the hybrid samples immersed in the Black Sea water, which has lower salinity.


ABSTRACT: This paper investigates the compression properties and energy-absorbing characteristics of a carbon fiber-reinforced honeycomb structure manufactured using the vacuum-assisted resin transfer molding method (VARTM). The composite core materials were manufactured using a machined steel baseplate onto which hexagonal blocks were secured. A unidirectional carbon fiber fabric was inserted into the slots and the resulting mold was vacuum bagged and infused with a two-part epoxy resin. After curing, the hexagonal blocks were removed, leaving a well-defined composite honeycomb structure. Samples were then cut from the composite cores and inspected in an X-ray computed tomography machine prior to testing. Mechanical tests on the honeycomb structures yielded compression strengths of up to 35 MPa and specific energy absorption values in excess of 47 kJ/kg. When normalized by the density of the core, the resulting values of specific strength were significantly higher than those measured on traditional core materials. The unidirectional cores failed as a result of longitudinal splitting through the thickness of the core, whereas the multidirectional honeycombs failed in a combined splitting/fiber fracture mode, absorbing significantly more energy than their unidirectional counterparts. Increasing the weight fraction of fibers served to increase the strength and energy-absorbing capacity of the core. Finally, it was also shown that introducing a chamfer acted to reduce the initial peak force and precipitate a more stable mode of failure.

Tao Fu, Zhaobo Chen, Hongying Yu, Zhonglong Wang and Xiaoxiang Liu (Primarily from: School of Mechatronics Engineering, Harbin Institute of Technology, PR China), “Mechanical behavior of laminated

ABSTRACT: The present study is concerned with static and free vibration analyses of laminated functionally graded carbon nanotube reinforced composite rectangular plates on elastic foundation based on nth-order shear deformation theory. Four types of carbon nanotubes distributions along the plate thickness are considered, which include uniformly distributed and three other functionally graded distributions. Governing differential equations are derived by means of Hamilton’s principle. The differential quadrature method is developed to formulate the problem, and rapid convergence is observed in this study. A numerical comparison with available results in the literature is carried out to show the validity of the proposed theory. Furthermore, effects of the carbon nanotubes volume fraction, thickness side ratio, aspect ratio, foundation parameters, different thermal environments, the number of layers, lamination angle, boundary condition, and carbon nanotubes distribution types on the static response of laminated functionally graded carbon nanotube reinforced composite plates are also investigated.


ABSTRACT: This study aims to enhance the flexural properties of sandwich composites made from glass or carbon face and glass and carbon fibre Z-pin inserted extruded-polystyrene (XPS) foam cores. Carbon and glass pins were placed through XPS foams with two different column and row densities (15 and 30 mm). Results indicated that flexural loads, strength and modulus of glass/XPS and carbon/XPS sandwich composites significantly increased after inserting of glass and carbon rods. Core shear strengths and facing stresses of glass/XPS and carbon/XPS increased by increasing of carbon or glass rod densities. The rod type, rod density and face type of the sandwich composites are considered as significant parameters which affect the flexural behaviour of sandwich composites while using carbon rods enhanced flexural properties more than that of using glass rods due to better interfacial bonding.


ABSTRACT: This paper details a complete crush model for composite materials with focus on shear dominated crushing under a three-dimensional stress state. The damage evolution laws and final failure strain conditions are based on data extracted from shear experiments. The main advantages of the current model include the following: no need to measure the fracture toughness in shear and transverse compression, mesh objectivity without the need for a regular mesh and finite element characteristic length, a pressure dependency of the nonlinear shear response, accounting for load reversal and some orthotropic effects (making the model suitable for noncrimp fabric composites). The model is validated against a range of relevant experiments, namely a through-the-thickness compression specimen and a flat crush coupon with the fibres oriented at 45° and 90° to the load. Damage growth mechanisms, orientation of the fracture plane, nonlinear evolution of Poisson's ratio and energy absorption are accurately predicted.


ABSTRACT: This work investigates the effects of interlayer hybrid fiber dispersion on the impact response of carbon-flax epoxy hybrid laminates at low carbon volume fractions, and benchmarks the mechanical performance enhancement against the non-hybrid flax epoxy. Five hybrid laminate stacking sequences with similar carbon-to-flax weight ratio were fabricated and subjected to low-velocity impact at three different energy values, generating non-perforated and perforated damage states. A virtual drop-weight impact test that
models intralaminar failure based on continuum damage mechanics approach, and delamination using cohesive elements, was also implemented to evaluate the material behavior and damage development in the composites. Simulation results were then verified against experimental data. Results suggested that positioning stiffer carbon plies at the impact face does not necessarily lead to enhancement of the hybrid's impact properties. On the contrary, flax plies at the impacted side lead to significant improvement in impact resistance compared to the non-hybrid flax composite with similar thickness. Results of finite element analysis showed that carbon plies play a significant role in the hybrid laminate's energy absorption characteristics due to lower failure strain.


ABSTRACT: The main purpose of this study is to investigate the time-dependent behavior of a sandwich panel numerically and experimentally. The core of the panel is made of poly vinyl carbon Airex 70.75, and shells are made by vacuum injection method from 600 g glass fiber per square meter. To determine the time-dependent compressive and shear modulus of the core, dynamic tests are performed at different temperatures. Using appropriate equations, time-dependent Bulk modulus and Poisson's ratio are calculated. Performing three-point-bend tests on sandwich panels, time-dependent behavior of this material is investigated. Finally, these three-point-bend tests are simulated using finite element method and calculated values of viscoelastic parameters. Accordingly, numerical simulation results are compared with experimental data. Regarding the well matching of the quasi-static model, modeling of the relaxation behavior of the beam sample is investigated.


ABSTRACT: A refined sinusoidal model considering transverse normal strain has been developed for thermoelastic analysis of functionally graded material plate. Although transverse normal strain has been considered, the additional displacement parameters are not increased as transverse normal strain only includes the thermal expansion coefficient and thermal loading. Moreover, the merit of the previous sinusoidal model satisfying tangential stress-free boundary conditions on the surfaces can be maintained. It is important that the effects of transverse normal thermal deformation are incorporated in the in-plane displacement field, which can actively influence the accuracy of in-plane stresses. To assess the performance of the proposed model, the thermoelastic behaviors of functionally graded material plates with various configurations have been analyzed. Without increase of displacement variables, accuracy of the proposed model can be significantly improved by comparing to the previous sinusoidal model. Agreement between the present results and quasi-dimensional solutions are very good, and the proposed model only includes the five displacement variables which can illustrate the accuracy and effectiveness of the present model. In addition, new results using several models considered in this paper have been presented, which can serve as a reference for future investigations.


ABSTRACT: In this paper, the vibration and damping properties of multiscale laminated fiberglass/epoxy composites modified with a wide range of carbon nanofillers, including multiwalled carbon nanotubes, graphene oxide, reduced-graphene oxide and graphene nanoplatelets were examined for use in structural vibration applications. Simultaneous reinforcement of matrix and fibers was carried out via a novel method that combines a nanoparticle spraying process with nanoparticle/epoxy mixture to incorporate nanoparticles for the enhancement of vibration and damping properties of multiscale laminated fiberglass/epoxy composites. The vibration and damping properties as well as morphological, mechanical properties of the glass fiber-reinforced multiscale composites were investigated. Using a forced vibration technique, the frequency-response functions, natural frequencies and damping ratios of the nanocomposites were measured. The experimental results revealed that the damped natural frequencies of the nanocomposites increased with an increase in nanoparticle
concentration. However, at higher contents of nanoparticles, the damped natural frequencies decreased and the damping ratio increased.


ABSTRACT: This paper investigates the behavior of woven prepreg plies being placed on a weakly double curved mold by a robot. It is essential that the draped configuration is free from wrinkles. The baseline is a virtual draping environment that can plan and simulate robot draping sequences. It consists of a kinematic mapping algorithm for obtaining target points for the grippers on the mold surface. A simple motion planner is used to calculate the trajectories of the grippers. Here, two conceptually different draping strategies are employed. Finally, the two generated draping sequences are simulated using a transient, non-linear finite element model and compared w.r.t. their predicted wrinkle formations. Material data are obtained by means of tension, bias-extension and cantilever tests. The numerical examples show that the virtual draping environment can aid in developing the automatic draping system but that the generation of feasible draping sequences is highly path dependent and non-trivial.


ABSTRACT: This study deals with the problem of the least-weight design of a composite multilayer plate subject to constraints of different nature (mechanical, geometrical and technological requirements). To face this problem, a multi-scale two-level design methodology is proposed. This approach aims at optimising simultaneously both geometrical and mechanical parameters of the laminate at each characteristic scale (mesoscopic and macroscopic ones). In this background, at the first level (macroscopic scale), the goal is to find the optimum value of geometrical and mechanical design variables minimising the structure mass and satisfying the set of imposed constraints (on first buckling load, membrane stiffness and feasibility constraints). The second-level problem (mesoscopic scale) aims at finding at least one stacking sequence meeting the geometrical and material parameters provided by the first-level problem. The multi-scale two-level optimisation approach is based on the polar formalism to describe the macroscopic behaviour of the composites (in the framework of the equivalent single-layer theories) and on a special genetic algorithm to perform composite calculations. The optimum solutions provided by the multi-scale two-level optimisation strategy are characterised by a weight saving of about 10% with enhanced mechanical properties when compared to conventional symmetric balanced stacks. The effectiveness of the optimum solutions is also proven through an experimental campaign of buckling tests. The experimental results are in excellent agreement with those foreseen by the numerical simulations.


ABSTRACT: To analyze the failure mechanism and energy-absorbing characteristics of composite thin-walled C-channels subject to the low-speed axial compression, 12 groups of T700/MTM28 specimens with three different layer numbers and four different layups were fabricated and tested. The failure modes and load–displacement curves were observed, and then the effects of layer numbers and layups on failure mechanism and energy-absorbing characteristics were further analyzed based on the crashworthiness indicators, such as peak crushing force ($F_c$), mean crushing force ($F_{av}$), specific energy absorption (SEA) and crushing force efficiency (CFE). The results show that for the C-channels with $0^\circ$ ply, overall instability occurs, which results in a reduction of SEA. The C-channels with $0^\circ/90^\circ$ ply, $\pm 45^\circ$ ply and $45^\circ/90^\circ/-45^\circ/0^\circ$ ply exhibit the stable progressive crushing progress with the local buckling failure mode, consisting of local buckling, fiber breakage, matrix cracks, delamination and corner cracking. Besides, the SEA of C-channels with $45^\circ/90^\circ/-45^\circ/0^\circ$ ply
increases with the increasing of layer numbers, and the C-channels with 45°/90°/-45°/0° ply have greater potential for the design and application of energy-absorbing structures.


ABSTRACT: The use of composite materials undergoes a significant growth in many industries including aeronautic, railway, and automotive. Laminated composites are often subjected to severe loading conditions such as hailstones on aircraft and road gravels on automobiles. The present paper deals with the damage tolerance in carbon fiber-reinforced polymer structures caused by low velocity multiple impacts. Low velocity multi-impact tests at different energy levels (10, 15, and 20 J) are performed in order to simulate the grains' impact conditions corresponding to mass of 10–50 g for velocity of 100–150 km/h. These tests were carried out on composite laminates with three types of stacking sequences (AERO, QIQH45, and QIQH60). AERO, widely used in aviation industry, is symmetric stacking sequence, and the two others QIQH45 and QIQH60 are quasi-isotropic and quasi-homogeneous laminates based on 45° and 60° ply orientation, respectively. Two specific parameters $D$ and $d$ are deduced from force–displacement and force–time responses which make it possible to rank the three stacking sequences to their damage tolerances. The impact damage assessment within the composite material with non-destructive testing method using ultrasonic inspection gives a good correlation with parameter $D$. Better impact damage tolerance is achieved with QIQH45 than the QIQH60 and AERO laminates. The parameter $D$ can be regarded as a failure criterion for dimensioning of composite structures subjected to repetitive impacts.


ABSTRACT: This research paper presents the results of an experimental investigation on the axial compressive behaviour of 24 geopolymer concrete-filled glass fibre-reinforced polymer tubes. The test variables considered are the compressive strength of geopolymer concrete (30 MPa and 35 MPa) and the shape of the cross section (square, circular and rectangular). All the glass fibre-reinforced polymer tubes had the same amount of fibres and similar fibre orientation together with the same aspect ratio. The failure of the square and rectangular columns initiated with the splitting of the corners and resulted in a lower load-carrying capacity compared to the circular columns whose failure was initiated by the crushing of glass fibre-reinforced polymer tube followed by the separation of glass fibre-reinforced polymer tube into strips. It can be concluded that axial load-carrying capacity of square and rectangular sections can be improved by a concrete filler with higher compressive strength. Adopted finite element analysis to simulate the behaviour of the columns is capable of predicting the stress–strain behaviour and the mode of failure.


ABSTRACT: This work is intended to characterize the mechanical behavior of hybrid carbon–glass composite plates under combined loading of bending and torsion, and to determine the optimal ply fiber orientations to minimize the maximum out-of-plane displacement under such loading conditions. Hybrid composite plates were manufactured with 10 plies each and different stacking sequences using hand lay-up, with carbon fiber and glass fiber reinforcements in an epoxy matrix. Two experimental setups (involving two distinct boundary conditions) are here considered to test the composite plates, both simulating combined loading of bending and torsion. Numerical simulations of the experimental tests were performed in ABAQUUS and validated with the experimental data. Using the ply fiber orientations as design variables, the hybrid composite plates were then optimized using global and local optimization using direct search (GLODS). The objective function of minimization of the maximum out-of-plane displacement is carried out through an interactive cycle between GLODS and ABAQUUS. Specimens of three optimized laminates were also manufactured for experimental validation. The optimization process contributed to improve the performance of the hybrid composite plates in more than 30% when compared to some non-optimized plates.

ABSTRACT: The effects of temperature and thermal cycling on the residual stress and failure behavior of different polymer matrix composites have been investigated in this paper. A new algorithm within the framework of the classical laminate plate theory (CLPT) has been presented to calculate the residual stresses. The modified Tsai-Wu failure criterion has been employed to study the failure behavior of different stacking sequences. Numerical results show that the residual stress and failure index of the composites decrease with the increase of the temperature. It has also been established that thermal cycling condition leads to reduction of the residual stresses and increment of the failure index.


ABSTRACT: In this study, mechanical properties of new-manufactured sandwich composites with various cell structures, having carbon fiber core have been investigated both numerically and experimentally. Three-point bending and compression tests are applied to the specimens as the experimental test approach. Failure behavior and strength of the specimens are extracted as a result of the measurements. The test results also give the opportunity to find out the optimum peak load/density ratio of various core types of sandwich composites. The commercial finite element software ANSYS has been used for numerical analysis. It should be remarked that a good agreement between numerical and experimental results is obtained. The cell shape and height are important parameters on peak load for bending. Additionally, change of cell density is a parameter having effect in same proportion for bending and compression peak loads for these type composites.


ABSTRACT: An updated Lagrangian-based nonlinear finite element method is developed to study the buckling behavior of damaged laminated composite plates under uniaxial compression. In this study, material imperfections are treated as existing static damage and a continuum damage mechanics-based approach is used to model such imperfections. The laminated plate is modeled as a set of elementary layers bonded together by matrix-rich elastic interface. This allows to model different modes of damage present at both elementary ply level and interply interface separately. A layerwise plate model is used to model both elementary ply and interface layers of the laminate. The effect of different forms of existing static damage on the limit point loads and the corresponding displacements of laminated plates are studied. It is observed that for the chosen modes and size of the damaged regions, the limit point load does not change much as compared to the undamaged plate. However, the deformed shapes show significant changes and some very interesting phenomena like local wrinkling behaviour of the damaged region is observed. The effect of ply orientation along with different modes of damage on the limit points and the corresponding deformed shapes of laminated plates are also discussed.


ABSTRACT: This work presents a comparison of various combinations of patch and parent laminates with different orientations and stacking sequence, on the performance of adhesively bonded external patch-repaired carbon/epoxy laminates under quasi-static compressive loading. The compressive behaviour and failure modes of pristine, damaged and repaired specimens of four different parent laminates ([0, 45], [0/45/45], [45/45/0]) are discussed. The repair of each parent laminate is carried out by bonding patches of four configurations ([0, 45], [45/0], [0/45]) having two plies on each side of the parent laminates. Real-time digital image correlation technique was employed to capture the development of the strain field with the increasing load. The results reveal the development of distinctive strain contours associated with different patch–parent configurations. The
inspection of damaged specimens revealed the fiber micro-buckling as the dominant mode of failure. The orientation of plies influences the overall failure mode of the laminates. The clustering of 0° plies results in laminate possessing higher strength. The less stiff [45] patch shows higher compliance with the increasing load.


ABSTRACT: Here, analytical studies have been carried out to determine the optimal values of effective parameters on the stress concentration factor around a cutout using genetic algorithm. Optimum designs of single lamina as well as symmetric laminates with 4, 8 and 12 layers of graphite/epoxy and glass/epoxy plates containing a circular cutout with various sizes are presented. The work focuses on extending the analytical solution given by Greszczuk to determine the stress distribution in multilayered composite plates subjected to arbitrary in-plane loadings. This is achieved by introducing an arbitrary oriented uniaxial, biaxial and shear loading conditions into Greszczuk solution. In order to mimic as much as possible the real structural behavior, the finite-width correction factor given by Tan is used. Effective parameters on stress distribution around the circular cutout in composite plates considered as design variables include: load angle, fiber orientation, cutout size and stacking sequence of the laminate. The objective function in this study is the minimization of maximum stress concentration around the cutout which is calculated by the present analytical solution. The first ply failure load predicted using Tsai–Wu criterion is maximized for both single lamina and symmetric laminates. Also, the weight of the plates is minimized by increasing the hole size to width ratio. The results obtained by the present analytical solution compare favorably with those obtained using complex variable method. For laminated plate subjected to shear loading, the stress concentration factor decreased drastically by 48.79% compared to a single lamina. The failure load is also increased in most of the loading cases. The results also showed that the genetic algorithm code converges rapidly in most of the cases. The accuracy, quickness, low computational cost and the simplicity of the present solution encourage the designers to use it in practical applications.


ABSTRACT: A micro-mechanics approach is put forward to predict the fiber kink inclination angle and the strength of a unidirectional composite under longitudinal compression. Internal stresses of constituent materials in the kink-band are calculated through Bridging Model; thus, only the constituent fiber and matrix properties of the composite are needed. Considering the non-uniform stress distribution caused by the embedded fiber, the homogenized stresses of the matrix are converted into true values with stress concentration factors before being used for failure analysis. The definition and application of stress concentration factors are introduced. A failure criterion based on Mohr’s theory is established to determine the orientation of potential failure surface and the failure situation of matrix, whereas a maximum normal stress failure criterion is used to detect the fiber breakage. The longitudinal compressive strength of a laminate is defined as the applied load at the moment when a failure of whichever constituent materials occurs first. The practicability and accuracy of the theory have been verified with a comparison between the predictions and the measurements obtained from the worldwide failure exercises and some other literatures.


ABSTRACT: This study investigates the effect of face materials, Z-pin types and distribution densities on drop-weight impact properties of foam core sandwich composites. The novelty of this study is to eliminate damage of face part by only reinforcing the core part of sandwich structures. Impact test was performed at different energy levels (20–50 J). The addition of Z-pins into the sandwich composites decreased the elasticity and ductility while it increased the stiffness of sandwich composites. The Z-pin reinforcement increased the peak forces, but decreased the peak deformations of the sandwich composites. However, higher energy absorption was only
observed at the higher Z-pin distribution density. The results showed that Z-pin distribution density, bonding between the face sheets/pins, and the face sheet material have a great influence on the impact behaviour of the Z-pin-reinforced sandwich composites besides the Z-pin types.

Tobias A. Weber (1), Markus Englhard (2), Jan-Christoph Arent (1) and Joachim Hausmann (3)
(1) Airbus Helicopters Deutschland GmbH, Germany
(2) FH Aachen, University of Applied Sciences, Germany
(3) Institute for Composite Materials (IVW), University of Kaiserslautern, Germany


ABSTRACT: Out-of-plane ply wrinkling is a major quality issue for carbon fiber reinforced prepreg parts. Its triggers are numerous and not every influencing parameter is fully understood, yet. The research presented in this paper aims at providing a better insight into ply wrinkling generated during autoclave compaction using caul plates. A detailed description of the experimental set-up and the applied methodology is provided. Statistical analyses of varying influencing factors such as part thickness, geometry, tool–part interaction, and laminate lay-up are presented. This, in turn, generates a better understanding of their impact on fiber wrinkling risk and size. Part geometry and compaction deformation show the most significant influence on wrinkle size. However, for the given manufacturing concept, tool–part interaction also plays a significant role. It influences both the dimension and location of the wrinkles, as well as the existence and size of a critical flange length of the part. A noteworthy effect on wrinkle generation and size can also be observed when adding unidirectional plies to an otherwise fabric laminate.

Xin Lan (1), Sida Hao (1), Liwu Liu (2), Yanju Liu (2) and Jinsong Leng (1)
(1) National Key Laboratory of Science and Technology on Advance Composites in Special Environments, Harbin Institute of Technology (HIT), P.R. China
(2) Department of Aerospace Science and Mechanics, Harbin Institute of Technology (HIT), P.R. China


ABSTRACT: Due to microscale fiber microbuckling, a fiber-reinforced soft composite demonstrates large macroscale bending deformation (e.g. 10% reversible macroscale compressive strain), which is larger than that of a convenient fiber-reinforced plastics (e.g. 1.5–2% elongation/compression at break). To investigate the deformation behavior, a normalized average energy density of a fiber-reinforced soft composite laminate was derived. By using a self-consistent approach according to the minimum energy principle, a series of analytical expressions were derived by a simplified theoretical method through solving simplified partial differential equations of average energy density. Furthermore, an improved numerical calculation method was developed using the full four terms of partial differential equations of average energy density by employing the results of simplified theoretical method as initial calculating values. The dimensionless results demonstrated that the trend correlated well between those two methods, and the improved numerical method obtained more accurate results than those of the simplified theoretical method. Analytical and numerical results in normalized expressions systematically described the bending large-deformation behavior including position of neutral surface and critical buckling, wavelength, amplitude, shearing strain, macroscale compressive/tensile strain, buckled fiber strain, and actuation moment. To design a fiber-reinforced soft composite for use in engineering, the simplified theoretical method is used to predict trend and obtain approximate results for preliminary design, and the improved numerical method is further used to check and obtain more accurate results on detailed design stage.

P. Bruenig (1), V. Damodaran (1), K. Shahapurkar (2), S. Waddar (3), M. Doddamani (3), P. Jayaraj (3) and P. Prabhakar (1)
(1) University of Wisconsin-Madison, USA
(2) Sanjeevan Engineering and Technology Institute, India
(3) National Institute of Technology, Karnataka, India

ABSTRACT: Sandwich composites and syntactic foams independently have been used in many engineering applications. However, there has been minimal effort towards taking advantage of the weight saving ability of syntactic foams in the cores of sandwich composites, especially with respect to the impact response of structures. To that end, the goal of this study is to investigate the mechanical response and damage mechanisms associated with syntactic foam core sandwich composites subjected to dynamic impact loading. In particular, this study investigates the influence of varying cenosphere volume fraction in syntactic foam core sandwich composites subjected to varying dynamic impact loading and further elucidates the extent and diversity of corresponding damage mechanisms. The syntactic foam cores are first fabricated using epoxy resin as the matrix and cenospheres as the reinforcement with four cenosphere volume fractions of 0% (pure epoxy), 20%, 40%, and 60%. The sandwich composite panels are then manufactured using the vacuum assisted resin transfer molding process with carbon fiber/vinyl ester facesheets. Dynamic impact tests are performed on the sandwich composite specimens at two energy levels of 80 J and 160 J, upon which the data are post-processed to gain a quantitative understanding of the impact response and damage mechanisms incurred by the specimens. A qualitative understanding is obtained through micro-computed tomography scanning of the impacted specimens. In addition, a finite element model is developed to investigate the causes for different damage mechanisms observed in specimens with different volume fractions.

S. Prabhakaran (1), V. Krishnaraj (2), Krishna Shankar (3), M. Senthilkumar (2) and R. Zitoune (4)
(1) Department of Robotics and Automation Engineering, PSG College of Technology, India
(2) Department of Production Engineering, PSG College of Technology, India
(3) Department of Mechanical Engineering, University of New South Wales, ADFA, Australia
(4) Composite Materials and Structures Group, Toulouse University, Clement Ader Institute, France

ABSTRACT: In recent years, material scientists have been focusing on the utilization of materials from natural resources due to environmental concerns. In the same context, the aim of this work is to evaluate impact response, sound absorption behavior, and vibration damping characteristics of natural-based composite sandwich made of flax as skin reinforcement and agglomerated cork as core. Vacuum bagging method was used for manufacturing composite sandwiches with different cork densities of 240, 280, and 340 kg/m³. Composite sandwiches have also been manufactured by using glass as skin reinforcement for comparison. Low velocity impact test was conducted and found that glass fiber reinforced composite sandwich required 73–77% more energy to perforate when compared to the flax fiber reinforced composite sandwich irrespective of core density. Flax fiber reinforced composite sandwich has 45–96% higher sound absorption capacity and 27–32% higher vibration damping ratio than glass fiber reinforced composite sandwich irrespective of core density. This is due to multiscale structure and cellular nature of the flax fiber and the cork materials, respectively. These enhancements in sound and vibration are accomplished with just little forfeits in perforation energy. This study recommends that, if optimized, the natural-based composite sandwich could be an ecologically appealing answer for automobile and construction applications, where impact behavior is important, along with sound and vibration properties.


ABSTRACT: Fibre reinforced plastic tubes with balanced off-axis ply orientation exhibit excellent mechanical properties and are widely used in various types of structures. In this study, a theoretical prediction model was proposed to determine the overall buckling load and the failure mode of fibre reinforced plastic laminated tubes with off-axis ply orientation under axial compression. This model considers the transverse shear effect and adopts Puck failure criteria to perform an analysis based on deduced three-dimensional stress and strain fields. A series of carbon fibre reinforced plastics tubes with varying off-axis ply orientations and lengths were designed and prepared. Axial compression tests with effective end-reinforcement and hinge support were performed to validate the proposed prediction model. The results indicated that the predicted model results were
in good agreement with the test results, with respect to ultimate loads, failure modes, and locations of failure. Parametric analysis on the influence of transverse shear effect was also conducted, which further explained the influencing degree of transverse shear effect considering different tube lengths, ply sequences, and initial deflection.

F. Batikoglu (1), N. Arsian (2), T.K. Demircioglu (1), O. Imal (3), M. Iren (1) and A. Atas (1,4)
(1) Department of Mechanical Engineering, Balikesir University, Turkey
(2) Department of Energy Systems Engineering, Manisa Celal Bayar University, Turkey
(3) School of Materials, University of Manchester, UK
(4) School of Mechanical, Aerospace and Civil Engineering, University of Manchester, UK
“Improving four-point bending performance of marine composite sandwich beams by core modification”,
Journal of Composite Materials, Vol. 54, No. 8, pp 1049-1066, April 2020,
https://doi.org/10.1177/0021998319874502

ABSTRACT: The aim of this study was to improve four-point bending performance of foam core sandwich composite beams by applying various core machining configurations. Sandwich composites have been manufactured using perforated and grooved foam cores by vacuum-assisted resin transfer moulding method with vinyl-ester resin system. The influence of grooves and perforations on the mechanical performance of marine sandwich composite beams was investigated under four-point bending test considering the weight gain. Bending strength and effective bending stiffness increased up to 34% and 61%, respectively, in comparison to a control beam without core modification. Analytical equations were utilised for calculating the mid-span deflection, equivalent bending stiffness and ultimate bending strength of the sandwich beams. Finite element analysis was also performed to analyse the flexural response of the specimens taking into account the combined effect of orthotropic linear elasticity of the face sheet and the non-linear behaviour of the foam core.

https://doi.org/10.1177/0021998319873025

ABSTRACT: This paper develops a Hamiltonian state space approach for analytic determination of deformation and stress fields in multilayered monoclinic angle-ply laminates under the combined action of extension, bending, and torsion. The present solution satisfies the equations of anisotropic elasticity, the end conditions, the traction-free boundary conditions on the four edge surfaces of the rectangular section, and the interfacial continuity conditions in multilayered laminates. The proposed method only requires the solutions of matrix and eigen equations, regardless of the number or lamination of the layers. The finite element analyses are used to validate the accuracy of the analysis. The analytical solution and the numerical solutions are in excellent agreement.

T. Shojaee, B. Mohammadi and R. Madoliat (School of Mechanical Engineering, Iran University of Science and Technology, Iran), “Experimental and numerical investigation of stiffener effects on buckling strength of composite laminates with circular cutout”, Journal of Composite Materials, Vol. 54, No. 9, pp 1141-1160, April 2020,
https://doi.org/10.1177/0021998319874101

ABSTRACT: In the notched structures, to achieve maximum buckling resistance in comparison with structural weight, the optimal design of a stiffener is very important. In this research, after a review of the existing literature, nonlinear buckling behavior of composite plates containing the cutout with three different designs of stringer was investigated. The considered stiffeners are planer, longitudinal, and ring types. The buckling experiments were carried out on the stiffened plates containing a circular notch. Moreover, to achieve an efficient prediction of the buckling in the stiffened laminate with the hole, a finite strip method is developed based on the Airy stress function and von Karman’s large deformation equations. Studies show that there is a good agreement between the postbuckling behaviors derived from developed finite strip method with experimental results. Fast convergence of the considered finite strip method compared with the finite element results shows its efficiency for prediction of buckling behavior in laminated composites. The results show that the buckling load-bearing capacities of perforated plates with a longitudinal and planer stiffener are higher compared with the other stiffener, respectively. The detailed parametric study on the effects of thickness of the plate and stiffener and opening diameter on buckling behavior was performed using experiments and modeling.


32. Ghannadpour, SAM, Barvaj, AK, Tornabene, F. A semi-analytical investigation on geometric nonlinear and progressive damage behavior of relatively thick laminated plates under lateral pressure and end-shortening. Compos Struct 2018; 194: 598–610.


44. Kharazi, M, Ovesy, HR, Taghizadeh, M. Buckling of the composite laminates containing through-the-width delaminations using different plate theories. Compos Struct 2010; 92: 1176–1183.


ABSTRACT: L-shaped stiffened composite panels provide an efficient structure for engineering applications. However, they often produce delamination in the preparation and service process due to a series of factors. To study the effect of different types of delamination on the compressive strength of stiffened composite panels, ABAQUS finite element software was used in combine with the progressive damage subroutine user-defined field variable (USDFLD), and the finite element model was established based on cohesive theory to realize the prediction of the progressive failure process and strength of the stiffened composite panels. The results showed that the delamination of a stringer had a greater impact on the strength of the stiffened composite panels than did the debonding between the skin panel and a stringer and the delamination of the skin panel. The debonding delamination and delamination of a stringer exhibited delamination growth near the damage position during static compression, but delamination of the skin panel exhibited no delamination growth. The experimental results were in good agreement with the finite element simulation results, which verified the validity of the finite element model.

References listed at the end of the paper:


ABSTRACT: The purpose of this study is to evaluate and compare the ability of various composite structures to dissipate the energy generated during a crash. To this end, circular composite tubes were tested in compression in order to identify their behavior and determine their absorbing capabilities using the specific energy absorption (energy absorbed per unit weight). Several composite tubular structures with different materials and architectures were tested, including hybrid composition of carbon–aramid and hybrid configuration of 0/90 UD with woven or braided fabric. Several inventive and experimental trigger systems have been tested to try and enhance the absorption capabilities of the tested structures. Specific energy absorption values up to 140\,kJ/kg were obtained, achieving better than most instances from the literature, reaching around 80\,kJ/kg. Specimens with 0°-oriented fibers coincidental with the direction of compression reached the highest specific energy absorption values while those with no fiber oriented in this direction performed poorly. Moreover, it has consequently been established that in quasi-static loading, a unidirectional laminate oriented at 0° and stabilized by woven plies strongly meets the expectations in terms of energy dissipation. Incidentally, an inner constrained containment is more effective in most cases, reducing the initial peak load without drastically reducing the specific energy absorption value.

References listed at the end of the paper:


ABSTRACT: This work presents an experimental and numerical investigation of the effects of pre-existing core damage on aluminum honeycomb core composite sandwich structures. Quasi static flexural and compression experiments were performed, where the effects of core damage on the shear modulus and Young's modulus were quantified. In addition, finite element analysis was performed on the sandwich structures to elucidate the effects of the core damage on the structural response. Comparisons of experimental and finite element responses are presented for sandwich structures consisting of carbon fiber facesheets and an aluminum honeycomb core. The pre-existing core damage is observed to cause up to an 8% reduction in shear modulus and a 9% reduction in elastic modulus. It is also determined that the presence of pre-existing core damage results in an asymmetrical compressive load distribution in the composite structures.

References listed at the end of the paper:


ABSTRACT: In this paper, a new bi-tubular corrugated composite tube, consisting of inner and outer cylindrical and conical tubes is proposed. Different models with various geometrical parameters including the radius of curvatures and their numbers are considered and studied numerically in axial and oblique crushing in order to achieve favorable crashworthiness parameters. Moreover, quasi-static compression tests have been conducted to obtain results in order to validate the finite element model. There has been a sensible agreement between the numerical results and experimental data. Finite element models are also validated using the analytical solutions for both straight and corrugated composite tubes. Regardless of the number and radius of curvatures, as the crashworthiness of bi-tubular corrugated structures both in axial and oblique crushing is investigated and compared with their single-wall and bi-tubular straight peers, a considerable improvement is achieved in all crashworthiness parameters, including desirable increase in specific energy absorption, favorable reduction in peak force, and consequently a beneficial rise in crushing force efficiency. In addition, an optimization study using a suitable multi-objective function is done to choose the best model among the existing models, in addition to finding an optimum model via genetic algorithm. In the next step, a parametric study is conducted on the best model to inspect how well it undergoes oblique crushing at different angles. Finally, this best model and two other candidates have been chosen to investigate the effect of using foams and then the energy absorption capability of the empty and foam-filled tubes has been compared.

References listed at the end of the paper:


ABSTRACT: An accurate and computationally attractive zigzag theory is developed for bending and buckling analysis of thick laminated soft core sandwich plates. The kinematic assumptions of the proposed zigzag theory are obtained by superimposing a nonlinear zigzag function on the first-order shear deformation theory. In order to obtain the accurate transverse shear stresses, a preprocessing approach based on the three-dimensional equilibrium equations and the Reissner mixed variational theorem is used. It is significant that the second-order derivatives of in-plane displacement variables have been removed from the transverse shear stresses, such that the finite element implementation is greatly simplified. Thus, based on the proposed zigzag model, a computationally efficient four-node C quadrilateral plate element with linear interpolation function is proposed for bending and buckling analysis of soft core sandwich plates. The advantage of the present formulation is that no post-processing approach is needed to calculate the transverse shear stresses while maintaining the computational accuracy of a linear plate element. Moreover, the accurate transverse shear stresses can be involved in the strain energy which can actively improve the accuracy of critical loads. Performance of the proposed model is assessed by comparing with several benchmark solutions. Agreement between the present results and the reference solutions is very good, and the proposed model only includes the seven displacement variables which can demonstrate the accuracy and effectiveness of the proposed model.

References listed at the end of the paper:


ABSTRACT: The effect of varying strain rate on the compression strength and energy absorption characteristics of a carbon fibre-reinforced plastic honeycomb core has been investigated over a wide range of loading rates. The honeycombs were manufactured by infusing an epoxy resin through a carbon fibre fabric positioned in a dismountable honeycomb mould. The vacuum-assisted resin transfer moulding technique yielded honeycomb cores of a high quality with few defects. Compression tests were undertaken on single and multiple cells and representative volumes removed from the cores in order to assess how the compression strength and specific energy absorption vary with test rate. Crushing tests over the range of strain rates considered highlighted the impressive strength and energy-absorbing response of the honeycomb cores. At quasi-static rates of loading, the compression strength and specific energy absorption characteristics of the unidirectional samples were higher than those of the multidirectional cores. Here, extensive longitudinal splitting and fibre fracture were the predominant failure mechanisms in the cores. For all three stacking sequences, the single-cell samples offered higher compression strength than their five-cell counterparts. In contrast, the specific energy absorption values were found to be slightly higher in the five-cell cores. The experiments highlighted a trend of increased compression strength with loading rate in the multidirectional samples, whereas the strength of the [0°] samples was relatively insensitive to strain rate. Finally, the energy absorbing capacity of all structures studied was found to be reasonably constant at increasing rates of strain.

References listed at the end of the paper:


ABSTRACT: The aim of the study is to investigate the behavior of laminated composites under low velocity impact both experimentally and numerically. With this aim, the effects of wide range impact energy values between 10 J and 60 J were evaluated experimentally and numerically for the laminate of [±45/(0/90)], oriented unidirectional E-glass as reinforcing material and epoxy resin for matrix material. Different impactor velocities were used to maintain the impact energy values and experimental impact tests were generated with drop weight impact testing machine at room temperature. Numerical simulations were performed using LSDYNA finite element analysis software with a continuum damage mechanics-based material model MAT058. Contact force between impactor and laminate, and transverse deflection at the center of laminate results were obtained as a function of time and used to plot contact force–time curves, contact force–deflection curves and absorbed energy–impact energy curves. Also, delamination area was examined. Finally, numerical results were compared with experimental results and a good correlation between them was observed.

References listed at the end of the paper:


ABSTRACT: The aim of this study was to analyze the effect of hybridization on impact and residual strength in composites as well as the types of damage caused by the impacts, quantifying the delaminated area of the test specimens. Two 11-layer composite laminates were developed, one with bidirectional glass fiber woven and the other a hybrid with three layers of bidirectional aramid fiber substituting the outer layers and the middle layer of the glass fiber. The materials revealed that the hybrid laminate obtained greater impact strength withstanding one impact of 76 J, albeit with an increase in the damaged area of between 64 and 85 cm, resulting in a decline in mechanical properties along nearly the entire test specimen. This contrasts with what occurred in the glass fiber laminates, which recovered over 80% of their mechanical properties for a distance of 35 mm from the edge of the impactor. Moreover, it demonstrated that the variation in residual strength can be represented by an equation and that there is a relation between the damage area and the residual properties of the glass fiber material.

References listed at the end of the paper:


Specimen thickness was obtained in accordance with the rule of the theoretical mixture. As a result of the metallographic and micromechanical examinations, the material composition variation through the plate thickness of the plate are manufactured with gradually varying material composition through the plate thickness. Two different structures (metal–ceramic), and the upper and lower surfaces are pure metal (Al) and the internal layers of the plate are manufactured with gradually varying material composition through the plate thickness. The low-velocity impact tests were conducted on both upper and lower surfaces of specimens using CEAST low-velocity impact device, and the contact force–time and the energy–time graphs were plotted. The importance of translaminar fracture toughness for the penetration impact behaviour of woven carbon/glass hybrid composites. Compos Part A Appl Sci Manuf 2017; 103: 1–8.


ABSTRACT: In this study, the mechanical behavior of sandwich plates with functionally graded core under low-velocity impact loads was investigated experimentally. Sandwich plate with functionally graded core has two different structures (metal–ceramic), and the upper and lower surfaces are pure metal (Al) and the internal layers of the plate are manufactured with gradually varying material composition through the plate thickness. The low-velocity impact tests were conducted on both upper and lower surfaces of specimens using CEAST low-velocity impact device, and the contact force–time and the energy–time graphs were plotted. Metallographic and micromechanical examinations were carried out on the specimens after impact tests. As a result of the metallographic and micromechanical examinations, the material composition variation through the specimen thickness was obtained in accordance with the rule of the theoretical mixture. As a result of impact
tests \( (v = 4 \text{ m/s}) \) on upper surface (ceramic-rich side), crack damages occurs on the plates with \( n = 10.0 \) material composition, whereas the specimens with \( n = 1.0 \) and \( n = 10.0 \) material compositions have crack damages after impact tests on its lower surfaces (metal-rich side). Impact force on the ceramic-rich upper surface provides to meet the transferred load waves through the plate thickness by metal-rich bottom surface. This situation makes the structure more resistant against damage. Moreover, the upper and lower surfaces of the functionally graded structure reinforced by ductile pure metal layers provide an important contribution to protection of functional integrity of the structure against damage.

References listed at the end of the paper:


ABSTRACT: In this study, the ballistic performance of Al6061-SiC functionally graded sandwich plate (FGSP) with varying number of layers and volume fractions was examined experimentally. For this purpose, the two outmost layers of the FGSP were designed to be aluminum and the volume fraction of remaining constituents was gradually changing in intermediate layers through the plate thickness. The specimen plates were manufactured via powder stacking-hot pressing method. Ballistic tests of specimens were conducted with a single-stage gas gun, shooting 0.3 caliber fragment simulated projectiles onto specimens. After the ballistic
tests, deformation and damage mechanisms in the front and rear surfaces were examined and ballistic performance evaluation was carried out in terms of depth of penetration of the projectile measurements. Results showed that the composition of the projectile impact surface, which was beneath the top aluminum layer, had a considerable effect on ballistic resistance capability. A volume fraction of ceramic constituent greater than 60% in the projectile impact surface reduced the ballistic performance of the specimen. Likewise, a decreasing volume fraction of ceramic constituent of projectile impact surface below 60% increased projectile penetration. Furthermore, increasing the number of layers within the functionally graded region did not have a significant effect on the ballistic resistance of the FGSPs.

References listed at the end of the paper:

ABSTRACT: Currently, the application of pultruded profiles is increasing owing to their advantages, such as light weight, high strength, improved durability, corrosion resistance, ease of transportation, speed of assembly, and nonmagnetic/nonconductive characteristics. This review analyzes the main application fields of elements produced by pultrusion manufacturing processes: bridges and bridge decks, cooling towers, building elements and complete building systems, marine construction, transportation, and energy systems. Analysis of the scientific literature in relation to the mechanical behavior of pultruded elements is presented as well. Finally, this review outlines the future study possibilities, giving the researchers and practitioners the directions for deeper investigation of specific features and exploration of new ones concerning the mentioned aspects of pultruded fiber-reinforced polymer composites.

References listed at the end of the paper:

15. Zhang, D, Zhao, Q, Huang, Y, et al. Flexural properties of a lightweight hybrid FRP-aluminum modular space truss bridge


35. Sebastian, WM, Ross, J, Keller, T, et al. Load response due to local and global indeterminacies of FRP-deck bridges. Compos...


Paulsen US, Madsen HA, Kragh KA, et al. The 5 MW deepwind floating offshore vertical wind turbine concept design – status
and perspective. In: European wind energy association conference and exhibition (EWEA 2014), Barcelona, Spain, 10–13 March 2014.


Pilato L. Resin chemistry. Berlin Heidelberg: Springer.


254. Zhang, S, Caprani, CC, Heidarpour, A. Strain rate studies of pultruded glass fibre reinforced polymer material properties: a

257. Hankinson, RL. Investigation of crushing strength of spruce at varying angles of grain. Air Serv Inf Circ 1921; 3: 130.


Hashem, ZA, Yuan, RL. Experimental and analytical investigations on short GFRP composite compression members. Compos Part B Eng 2000; 31: 611–618.

Russo, S. A review on buckling collapses of simple and complex columns made from pultruded frp material. Compos Mech Comput Appl 2017; 8: 1–34.


Kim, YJ, Qian, KZ. Compressive behavior of non-slender hollow GFRP structural shapes in thermomechanical loading. Compos Struct 2017; 160: 813–823.


Keller, T, Gürttler, H. In-plane compression and shear performance of FRP bridge decks acting as top chord of bridge girders. Compos Struct 2006; 72: 151–162.


Neagoe, CA, Gil, L. Analytical procedure for the design of PFRP-RC hybrid beams including shear interaction effects. Compos Struct 2015; 132: 122–135.


<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
</table>


396. Ribeiro, MCS, Tavares, CML, Ferreira, AJM, et al. Static flexural performance of GFRP-polymer concrete hybrid beams. Key...


Xu, Y. Delamination detection at web/flange junction of I-section composite beam with fiber optical interferometer sensor. Compos Part B Eng 2014; 58: 140–146.


References listed at the end of the paper: show the lamina bending failure mode with medium specific energy absorption. The failure mode of [±45]

etc. The [±45/0/0/90/0] fiber fracture, matrix deformation, and cracking, interlamination and intralamination cracks, cracks propagation,

and specific energy absorption, peak crushing force were further researched. The results show that the
X
square tubes, [0/90] circular tube shows the transverse shearing failure mode with high specific energy absorption. The [±45], square tube and [±45], sinusoidal specimen show the local buckling failure mode with low specific energy absorption. The [0/90], sinusoidal specimen, [0/90], circular tube, and [0/90], square tube show the lamina bending failure mode with medium specific energy absorption. The failure mode of thin-walled structure can be changed by reasonable layups design, and the energy absorption can further be improved.


ABSTRACT: To research the failure of carbon fiber-reinforced composite laminated specimens, the tensile tests and compressive tests were conducted for [90], and [0], specimens, and the shear tests were conducted for [±45], specimens, and the microscopic failure mechanisms were observed by scanning electron microscopy. To research the failure and energy absorption of different thin-walled structures with different layups, the quasistatic axial crushing tests were conducted for [±45/0/0/90/0], and [0/90], circular tubes, [0/90], and [±45], square tubes, [0/90], and [±45], sinusoidal specimens, and the internal failure were further investigated by 3D X-ray scan. Based on the load-displacement curves, the energy absorptions were evaluated and compared according to specific energy absorption and peak crushing force, and the relationships between failure modes and specific energy absorption, peak crushing force were further researched. The results show that the macroscopic failure modes are the collective results of varieties of microscopic failure mechanisms, such as fiber fracture, matrix deformation and cracking, interlamination and intralamination cracks, cracks propagation, etc. The [±45/0/0/90/0] circular tube shows the transverse shearing failure mode with high specific energy absorption. The [±45], square tube and [±45], sinusoidal specimen show the local buckling failure mode with low specific energy absorption. The [0/90], sinusoidal specimen, [0/90], circular tube, and [0/90], square tube show the lamina bending failure mode with medium specific energy absorption. The failure mode of thin-walled structure can be changed by reasonable layups design, and the energy absorption can further be improved.

References listed at the end of the paper:

3. Azarakhsh, S, Ghamarian, A. Collapse behavior of thin-walled conical tube clamped at both ends subjected to axial and oblique loads. Thin-Walled Struct 2017; 112: 1–11.
<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Journal</th>
<th>Year</th>
</tr>
</thead>
</table>


ABSTRACT: This work presents an experimental study characterizing the crush performance of hollow cylindrical tubes made with prepreg platelet molding compound (PPMC). PPMC is a composite material system
that uses platelets from chopped and slit unidirectional prepreg as the basis for a molding compound. This material system has a higher fiber volume fraction and better mechanical properties than traditional short fiber systems and can be molded into complex geometries unlike continuous fiber systems. As such, this material system shows promise for use with complex structural members in vehicles. The failure morphology and specific energy absorption of the material are evaluated with different thickness-to-diameter geometries and test speeds. In addition, this work investigates how PPMC components compare to traditional continuous fiber components and finds that PPMC performs as well as continuous fiber layups with similar effective laminate stiffnesses.

References listed at the end of the paper:


ABSTRACT: In this study, numerical modeling is used to investigate the performance of a single-sided composite patch with different scale fillers, as reinforcement of a cracked aluminum plate under static tension. The main concerns of previous studies are about the geometry of patches, composite layups, and failure of adhesive. In this research, the effect of patch properties such as size and fiber volume fraction, the thickness of patch, and thickness of adhesive on the overall performance of the cracked aluminum plate are investigated numerically. Indeed, first, a 3D representative volume element (RVE) is adopted to calculate the mechanical properties of carbon nanotube (CNT)/epoxy and carbon fiber (CF)/epoxy composite patch at each specified volume fraction for investigating the effect of patch properties on the performance of a single-sided patch for crack repairing. In this regard, the cohesive zone model is adopted to analyze the debonding between the epoxy matrix and reinforcement to characterize the mechanical properties of composite patches. Finally, a linear 3D finite element analysis is performed to calculate the stress intensity factor (SIF) for cracked aluminum plate repaired by a single-sided composite patch at each specified reinforcement volume fraction for different thickness of patch and different thickness of adhesive. The results demonstrated that the stress intensity factor highly depends on the patch properties (patch stiffness) in addition to patch thickness and adhesive thickness.

References listed at the end of the paper:


Tsai, G-C, Shen, SB. Fatigue analysis of cracked thick aluminum plate bonded with composite patches. Compos Struct 2004; 64: 79–90.


specimens were fabricated in the between CFRP tube and sectional steel to study the mechanical properties of high structural load carrying capacity and deformability. In this study, expansive high strength concrete (HCSFC) takes advantages of high strength of concrete, steel and confinement of FRP, resulting in enhanced material properties.

**ABSTRACT:** High strength expansive concrete (HCSFC) takes advantages of high strength of concrete, steel and confinement of FRP, resulting in enhanced material properties.

Qi Cao, Xiannui Lv, Xiaojun Li, Changjun Zhou and Shide Song, “High strength expansive concrete-encased-steel filled CFRP tube and sectional steel to study the mechanical properties of high-strength expansive concrete-encased-steel filled CFRP tube (HECSFC) under monotonic and cyclic axial compression. Twenty-four specimens were fabricated in this study. The variables included the number of CFRP layers (0, 1, 2 layers),


ABSTRACT: In this study, low velocity impact behavior of E-glass fiber-reinforced thermoplastic composites repaired by pressing external laminated composite patches was investigated by experimental methods. Thermoplastic composites were manufactured from polypropylene granules with two different fiber contents of 40 wt. % and 60 wt. %. Repaired specimens were prepared by using unidirectional E-glass reinforced polypropylene based thermoplastic prepregs. In order to compare the low velocity impact behavior of the repaired and un repaired specimens, a number of single impact tests (ranging from energy levels of 10 J to 50 J) were carried out through a drop weight impact test machine with a hemispherical impactor. Low-velocity impact response of the specimens was investigated with cross-examining contact force-deformation curves and damaged specimens. Impact damages occurred in the upside and bottom surfaces of the composites were recorded from the visual inspection and compared for repaired and un repaired specimens. According to experimental results, bending stiffness and maximum contact force of the specimens having fiber content of 60 wt.% are higher than those of 40 wt.%. Moreover, it was concluded that the patch repaired specimens have achieved a better performance in terms of maximum contact force and absorbed energy compared to the intact specimens.
cross-sectional shape (circular and square), self-stress level (with or without self-stress) and loading mode (monotonic and cyclic). Test results show that the peak load of HCSFC specimen is greater than their nominal load-carrying capacity, which indicates that CFRP plays a confinement role on the internal core concrete-encased-steel. As the number of layers increases, both the normalized peak load and the ultimate axial strain increase. For specimens under the same number of layers, cross sectional shape and loading mode, the ultimate axial strain and strain reduction factor of self-stressing specimens are higher than those of nonprestressed specimens. At the same time, it is found that the confinement efficiency of CFRP on circular specimen is higher than that of square specimen. Analytical results show that the modified existing stress-strain models of CFRP confined concrete predict well with the experimental results.


ABSTRACT: This paper introduces a methodology utilising a ply-ply damage Finite Element models with Genetic algorithm optimisation procedure to investigate the effect of lay-up configuration on the impact absorption properties of fibre metal laminates (FMLs). The methodology was carried out in two steps. In the first step, a pseudo-2D model was used to explore the vast design space to identify potential optimised layup-configurations. In the second step, the optimised configurations were studied in full 3D, with high fidelity simulations, verifying the results obtained from the optimisation process. The design variables used include thickness and material (including fibre orientation) of each ply. The results produced an optimised configuration consisting of a metallic ply on the impacted side followed by a cross-ply composite lay-up. The results also suggest that the first composite ply (second ply of the FML) should be about 3 times thicker than the other plies.


ABSTRACT: The analytical solution for static analysis of laminated composite plate integrated with piezoelectric fiber reinforced composite actuator is obtained using a recently developed Trigonometric Zigzag theory. The kinematic field consists of five independent field variables accommodating non-linear variation of transverse shear strains through the thickness of the laminated composite plate. The principle of minimum potential energy is adopted to derive the governing equations of equilibrium. Navier’s solution technique is employed to convert the system of coupled partial differential equations into a system of algebraic equations. The electric potential is assumed to vary linearly through the thickness of the piezoelectric layer. The analytical formulation also does not include voltage as an additional primary variable. The response in the form of deflection and stresses are obtained for smart composite plates subjected to electro-mechanical loads and compared with the elasticity solutions and available results reported by other researchers in the existing literature. The transverse shear stresses are accurately determined by an efficient post-processing technique of integrating the equilibrium equations of elasticity. Parametric studies on actuation in the response of the smart composite plate are also presented graphically in order to have a clear understanding of the static behavior.


ABSTRACT: The analysis of several micromechanical models for estimating strength of composite laminae is presented. Longitudinal tensile, compressive and in-plane onset shear strengths are analytically estimated and compared with experimental data available in the literature. The tensile longitudinal load predominantly induces rupture of fibers. On the other hand, the compressive strength is highly influenced by fiber misalignment, inducing a wide range of failure mechanisms. The material response to in-plane shear presents a strong nonlinear response. The estimation of longitudinal tensile strength based on the rule of mixture approaches is compared with 27 experimental data. A novel improvement is proposed assuming that in situ strength of fiber is smaller than fiber strength measured individually due to manufacturing induced damage. For the in-plane shear, 6 models are compared with 10 experimental stress-strain curves, including a novel closed-form expression based on the concentric cylinders model. Finally, for the longitudinal compressive strength, 8 micromechanical
models, including a novel model to estimate misalignment effect in fiber crushing, are compared with 61 experimental data are analyzed. Results indicate that the minimal average error for the longitudinal tensile strength is 12.4% while for the compressive strength it is 15%. For the shear strength, the closest prediction depends on the strength definition and the proposed damage onset strength presents the best predictions. In general, the newly proposed models present the best estimations compared with the other models.


ABSTRACT: This paper presents the results of experimental and analytical studies on the behaviour of sandwich beams fabricated with layered cores and glass fiber-reinforced polymer (GFRP) composite facings. The GFRP facings were fabricated using a unidirectional fiberglass fabric and epoxy resin, and the cores were fabricated using a thin non-woven continuous-strand polyester fiber mat with a thickness of 4.1 mm. A total of 30 sandwich beams with the width of 50 mm were prepared tested with five varying core configurations including cores made with one, two, or three layers of the fiber mat core and with or without the inclusion of intermediate GFRP layers. The specimens were tested up to failure under four-point bending at two different spans to characterize flexural and shear properties of the specimens. Two types of failure were observed, namely crushing of the compression facesheet and core shear. The load-deflection, load-strain, and moment-curvature behaviour were analyzed and using the results the flexural stiffness, shear stiffness, and core shear modulus were calculated. An analytical model was also developed to predict load-deflection behaviour and failure loading of sandwich specimens with varying core layouts. After verification, the analytical model was used for a parametric study of cases not considered in the experimental study, including additional GFRP and fiber mat core layers. It was shown that additional fiber mat core layers and the inclusion of intermediate GFRP layers can increase the strength and overall stiffness of a sandwich beam, while additional GFRP layers can only increase the overall stiffness of the system. The analytical model can be used to optimize the configuration of layered sandwich composites for cost effective rehabilitation techniques of culverts, pipelines, and other curved-shape structures where a thin, flexible core is needed to accommodate the curvature of the existing structure.


ABSTRACT: In this paper, the compressive behavior of a carbon fiber composite pyramidal lattice cylinder has been predicted based on initial failure criteria and progressive damage. To this end, the 3D Hashin failure criteria have been employed with instantaneous and gradual unloading models using the user subroutine UMAT in ABAQUS/Standard. In the gradual unloading model, progressive damage has been controlled by exponential damage function. In addition, a new mold has been designed and manufactured for the experimental test of composite pyramidal lattice cylinders, which allows the use of the maximum essential strength of the fiber-reinforced composite. The predicted load-displacement curves using the finite element models are in good agreement with the experimental test results.

More papers published in the journal, Experimental Mechanics (2019 and on);

Google the string: “Experimental Mechanics”, then click on the first entry, “Experimental Mechanics – Springer”, then, on the resulting screen, click on “All Volumes & Issues” (located on the right-hand side of the screen near the top, in blue color)

S.E. Rigby, A. Tyas, R.J. Curry and G.S. Langdon (First author is from: Department of Civil & Structural Engineering University of Sheffield, Sheffield UK), “Experimental measurement of specific impulse
distribution and transient deformation of plates subjected to near-field explosive blasts”, Experimental Mechanics, Vol. 59, No. 2, pp 163-178, February 2019

ABSTRACT: The shock wave generated from a high explosive detonation can cause significant damage to any objects that it encounters, particularly those objects located close to the source of the explosion. Understanding blast wave development and accurately quantifying its effect on structural systems remains a considerable challenge to the scientific community. This paper presents a comprehensive experimental study into the loading acting on, and subsequent deformation of, targets subjected to near-field explosive detonations. Two experimental test series were conducted at the University of Sheffield (UoS), UK, and the University of Cape Town (UCT), South Africa, where blast load distributions using Hopkinson pressure bars and dynamic target deflections using digital image correlation were measured respectively. It is shown through conservation of momentum and Hopkinson-Cranz scaling that initial plate velocity profiles are directly proportional to the imparted impulse distribution, and that spatial variations in loading as a result of surface instabilities in the expanding detonation product cloud are significant enough to influence the transient displacement profile of a blast loaded plate.

References listed at the end of the paper:

5. Rigby SE, Tyas A, Fay SD, Clarke SD, Warren JA (2014) Validation of semi-empirical blast pressure predictions for far field explosions – is there inherent variability in blast wave parameters?. In: 6th international conference on protection of structures against hazards (PSH14), Tianjin, China
9. Hopkinson B (1914) A method of measuring the pressure produced in the detonation of high explosives or by the impact of bullets. Philosophical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physical Character 213(1914):437–456
43. Hopkinson B (1915) British Ordnance Board Minutes, 13565
44. Cranz C (1926) Lehrbuch der Basillistik. Springer, Berlin
52. Baker WE (1973) Explosions in air. University of Texas Press, Austin

ABSTRACT: We report the nanomechanical unfolding of individual self-folded graphene flakes on a flat substrate by using atomic force microscopy techniques. The nanomechanical measurements and molecular dynamics simulations reveal the detailed unfolding process that turns a z-shaped self-folded graphene segment into a flat membrane. A reversible sliding phenomenon in the adhered graphene region during the unfolding process is observed. The findings are useful to better understand the reversible folding properties of graphene and in pursuit of reversible and morphing graphene origami.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: Deformation fields at the surface of diametrically squeezed shallow cylinders in the large deformation regime are measured experimentally and numerically for different material behaviour in the large deformation regime. By means of a digital image correlation method optimized for large displacements, strain fields are measured and compared with finite element simulations. Assuming a neo-Hookean behaviour for cylinders made of rubber silicone, the strain field is found to be in quantitative agreement with non-linear finite element simulations up to the highest deformations reached in our experiments (15%). For materials that follow an elastoplastic constitutive law, agreement is lost after few percents of deformation and location of the strain field differences are identified up to strains as high as 30%. Strain field evolution is also measured for solid foam cylinders up to 60% of global deformation strain. This method that can be applied to a broad variety of materials, even in the occurrence of large deformations, provides a way to study quantitatively local features of the mechanical contact.


ABSTRACT: Stereo digital image correlation (StereoDIC) measurements of wrinkle shapes and surface deformations along with numerical simulation results of prepreg tapes steered along paths having different radii of curvature without adhesion to a Teflon-coated substrate are presented. Experiments are conducted at temperatures ranging from 25 to 350 °C on thermoplastic prepreg tape (APC-2/AS4) having various widths. For the baseline studies at room temperature (25 °C), finite element simulation results from the combined experimental-computational study show very good agreement for both the wrinkling mode shape and general trends in the surface strains. Measurements do indicate a sharp change in the longitudinal and transverse strains for the two smallest steering radii, indicating the development of mesoscale damage in the prepreg. Finally, results from the experiments confirm that there is no significant deviation in the deformation response of the prepreg tape when performing steering at temperatures from 25 to 110 °C. However, significant differences in the deformation pattern of the thermoplastic tape are observed above the glass transition temperature, Tg, of the matrix material.
ABSTRACT: An experimental investigation is conducted to study the mechanics of underwater implosion of cylindrical bonded sandwich composite shells. Sandwich structures comprised of concentric carbon-fiber/epoxy shells with PVC foam cores of different densities are imploded in a large-diameter pressure vessel. High-speed photography in conjunction with Digital Image Correlation (DIC) measurements are employed to obtain full-field displacements of the dynamic collapse process. Local dynamic pressure histories are also simultaneously recorded to investigate fluid structure interaction during implosion. Observations of collapse mode, radial displacement and velocity of collapse, interaction between the concentric shells and the foam core and post-
buckling failure sequence are made. Increasing foam core shear modulus linearly increases the experimental buckling pressures. Weaker growth of incipient modal deformations are understood to play a pivotal role in obtaining higher critical buckling pressures from bonded sandwich shells than previously studied unbonded sandwich constructions. Three dynamic collapse behaviors as determined by the relative orientation of collapse between the inner and outer shell are observed. Core foam density and imperfections also strongly influence the impulse, energy and pressure pulses released from the implosions.

References listed at the end of the paper:

5. (2014) Robotic deep-sea vehicle lost on dive to 6-mile depth
15. Koudela KL, Strait LH Simplified methodology for prediction of critical buckling pressure for smooth-bore composite cylindrical shells
K. Osnes (1,2), S. Dey (3), O.S. Hopperstad (1,2) and T. Borvik (1,2)

(1) Structural Impact Laboratory (SIMLab), Department of Structural Engineering, NTNU, Norwegian University of Science and Technology, Trondheim, Norway
(2) Centre for Advanced Structural Analysis (CASA), NTNU, Norwegian University of Science and Technology, Trondheim, Norway
(3) Research and Development Department, Norwegian Defence Estates Agency, Oslo, Norway

ABSTRACT: In this study, the effect of fragment or bullet impact before blast loading on laminated glass is studied experimentally. First, laminated windows consisting of two 3.8 mm thick annealed float glass plates and a 1.52 mm thick PVB interlayer were blast loaded in a shock tube with various pressures as a reference. In these tests, the blast loading was successively increased until fracture occurred not only in the glass plates but also in the PVB interlayer. Second, a diamond drill was used to make a 5 mm diameter centrally placed hole in some windows before they were blast loaded with the same pressures as those used for the undamaged windows. Third, windows were impacted by 7.62 mm AP bullets, both with and without the brass jacket, before they were blast loaded. Such bullets may have similar mass and velocity to typical primary fragments from an explosive detonation. The results are finally compared with each other and discussed with respect to the blast protection offered. It is found that the capacity is significantly reduced if the laminated glass is perforated by a fragment or a bullet before it is blast loaded and that such impacts should be considered in the design of blast-resistant windows.

References listed at the end of the paper:
image correlation (DIC) was used to measure surface displacements and a micro
were achieved using quartz lamps arranged in various configurations
an aircraft’s skin with the reinforced edges performing the function of stringers and ribs. High temperatures

temperature and deflection of a

ABSTRACT:

A. Santos Silva (1), J. Lambros (2), D. M. Garner (3), E. A. Patterson (1)
(1) School of Engineering, University of Liverpool, Liverpool, UK
(2) Department of Aerospace Engineering, University of Illinois, Urbana, USA
(3) European Office of Aerospace Research and Development (EOARD), Ruislip, UK


A critical evaluation of indentation techniques for measuring fracture
27. Franz J, Schneider J (2014) Through-cracked-tensile tests with polyvinylbutyral (PVB) and different adhesion grades. In: Engineered Transparency International Conference at Glasstec, pp 135–142

A. Santos Silva (1), J. Lambros (2), D. M. Garner (3), E. A. Patterson (1)
(1) School of Engineering, University of Liverpool, Liverpool, UK
(2) Department of Aerospace Engineering, University of Illinois, Urbana, USA
(3) European Office of Aerospace Research and Development (EOARD), Ruislip, UK


A critical evaluation of indentation techniques for measuring fracture
27. Franz J, Schneider J (2014) Through-cracked-tensile tests with polyvinylbutyral (PVB) and different adhesion grades. In: Engineered Transparency International Conference at Glasstec, pp 135–142
temperature distribution across the plate. Deflection results for the reinforced plate showed it to behave as a dynamic system that buckles out-of-plane when heated before relaxing to a steady state. It is demonstrated that the out-of-plane displacement field experienced by the plate is influenced both by the in-plane temperature gradient and the energy supplied.

References listed at the end of the paper:

23. Mansfield EH (1962) The effect of temperature variations in the plane and through the thickness of a circular lenticular plate the effect of temperature variations in the plane and through the thickness of a circular lenticular plate. Ministry of Aviation Aeronautical Research Council, HM Stationery Office, Richmond


ABSTRACT: Impulsive blast loading studies typically require facilities with sub-millisecond decay time simulation capability. Using a conventional shock tube for such studies, however, is not viable due to a finite shock formation distance that limits the size of the shortest, functional driven tube. To overcome this, a diverging (conical) shock tube has been proposed in this work, motivations for which are grounded in simple shock tube theory. Using such a shock tube, for the first time, blast pulses having decay times of around 0.7 ms have been achieved repeatably (± 5.5%). Subsequently, blast loading experiments (equated to 30 - 40 g TNT surface explosion at 0.5 m stand-off distance) carried out on metal plates showed that this device can replicate
the deflection patterns of an impulsive blast loading which could not be obtained so far using conventional shock tubes.

References listed at the end of the paper:


Google the string: “Acta Mechanica”, then click on the first entry, “Acta Mechanica – Springer”, then, on the resulting screen, click on “Browse Volumes & Issues”


ABSTRACT: This article is motivated by the lack of a study on the size-dependent shear buckling force of functionally graded materials. In this study, the shear buckling force of imperfect FG nanoplates including porosities while resting on an elastic Kerr foundation and exposed to hygrothermal environment is analyzed. Three different templates of porosity distributions (even, uneven, and logarithmic-uneven distribution templates) are taken into account. Hamilton’s principle is employed to derive the governing equations based on a new polynomial quasi-three-dimensional (quasi-3D) shear deformation theory in conjunction with the Eringen nonlocal differential model (ENDM). Coupling effects between bending, shear, and thickness stretching are included by using the quasi-3D theory, and the size effects are considered by using the ENDM. Galerkin method is applied to find the shear buckling forces. A comparative study is given by using various structural models. By considering the size-dependent effects on the shear buckling of FG nanoplates, the influence of power-law index, porosity amount, and template, geometry, temperature, moisture, and elastic foundation components is explored.

References listed at the end of the paper:

ABSTRACT: In this study, a geometrically nonlinear coupled analysis of thin-walled Al/Al2O3 functionally graded (FG) sandwich box beams with single and double-cell sections is presented. The material properties such as Young’s modulus and Poisson’s ratio are continuously graded through the thickness of wall. The geometric nonlinearity is considered in the von Kármán sense, and the analysis model includes the effects of elastic coupling and restrained warping. The nonlinear governing equations are derived and solved by the Newton–Raphson method. The displacement-based one-dimensional finite element model using the Hermite cubic interpolation polynomials is employed with the scope to discretize the nonlinear governing equations. Numerical results are obtained for Al/Al2O3 FG sandwich box beams with single- and double-cell sections. Three types of material distributions are considered to investigate the effects of geometric nonlinearity, gradient index, thickness ratio of ceramic, material ratio, span-to-height ratio, and boundary conditions on the nonlinear coupled responses of Al/Al2O3 FG sandwich box beams. Numerical results show that above-mentioned effects play an important role on the nonlinear behavior of FG sandwich box beams.

References listed at the end of the paper:

We investigate equilibrium configurations of the clamped–pinned elastica where the pinned end can be displaced towards, and past, the clamped end. Solving the nonlinear ordinary differential equation for the clamped–pinned elastica for any mode in terms of elliptic integrals, we find sets of equations which govern the equilibrium configurations for given displacements. Equilibrium configurations for various displacements of the pinned end and any mode are obtained by numerically solving those sets of equations. A physical quantity, such as the force that arises in the elastica due to displacement of the pinned end, is taken to be a function of displacement. Although it is generally not possible to define a physical quantity as a function of displacement explicitly, an equation for the rate of change of this physical quantity with respect to displacement can be found by partial differentiation of the sets of equations which govern the equilibrium configurations. Setting that rate of change to zero provides a constraint equation for locating the critical points of that physical quantity. That constraint equation and the sets of equations which govern the equilibrium configurations are solved numerically to obtain the critical points of the physical quantity. Our procedure is demonstrated by finding local extrema on force–displacement plots (useful when analysing the stability of equilibrium configurations) and the maximum deflection of the elastica. Finally, we suggest how our procedure has scope for wider application.

References listed at the end of the paper:

1. Euler, L.: Methodus inveniendi lineas curvas maximi minimive proprietate gaudentes. Appendix 1: De curvis elasticis, Bousquet, Lausanne, and Geneva (1744)
References listed at the end of the paper:


ABSTRACT: A buckling analysis of stiffened plates including curvilinear surfaces is carried out by an effective meshfree model. The buckling loads and modes computed by the present method are analyzed. Six degrees of freedom (6-DOFs) curved shell meshfree formulation in a convected coordinate system including a drilling rotation component is employed, which enables the assembly of curved shells for the modeling of more complex structures. By this formulation, the assembly of any arbitrary shape of geometry can be modeled in convected coordinates, while the 5-DOFs shell formulation suffers from the modeling of shell assemblies. Particularly, curved shells with straight stiffeners and plates with curvilinear stiffeners are considered. Furthermore, a twisted T-shaped structure where both web and flange have curvilinear geometry is analyzed. A meshfree discretization is employed, with which the reproducing kernel particle method is used as the meshfree interpolant. A boundary singular kernel method is adopted to precisely impose an essential boundary condition and to model folded shell geometries. The accuracy and effectiveness of the proposed method are demonstrated by several shell buckling problems for stiffened plate structures with curvilinear surfaces. The obtained meshfree results are compared with the linear and quadratic shell element results of finite element method ANSYS and discussed.

References listed at the end of the paper:
50. ANSYS vers. 17.2: User’s guide (2016)

ABSTRACT: In this study, vibration and dynamic stability of fluid-conveying thin-walled rotating pipes reinforced with functionally graded carbon nanotubes are studied. The pipe is modeled based on thin-walled Timoshenko beam theory and reinforced by single-walled carbon nanotubes with uniform distribution as well as three types of functionally graded distribution patterns. The governing equations of motion and the associated boundary conditions are derived via Hamilton’s principle. The governing equations of motion are discretized via the Galerkin method, and the eigenfrequency and the stability region of the pipe are found using the eigenvalue analysis. Some numerical examples are presented to study the effects of length–radius ratio, carbon nanotubes distribution, volume fraction of carbon nanotubes, rotational speed and mass ratio on the non-dimensional eigenfrequency and critical flutter velocity of the thin-walled rotating pipe conveying fluid. The results show that the carbon nanotubes distribution has a significant effect on the non-dimensional eigenfrequency and critical flutter velocity. Also, it is found that the rotational speed has a stabilizing effect on the dynamic behavior of the system.

References listed at the end of the paper:
comparison with previous existing data. It is revealed that the presented theory is comparable to the other shear buckling load conditions. Navier's approach is used to analytically obtain the deflections, natural frequencies and critical and the modified couple stress theory are applied to obtain the governing equations and corresponding boundary conditions on the top and bottom surfaces of the plate without any shear correction factor.

deformation plate theory. This theory includes two unknown functions and meets the shear and couple behavior and buckling analysis of a simp

M. Bahreman, H. Darijani and A. Bahrani Fard (Department of Mechanical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran), “The size-dependent analysis of microplates via a newly developed shear deformation theory”, Acta Mechanica, Vol. 230, No. 1, pp 49-65, January 2019

ABSTRACT: This work deals with considering the small-scale effects on the static bending, vibrational behavior and buckling analysis of a simply supported microplate based on the newly developed shear deformation plate theory. This theory includes two unknown functions and meets the shear and couple-free conditions on the top and bottom surfaces of the plate without any shear correction factor. Hamilton’s principle and the modified couple stress theory are applied to obtain the governing equations and corresponding boundary conditions. Navier’s approach is used to analytically obtain the deflections, natural frequencies and critical buckling loads of the microplate. The reliability of the presented formulation in this paper is studied through comparison with previous existing data. It is revealed that the presented theory is comparable to the other shear
deformation theories. Also, numerical results of this work demonstrate that the proposed theory predicts lower natural frequencies and critical buckling loads compared to the other theories because of the lower stiffness of the plate.

References listed at the end of the paper:
Min Zhang, Kai Feng, Kai Zhang, Zilong Zhao and Yuanlong Cao (State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, People’s Republic of China), “Transient characteristics of a straight tube actuated by viscous compressible flow with consideration of large axisymmetric deformation”, Acta Mechanica, Vol. 230, No. 1, pp 105-120, January 2019

ABSTRACT: Advancements in soft materials and advantages brought by unlimited degrees of freedom have led to the wide acceptance of soft robotics in medical and military fields. Gas actuation has been widely adopted in soft robotics due to its low gas viscosity, high power density, and rapid response capability. Many researchers have developed kinematic models to investigate its free-form deformation. Nevertheless, serious challenges still remain. These challenges are related to the transient characteristics of a gas actuator subjected to inner fluid and external force. This paper presents a numerical study on the transient characteristics of a straight tube actuated with viscous compressible flow by taking compressibility of gas and large deformation of the tube wall into account. The equation governing compressible flow is coupled with equations governing wall elasticity deformation to generate an integrodifferential equation. The equation is solved with finite difference and Newton–Raphson methods to obtain the transient properties. The effect of fluid and structure parameters on the transient properties under sudden inlet pressure and external force is investigated. Predictions show that the propagation speed with the consideration of large tube deformation is larger than that without the consideration of large tube deformation. In addition, the propagation speed of pressure decreases as the tube wall thickness increases, while the radial impact and axial compression on tube help in the propagation speed of fluid pressure. These findings can lead to improved applications of gas actuation in soft robotics.

References listed at the end of the paper:

ABSTRACT: A semi-analytical approach to eccentrically stiffened functionally graded truncated conical shells surrounded by an elastic medium in thermal environments is presented. Based on the classical thin shell theory with geometrical nonlinearity in von Karman Donnell sense, the smeared stiffeners technique and the Galerkin method, this paper deals with vibration and nonlinear dynamic problems. The truncated conical shells are reinforced by ring stiffeners made of full metal or full ceramic depending on the situation of the stiffeners at the metal-rich or ceramic-rich side of the shell, respectively. In addition, the study not only assume that the material properties depend on environment temperature variation, but also consider the thermal stresses in the stiffeners. Numerical results are given to evaluate effects of inhomogeneous, dimensional parameters, outside stiffeners, temperatures and elastic foundations on the vibration and nonlinear dynamic response of the structures.

References listed at the end of the paper:
3. Huang, H., Han, Q.: Nonlinear dynamic buckling of functionally graded cylindrical shells subjected to time-dependent axial load. Compos. Struct. 92(2), 593–598 (2010)


Y.P. Zhang, N. Challamel, C.M. Wang and H. Zhang (First author is from: School of Mechanical and Mining Engineering, University of Queensland, St Lucia, Australia), “Comparison of nano-plate bending behaviour by...

ABSTRACT: This paper is concerned with the bending behaviour of small-scale simply supported plates as predicted by using the Eringen nonlocal plate model (ENM), the Hencky bar-net model (HBM) and the continualised nonlocal plate model (CNM). HBM comprises rigid beam segments connected by rotational and torsional springs. CNM is a nonlocal model derived by using a continualisation approach that does away with the unknown scale coefficient $\epsilon$ in ENM. The exact bending solutions for simply supported rectangular nanoplates are derived by using ENM, HBM and CNM. By making the segment length $\nu$ of HBM equal to the scale length of continualised and Eringen’s nonlocal plate model and noting the phenomenological similarities between ENM, HBM and CNM, the Eringen’s length scale value $\epsilon$ is found to be dependent on the aspect ratio of the simply supported plate and independent of the applied transverse loading. For a very small scale length $\nu$, $\epsilon$ of ENM converges to values ranging from $1/8\sqrt{3}$ to $1/6\sqrt{3}$ for square plate to longish rectangular plate when calibrated by either HBM or CNM.

References listed at the end of the paper:
ABSTRACT: This paper presents a new mathematical model for analytical investigation of global buckling behavior of slender concrete-filled steel tubular (CFST) columns with circumferential gaps and partial debonding between the concrete core and the steel tube. The analytical buckling load of circular and slender CFST columns with circumferential gaps and partial debonding is derived for the first time. The critical buckling load decreases as the magnitude and length of the circumferential gap increases. Nevertheless, it is shown that if the length of the circumferential gap is smaller than the length of the CFST column, this effect is less than 4%. On the other hand, for a fully delaminated CFST column, this effect can be up to approximately 40%. Similarly, the first buckling shape modes proved to be notably affected by the circumferential gap only if its length is greater than 75% of the CFST column length. The results can be used as a benchmark solution for the buckling problem of slender circular CFST columns with circumferential gaps and partial debonding between the materials.

References listed at the end of the paper:
Guided evanescent waves in spherically curved plates composed of fiber reinforced composites,” Acta Mechanica, Vol. 230, No. 4, pp 1219-1231, April 2019

ABSTRACT: A sound knowledge of both the propagating and the evanescent waves in waveguides is very essential for nondestructive evaluation. Guided propagating waves have received considerable attention. However, the research on guided evanescent waves is quite limited, because it is relatively difficult to find the roots of evanescent modes, especially for demanding cases such as those involving anisotropy and curved structures. This paper presents an analytical approach, based on the orthogonal function technique, to solve the evanescent waves in spherical curved plates composed of fiber reinforced composites. The proposed approach can transform the set of partial differential equations for the acoustic waves into a simple eigenvalue problem that can give the generally complex wave numbers and the field profiles. Results are compared with the available data to check the validity of the present approach, and the convergence is also discussed. Three-dimensional dispersion curves of the guided evanescent waves in various spherical curved plates are obtained using the proposed approach, the effects of different radius/thickness ratios and anisotropy on the dispersion characteristics of guided evanescent waves are illustrated, and the displacement amplitude distributions are also discussed to analyze the specificities of the guided evanescent waves.

References listed at the end of the paper:

Yang Li, Lian-zhi Yang and Yang Gao (First author is from: College of Engineering, China Agricultural University, Beijing, China), “An exact solution for a functionally graded multilayered one-dimensional orthorhombic quasicrystal plate”*, Acta Mechanica, Vol. 230, No. 4, pp 1257-1273, April 2019

**ABSTRACT:** This paper investigates the problem of a functionally graded multilayered one-dimensional orthorhombic quasicrystal plate with simply supported edge conditions. Assuming that the functionally graded material properties vary exponentially along the thickness direction, a solution for a functionally graded plate subjected to top surface loading is obtained by using the pseudo-Stroh formalism. The propagator matrix method is utilized to get the solution for the corresponding multilayered case. The exact solution is applied to a multilayered plate made of quasicrystals and crystals. The influences of the exponential factor, load form, and stacking sequence on physical quantities are studied in numerical examples. The exact solution can be used to design a functionally graded multilayered plate composed of one-dimensional quasicrystals and crystals. The numerical results can also serve as a basis for other numerical methods, such as finite element and boundary element methods.

**References listed at the end of the paper:**

ABSTRACT: In this work, a stochastic time domain spectral element method (STSEM) is proposed for stochastic modeling and uncertainty quantification of engineering structures. To perform the analysis, both an isotropic Timoshenko beam (TB) and a sandwich beam are considered. The sandwich beam is modeled considering higher-order sandwich panel theory which is capable of addressing the core flexibility. The material properties are considered as 1D non-Gaussian random fields, and optimal linear estimation (OLE) is used for


References listed at the end of the paper:


7. ANSYS, Academic Research, Release 17.2


ABSTRACT: In this work, a stochastic time domain spectral element method (STSEM) is proposed for stochastic modeling and uncertainty quantification of engineering structures. To perform the analysis, both an isotropic Timoshenko beam (TB) and a sandwich beam are considered. The sandwich beam is modeled considering higher-order sandwich panel theory which is capable of addressing the core flexibility. The material properties are considered as 1D non-Gaussian random fields, and optimal linear estimation (OLE) is used for
the discretization of the random fields. The OLE-based discretization of a random field allows simulating the random fields numerically, resulting in realizations of the stiffness, mass matrix, and dynamic stiffness matrix. In the current work, the computationally efficient time domain spectral element method (TSEM) is used to develop the STSEM formulation. The STSEM reduces the CPU time significantly as the number of degrees of freedom (dof) is much smaller than in FEM. TSEM also provides a consistent diagonal mass matrix which reduces the computation cost in case of dynamic problems. The deflection statistics of the beam for static, free vibration and dynamic cases are investigated for both TB and sandwich beam. The computational efficiency of the proposed method and the effect of material variability on the response statistics are also discussed. Moreover, the effect of different correlation lengths on the response statistics is studied.

References listed at the end of the paper:

impact · 1. Refer increases with increasing velocity. dominant deformation modes of the collapse mechanism maps. The region of Euler buckling of small struts in good agreement with numerical results. The results reveal that the increase in the velocity changes the representing the slenderness ratio of the big and small struts for hierarchical corrugated sandwich cores and model captures the average reaction forces reasonably. The collapse mechanism maps are constructed with axes element analysis is conducted to investigate the dynamic collapse of the self—ABSTRACT: Vol. 230, No. 5, pp 1549 Vibration of Mechanical Structures, School of Aerospace Engineering, AIAA J. · 52. Lee, J., Schultz, W.: Eigenvalue analysis of Timoshenko beams and axisymmetric Mindlin plate...

Jianxun Zhang, Yang Ye, Yuan Zhu, Qinghua Qin and T.J. Wang (State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace Engineering, Xi’an Jiaotong University, Xi’an, China), “Dynamic collapse of metal self-similar hierarchical corrugated sandwich plates”, Acta Mechanica, Vol. 230, No. 5, pp 1549–1563, May 2019

ABSTRACT: The dynamic collapse response of metal self-similar hierarchical corrugated sandwich plates is analyzed. The analytical model is derived for the reaction forces of the top and bottom face sheets. Finite element analysis is conducted to investigate the dynamic collapse of the self-similar hierarchical corrugated sandwich cores. Collapse modes of cores are found compressed at different impact velocities. The analytical model captures the average reaction forces reasonably. The collapse mechanism maps are constructed with axes representing the slenderness ratio of the big and small struts for hierarchical corrugated sandwich cores and are in good agreement with numerical results. The results reveal that the increase in the velocity changes the dominant deformation modes of the collapse mechanism maps. The region of Euler buckling of small struts increases with increasing velocity.

References listed at the end of the paper:

Along the thickness direction. By utilizing the pseudo-Stroh formalism and propagator matrix method, exact
closed-form solutions of functionally graded multilayered 1D hexagonal PQC nanoplates are then obtained by assuming that the layer interfaces are perfectly contacted. Numerical examples for six kinds of sandwich functionally graded nanoplates made up of piezoelectric crystals, quasicrystal and PQC are presented to illustrate the influence of the exponential factor, nonlocal parameter and stacking sequence on the phonon, phason and electric fields, which play an important role in designing new composite structures in engineering. References listed at the end of the paper:

... disked first, and it was observed that when the LaSMP patch pair was located at antinodes of each mode, the increase with increasing length. The strategy of locating the LaSMP patch pair on a single location was for a simply supported beam laminated with LaSMP patches. The effect of LaSMP patch properties on the response of the beam can be influenced. Based on the stepped beam theory, dynamic equations were established for a simply supported beam laminated with LaSMP patches. The effect of LaSMP patch properties on the frequency variation of the first three modes was analyzed. It was found that the frequency variation range increases with increasing length. The strategy of locating the LaSMP patch pair on a single location was discussed first, and it was observed that when the LaSMP patch pair was located at antinodes of each mode, the widest frequency control range can be obtained. When multiple LaSMP patch pairs were considered, analytical
results showed that the natural frequency ranges were 24.97% and 52.47% higher than by concentrating the patches on a single location for the second and third mode, respectively. When the controllable natural frequency range increases, the control capability of the LaSMP patch on the dynamic response of the beam structure increases as well. As a result, multiple LaSMP patches would have better potential for vibration control than single patches.

References listed at the end of the paper:

shapes in FG shells are verified with those obtained from ABAQUS code. Finally, the case studies are presented for FG shells and laminated sandwich shells with different layups such as [Al; ZrO₂], [Al; FG core; ZrO₂], [Al; Gr; ZrO₂], [Al; Gr; FG core; ZrO₂], [Al; isogrid lattice core; Al]. The closed-form solutions presented here for the kinetic parameters and critical axial loading in a nonlinear analysis can be used in the conceptual design of laminated sandwich cylindrical shells with arbitrary layups and boundary conditions. Furthermore, introducing an equivalent Young’s modulus through the shell thickness, a simple formula is presented for the calculation of critical load in long shells with simple and clamped ends under axial loading with a maximum error of 10%. Moreover, findings show that the boundary-layer type behavior is seen only in long cylindrical shells in the pre-buckling region. Under thermal loading, snap-through buckling is observed in clamped shells. However, in simply supported shells by increasing the temperature, the transverse deflection increases, and while $\Delta T - w/h$ curves do not show any buckling phenomenon, the $N_0/N_{cr} - \Delta T$ curves show such a behavior.

References listed at the end of the paper:
numerical methods are used to study the fundamental concept of auxetic structures. Understanding the
underlying the main characteristics of auxetic structures. The energy methods of solid mechanics along with
used in high stiffness applications. A re
auxetic materials. In this study, a dense re
2019
to the dense re
2019
Kaplan, W.: Oeuvres complètes. Number v. 2 in Oeuvres complètes (1854)
Shen, H.S.: A Two
Huang, H., Han, Q.: Nonlinear buckling and postbuckling of heated functionally graded cylindrical shells under combined axial
Huang, H., Han, Q.: Research on nonlinear postbuckling of functionally graded cylindrical shells under radial loads. Compos.
Struct. 92, 1352–1357 (2010)
Soltanieh, G., Kabir, M.Z., Shariyat, M.: Snap instability of shallow laminated cylindrical shells reinforced with functionally
Dung, D.V., Nga, N.T., Hoa, L.K.: Nonlinear stability of functionally graded material (FGM) sandwich cylindrical shells
Dung, D.V., Nga, N.T., Vuong, P.M.: Nonlinear stability analysis of stiffened functionally graded material sandwich cylindrical
shells with general Sigmoid law and power law in thermal environment using third-order shear deformation theory. J. Sandw.
Huang, H., Han, Q.: Nonlinear buckling of torsion-loaded functionally graded cylindrical shells in thermal environment. Eur. J.
Mater. Struct. 18, 337–346 (2011)
Huang, H., Han, Q., Wei, D.: Buckling of FGM cylindrical shells subjected to pure bending load. Compos. Struct. 93, 2945–
2952 (2011)
Sofiyev, A.H., Kuruoglu, N.: Parametric instability of shear deformable sandwich cylindrical shells containing an FGM core
Mohammadzadeh, R., Najafizadeh, M.M., Nejati, M.: Buckling of 2D-FG cylindrical shells under combined external pressure
Allahkarami, F., Satouri, S., Najafizadeh, M.M.: Mechanical buckling of two-dimensional functionally graded cylindrical shells
Lopotin, A.V., Morozov, E.V.: Buckling of the composite sandwich cylindrical shell with clamped ends under uniform external
Sun, F., Fan, H., Zhou, C., Fang, D.: Equivalent analysis and failure prediction of quasi-isotropic composite sandwich cylinder
Xiong, J., Ghosh, R., Ma, L., Vaziri, A., Wang, Y., Wu, L.: Sandwich-walled cylindrical shells with lightweight metallic lattice
Ghahfarokhi, D.S., Rahimi, G.: An analytical approach for global buckling of composite sandwich cylindrical shells with lattice
Fallah, F., Taati, E., Asghari, M.: Decoupled stability equation for buckling analysis of FG and multilayered cylindrical shells


ABSTRACT: Chiral, star honeycomb, and re-entrant structures are among the most important structures of auxetic materials. In this study, a dense re-entrant unit cell is introduced for making a 3D auxetic structure to be used in high stiffness applications. A re-entrant structure is chosen due to its fundamental characteristics underlying the main characteristics of auxetic structures. The energy methods of solid mechanics along with
numerical methods are used to study the fundamental concept of auxetic structures. Understanding the
characteristics of the re-entrant structure will lead to the better comprehension of other structures of auxetic materials, which will eventually contribute to the advance of research in this new class of materials.

References listed at the end of the paper:
1. Arago, F.: Oeuvres complètes. Number v. 2 in Oeuvres complètes (1854)


ABSTRACT: A linear stability analysis of a thin shear-thinning film with a deformable top surface flowing down an inclined porous substrate modelled as a smooth substrate with velocity slip at the wall is examined, and the physical mechanism for the long-wave instability is analysed. Through a phenomenological model, the influence of slip velocity and the shear-thinning rheology on the wave speed of long surface waves on a non-
Newtonian shear-thinning film down a substrate with velocity slip is predicted. The viscosity disturbance plays a significant role in the destabilization of the flow system. Indeed, slip at the bottom that accounts for the characteristics of the porous/rough substrate does not affect the physical mechanism of the instability. However, it is shown that slip at the bottom enhances the inertia effects which in turn destabilizes the flow system at smaller Reynolds numbers.

References listed at the end of the paper:

ABSTRACT: Based on the modified couple stress theory, nonlinear thermally induced large deflection analysis of shallow sandwich arches is studied. A functionally graded material (FGM) micro-arch with piezoelectric layers integrated into the surfaces and with immovable pinned and fixed edges is analyzed. Temperature and position dependence of the thermomechanical properties for an FGM micro-arch are taken into account. The piezo-FGM arches are subjected to different types of thermal loads such as uniform temperature, linear temperature, and heat conduction. A modified couple stress theory is combined with the uncoupled thermoelasticity assumptions to derive the governing equations of the arch by using the virtual displacement principle. The von Kármán type of geometrical nonlinearity and first-order shear deformation theory are also used to obtain the equilibrium equations. The nonlinear governing equilibrium equations of the piezo-FGM sandwich arch under different thermal loads are solved analytically. The solutions of the system of ordinary differential equations for both cases of boundary conditions are established by employing the two-step perturbation technique. Comparison is made with the existing results for the cases of FGM arch without couple stress and piezoelectric layers under uniform temperature rise, and good agreement is obtained. Also, parametric studies are proposed to show the effects of couple stress, piezoelectric layers, volume fraction index, geometrical parameters, and temperature dependence, the thermally induced deflection of the piezo-FGM sandwich arch.

References listed at the end of the paper:


ABSTRACT: In this paper, a semi-analytical formulation is developed to examine the swelling-induced finite bending of a functionally graded hydrogel strip, when the strip is embedded in a solvent bath of an assigned chemical potential. The cross-link density of the hydrogel polymeric network varies through the strip thickness either linearly or exponentially. As a result of inhomogeneous swelling ratio through the hydrogel strip thickness, the strip bends in a circle. In contrast to earlier solution methods, the initial configuration is mapped to the deformed state without assuming any intermediary virtual state, using a total deformation gradient tensor. The swelling response of the hydrogel is studied utilizing the Flory–Huggins model for the free energy changes due to the mixing and deformation of the hydrogel network. In order to validate the presented method, FEM is employed to solve the finite bending of the functionally graded hydrogel strip. Using the presented method, the effects of the hydrogel network cross-link density distribution on the radial and tangential stress fields, strip bending curvature, and semi-angle are studied. In contrast to hydrogel-based multilayers, continuous stress and deformation field are found for the functionally graded hydrogel strip. Also, multiple tangential stress-free axes are observed for functionally graded hydrogel strips under bending configuration.

References listed at the end of the paper:


ABSTRACT: Free vibration and parametric instability analyses of a three-layered sandwich plate with viscoelastic constrained layer and functionally graded material constraining layer are carried out in this work. A finite element model is developed for the vibration and parametric instability analyses of the sandwich plate. The lateral and transverse displacements of the viscoelastic core layer are considered as linear functions of top and bottom layer displacements. The first-order shear deformation theory is used to incorporate the effect of transverse shear of the face layers, and in addition to the effect of shear deformation of the core, the effects of transverse and longitudinal deformations are also considered in this analysis. So that the present finite element model can be applied to the sandwich plates with thin as well as thick layers of core. The variations of fundamental frequency, mode loss factors and instability regions with different aspect ratios, thickness ratios, and boundary conditions are examined.

References listed at the end of the paper:

1. Faraday, M.: On a peculiar class of acoustical figures; and on certain forms assumed by groups of particles upon vibrating elastic surfaces. Philos. Trans. R. Soc. Lond. 121, 299–340 (1831)
References listed at the end of the paper:


ABSTRACT: It might seem amazing: Cutting a hole in a plate can increase the buckling strength! It is the objective of this paper to present and clarify this astounding phenomenon. In lightweight design, typically thin-walled structures are used. Therefore, buckling must be considered as a possible failure mode. One might assume that removing material, and thus, reducing stiffness must result in a reduction of the buckling strength. However, perhaps surprisingly, it can be shown that introduction of cutouts, placed appropriately, can under certain conjunctures increase buckling loads. At the same time, the structural mass is reduced. Thus, the paper presents a measure, which can be used for fulfillment of a requirement in lightweight design in a twofold manner: increase in buckling strength by reduction of mass! In addition to describing a nice theoretical peculiarity, it might be of more importance from the engineering point of view that the presented methodology may help designers of lightweight structures, e.g., for aerospace applications, to place openings, which are required for some reasons in a plate being part of the construction, at such positions, at which the plate’s buckling resistance is just slightly or not at all reduced or even increased, and to avoid placing holes in unfavorable areas. Based on the Rayleigh–Ritz method in terms of the Rayleigh quotient, criteria and procedures are derived which can be used to find beneficial positions for cutouts and such ones, at which cutouts should not be placed.

References listed at the end of the paper:


ABSTRACT: A two-dimensional model describing the multilayered anisotropic plate deformations is proposed. The plate is assumed to consist of some orthotropic layers with arbitrary orientation of axes relative to the plate frame. The studied multilayered plate is replaced by the equivalent plate composed of a monoclinic material with piecewise elastic modules. An asymptotic solution is constructed for long-wave deformations. This problem was solved earlier in the first approximation; however, the obtained solution is not applicable for the case in which the stiffness of layers differs essentially from each other. The second asymptotic approximation is constructed in the present paper. It takes into account the effects of transversal shear and the normal fibers extension. Some special cases resulting in simple equations are studied in detail. The asymptotic solution error is estimated by comparison with the exact three-dimensional solutions for some test examples.

References listed at the end of the paper:

M. Javani (1), Y. Kiani (2), M. R. Eslamii (1)
(1) Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran
(2) Faculty of Engineering, Shahrekord University, Shahrekord, Iran


ABSTRACT: Considering the uncoupled thermoelasticity assumptions, a thermally induced vibration analysis for functionally graded material (FGM) conical shells is performed in this research. Thermo-mechanical properties of the conical shell are assumed to be temperature and position dependent. The conical shell is under rapid heating with various cases of thermal loads on the outer surface, whereas the opposite surface is kept at reference temperature or thermally insulated. Since the ratio of thickness to radius is much smaller than one, the transient heat conduction equation, for simplicity, may be established and solved for one-dimensional condition. Assuming temperature-dependent material properties, the heat conduction equation is nonlinear and should be solved using a numerical method. A hybrid generalized differential quadrature (GDQ) and Crank–Nicolson method is used to obtain the temperature distribution in thickness direction, respectively. Based on the first-order shear deformation theory and geometrically nonlinear assumptions, the equations of motion are obtained applying the Hamilton principle. Discretization of the equations of motion in the space domain and boundary conditions is performed by applying the GDQ method, and then, the system of highly nonlinear coupled ordinary differential equations is solved by the iterative Newmark time-marching scheme and well-known Newton–Raphson method. Since the thermally induced vibration of the conical shells is not reported in the literature, the results are compared with the case of a circular plate. Also, studies of the FGM conical shells for various types of boundary conditions, functionally graded patterns, and thermal loads are provided. The effects of temperature dependency, geometrical nonlinearity, semi-vertex angle, shell length, and shell thickness upon the deflections of the conical shells are investigated.

References listed at the end of the paper:

Rui Li (1), Xinran Zheng (1), Pengcheng Wang (1), Bo Wang (1), Hao Wu (2), Yu Cao (2) and Zhentao Zhu (2)

(1) State Key Laboratory of Structural Analysis for Industrial Equipment, Department of Engineering Mechanics, and International Research Center for Computational Mechanics, Dalian University of Technology, Dalian, China

(2) Department of Structural Design, Beijing Institute of Astronautical Systems Engineering, Beijing, China


ABSTRACT: This paper aims at analytically solving the free vibration problems of orthotropic rectangular plates, which have found broad applications as a class of crucial aerostructures. A novel symplectic superposition method is presented to give analytic solutions of plates without two opposite edges simply supported (i.e., non-Lévy-type plates). Since these solutions are very difficult to obtain within the classical Lagrangian system framework, in physics, and in the symplectic space, in mathematics. The validity of separation of variables and symplectic eigenexpansion guarantees the realization of new analytic solutions in a rigorous step-by-step way, which cannot be achieved by some classical analytic methods where the predetermination of solution forms is usually inevitable.

Representative challenging problems, including those incorporating two adjacent free edges (e.g., cantilever and free plates), are successfully solved and validated by the refined finite element modeling. Comprehensive natural frequency and mode shape results show the accuracy of the present solutions. The generality of the symplectic superposition method enables one to pursue more analytic solutions of similar problems that are governed by higher-order partial differential equations.

References listed at the end of the paper:

Vu Hoai Nam (1,2), Nguyen Thi Phuong (3) and Nguyen Thoi Trung (1,2)

(1) Division of Computational Mathematics and Engineering, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Vietnam
(2) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
(3) Faculty of Civil Engineering, University of Transport Technology, Hanoi, Vietnam

“Nonlinear buckling and postbuckling of sandwich FGM cylindrical shells reinforced by spiral stiffeners under torsion loads in thermal environment”, Acta Mechanica, Vol. 230, No. 9, pp 3183-3204, September 2019,

ABSTRACT: The main purpose of this paper is the investigation of the nonlinear torsional buckling and postbuckling of sandwich functionally graded cylindrical shells with the von Karman large deflection nonlinearities under thermal effect by an analytical method. The shell skin is reinforced by stringer, circular ring and spiral stiffeners, the material properties of shell skin and stiffeners are assumed to vary continuously through the thickness. The very large effect of spiral stiffeners on the buckling load-carrying capacity of a cylindrical shell in comparison with orthogonal stiffeners is clearly proved in numerical investigations. Based on the Donnell shell theory and the improved smeared stiffener technique for both thermal and mechanical terms of spiral stiffeners, the equilibrium equations of the shell are established in this paper. By using the Galerkin method, the postbuckling curves and critical buckling loads are obtained. The effects of temperature change, stiffeners, material and dimensional parameters on the nonlinear torsional buckling and postbuckling of shell are numerically analyzed.

References listed at the end of the paper:

ABSTRACT: The current work presents an analytical procedure for the free vibration characteristics and dynamic response of an axisymmetric cylindrical shell that has finite length and it is made of functionally graded materials. The shell is subjected to a moving internal pressure. The material properties are assumed to vary along the axial direction according to an exponential law. The equations of motion are extracted based on the classical shell theory using Hamilton’s principle. These equations, which are a system of coupled partial differential equations with variable coefficients, are solved analytically to find the natural frequencies and the responses of the structure. A sensitivity analysis is performed, and the effects of different parameters on the results are studied. The results are compared with the results available in the literature. Also, the results of the free vibration problem are compared with those of the finite element method.

References listed at the end of the paper:

Konstantin Avramov (1) and Balzhan Kabylbekova (2)

(1) Department of Vibrations, Podgorny Institute for Mechanical Engineering, National Academy of Science of Ukraine, Kharkiv, Ukraine
(2) Department of Metallurgy, M. Auezov South Kazakhstan State University, Shymken, Republic of Kazakhstan


ABSTRACT: A beam model of geometrical nonlinear longitudinal-flexural self-sustained vibrations of nanotubes conveying fluid is obtained with account of nonlocal elasticity. The system of two nonlinear partial differential equations is derived to describe the nanotube’s self-sustained vibrations. The Galerkin method is applied to obtain the system of nonlinear ordinary differential equations. The harmonic balanced method is used to analyze the monoharmonic vibrations. The infinite sequence of the period-doubling bifurcations of the longitudinal-flexural self-sustained vibrations is observed numerically. The chaotic motions occur after these bifurcations. The multiharmonic self-sustained vibrations of the nanotube are analyzed. Significant longitudinal self-sustained vibrations of the nanotube are observed in this case. Such motions are not observed with macrobeams.

References listed at the end of the paper:


ABSTRACT: In this work, a shear locking-free three-node shell element based on Mindlin–Reissner theory is presented for a nonlinear dynamic analysis including sheet metal forming. In the present formulation, only displacement and rotational degrees of freedom are utilized, and the discrete shear gap of each field node is deduced using rotations of all three field nodes in a local coordinate system by the integral from the fictitious central point to the corresponding field node, which makes it alleviate the shear locking phenomenon. In order to validate the availability in solving nonlinear dynamic problems, several benchmark problems and sheet metal forming applications are employed. The results show potentiality in application to practical problems because of the simple implementation.

References listed at the end of the paper:


ABSTRACT: This paper is concerned with the dynamics and stability of a flapping flag, with emphasis on the onset of flutter instability. The mathematical model is based on the one derived in a paper by Argentina and Mahadevan (Proc Nat Acad Sci 102:1829–1834, 2005). In that paper, it is reported that the effect of vortex shedding from the trailing edge of the flag, represented by the complex Theodorsen function $C$, has a stabilizing effect, in the sense that the critical flow speed (where flutter is initiated) is increased significantly when vortex shedding is included. The numerical eigenvalue analyses of the present paper display the opposite effect: the critical flow speed is decreased when the Theodorsen function (i.e., vortex shedding) is included. These predictions are verified by an analytical energy balance analysis, where it is proved that a small imaginary part of the Theodorsen function, $C=1-\epsilon i$, with $0<\epsilon<1$, has a destabilizing effect, i.e., the critical flow speed is smaller than by the so-called quasi-steady approximation $C=1-\epsilon$. Furthermore, order-of-magnitude considerations show that Coriolis and centrifugal force terms in the equation of motion, previously discarded on the assumption that they are associated with very slow changes across the flag, have to be retained. Numerical results show that these terms have a significant effect on the stability of the flag; specifically, the said destabilizing effect of the vortex shedding is significantly reduced when these terms are retained. The mentioned energy balance analysis illuminates the nature of the flutter oscillations and the ‘competition’, at the flutter threshold, between the different types of fluid forces acting on the flag.

References listed at the end of the paper:


ABSTRACT: This study presents an isogeometric analysis (IGA) for investigating the buckling behavior of functionally graded material (FGM) plates in thermal environments. The material properties of the FGM plate are considered to be graded across the thickness, and temperature dependency of the material properties is taken into account. A new n-th-order shear deformation theory with the von Kármán type of geometric nonlinearity, in which the optimum order number to best approximate the thermal buckling problem can be chosen, is
developed. The principle of virtual work is used to derive the governing equations for the nonlinear thermal buckling analysis. The nth-order shear deformation theory is incorporated into the non-uniform rational B-spline-based IGA which fulfills the C1-continuity requirement of the proposed higher-order plate theory. The discrete nonlinear system equations are solved by utilizing the modified Newton–Raphson iterative technique. Parametric studies on the buckling behavior of FGM plates subjected to diverse through-thickness temperature variations are performed, and the influence of temperature dependency of the material properties is examined. Results validate the performance accuracy and effectiveness of the proposed IGA based on the nth-order shear deformation theory, and they demonstrate that temperature-dependent material properties should be included in the thermal buckling analysis.

References listed at the end of the paper:
ABSTRACT: The work investigates numerically the dynamic behavior of the system, which consists of horizontally oriented, elastic coaxial shells and a flowing compressible fluid partially or completely filling the annular gap between the shells. The solution of the problem is carried out in a three-dimensional formulation using the finite element method. The motion of the compressible non-viscous liquid is described by the wave equation, which together with the impermeability condition and the corresponding boundary conditions is transformed by the Bubnov–Galerkin method. The mathematical formulation of the problem of the dynamics of thin-walled constructions is based on the variational principle of virtual displacements. The simulation of the shell behavior is performed under the assumption that the curvilinear surface is accurately approximated by a set of flat segments, in which the strains are determined using the relations of the classical plate theory. The stability estimate is based on the results of computation and analysis of the complex eigenvalues of the coupled system of equations. The influence of the filling level and the size of the annular gap on the boundaries of hydroelastic stability of rigidly fixed coaxial shells is analyzed. It is shown that a decrease in the filling level leads to an increase in the stability boundaries.

References listed at the end of the paper:

Alexander Humer and Astrid S. Pechstein (Institute of Technical Mechanics, Johannes Kepler University Linz, Linz, Austria), “Exact solutions for the buckling and postbuckling of a shear-deformable cantilever subjected to a follower force”, Acta Mechanica, Vol. 230, No. 11, pp 3889–3907, November 2019, ABSTRACT: The buckling and postbuckling of a shear-deformable cantilever is studied using Reissner’s geometrically exact relations for the planar deformation of beams. The cantilever is subjected to a compressive follower force whose line of action passes through a spatially fixed point. To study the buckling behavior, a consistent linearization of equilibrium and kinematic relations is introduced. The influence of shear deformation and extensibility on the critical loads is studied. The buckling behavior turns out to crucially depend on the ratio between the shear stiffness and the extensional stiffness of the structure. Closed-form solutions in terms of elliptic integrals for buckled configurations of the cantilever are derived in the present paper.

References listed at the end of the paper:

ABSTRACT: In this paper, we present a complete direct approach to nonlinear modeling of thin plates, which are made of incompressible dielectric elastomers. In particular, the dielectric elastomers are assumed to exhibit a neo-Hookean elastic behavior, and the effect of electrostatic forces is incorporated by the purely electrical contribution to the augmented Helmholtz free energy. Our approach does not involve any extraction-type procedure from the three-dimensional energy to derive the plate augmented free energy, but directly postulates the form of this energy for the structural plate problem treated in this paper. Results computed within the framework of this novel approach are compared to results available in the literature as well as to our own three-dimensional finite element solutions. A very good agreement is found.

References listed at the end of the paper:

Czesław Szymczak (1) and Marcin Kujawa (2)

(1) Department of Structural Engineering, Faculty of Ocean Engineering and Ship Technology, Gdańsk
University of Technology, Gdańsk, Poland

(2) Department of Structural Mechanics, Faculty of Civil and Environmental Engineering, Gdańsk University of Technology, Gdańsk, Poland


ABSTRACT: Distortional buckling of axially compressed columns of box-like composite cross sections with and without internal diaphragms is investigated in the framework of one-dimensional theory. The channel members are composed of unidirectional fibre-reinforced laminate. Two approaches to the member orthotropic material are applied: homogenization based on the theory of mixture and periodicity cells, and homogenization based on the Voigt–Reuss hypothesis. The principle of stationary total potential energy is applied to derive the governing differential equation. The obtained buckling stress is valid in the linear elastic range of column material behaviour. Numerical examples address simply supported columns, and analytical critical stress formulas are derived. The analytical and FEM solutions are compared, and sufficient accuracy of the results is observed.

References listed at the end of the paper:

16. Hancock, G., Pham, C.: Buckling analysis of thin-walled sections under localised loading using the semi-analytical finite strip method. Thin Walled Struct. 86, 35–46 (2015)
References listed at the end of the paper: illustrated numerically. In this, one can see similarity with the partitioning procedure in the theory of integrals.

... improved understanding of the interplay between multilayered and laminated structures, the stresses and inhomogeneity related with volume. Meanwhile, the number of layers increases with their order in the sequence. The measure for multilayered structures have been examined. The common factor of these structures is that they have equal final... compare a discrete inhomogeneity with its continuous counterpart, the stress... formalism, adopted in the theory of smooth manifolds with non-Euclidean connection, are also given. To... buckling of composite channel columns. Contin. Mech. Thermodyn. (2018). https://doi.org/10.1007/s00161-018-0674-2

... nonlinear mechanics for laminated inhomogeneous spherical shell”, Acta Mechanica, Vol. 230, No. 11, pp 3989–4020, November 2019, ABSTRACT: In the present paper, the finite deformations of a laminated inhomogeneous spherical shell are studied. A laminated shell can be considered as a limit case for multilayered shells when the thickness of each layer tends to zero while their quantity tends to infinity. Such a limit might be useful in modeling of multilayered structures with large amount of layers, for example, produced by layer-by-layer additive manufacturing. It is easy to explain the nature of inhomogeneity for multilayered structures (discrete inhomogeneity). It is just the result of the fact that in the stress-free state the shapes of layers do not fit to each other. Thus, they cannot be assembled without gaps or overlaps. Proper assembly becomes possible only after individual deformations of layers that cause self-equilibrated stresses in their assembly. The explanation of inhomogeneity for laminated structures (continuous inhomogeneity) is slightly more complicated. It can be given upon the idea of a continuous family of reference shapes that are free from stresses only locally. In the present paper, this approach is discussed in detail. To define measures for stresses and strains on laminated structures, one has to determine corresponding fields in some specific way. Such definitions that are obtained by formalism, adopted in the theory of smooth manifolds with non-Euclidean connection, are also given. To compare a discrete inhomogeneity with its continuous counterpart, the stress–strain states for the sequence of multilayered structures have been examined. The common factor of these structures is that they have equal final volume. Meanwhile, the number of layers increases with their order in the sequence. The measure for inhomogeneity related with non-Euclidean connection is found from a nonlinear evolutionary problem. To support improved understanding of the interplay between multilayered and laminated structures, the stresses and strains exerted in them are studied in comparison. Considerations of the reverse situation, in which some multilayered structure with discrete inhomogeneity is defined upon a given laminated structure, are also carried out. The convergence with decreasing maximal thickness for layers to the original laminated structure is illustrated numerically. In this, one can see similarity with the partitioning procedure in the theory of integrals. References listed at the end of the paper:

ABSTRACT: A hierarchical approach for the derivation of an infinite series of nonlinear $\ell$th-order shell theories from three-dimensional continuum mechanics based on a polynomial series expansion of the displacement field is recapitulated. Imposing the static constraints that second- and higher-order moments vanish, a ‘first-order’ shell theory is obtained without employing any kinematic constraints or geometric approximations. In particular, it is shown in full generality that, within the same theoretical framework, this static assumption, on the one hand, and a common Reissner–Mindlin-type kinematic assumption, on the other hand, lead to the same theory, for which the attribute geometrically exact is adopted from the literature. This coincidence can be interpreted as a theoretical justification for the heuristic Reissner–Mindlin assumption. Further, the unexpected but unavoidable appearance of transverse moment components (residual drill moments) is addressed and analysed. Feasible assumptions are formulated which allow to separate these drill components from the remaining balance equations without affecting the equilibrium of the standard static variables. This leads to a favourable structure of the component representation of balance equations in the sense that they formally coincide with the ones of linear shear-deformable shell theory. Finally, it is shown that this result affects the interpretation of applied boundary moments.

References listed at the end of the paper:

Ning Liu (1), Wenbin Yu (1), Dewey H. Hodges (2)
(1) School of Aeronautics and Astronautics, Purdue University, West Lafayette, Indiana, USA
(2) Daniel Guggenheim School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA, USA


ABSTRACT: Stiffened panels buckle under compressive loads which would degrade load-bearing capabilities of the structures. Fast yet accurate estimations of buckling loads and associated mode shapes are critical in the early stages of design and optimization. This paper presents a method based on the mechanics of structure genome (MSG) for the global buckling analysis of stiffened composite panels. The original geometrically nonlinear problem is mathematically reduced to a geometrically linear constitutive modeling of the structure genome and a geometrically nonlinear formulation of the macroscopic plate analysis. Validation case studies show that MSG is highly accurate and efficient as compared to the detailed finite element analysis. The buckling behaviors of stiffened panels under various boundary conditions and loadings are investigated.

References listed at the end of the paper:

45. Lopatin, A., Morozov, E.: Buckling of the SSCF rectangular orthotropic plate subjected to linearly varying in-plane loading. Compos. Struct. 93(7), 1900 (2011)

ABSTRACT: The problem of stability of corrugated thin-wall expansion bellows under hydrostatic internal load is considered. The bellows is modeled by an elastic rod with equivalent tensile, bending, and shear stiffness. Equations for calculating the critical value of fluid pressure at which the bellows loses stability are analytically derived, using an expression for hydrostatic follower load. The equivalent stiffness of the bellows is determined further from the solution of static problems for the elastic corrugated shell. The numerical solutions of the boundary value problems and the critical values of the pressure are obtained by the finite difference method. Additionally, a computer model of the expansion bellows was developed by ANSYS software, and the bellows stability was analyzed using shell finite elements. Calculations confirm the necessity of accounting for the axial displacement of expansion joint support when determining the critical pressure.

References listed at the end of the paper:

25. ANSYS Inc. PDF Documentation for Release 15.0
ABSTRACT: The problem of large deformations of a composite nonlinear elastic hollow cylinder subjected to internal and external pressures and loaded at the ends by axial force and torque is considered. The composite cylinder is a tube with internal and external coatings in the form of prestressed hollow circular cylinders. The exact solution of the problem, which is valid for any models of isotropic incompressible elastic materials, is found.

References listed at the end of the paper:

Y. Gholami (1), A. Shahabodini (2), R. Ansari (1) and H. Rouhi (3)
(1) Department of Mechanical Engineering, University of Guilan, Rasht, Iran
(2) Department of Mechanical Engineering, Vali-e-Asr University of Rafsanjan, Rafsanjan, Iran
(3) Department of Engineering Science, Faculty of Technology and Engineering, East of Guilan, University of Guilan, Rudas-Vajargah, Iran

ABSTRACT: Based on the higher-order Cauchy–Born (HCB) rule, an atomistic-continuum multiscale model is proposed to address the large-amplitude vibration problem of graphene sheets (GSs) embedded in an elastic medium under various kinds of boundary conditions. By HCB, a linkage is established between the deformation of the atomic structure and macroscopical deformation gradients without any parameter fitting. The elastic foundation is formulated according to the Winkler–Pasternak model which considers both normal pressure and transverse shear stress effects. The weak form of nonlinear governing equations is derived via a variational approach, namely based on the variational differential quadrature (VDQ) method and Hamilton’s principle. In order to solve the obtained equations, a numerical scheme is adopted in which the generalized differential quadrature (GDQ) method together with a numerical Galerkin technique is utilized for discretization in the space domain, and the time-periodic discretization method is used to discretize in the time domain. The effects of the arrangement of atoms, the Winkler and Pasternak coefficients of the elastic foundation, and boundary
conditions on the frequency–response curves of GSs are illustrated. It is revealed that the nonlinear effects on the response of GSs with larger size in armchair direction are less important.

References listed at the end of the paper:
15. Rouhi, H., Ansari, R.: Nonlocal analytical Flugge shell model for axial buckling of double-walled carbon nanotubes with different end conditions. NANO 7, 1250018 (2012)
SMA hybrid composite conical shells. It is shown that a volume fraction, pre-strain of motion along the longitudinal direction. Finally, parametric studies are done to investigate the temperature change are calculated for SMA fibers. Love’s first approximation classical shell theory with von-Kármán type of geometrical nonlinearity is used in conjunction with Hamilton’s principle for deriving the equations of motion. A semi-analytical solution is presented so that trigonometric functions are applied in the circumferential direction, and the generalized differential quadrature method is used to discretize the equations of motion along the longitudinal direction. Finally, parametric studies are done to investigate the effects of volume fraction, pre-strain, location of SMA fibers, boundary conditions, semi-vertex angle of the cone, and temperature on the vibration characteristics of the SMA hybrid composite conical shells. It is shown that a proper utilization of SMA fibers significantly increases the fundamental frequency and vibration control of the SMA hybrid composite conical shells.
References listed at the end of the paper:


“Correction to: Free vibration analysis of laminated composite conical shells reinforced with shape memory alloy fibers”, Acta Mechanica, Vol. 230, No. 12, pp 4257-4257, December 2019,

A. H. Sofiyev, Z. Zerin and N. Kuruoglu (First author is from: Department of Civil Engineering of Engineering Faculty, Süleyman Demirel University, 32260, Isparta, Turkey), “Dynamic behavior of FGM viscoelastic plates resting on elastic foundations”, Acta Mechanica, Vol. 231, No. 1, pp 1-17, January 2020,

ABSTRACT: The free vibration (FV) and dynamic stability (DS) analyzes are presented for functionally graded viscoelastic plates (FGVPs) under compressive load and resting on elastic foundations (EFs). Winkler elastic foundation models and Pasternak elastic foundation models are used as elastic foundations. The basic equations of FGVPs interacting with EFs are derived using the concepts of Boltzmann and Volterra. An analytical method for studying the DS and FV of FGVPs interacting with EFs is developed using the integro-differential equations. To solve the current problem, Galerkin and Laplace methods are used. A technique for the analysis of DS and FV of FGVPs on the EFs is developed. To confirm the proposed formulation, the results are compared with other available solutions. Finally, the influences of EFs, volume fractions and rheological constants on the critical times and frequencies depending on the geometrical characteristics and loading parameters are examined.

References listed at the end of the paper:
ABSTRACT: This paper presents a higher-order shear deformation beam theory for modeling and nonlinear vibration analysis of hyper-elastic beams made of silicon rubber and unfilled natural rubber. Four models named neo-Hookean, Mooney–Rivlin, Ishihara, and Yeoh models are presented, and their efficacy in nonlinear dynamic modeling of hyper-elastic beams has been explored. Geometric nonlinearity of the hyper-elastic beam is considered based on von-Kármán-type nonlinearity. The hyper-elastic beam is resting on a nonlinearly hardening elastic foundation. It is shown that the Ishihara model is a suitable model for nonlinear vibration analysis of hyper-elastic beams accounting for the shear deformation effect. The nonlinear governing equations based on the presented beam theory are analytically solved via the Hamiltonian method to find nonlinear vibration frequencies. It is shown that the nonlinear vibration behavior of hyper-elastic beams is influenced by rubber-material type and material parameters of the hyper-elastic model.

References listed at the end of the paper:

ABSTRACT: Due to the use of materials with high structural damping in new applications and the role of plates as one of the basic elements of many engineering and interdisciplinary structures, the study of the stability of viscoelastic plates is very important in real conditions. In this article, the border curves of instability for a nonlinear Kelvin–Voigt viscoelastic plate under combined lateral periodic and white noise excitation are obtained analytically. Firstly, the governing equation of the plate is derived and then transformed into a nonlinear stochastic ordinary differential equation using Galerkin’s method. Second, Melnikov’s equation and its modified version in a stochastic sense are evaluated. At last, the border curves of instability for many types of plates and different variations of plate parameters and external excitations are obtained and drawn. The results show how and when the chaotic behavior changes by varying the plate parameters or fluctuating the intensities, magnitudes or frequencies of the external loads. It is shown that in the presence of white noise excitation the chaotic area become larger and this effect is larger at the frequencies far from the natural frequency of the corresponding linear system. It is also shown that under a combination of periodic and white noise excitations the chaotic behavior at low damping values might be completely different from the case there is only a periodic force.

References listed at the end of the paper:
Mohammad Khorsand and Youhong Tang (Institute for NanoScale Science and Technology, College of Science and Engineering, Flinders University, Bedford Park, SA, 5042, Australia). “Durable pyroelectric shell structures for energy scavenging applications”, Acta Mechanica, Vol. 231, No. 1, pp 205–220, January 2020, ABSTRACT: In the light of the increasing growth of requests for applicable energy accounts, this study is driven by the desire to determine the energy interactions among the electrical, thermal and mechanical fields in pyroelectric shell structures. The principal purpose of the proposed work is to scrutinize how material properties synthesize new smart systems exhibiting higher levels of electrical energy while possessing considerably lower weight. To achieve such an aim, it is assumed that the material properties of the elastic medium would be graded through the thickness and the mechanical, electrical and thermal fields would have their own independent gradient indexes. If we nominate the grading indexes as design variables, the material elements of the solid should be appropriately functionalized, avoiding any problems stemming from the low electrical outputs of shell structures in energy-harvesting applications. To untangle the complex mathematics governing this problem, a skilfully merged algorithm of an advanced optimization method with two semi-analytical approaches is exploited. When the simulation is implemented, a significant increment in electrical energy in conjunction with a marked reduction in weight is reported. Further, the effects of inhomogeneity and thermal gradient on the electrostatic energy and weight, as well as the stress, displacement, electrical and thermal fields are graphically presented and discussed. With its material development and structural integrity, this study presents an efficient and cost-effective criterion for smart structures for scavenging energy from available thermo-electromechanical energy sources.

References listed at the end of the paper:

ABSTRACT: This paper addresses moderately large vibrations of immovably supported three-layer composite beams with interlayer slip. The layers of these structural members are elastically bonded, and as such, subjected to interlayer slip when excited. To capture the moderately large response, in the structural model a nonlinear axial strain–displacement relation is implemented. The Euler–Bernoulli kinematic assumptions are applied layerwise, and a linear interlaminar slip law is utilized. Accuracy and efficiency of the resulting nonlinear beam theory are validated by selective comparative plane stress finite element calculations. The outcomes of application
examples demonstrate the grave effect of interlayer slip on the geometrically nonlinear dynamic response characteristic of layered beams.

References listed at the end of the paper:


ABSTRACT: This paper provides an overview of the modeling approaches adopted over the years to develop shell theories for composite structures. Furthermore, it presents a method to assess any structural theory concerning the accuracy and computational efficiency and trigger informed decisions on the structural theory to use for a given problem. This method exploits the synergies between the Carrera unified formulation and the axiomatic/asymptotic method. Typical outcomes are the best theory diagrams or the estimation of accuracy of a theory as compared to quasi-3D solutions. The proposed framework can be useful to provide guidelines on the construction of structural theories and can serve as a trainer for the deep learning of neural networks.

References listed at the end of the paper:

Nguyen Dinh Duc, Pham Tien Lam, Tran Quoc Quan, Pham Minh Quang and Nguyen Van Quyen (The first author is from: Advanced Materials and Structures Laboratory, VNU, Hanoi - University of Engineering and Technology, 144 Xuan Thuy, Cau Giay, Hanoi, Vietnam and National Research Laboratory, Department of Civil and Environmental Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul, 05006, Korea), “Nonlinear post-buckling and vibration of 2D penta-graphene composite plates”, Acta Mechanica, Vol. 231, No. 2, pp 539-559, February 2020.

ABSTRACT: The newly developed penta-graphene is a two-dimensional (2D) carbon allotrope with promising mechanical properties. This paper investigates the nonlinear post-buckling and vibration of imperfect three-dimensional penta-graphene composite plates resting on elastic foundations and subjected to uniform external pressure and axial compressive load. The elastic constants of the single-layer penta-graphene are fully determined by the density functional theory by fitting the equation of strain energy to the density functional theory energy. Specifically, the elastic constant $C_{66}$ which has not been considered by other authors is also determined. The motion and compatibility equations are derived based on the classical plate theory taking into account von Karman geometrical nonlinearity, initial geometrical imperfection and Pasternak type elastic foundations. For nonlinear post-buckling, the Bubnov–Galerkin method is applied to obtain the load–deflection amplitude curves while the Runge–Kutta method and harmonic balance method are used to obtain the deflection amplitude–time curves and the amplitude–frequency curves for nonlinear vibration. Numerical results show the effects of geometrical parameters, initial imperfection and elastic foundations on the nonlinear post-buckling and vibration of the imperfect 2D penta-graphene plates. The present results are also compared to others to validate the accuracy of the applied method and approach.

References listed at the end of the paper:


ABSTRACT: In the present study, nonlinear flutter and post-flutter behavior of a variable stiffness composite wing-like plate is investigated. The variable stiffness is obtained by varying fiber angles continuously according to a selected curvilinear fiber path function in the composite laminates. Flutter speed, limit cycle oscillations and bifurcation diagrams of the composite plate are explored for three different fiber path functions using the nonlinear structural model obtained based on the virtual work principle. The paper aims to exploit the ideal fiber paths with enhanced aeroelastic flutter and post-flutter properties for a composite plate in supersonic flow speed. First-order linear piston theory is applied to model the aerodynamics, and generalized differential quadrature is employed to solve the governing equations. Von Karman nonlinear strain theory is used to account for the geometric nonlinearities, and first-order shear deformation theory is employed to consider the transverse shear effects in the structural model. Time integration of the equation of motion is carried out using the Newmark average acceleration method. Different curvilinear fiber paths are introduced to enhance flutter instabilities and post-flutter behavior of the composite plate. Results demonstrate that the fiber orientation has a significant effect on the dynamic behavior of the plate and the asymmetric properties as well as the behavior of the limit cycle oscillation.

References listed at the end of the paper:
ABSTRACT: A generalized variational principle and a parameterized generalized variational principle are obtained for large deformation analysis of circular cylinders by the semi-inverse method; all known variational principles in the literature are special cases of the obtained parameterized functional. In this approach, a trial functional is constructed with an energy-like integral involving an unknown function, which is identified step by step. The present paper is constructed with a quite straightforward but rigorous tool to the construction of a variational principle for the shell or plate buckling.


References listed at the end of the paper:

ABSTRACT: The large deformation and stresses (normal and shear) of the graded nanotube-reinforced sandwich structure are numerically investigated under the influence of mechanical loading and a uniform temperature field. A higher-order nonlinear finite element model in conjunction with the direct iterative technique has been adopted for the solution purpose. Also, the structural distortion was modeled via the full-scale geometrical nonlinearity (Green–Lagrange strain) in the framework of higher-order displacement functions. Further, to replicate the actual operational conditions, the temperature-dependent properties of the individual material constituents (i.e., carbon nanotube and polymer) have been implemented in the current material modeling steps. The final deflections and stress values are evaluated via an own developed computer code using the currently proposed nonlinear mathematical formulation. The model accuracy and solution stability are checked by comparing the responses (deflection and stress) with available published results. Lastly, a variety of numerical examples is solved for different design parameters and deliberated in detail.

References listed at the end of the paper:


ABSTRACT: A precise global–local shear deformation theory is developed for the prediction of static and dynamic behaviors of thin and thick layered curved beams. The effect of deepness is considered in the derivation of the proposed beam theory. Variations of the shear stress along the thickness direction of the curved beam are approximated by using a global parabolic shear stress function which is locally refined at each layer. The zero conditions of shear stresses on the boundary surfaces of the curved beam are exactly satisfied, and no shear correction coefficient is needed. One of the important features of the present theory is that it has only four unknown field variables, which is only one more than the first-order shear deformation theory. A displacement-based finite element model is employed for solving the governing equations. For validation, the results obtained from static and free vibration tests are compared with the results of three-dimensional (3D) finite element analysis, classical theories, and other advanced shear deformation beam theories. The obtained numerical results show that the present model can precisely predict static and free vibration responses of both shallow and deep composite beams with arbitrary boundary and layup conditions.

References listed at the end of the paper:


The dynamic response of an elastic thin plate to a load moving on its surface with constant velocity is determined analytically. The plate rests on a cross-anisotropic and continuously nonhomogeneous viscoelastic half-plane soil medium. Soil nonhomogeneity is associated with elastic moduli increasing with depth. Viscoelastic effects are introduced via the hysteretic damping model. The solution of the problem is obtained with the aid of the complex Fourier series method involving the horizontal coordinate \( x \) and the time \( t \). Thus, the governing partial differential equations of motion for the plate–soil system are reduced to an algebraic equation for the plate and a system of two ordinary differential equations with variable coefficients for the soil. This system is solved analytically by the method of Frobenius. Compatibility and dynamic equilibrium at the plate–soil interface as well as boundary conditions at the plate surface and at infinite soil depth enable one to finally obtain the response for both the plate and the soil analytically. Verification of the solution is done by means of comparisons with the known existing analytical solutions for the special cases of isotropy and homogeneity with or without the plate. Parametric studies are finally performed, and the effects of soil anisotropy, nonhomogeneity and damping on the plate and the supporting soil are assessed.

ABSTRACT: The main objective of this work is to present a finite element model for the stability analysis of functionally graded material thin plates subjected to uniaxial and biaxial loads. This model is developed using the classic thin plate’s kinematics of von Kármán. Static equilibrium equations are established by means of the principle of stationary potential energy. The formulation is made without any homogenization technique or rule of mixtures; thus, the stress and strain vectors are split into two parts: a membrane part and a second bending part. For the elastic behavior matrix, it is written in dimensionless form. The finite element discretization is done using a four-node quadrilateral element with five degrees of freedom per node. Lagrange bilinear shape function are adopted for the membrane components, and Hermite’s high-degree shape function are adopted for the flexural component. The critical buckling loads are established by solving the eigenvalue problem. The efficiency of the model is tested on several examples of buckling plates under different types of loading. In the present study, specimens of rectangular and perforated plates were tested in three different loading conditions: uniaxial compression, biaxial compression, and compression–traction.

References listed at the end of the paper:

"Eigenfrequencies of microtubules embedded in the cytoplasm by means of the nonlocal integral elasticity (3)

ABSTRACT: A biologically microscopic system presenting a highly scientific interest is the microtubule (MT). Our research endeavor revolves around the eigenfrequencies' analysis of an MT embedded in the cytoplasm for the first time. The MT is simulated as a beam and the cytoplasm as a Pasternak-type elastic foundation, respectively. The responses of the nonlocal integral stress models show to have a softening behavior in comparison with that of the classical model. Unlike the nonlocal differential model, no paradoxes and inconsistencies are raised for the nonlocal integral models. Our research endeavor revolves around the eigenfrequencies’ analysis of an MT embedded in the cytoplasm by means of the nonlocal integral elasticity for the first time. The MT is simulated as a beam and the cytoplasm as a Pasternak-type elastic foundation, respectively. The responses of the nonlocal integral stress models show to have a softening behavior in comparison with that of the classical model. Unlike the nonlocal differential model, no paradoxes and inconsistencies are raised for the nonlocal integral models. Our research endeavor revolves around the eigenfrequencies’ analysis of an MT embedded in the cytoplasm by means of the nonlocal integral elasticity. Our research endeavor revolves around the eigenfrequencies’ analysis of an MT embedded in the cytoplasm by means of the nonlocal integral elasticity for the first time. The MT is simulated as a beam and the cytoplasm as a Pasternak-type elastic foundation, respectively. The responses of the nonlocal integral stress models show to have a softening behavior in comparison with that of the classical model. Unlike the nonlocal differential model, no paradoxes and inconsistencies are raised for the nonlocal integral models. Our research endeavor revolves around the eigenfrequencies’ analysis of an MT embedded in the cytoplasm by means of the nonlocal integral elasticity for the first time. The MT is simulated as a beam and the cytoplasm as a Pasternak-type elastic foundation, respectively. The responses of the nonlocal integral stress models show to have a softening behavior in comparison with that of the classical model. Unlike the nonlocal differential model, no paradoxes and inconsistencies are raised for the nonlocal integral models. Our research endeavor revolves around the eigenfrequencies’ analysis of an MT embedded in the cytoplasm by means of the nonlocal integral elasticity for the first time. The MT is simulated as a beam and the cytoplasm as a Pasternak-type elastic foundation, respectively. The responses of the nonlocal integral stress models show to have a softening behavior in comparison with that of the classical model. Unlike the nonlocal differential model, no paradoxes and inconsistencies are raised for the nonlocal integral models. Our research endeavor revolves around the eigenfrequencies’ analysis of an MT embedded in the cytoplasm by means of the nonlocal integral elasticity for the first time. The MT is simulated as a beam and the cytoplasm as a Pasternak-type elastic foundation, respectively. The responses of the nonlocal integral stress models show to have a softening behavior in comparison with that of the classical model. Unlike the nonlocal differential model, no paradoxes and inconsistencies are raised for the nonlocal integral models. Our research endeavor revolves around the eigenfrequencies’ analysis of an MT embedded in the cytoplasm by means of the nonlocal integral elasticity for the first time. The MT is simulated as a beam and the cytoplasm as a Pasternak-type elastic foundation, respectively. The responses of the nonlocal integral stress models show to have a softening behavior in comparison with that of the classical model. Unlike the nonlocal differential model, no paradoxes and inconsistencies are raised for the nonlocal integral models. Our research endeavor revolves around the eigenfrequencies’ analysis of an MT embedded in the cytoplasm by means of the nonlocal integral elasticity for the first time. The MT is simulated as a beam and the cytoplasm as a Pasternak-type elastic foundation, respectively. The responses of the nonlocal integral stress models show to have a softening behavior in comparison with that of the classical model. Unlike the nonlocal differential model, no paradoxes and inconsistencies are raised for the nonlocal integral models. Our research endeavor revolves around the eigenfrequencies’ analysis of an MT embedded in the cytoplasm by means of the nonlocal integral elasticity for the first time. The MT is simulated as a beam and the cytoplasm as a Pasternak-type elastic foundation, respectively. The responses of the nonlocal integral stress models show to have a softening behavior in comparison with that of the classical model. Unlike the nonlocal differential model, no paradoxes and inconsistencies are raised for the nonlocal integral models.

References listed at the end of the paper:

Run Zhang (1), Hongzhi Zhong (2), Xiaohu Yao (1), Qiang Han (1)

(1) Department of Engineering Mechanics, School of Civil and Transportation Engineering, South China University of Technology, Guangzhou, 510641, People’s Republic of China
(2) Department of Civil Engineering, Tsinghua University, Beijing, 100084, People’s Republic of China


ABSTRACT: In this paper, we present a new quadrature element formulation of a geometrically nonlinear shell model that is proposed and applied for analysis of laminated composite shell structures. Thickness stretch parameters of the shell are incorporated for introducing 3D constitutive relations in the formulation. A drilling rotation constraint on the basis of polar decomposition of a modified deformation gradient is enforced by the Lagrange multiplier method and employed for implementing spatial finite rotations. The present formulation is shown to be feasible to model complex structures and circumvent locking problems naturally. A series of numerical benchmark examples are presented to demonstrate the validity of the new formulation. References listed at the end of the paper:

Dinesh Kumar Sharma (1), Mitali Bachher (2), Santanu Manna (3) and Nantu Sarkar (4)

(1) Department of Mathematics, School of Basic and Applied Science, Maharaja Agrasen University, Baddi, Solan, H.P., India
(2) Department of Mathematics, Dinabandhu Mahavidyalaya, Bongaon, West Bengal, 743235, India
(3) Discipline of Mathematics, Indian Institute of Technology Indore, Indore, 453552, M.P., India
(4) Department of Applied Mathematics, University of Calcutta, Kolkata, 700009, India


ABSTRACT: The vibration of a functionally graded axisymmetric nonlocal thermoelastic hollow sphere with dual-phase-lag effect is addressed in this paper. Surfaces of the sphere are assumed to be thermally insulated or isothermal and stress free. According to a simple power law, the material is assumed to be graded in the radial direction. The linear theory of modified thermoelasticity with a dual phase lag based on Eringen’s nonlocal elasticity is employed to model this problem. The Matrix Frobenius method of continued power series is introduced to derive the analytical solutions. The phase velocity relations for the existence of various modes of vibrations in the designed hollow sphere are derived in compact forms. In order to explore the attributes of vibrations, the fixed-point numerical iteration technique is used to solve the secular equations. The numerical computations for the material crust in respect of the natural frequencies, thermoelastic damping and the frequency shifting are presented graphically using MATLAB software tools.

References listed at the end of the paper:
40. Keles, I., Tutuncu, N.: Exact analysis of axisymmetric dynamic response of functionally graded cylinders (or disks) and spheres. J. Appl. Mech. 78, 061014 (2011)

ABSTRACT: The present work focuses on the effect of rotational restraints on the shear buckling of symmetrically laminated curved composite panels. The Sanders–Koiter shell theory and a first-order shear deformation scheme were used for the mathematical representation of the deformation kinematics of cylindrical shells. The eigenvalue buckling equations were obtained using the principle of minimum total potential energy and by employing the Ritz method. The solution for the deformed shape was approximated as a series of trigonometric functions compatible with the essential boundary conditions of the problem. The effect of the rotational and torsional springs was incorporated by adding their corresponding potential energy to the total potential energy of the panel-loading system. Using the developed formulation, the effect of the influential parameters such as aspect ratio, panel curvature and restraint stiffness on the buckling strength of a specific class of laminates was studied extensively. To present the results in a more insightful manner, non-dimensional parameters were used in parametric studies. To normalize the effect of torsional elements, a new non-dimensional parameter was introduced.

References listed at the end of the paper:


ABSTRACT: In this article, buckling analysis of a porous nanocomposite cylindrical shell reinforced with graphene platelets (GPLs) using first-order shear deformation theory is carried out. Internal pores and GPLs are scattered uniformly and/or nonuniformly in the thickness direction. The mechanical properties such as the effective modulus of elasticity through the thickness direction are computed by the modified Halpin–Tsai micromechanics approach, whereas density and Poisson ratio are in accordance with the rule of mixtures. The Rayleigh–Ritz method is employed to obtain a critical buckling load of the graphene-reinforced porous cylindrical shell. The accuracy of the obtained formulation is validated by comparing the numerical results with those reported in the available literature as well as with the software ABAQUS. Moreover, the effects of patterns of internal pores and GPLs distribution, GPLs weight fraction, density and size of internal pores, different boundary conditions, geometric factors such as mid-radius to thickness ratio and shape of graphene platelets on the buckling performance of the functionally graded graphene platelet-reinforced composite porous cylindrical shell are explored.

References listed at the end of the paper:
1. Lopatin, A., Morozov, E.: Buckling of a composite cantilever circular cylindrical shell subjected to uniform external lateral pressure. Compos. Struct. 94(2), 553–562 (2012)
Deepak Kumar Biswal (1), Sukesh Chandra Mohanty (2)
(1) School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamilnadu, 632 014, India
(2) Department of Mechanical Engineering, National Institute of Technology, Rourkela, Odisha, 769008, India

ABSTRACT: The buckling and parametric resonance characteristics of laminated composite spherical sandwich shell panels with viscoelastic material (VEM) core are investigated in the present analysis considering full geometric nonlinearity in the Green–Lagrange sense. The study includes the longitudinal strain and normal strain in the transverse direction along with transverse shear deformation of the VEM core. The core displacements are considered to be varying linearly along the thickness and those of the face sheets follow first-order shear deformation theory. An eight-noded sandwich shell finite element of the serendipity family is adopted to discretize the sandwich shell panel domain. The finite element-based equation of motion is derived using Hamilton’s principle in the form of the Mathieu–Hill-type equation. The dynamic instability regions are obtained by applying Hsu’s criteria-based Saito–Otomi conditions to the transformed equation motion. An in-house finite element-based code is developed in the MATLAB platform to solve the stability problem and to establish the stability regions. A parametric study is carried out to investigate the influence of different system parameters on the critical buckling load and the parametric resonance of the sandwich shell panels. It is noted that an increase in core and constraining layer thicknesses increases the critical buckling load of the sandwich shell panels. The stability boundaries are observed to shift toward a higher-excitation-frequency region in the stability diagram with an increase in constraining layer thickness and a decrease in aspect ratio.

References listed at the end of the paper:

https://doi.org/10.1177/109963621772230
ABSTRACT: Ceramic coatings are ideal materials for thermal protection systems such as the thermal shield of the space shuttle. In a high temperature environment, material properties of ceramics strongly depend on the temperature. The severe mismatch of material properties between the ceramic coating and the substrate can result in progressive mechanical failure of thermal protection system. This paper investigates delamination and buckling behaviors between a temperature-dependent ceramic coating and a porous substrate. The shear stress intensity factor at the tips of the delamination crack and buckling region are derived. Based on the stress intensity factor, the critical temperature of the coating buckling from the substrate is obtained. A fitting formula of the critical buckling temperature with respect to the length-to-thickness ratio of the coating, and the buckling region is obtained. It is found that the effect of the temperature dependence of material properties on delamination and buckling is more significant for higher temperatures than for lower temperatures. The critical temperatures of delamination and buckling are overestimated if the temperature dependence of material properties is neglected. The critical temperatures of delamination and buckling increase with the porosity of the substrate.

References listed at the end of the paper:


ABSTRACT: Ceramic coatings are ideal materials for thermal protection systems such as the thermal shield of the space shuttle. In a high-temperature environment, material properties of ceramics strongly depend on the temperature. The severe mismatch of material properties between the ceramic coating and the substrate can result in progressive mechanical failure of thermal protection system. This paper investigates delamination and buckling behaviors between a temperature-dependent ceramic coating and a porous substrate. The shear stress intensity factor at the tips of the delamination crack and buckling region are derived. Based on the stress intensity factor, the critical temperature of the coating buckling from the substrate is obtained. A fitting formula of the critical buckling temperature with respect to the length-to-thickness ratio of the coating, and the buckling region is obtained. It is found that the effect of the temperature dependence of material properties on delamination and buckling is more significant for higher temperatures than for lower temperatures. The critical temperatures of delamination and buckling are overestimated if the temperature dependence of material properties is neglected. The critical temperatures of delamination and buckling increase with the porosity of the substrate.
References listed at the end of the paper:


Yunzhi Huang, Yang Li, Liangliang Zhang, Han Zhang and Yang Gao, “Dynamic analysis of a multilayered piezoelectric two-dimensional quasicrystal cylindrical shell filled with compressible fluid using the state-space approach”, Acta Mechanica, Vol. 231, No. 6, pp 2351-2368, June 2020,

ABSTRACT: The state-space approach is developed to analyze the dynamic behaviors of a multilayered two-dimensional piezoelectric quasicrystal circular cylinder filled with the compressible fluid. With simple support at both ends, the hollow cylindrical shell has imperfect bonding between the layers. The analytical solution of a homogeneous cylindrical shell has been derived based on the state equations. The general solution for the corresponding multilayered case is also obtained by utilizing the propagator matrix method. The numerical results present the natural frequencies in free vibration with different length-to-radius and radius-to-thickness ratios. The critical load and dynamic behaviors of the model are exactly predicted in the axial buckling problem. For the impulse case, the influences of the density of the filled fluid and coefficients of interfacial imperfections on the dynamic responses are also discussed.

ABSTRACT: This paper investigates the buckling analysis of periodic beams by a geometrically nonlinear equivalent micro-polar model that is built through the results of the unit cell transfer matrix eigenanalysis. The periodic system considered is the Vierendeel girder under compressive axial loads. The stiffness properties of the equivalent model are evaluated by an averaging process of unit cell strain energies associated with the inner force transmission modes, without any assumption on the real beam kinematics. Hence, equilibrium equations are achieved by the virtual power principle. Closed-form solutions are obtained for the girder critical loads and deformed shapes. They are of great accuracy in a wide range of conditions. However, model longitudinal shear strains are geometrically not compatible when the shear force is not uniform. Therefore, in cases where the girder response is dominated by these strains, the accuracy of buckling load estimates may be poor. To overcome this limitation, using a particular solution of the model equilibrium equations, the search for the critical load is carried out re-stating the buckling problem in an alternative form: conditions are investigated under which a system of self-equilibrated inner bending moments, able to bend the equivalent beam without violating geometrical compatibility, will exist. It is shown that this system is defined by an integral equation that, when solved by the Galerkin method, leads to buckling load estimates and deformed shapes that are in very close agreement with the ones obtained from classical finite element models.

References listed at the end of the paper:
ABSTRACT: A new, general hp-version axisymmetric finite element is derived for the boundary value problems of thin linearly elastic shells of revolution, applying a complementary strain energy-based three-field dual-mixed variational principle. For the interpolation of the mid-surface geometry, non-uniform rational B-splines—NURBS—is used. The independent field variables of the weak formulation are the a priori non-symmetric stress tensor, the displacement vector, and the infinitesimal skew-symmetric rotation tensor. The theoretical model of the shell formulation is based on a consistent dimensional reduction process and a systematic variable-number reduction procedure. The inverse of the unvaried three-dimensional constitutive equation is employed since neither the classical kinematical assumptions nor the stress hypotheses are built in the mathematical model; namely, both the through-the-thickness variation and the normal stress to the shell
mid-surface are not excluded. The new hp axisymmetric shell finite element is tested by a representative model problem for extremely thin and moderately thick, singly and doubly curved shells of negative and positive Gaussian curvature. Following from the numerical experiments, the constructed hp-shell finite element gives locking-free results not only for the displacement but also for the stresses.

References listed at the end of the paper:


ABSTRACT: The nonlinear forced vibration characteristics of functionally graded carbon nanotube reinforced composite (FG-CNTRC) circular cylindrical shells are investigated. On the basis of Reddy’s first-order shear deformation theory, von Kármán geometric nonlinearity and Hamilton’s principle, the equations of motion are derived. The Galerkin technique is applied to discretize the partial differential equations into nonlinear ordinary differential equations, which are reduced by using Volmir’s assumption and the static condensation method. The incremental harmonic balance method is applied to analyze the dynamic response of FG-CNTRC cylindrical shells. A convergence study on the mode expansions is conducted by considering both axisymmetric and asymmetric modes. The natural frequencies and the resonance responses are compared with existing studies to examine the validity of this study. The effects of distribution and volume fraction of carbon nanotube, thickness-to-radius ratio, length-to-radius ratio, dimensionless radial excitation amplitude and damping ratio on the resonance responses of FG-CNTRC cylindrical shells are discussed. The results show that the reduced model of the system is reasonable. The frequency responses of FG-CNTRC cylindrical shells show both hardening and softening types of nonlinearities, and they are greatly influenced by the change of the fundamental vibrational mode.

References listed at the end of the paper:


Minh-Tu Tran, Van-Loi Nguyenn At-Sonf Pham and Jaroon Rungamornrat, “Free vibration of stiffened functionally graded circular cylindrical shell resting on Winkler–Pasternak foundation with different boundary conditions under thermal environment”, Acta Mechanica, Vol. 231, No. 6, pp 2545-2564, June 2020.

ABSTRACT: In this paper, the analytical free-vibration analysis of a stiffened functionally graded circular cylindrical shell resting on a Winkler–Pasternak foundation is reported. Various boundary conditions and the thermal effect are considered. Material properties are assumed to be temperature-dependent and vary continuously across the shell’s thickness according to the power law distribution of the volume fraction of constituents. In order to derive the governing equations of the cylindrical shell structure, Hamilton’s principle together with the first-order shear deformation theory and the Lekhnitsky smeared stiffener technique is applied. The natural frequencies of the shell are determined by applying the Galerkin method together with the beam functions for the axial displacement fields. A good agreement between the present results and those available in the literature is observed. In numerical investigations, the influence of temperature field, material volume fraction index, elastic foundation coefficients, boundary conditions, and geometrical ratios on the fundamental natural frequencies of the shell is also given and discussed in detail.

References listed at the end of the paper:


ABSTRACT: A geometric transformation method based on discrete singular convolution (DSC) is firstly applied to solve the buckling problem of a functionally graded carbon nanotube (FG-CNT)-reinforced composite skew plate. The straight-sided quadrilateral plate geometry is mapped into a square domain in the computational space using a four-node DSC transformation method. Hence, the related governing equations of plate buckling and boundary conditions of the problem are transformed from the physical domain into a square
computational domain by using the geometric transformation-based singular convolution. The discretization process is achieved via the DSC method together with numerical differential and two different regularized kernels such as regularized Shannon’s delta and Lagrange-delta sequence kernels. The accuracy of the present DSC results is first verified, and then, a detailed parametric study is presented to show the impacts of CNT volume fraction, CNT distribution pattern, geometry of the skew plate and skew angle on the axial and biaxial buckling responses of FG-CNTR composite skew plates with different boundary conditions. Some new results related to critical buckling of an FG-CNT-reinforced composite skew plate are also presented, which can serve as benchmark solutions for future investigations.

References listed at the end of the paper:

71. Mercan, K., Civelek, Ö.: Buckling analysis of Silicon carbide nanotubes (SiCNTs) with surface effect and nonlocal elasticity using the method of HDQ. Compos. Part B Eng. 114, 34–45 (2017)

ABSTRACT: In the present paper, a flexible framework is developed for the optimization of composite laminate plates. In this framework, an optimization algorithm is employed to find the optimal stacking sequence design of the FE models by interfacing the Abaqus solver with MATLAB through a Python script. The Python script submits dimension, orientation, and diameter of the cutout combinations to Abaqus/CAE. The performance of the codes is validated by applying them to several problems of previous research. Three distinct types of boundary conditions, namely CCCC, SCSC, and SSSS, with different geometries comprising a square and rectangular plates with and without cutouts, are considered as optimal design problems. Besides that, analyses are performed on new symmetrical composites with 16 and 80 plies. The framework is equipped with the GA for optimizing the fiber orientations and maximizing the buckling capacities. The results are comprehensively discussed, showing a reasonable agreement with the literature. This code can easily be used by scientists and industry professionals as an automated tool for optimizing different finite element models and using any arbitrary optimization algorithm.

References listed at the end of the paper:


ABSTRACT: In this study, the nonlinear forced vibration of simply supported multilayered nanoplates in the framework of the first-order shear deformation of Mindlin plate theory based on the nonlocal strain gradient elasticity theory is investigated. The nonlinear von Karman strain–displacement relation is employed. The interaction of van der Waals forces between adjacent layers of a multilayered nanoplate is considered. The harmonic balance method is used to analyze the nonlinear resonance behavior of a thick nanoplate. The primary resonance and the secondary resonance which consist of superharmonic and subharmonic resonance are investigated. As a main result, by increasing the thickness of a thick nanoplate, the subharmonic resonance disappears and the frequency response curves imply non-resonant behavior, responses with finite amplitudes and different shapes for different thicknesses of thick nanoplates. At the end, the natural frequencies of thick multilayered nanoplates are obtained, and the effect of variation of nonlocal parameter, strain gradient parameter, number of layers and thickness of the nanoplate on the frequency response curves and stable and unstable regions is investigated.

References listed at the end of the paper:


ABSTRACT: This paper presents a new total Lagrangian Timoshenko beam formulation with the isogeometric analysis approach for a geometrically nonlinear analysis of planar curved beams. The proposed formulation is derived from the two-dimensional continuum theory, and a beam configuration is characterized by the beam axis and the director vectors of cross sections. Non-uniform rational B-spline (NURBS) curves are used for the geometric representation of the beam axis and the discretization of the unknown kinematics, i.e., the translational displacements of the beam axis and the cross-sectional rotation angle. Several well-established examples covering the analysis of many types of beam, i.e., straight, curved, and free-form beams with varying curvature, are considered. The obtained results by the proposed formulation are compared with those in the literature, and the accuracy and efficiency of the proposed formulation are assessed. The prominent properties of using NURBS curves in analysis, i.e., effective reduction in locking effects, higher accuracy per degree-of-freedom, and better geometric representations, are also verified for the proposed beam formulation.

References listed at the end of the paper:


ABSTRACT: In this study, an aeroelastic model that accounts for the fluid–structure interaction is developed to investigate vibration and stability of rectangular plates in contact with sloshing fluid on one side and under supersonic aeroelastic load on the other side. The fifth-order shear deformation theory, which is capable of considering rotary inertia and transverse shear stress, is employed to model the structure. Bulging and sloshing modes of the incompressible, inviscid and irrotational fluid are obtained with satisfying Laplace’s equation and fluid boundary conditions. The first-order piston theory is applied to consider the supersonic aeroelastic load. On the basis of Hamilton’s principle, the governing equations of the coupled fluid–structure system are derived and discretized using the Galerkin method. Numerical results for specific cases are compared with available results in the literature and an excellent agreement is observed. In the discussion section, influences of various parameters such as the dimensions of the fluid domain, plate dimensions and aerodynamic parameters on the natural frequencies and flutter behavior are studied.

References listed at the end of the paper:


ABSTRACT: This paper aims to investigate the free and forced vibration behavior of a sandwich beam with functionally graded porous core and composite face layers embedded with shape memory alloy (SMA). Three different porosity patterns are assumed through the thickness direction of the core, and composite face layers are reinforced with carbon nanotubes (CNT). The sandwich beam is resting on an elastic foundation which is simulated by Vlasov’s model. By using Hamilton’s principle and first-order shear deformation theory, the governing equations of motion are derived. The analytical solution is presented to solve the equations of motion using Navier’s solution. Results are verified with corresponding literatures. Finally, the effects of important parameters such as temperature, volume fraction of SMA, porosity distribution, weight fraction of CNT, and geometric parameters are explored in detail.

References listed at the end of the paper:

In the current paper, the vibrational behavior of viscoelastic cylindrical shells under moving internal pressure is studied, analytically. The viscoelastic behavior is considered as viscoelastic in shear and elastic in the bulk. The equations of motion are extracted based on the classical shell theory by applying Hamilton’s principle. These equations which are a system of coupled partial differential equations are solved by employing a closed form mathematical method, and the natural frequencies, the critical velocity, and response due to moving pressure are determined. Moreover, the effects of different geometric and viscoelastic parameters on the results are studied. The results are compared with the finite element analysis and the results available in the literature.

References listed at the end of the paper:

ABSTRACT: This paper aims to study the buckling and bending analysis of curvilinearly stiffened plates using an isogeometric approach. First-order shear deformation theory is adopted to model the behaviors of stiffened plates. Based on the employed approach, it is easy to model stiffeners with different sizes and layouts, since the degrees of freedom for the whole structure are integrated into those of the original plate leading to a relatively low computational cost. The performance of the proposed approach is validated via a couple of benchmark problems available in the literature, and the effect of different parameters including bending stiffness, relative mass, cross section, and shape of stiffener on the buckling and bending behavior of curvilinearly stiffened plates is investigated. The results show the relative high accuracy of this method using fewer degrees of freedom for stiffeners, which is beneficial in optimization procedures.

References listed at the end of the paper:


ABSTRACT: A relief cutting method, or kerfing, is considered to create flexible freeform surfaces from relatively stiff and thick panels. The flexibility and moldability are achieved by introducing slender components within the panel, forming kerf patterns, and hence reducing the second moment and polar moment of an area of the solid panel. This paper presents a systematic study on the deformations of kerf unit-cells and of kerf panels. Two different kerf patterns, i.e., square and hexagon, with various cut densities are studied. The effects of different cutting density and kerf patterns on the stretching, bending, and twisting deformations are examined. Understanding the influence of kerf patterns and cut densities on various deformation mechanisms will guide the design of freeform complex shapes out of kerf panels. Experimental tests were performed on unit-cells under different boundary conditions, e.g., uniaxial and biaxial stretching and bending. The tests were also performed on kerf panels with different kerf patterns and varying cut densities. We used a nonlinear beam element in order to describe the deformations of the slender components within the kerf patterns. We compared the overall deformations in the kerf unit-cells and panels from the beam element model and experimental tests. Using the kerfing technique allows for generating flexible structures with complex geometries from mass-produced panels of standard shape and size. When using the kerfing method to achieve the desired surface topology, the stresses, strains, and displacements in the surface will depend on the kerf pattern, cut density, and constituent behavior.

References listed at the end of the paper:


ABSTRACT: This paper concerns a novel isogeometric Timoshenko beam formulation for a geometrically nonlinear analysis of spatial beams using the total Lagrangian description. Constitutive laws for hyperelastic materials, whose behavior varies with their deformations, are widely defined by using strain energy density functions that are written in terms of the Green–Lagrange strain tensor. Many finite element beam formulations for geometrically nonlinear analyses of spatial beams are developed using the Green–Lagrange strain tensor and its energy conjugate, the second Piola–Kirchhoff stress tensor. Unfortunately, there virtually exist no isogeometric Timoshenko beam formulations for this type of analysis that are derived by using this energy conjugate pair. To allow the possibility of considering hyperelastic materials, the present isogeometric beam formulation is developed in the total Lagrangian description using the Green–Lagrange strain tensor and the second Piola–Kirchhoff stress tensor. The proposed formulation is capable of simulating beam structures that are subjected to large displacements and rotations, without any restriction in magnitude. Three-dimensional beam configurations are reduced into one-dimensional structures using the beam axis and director vectors of the cross sections. The cross-sectional rotation along the beam axis is represented by an orthogonal tensor, which is parameterized by a vector-like parameter. Updating the cross-sectional rotations is performed purely by natural exponentiation and superposition of relevant rotational quantities. To show the accuracy and efficiency of the proposed beam formulation, some benchmark and well-established numerical examples with various types of beam, i.e., straight, curved, pre-twisted beams, are analyzed. The obtained results are compared with those results in the literature, obtained from both analytical and numerical methods.

References listed at the end of the paper:


References listed at the end of the paper:

solved by the finite element method. The validity of the result is examined by comparison with those in the constrained by elastic layers. The structural governing equations are derived using Hamilton's principle and boundary conditions. The considered sandwich beam consists of

ABSTRACT: In the present study, the effect of using magneto rheological elastomer materials and a magnetic field on the dynamic stability of a sandwich beam under a follower force has been investigated for various boundary conditions. The considered sandwich beam consists of a magneto rheological elastomer core constrained by elastic layers. The structural governing equations are derived using Hamilton’s principle and solved by the finite element method. The validity of the result is examined by comparison with those in the
literature. The effects of variation in the parameters such as magnetic field intensity and the thickness of the layers on the stability of the sandwich beam are studied. Finally, some conclusions for the effects of the magnetic field intensity on the magnetorheological elastomer sandwich beam subjected to the follower force are discussed.

References listed at the end of the paper:
Ngo Dinh Dat, Tran Quoc Quan, Phuong Tien Lam and Nguyen Dinh Duc, “A first-principle study of nonlinear large amplitude vibration and global optimization of 3D penta-graphene plates based on the Bees Algorithm”, Acta Mechanica, Vol. 231, No. 9, pp 3799-3823, September 2020, ABSTRACT: Penta-graphene, a new monolayer of carbon atoms, has been synthesized with ideal strength and temperature resistance. However, the mechanical behavior of penta-graphene has not been fully investigated yet. This paper presents an analytical investigation on the nonlinear large amplitude vibration of imperfect three-dimensional (3D) penta-graphene plates subjected to uniformly distributed external pressure with simply supported and immovable edges in thermal environments. The elastic constants and the thermal expansion coefficients of the 3D penta-graphene plate are determined using the density functional theory. The motion and compatibility equations are established based on the Reddy’s higher-order shear deformation plate theory in which the effect of von Karman nonlinear terms, the initial imperfection and the Pasternak elastic foundation are taken into consideration. The Galerkin method is applied to determine the closed-form expressions of linear frequency and nonlinear to linear frequency ratio while the dynamic response of the plate is obtained by using the fourth-order Runge–Kutta method. The Bees Algorithm is used to determine the optimum value of the natural frequency which depends on five variables including the thickness, the length and the width of penta-graphene plates and two stiffness coefficients of elastic foundations. The numerical results show the effects of width-to-thickness ratio, elastic foundations coefficients, initial imperfection parameter and temperature increase on the nonlinear vibration of the 3D penta-graphene plates.

References listed at the end of the paper:


https://doi.org/10.1016/j.susmat.2019.e00100


ABSTRACT: Based on Hamilton’s principle, a general three-dimensional mechanical model with consideration of the consistent couple stress theory is established in this paper, and the dynamic governing equations and boundary conditions are derived strictly. After that, inspired by the high-frequency theory established by Mindlin, a novel two-dimensional theory of micro-plates is proposed. Governing equations and boundary conditions are simplified and further validated via some reductions and comparisons with the traditional Mindlin plate and the Timoshenko beam. As an application, the propagation property of straight-crested waves in a micro-plate is investigated, and the effect of couple stress is revealed. Then, the static bending and free vibration of a simply supported rectangular micro-plate is investigated with the aid of the double Fourier series. It is demonstrated that the couple stress has significant influence on the mechanical behaviors, including the static deflection and natural frequency, as the plate thickness shrinks. Physically, the couple stress effect is equivalent to an increase in structural stiffness. In order to illustrate the effect of the couple stress, a general criterion for quantifying the critical size that distinguishes microscale from macroscale is proposed numerically. To some extent, it can also be viewed as a criterion for distinguishing the consistent couple stress theory of micro-structures from the classical continuum mechanics theory of macro-structures.

References listed at the end of the paper:

ABSTRACT: In this paper, the dynamic stiffness method (DSM) is developed for the vibration analysis of laminated cylindrical and conical shells, which are partially filled or surrounded by quiescent fluid. The Reissner and Naghdi’s thin shell theory and incompressible fluid equations are employed on the structures and fluid, respectively, so as to characterize the fluid–structure coupling model. Shell elements with/without fluid loadings are derived and assembled by using the dynamic stiffness method. Numerical examples of the free vibration analysis for both empty and fluid-filled shells are validated against previous studies. Remarkable advantages regarding computational efficiency and accuracy of the DSM, especially in high-frequency domain, are presented through response curves compared with finite element calculations. As for partially fluid-filled or fluid-surrounded laminated shells, parametric studies are made to find the effects of material properties, fluid heights and semi-vertex angles on the dynamic characteristics.

References listed at the end of the paper:

A novel active elastic metamaterial plate is proposed, with tunable vibration band pass characteristics by using the periodically placed piezoelectric actuator and sensor pairs along one direction of the plate. Active control strategies are employed to actively adjust the band-gap properties of the metamaterial plate. Displacement and acceleration feedback control methods are applied to design the controllers so that the positive active stiffness and inertia for the elastic metamaterial plate can be provided. The dynamic responses of

References listed at the end of the paper:

ABSTRACT: We first characterize strain solitary waves propagating in a fluid-filled hyperelastic membrane tube when the fluid is stationary prior to wave propagation and the tube is also subjected to a finite stretch. We consider the parameter regime where all traveling waves admitted by the linearized governing equations have nonzero speed. Solitary waves are viewed as waves of finite amplitude that bifurcate from the quiescent state of the system with the wave speed playing the role of the bifurcation parameter. Evolution of the bifurcation diagram with respect to the pre-stretch is clarified. We then study the stability of solitary waves for a representative case that is likely of most interest in applications, the case in which solitary waves exist with speed \( c \) lying in the interval \([0, \sigma]\) where \( \sigma \) is the bifurcation value of \( c \), and the wave amplitude is a decreasing function of speed. It is shown that there exists an intermediate value \( \sigma \) in the above interval such that solitary waves are spectrally stable if their speed is greater than \( \sigma \) and unstable otherwise.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: Two ways of incorporating moderate rotations of planes normal to the axis of a straight beam into the Euler–Bernoulli and the Timoshenko micropolar beam theories are presented. In the first case, the von Kármán nonlinear strains are used to incorporate the moderate rotations of normal planes into the beam theories. In the second case, appropriate approximations are made on the nonlinear Cosserat deformation gradient to reflect the condition of moderate rotations of the normal planes. The governing nonlinear differential equations and corresponding natural boundary conditions in both cases are derived using the principle of virtual displacements. A weak-form Galerkin displacement finite element formulation is presented for the developed nonlinear beam theories. The phenomenon of locking usually encountered in beam displacement finite elements is eliminated using higher-order finite elements with nodes located at spectral points. Finally, numerical examples are presented to illustrate the effect of coupling number and bending characteristic length scale on deflections and microrotations when a micropolar beam is modeled with the developed nonlinear beam theories. (A correction to this article is available online at https://doi.org/10.1007/s00707-020-02822-4.)

References listed at the end of the paper:
Yangyang Dong, Tong Yu and Zijian Zhang, “Mechanical design and energy absorption analysis of spherical honeycomb core for soft-landing device buffer shell”, Acta Mechanica, Vol. 231, No. 10, pp 4243-4257, October 2020,

ABSTRACT: Soft-landing buffer systems with spherical curvature outer shells are widely used in the aerospace field, which not only requires its efficient and smooth buffer performance, but also that the shell of the landing buffer system is compact and lightweight. This paper presents a novel design method for the spherical honeycomb core structure for a soft-landing device buffer shell. The proposed method aims to realize the positive sphere characteristics of the honeycomb core by adopting the spherical mosaic of a truncated icosahedron and the triangle formation principle. Furthermore, according to the relationship of the deformation and the energy absorption performance, the optimum structural parameters are obtained by discussing the mechanical properties of the inner core, which determine the unit size and density of the whole model. At the same time, we estimate the distortion rate caused by projection that can be considered as an evaluation criterion to describe the performance of the proposed structure of the spherical honeycomb core. Simulation tests are carried out employing Abaqus/explicit to analyze the distortion impact and the energy-absorption properties of the proposed structures under different actual environments.

References listed at the end of the paper:

and the nonlocal size scale parameter. Then, the nonlinear vibration of piezoelectricity and a nonlinear strain characteristic of the substance, biological effects and occupational exposure levels. Med. Pracy 68, 259 (2017)


investigated at higher modes of vibration and the size scale effects are reviewed comprehensively. It is observed that the nonlocal parameter decreases the nonlinear natural frequencies and becomes noticeable at higher modes of vibration. Moreover, by increasing the amplitude ratio, the nonlocal effects are decreased and the nonlocal nonlinear frequency approaches the local one. Also, the amplitude ratio has increasing effects on the nonlinear frequencies.

References listed at the end of the paper:

ABSTRACT: The theoretical analysis of thick plate vibration behavior has been investigated in the literature, but most of the studies were focused on flexural dynamic characteristics and lack experimental verification. In this study, the analytical solutions based on the superposition method for both the flexural and extensional vibrations are presented to obtain resonant frequencies and associated mode shapes for a transversely isotropic thick rectangular plate. The displacement equilibrium equations and boundary conditions of the modified first-order shear deformation theory (FSDT) are derived by utilizing Hamilton’s principle and the variation method. To verify the validity of the theoretical model, the finite-element method (FEM) and impact experiment results for thick plates are employed in this work. Excellent agreement of resonant frequencies and associated mode shapes is obtained for FEM calculation and theoretical analysis. To excite vibrations of a thick rectangular plate, a steel ball controlled by an electromagnet is utilized. A steel ball is dropped freely from a height of 231 mm on the top of the plate surface, and a transient wave will be generated after the ball impact on the specimen. The frequency spectrum of the thick rectangular plate is constructed by using the fast Fourier transform of the time-domain transient response. The excited resonant frequencies obtained from experimental measurement are compared with theoretical results. The comparisons show that the modified FSDT provides an excellent prediction of the resonant frequencies and mode shapes for the dynamic characteristics of thick rectangular plates.

References listed at the end of the paper:


ABSTRACT: A new model for anisotropic magneto-electro-elastic Mindlin plate is developed by using an extended modified couple stress theory. The equations of motion and complete boundary conditions are simultaneously obtained by a variational formulation based on Hamilton’s principle. The new anisotropic magneto-electro-elastic plate model includes the models for orthotropic and transversely isotropic magneto-electro-elastic Mindlin plates and the model for isotropic Mindlin plates, all incorporating the microstructure effect, as special cases. To illustrate the new model, the static bending and free vibration problems of a simply supported transversely isotropic magneto-electro-elastic plate are analytically solved by directly applying the general formulas derived. For the static bending problem, the numerical results reveal that the deflection, rotation, electric potential, and magnetic potential of the simply supported plate predicted by the current non-classical model are always smaller than those predicted by the classical elasticity-based model, and the differences are significant when the plate thickness is very small but is diminishing as the thickness increases. For the free vibration problems, it is found that the natural frequency predicted by the new plate model is higher than that predicted by the classical model, and the difference is quite large for very thin plates.

References listed at the end of the paper:

ABSTRACT: A nonlocal Kirchhoff plate model with fourth-order strain gradient theory is firstly proposed to study variations with band gap frequencies and vibration energy distribution. The temperature rise is supposed to vary linearly through the thickness of the periodic nanoplate structures. The dynamic equations of finite periodic nanoplate structures under thermal load with the small-scale effect and the nonlinear membrane strain taken into consideration are derived based on the finite element method. The structural intensity approach is developed to predict the vibration energy flow of the periodic nanoplates. Effects of the temperature rise on band gaps and the structural intensity are divided into two parts. One is nonlinear effects of temperature rise, and the other is effects of thermal load. In the numerical calculation, the natural frequencies of single-layer graphene sheets computed by the nonlocal finite element method with fourth-order strain gradient agree well with analytical results, which validate the effectiveness of the present method. The influences of nonlocal parameters and thermal load on the band gap and structural intensity are considered, respectively. The boundary value has been achieved to determine the critical mechanical load or thermal load for analyzing in depth the effects of the mechanical load and thermal load on the structural intensity. The proposed method shows that the vibration energy flow pattern may be controlled by adjusting the magnitude of the mechanical or thermal load.

References listed at the end of the paper:

ABSTRACT: The paper is devoted to simply supported beams under three-point bending. Their mechanical properties symmetrically vary in the depth direction. The individual shear deformation theory for beams of such features is proposed. Based on the principle of stationary total potential energy the differential equations of equilibrium are obtained. The system of the equations is analytically solved, and the shear coefficients and deflections of example beams are calculated. The solution is compared with other analytical results obtained with the use of another deformation function. Moreover, the bending problem of these beams is also numerically studied using the finite element method. Results of analytical and numerical studies are presented in Figures and Tables.

References listed at the end of the paper:

References


ABSTRACT: In this study, the stability of sandwich conical shells covered by functionally graded and uniform distributed carbon nanotube-reinforced composite coatings under external pressures is carried out. The mechanical properties of the carbon nanotube and matrix are assumed to be graded through the thickness of the coatings via three types of grading rule. The basic relationships and stability equations of sandwich conical shells reinforced by carbon nanotubes are obtained employing the modified Donnell-type shell theory and generalized first-order shear deformation theory. The Galerkin procedure is employed to define expressions for the external buckling pressures. For the accuracy of the proposed formulation, the results are compared with the results that are published in the literature. It follows a systematic study aimed at checking the sensitivity of the structural response to the type of pattern and the volume fraction of carbon nanotubes in the composite coatings.

References listed at the end of the paper:

ABSTRACT: An imperfection sensitivity analysis for the nonlinear post-buckling behavior of functionally graded (FG) porous micro-tubes is performed in this research. The case of geometrically imperfect micro-tubes surrounded by a nonlinear elastic medium under axial compressive load is analyzed. Properties of the micro-tube with uniform distributed porosity are FG across the radius of the cross-section. Two types of boundary conditions as simply-supported and clamped are considered. The high-order shear deformation theory of tubes
is utilized to approximate the displacement field. Differential equations governing the equilibrium position of the micro-tube are extracted using the virtual displacement principle. These nonlinear equations are analytically solved by means of the two-step perturbation technique and Galerkin procedure. It is shown that when the imperfect micro-tube is in contact with a sufficiently soft foundation, the post-buckling path of the structure is unstable, and therefore the structure is imperfection sensitive. Since the imperfection sensitivity of micro-tubes is not reported in literature, results of this study are compared with buckling responses of perfect FGM tubes. The effects of porosity coefficient, power law index, length scale parameter, and geometrical parameters upon the limit buckling load of imperfect micro-tubes are investigated.

References listed at the end of the paper:
Newton's second law, and the Galerkin method is used to discretize the nonlinear partial differential equations.
into the set of nonlinear ordinary differential equations. The method of multiple scales is used to solve the nonlinear ordinary differential equations, and the amplitude–frequency and phase–frequency equations are extracted. The obtained results are verified with available investigations, and the effects of fractional parameters, excitation, and nonlinearity on the amplitude–frequency and phase–frequency responses of the viscoelastic cylindrical shells are outlined.

References listed at the end of the paper:


ABSTRACT: The dynamic response of an elastic thin plate resting on a cross-anisotropic elastic half-space to a rectangular load moving on its surface with constant speed is analytically obtained. The moving load and the plate and soil displacements are expanded in double complex Fourier series involving the two horizontal coordinates x and y as well as the time and the load velocity. Thus, the plate equation of lateral motion reduces to an algebraic equation, while the soil equations of motion reduce to a system of three ordinary differential equations with respect to the vertical coordinate z, which can be easily solved. Compatibility and equilibrium at the plate–soil interface as well as employment of the boundary conditions of the system enable one to determine the solution in terms of displacements of the plate and the half-space soil medium. The solution is first verified by using it to obtain as special cases the solutions for isotropic and cross-anisotropic half-space problems and compare them against existing analytical solutions. Parametric studies are conducted to assess the effects of the degree of cross-anisotropy on the plate and soil responses in conjunction with the effects of other important parameters, such as the speed of the moving load.

References listed at the end of the paper:

Mohammad Malikan (1), Victor A. Eremeyev (1) and Hamid M. Sedighi (2)

(1) Department of Mechanics of Materials and Structures, Faculty of Civil and Environmental Engineering, Gdansk University of Technology, Gdansk, Poland

(2) Mechanical Engineering Department, Faculty of Engineering, Shahid Chamran University of Ahvaz, Iran

ABSTRACT: On the basis of a theoretical study, this research incorporates an eccentricity into a system of compressed double-walled carbon nanotubes (DWCNTs). In order to formulate the stability equations, a kinematic displacement with reference to the classical beam hypothesis is utilized. Furthermore, the influence of nanoscale size is taken into account with regard to the nonlocal approach of strain gradient, and the van der Waals interaction for both inner and outer tubes is also considered based on the Lennard–Jones model. Galerkin decomposition is employed to numerically deal with the governing equations. It is evidently demonstrated that
the geometrical eccentricity remarkably affects the stability threshold and its impact is to increase the static stability of DWCNTs.

References listed at the end of the paper:


ABSTRACT: A new analytical approach to the nonlinear buckling and postbuckling analyses of functionally graded graphene-reinforced composite laminated cylindrical shells stiffened by functionally graded graphene-reinforced composite laminated stiffeners under external pressure taking into account the elastic foundation effect in a uniformly distributed thermal environment is presented in this paper. An improved smeared stiffener technique is developed for anisotropic stiffeners, and a special design for ring and stringer functionally graded graphene-reinforced composite laminated stiffeners is presented and successfully applied in this paper. The governing equations for the cylindrical shells are established by using the Donnell shell theory with the geometrical nonlinearity term in the von Kármán sense with the shell-foundation interaction formulated by the Pasternak elastic foundation model. A three-term solution form is chosen for the deflection, the stress function is introduced, and the Galerkin method is used to establish the nonlinear postbuckling relation. The numerical results validate the effects of the stiffeners, volume fraction of graphene, type of graphene distribution of the shell skin and stiffeners with different geometrical parameters, elastic foundation moduli, and uniformly distributed temperature changes on the nonlinear buckling and postbuckling behaviors of stiffened cylindrical shells.

References listed at the end of the paper:


34. Sofiyev, A.H., Tornabene, F., Dimitri, R., Kuruoglu, N.: Buckling behavior of FG-CNT reinforced composite conical shells subjected to a combined loading. Nanomaterials 10(3), 419 (2020)


Khaled M. Elmorabie, Kadry Zakaria and Magdy A. Sirwah, “Nonlinear instability of a thin laminated composite circular plate subjected to a tensile periodic load”, Acta Mechanica, Vol. 231, No. 12, pp 5213-5238, December 2020,

ABSTRACT: In this work, we have investigated the nonlinear instability behavior of a thin laminated composite circular plate subjected to a tensile periodic load. A nonlinear system with quadratic and cubic nonlinear terms, referred to the effect of large deflection, is obtained. The method of multiple time scales is used to obtain periodic solutions for the second- and third-order systems, which directly leads to the solvability conditions of the two orders including the nonlinearity terms. Different cases of resonance with the instability criteria are taken into account. For the numerical application, the effect of the tensile periodic load was studied on a plate of graphite fabric-carbon material.

References listed at the end of the paper:


Pei Zhang and Hai Qing, “Exact solutions for size-dependent bending of Timoshenko curved beams based on a modified nonlocal strain gradient model”, Acta Mechanica, Vol. 231, No. 12, pp 5251-5276, December 2020,

ABSTRACT: Size-dependent bending analysis of Timoshenko curved beams is performed with a modified nonlocal strain gradient integral model, in which the integral constitutive equation is transformed into an equivalent differential form equipped with two constitutive boundary equations. The governing equations and boundary conditions are derived via the minimum total potential energy principle and solved analytically using the Laplace transformation technique and its inverse version. In numerical examples, the inconsistency of the
nonlocal strain gradient model is examined extendedly under different boundary and loading conditions, while consistent softening and stiffening responses can be observed via the modified nonlocal strain gradient integral model. In addition, within the modified nonlocal strain gradient model, numerical examples also show that the increase of the opening angle can affect the total size effects of the combination of the two scale parameters (i.e., nonlocal and gradient), and these effects are inconsistent for different beam boundaries. Finally, by comparing with the results of the Euler–Bernoulli theory, an interesting finding is that as the nonlocal (or gradient length-scale) parameter increases, the shear deformations of simply supported–simply supported beams (or clamped-clamped/simply supported beams) become more significant.

References listed at the end of the paper:


Acta Mechanica, Vol. 231, No. 12, pp 5251-5276, December 2020,

Google the string: “Acta Mechanica Sinica”, then click on the first entry, “Acta Mechanica Sinica – Springer”, then, on the resulting screen, click on “All Volumes & Issues” (located on the right-hand side of the screen near the top, in blue color)


ABSTRACT: Eringen’s nonlocal elasticity theory is extensively employed for the analysis of nanostructures because it is able to capture nanoscale effects. Previous studies have revealed that using the differential form of the strain-driven version of this theory leads to paradoxical results in some cases, such as bending analysis of cantilevers, and recourse must be made to the integral version. In this article, a novel numerical approach is developed for the bending analysis of Euler–Bernoulli nanobeams in the context of strain- and stress-driven integral nonlocal models. This numerical approach is proposed for the direct solution to bypass the difficulties related to converting the integral governing equation into a differential equation. First, the governing equation is derived based on both strain-driven and stress-driven nonlocal models by means of the minimum total potential energy. Also, in each case, the governing equation is obtained in both strong and weak forms. To solve numerically the derived equations, matrix differential and integral operators are constructed based upon the finite difference technique and trapezoidal integration rule. It is shown that the proposed numerical approach can be efficiently applied to the strain-driven nonlocal model with the aim of resolving the mentioned paradoxes. Also, it is able to solve the problem based on the strain-driven model without inconsistencies of the application of this model that are reported in the literature.

References listed at the end of the paper:


Chengfu Shu and Shujuan Hou, “Theoretical prediction on corrugated sandwich panels under bending loads”, Acta Mechanica Sinica, Vol. 34, No. 5, pp 925-935, October 2018

ABSTRACT: In this paper, an aluminum corrugated sandwich panel with triangular core under bending loads was investigated. Firstly, the equivalent material parameters of the triangular corrugated core layer, which could be considered as an orthotropic panel, were obtained by using Castigliano’s theorem and equivalent homogeneous model. Secondly, contributions of the corrugated core layer and two face panels were both considered to compute the equivalent material parameters of the whole structure through the classical lamination theory, and these equivalent material parameters were compared with finite element analysis solutions. Then, based on the Mindlin orthotropic plate theory, this study obtain the closed-form solutions of the
displacement for a corrugated sandwich panel under bending loads in specified boundary conditions, and parameters study and comparison by the finite element method were executed simultaneously. References listed at the end of the paper:


H.X. Wu, Y. Liu and X.C. Zhang, “In-plane crushing behavior and energy absorption design of composite honeycombs”, Acta Mechanica Sinica, Vol. 34, No. 6, pp 1108-1123, December 2018

Theoretical analysis and numerical simulation methods were used to study the in-plane crushing behavior of single-cell structures and regular and composite honeycombs. Square, hexagonal, and circular honeycombs were selected as honeycomb layers to establish composite honeycomb models in the form of composite
structures and realize the complementary advantages of honeycombs with type I and type II structures. The effects of honeycomb layer arrangement, plastic collapse strength, relative density, and crushing velocity on the deformation mode, plateau stress, load uniformity, and energy absorption performance of the composite honeycombs were mainly considered. A semi-empirical formula for plateau stress and energy absorption rate per unit mass for the composite honeycombs was developed. The results showed that the arrangement mode of honeycomb layers is an important factor that affects their mechanical properties. Appropriately selecting the arrangement of honeycomb layers and the proportion of honeycomb layers with different structures in a composite honeycomb can effectively improve its load uniformity and control the magnitude of plateau stress and energy absorption capacity.

References listed at the end of the paper:

Nuttawit Wattanasakulpong and Arisara Chaikittiratana, “Chebyshev collocation approach for vibration analysis of functionally graded porous beams based on third-order shear deformation theory”, Acta Mechanica Sinica, Vol. 34, No. 6, pp 1124-1135, December 2018

ABSTRACT: In this paper, vibration analysis of functionally graded porous beams is carried out using the third-order shear deformation theory. The beams have uniform and non-uniform porosity distributions across their thickness and both ends are supported by rotational and translational springs. The material properties of the beams such as elastic moduli and mass density can be related to the porosity and mass coefficient utilizing the typical mechanical features of open-cell metal foams. The Chebyshev collocation method is applied to solve the governing equations derived from Hamilton’s principle, which is used in order to obtain the accurate natural frequencies for the vibration problem of beams with various general and elastic boundary conditions. Based on the numerical experiments, it is revealed that the natural frequencies of the beams with asymmetric and non-uniform porosity distributions are higher than those of other beams with uniform and symmetric porosity distributions.

References listed at the end of the paper:

Lang Li, Zhenyu Zhao, Rui Zhang, Bin Han, Qiancheng Zhang and Tian Jian Lu (Primarily from: State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi’an Jiaotong University, Xi’an, China), “Dual-level stress plateaus in honeycombs subjected to impact loading: Perspectives from bucklewaves, buckling and cell-wall progressive folding”, Acta Mechanica Sinica, Vol. 35, No. 1, pp 70–77, February 2019

ABSTRACT: Dual-level stress plateaus (i.e., relatively short peak stress plateaus, followed by prolonged crushing stress plateaus) in metallic hexagonal honeycombs subjected to out-of-plane impact loading are characterized using a combined numerical and analytical study, with the influence of the strain-rate sensitivity of the honeycomb parent material accounted for. The predictions are validated against existing experimental measurements, and good agreement is achieved. It is demonstrated that honeycombs exhibit dual-level stress plateaus when bucklewaves are initiated and propagate in cell walls, followed by buckling and progressive folding of the cell walls. The abrupt stress drop from peak to crushing plateau in the compressive stress versus strain curve can be explained in a way similar to the quasi-static buckling of a clamped plate. The duration of the peak stress plateau is more evident for strain-rate insensitive honeycombs.

References listed at the end of the paper:

ABSTRACT: In this study, forced nonlinear vibration of a circular micro-plate under two-sided electrostatic, two-sided Casimir and external harmonic forces is investigated analytically. For this purpose, at first, von Kármán plate theory including geometrical nonlinearity is used to obtain the deflection of the micro-plate. Galerkin decomposition method is then employed, and nonlinear ordinary differential equations (ODEs) of motion are determined. A harmonic balance method (HBM) is applied to equations and analytical relation for nonlinear frequency response (F–R) curves are derived for two categories (including and neglecting Casimir force) separately. The analytical results for three cases: (1) semi-linear vibration; (2) weakly nonlinear vibration; (3) highly nonlinear vibration, are validated by comparing with the numerical solutions. After validation, the effects of the voltage and Casimir force on the natural frequency of two-sided capacitor system are investigated. It is shown that by assuming Casimir force in small gap distances, reduction of the natural frequency is considerable. The influences of the applied voltage, damping, micro-plate thickness and Casimir force on the frequency response curves have been presented too. The results of this study can be useful for modeling circular parallel-plates in nano/microelectromechanical transducers such as microphones and pressure sensors.

References listed at the end of the paper:


ABSTRACT: We extend the differential quadrature element method (DQEM) to the buckling analysis of uniformly in-plane loaded functionally graded (FG) plates fully or partially resting on the Pasternak model of elastic support. Material properties of the FG plate are graded in the thickness direction and assumed to obey a power law distribution of the volume fraction of the constituents. To set up the global eigenvalue equation, the plate is divided into sub-domains or elements and the generalized differential quadrature procedure is applied to discretize the governing, boundary and compatibility equations. By assembling discrete equations at all nodal points, the weighting coefficient and force matrices are derived. To validate the accuracy of this method, the results are compared with those of the exact solution and the finite element method. At the end, the effects of different variables and local elastic support arrangements on the buckling load factor are investigated.

References listed at the end of the paper:

Jifan Zhong, Yaochen Zheng, Jianqiao Chen and Zhao Jing (Department of Mechanics, Huazhong University of Science and Technology, Wuhan, China), “Variable-stiffness composite cylinder design under combined loadings by using the improved Kriging model”, Acta Mechanica Sinica, Vol. 35, No. 1, pp 201-211, February 2019

ABSTRACT: The large design freedom of variable-stiffness (VS) composite material presupposes its potential for wide engineering application. Previous research indicates that the design of VS cylindrical structures helps to increase the buckling load as compared to quasi-isotropic (QI) cylindrical structures. This paper focuses on the anti-buckling performance of VS cylindrical structures under combined loads and the efficient optimization design method. Two kinds of conditions, bending moment and internal pressure, and bending moment and torque are considered. Influences of the geometrical defects, ovality, on the cylinder’s performances are also investigated. To increase the computational efficiency, an adaptive Kriging meta-model is proposed to approximate the structural response of the cylinders. In this improved Kriging model, a mixed updating rule is used in constructing the meta-model. A genetic algorithm (GA) is implemented in the optimization design. The
optimal results show that the buckling load of VS cylinders in all cases is greatly increased as compared with a QI cylinder.

References listed at the end of the paper:
References listed at the end of the paper:

ABSTRACT: Cells were suggested to sense matrix rigidity by applying fluctuating forces, but the underlying mechanism remains elusive. Here, with a generic filament-crosslinker modeling system for stress fibers, we demonstrate that high mechanical forces can be induced by specific protein–protein interactions with biased kinetics. Strikingly, we further find that there exist two patterns of force generation, a stable pattern and a fluctuated pattern, in agreement with previous experimental observations. Our analysis indicates that the fluctuated force profile is essentially due to force-induced structural instability during structural assembly. We suggest that how cells utilize or circumvent such stable forces or fluctuated forces may be important in other biological processes as well, though whether such forces should be regarded as passive or active is still tentative.

References listed at the end of the paper:


ABSTRACT: The mechanical behavior of filamentous actin bundles plays an essential role in filopodial protrusions at the leading edge of crawling cells. These bundles consist of parallel actin filaments that are hexagonally packed and interconnected via cross-linking proteins including α-actinin, filamin, and fascin. When pushing against the plasma membrane and/or external barriers, actin bundles in filopodial protrusions inevitably encounter a compressive load. The bending stiffness and buckling stability of actin bundles are therefore important in determining the filopodial architecture and subsequent cell morphology. In this work, we employ a coarse-grained molecular dynamics model to investigate the buckling behavior of cross-linked actin bundles under compression, explicitly accounting for the properties of the constituent filaments and the mechanical description of the cross-linkers. The bending stiffness of actin bundles exhibits a generic size effect depending on the number of filaments in the bundle, explicitly depending on the degree of interfilament coupling. The distinct buckling modes are analyzed for bundles with different coupling states and crosslinker strengths. This study could clarify the stability and buckling mechanisms of parallel packed actin bundles and the structure–function relations of mechanical components in filopodial protrusions.

References listed at the end of the paper:

reveals that sectional cells experience a process from the precursor elastic behavior to the shock stress state, and the strain rate is established, which confirms the strain rate effect of cellular materials. By extracting the continuous velocity distribution is derived based on the features of single actin filaments with and without tropomyosin by in vitro nanomanipulation. Proc. Natl. Acad. Sci. USA 91, 12962–12966 (1994)


the critical points immediately before the unloading stage in the local dynamic stress–strain history curves, the dynamic stress–strain states of cellular materials are determined. They exhibit loading rate dependence but are independent of the initial impact velocity. Furthermore, with increase of the relative density, the dynamic hardening behavior of the cellular specimen is enhanced and the crushing process event is advanced. The particle velocity-based analytical method is applied to analyze the dynamic responses of cellular materials. This method is better than continuum-based shock models, since it does not require a preassumed constitutive relation. Therefore, the particle velocity-based analytical method proposed herein may provide new ideas to carry out dynamic experimental measurements, which is especially applicable to inhomogeneous materials. References listed at the end of the paper:

30. ABAQUS, Version 6.11. ABAQUS Analysis User’s Manuals, Simulia, Dassault Systmes, Rising Sun Mills, USA
Wei Li, Xiao-Dong Yang, Wei Zhang, Yuan Ren, Tian-Zhi Yang, “Free vibration analysis of a spinning piezoelectric beam with geometric nonlinearities”, Acta Mechanica Sinica, Vol. 35, No. 4, pp 879-893, April 2019

ABSTRACT: The linear and non-linear free vibrations of a spinning piezoelectric beam are studied by considering geometric nonlinearities and electromechanical coupling effect. The non-linear differential equations of the spinning piezoelectric beam governing two transverse vibrations are derived by using transformation of two Euler angles and the extended Hamilton principle, wherein an additional piezoelectric coupling term and different linear terms are present in contrast to the traditional shaft model. Linear frequencies are obtained by solving the standard eigenvalues of the linearized system directly, and the non-linear frequencies and non-linear complex modes are achieved by using the method of multiple scales. For free vibrations analysis of a spinning piezoelectric beam, the non-linear modal motions are investigated as forward and backward precession with different spinning speeds. The responses to the initial conditions for this gyroscopic system are studied and a beat phenomenon is found, which are then validated by numerical simulation. The influences of some parameters such as electrical resistance, rotary inertia and spinning speeds to the non-linear dynamics of a spinning piezoelectric beam are investigated.

References listed at the end of the paper:


ABSTRACT: A lumped parameter transverse vibration model of a composite plate harvester is analyzed via harmonic balance approaches. The harvester is mainly composed of a piezoelectric circular composite clamped by two steel rings and a proof mass on the plate. The lumped parameter model is a 1.5 degree-of-freedom strongly nonlinear system with a higher order polynomial stiffness. A harmonic balance approach is developed to analyze the system, and the resulting algebraic equations are numerically solved by adopting an arc-length continuation technique. An incremental harmonic balance approach is also developed for the lumped parameter model. The two approaches yield the same results. The amplitude-frequency responses produced by the harmonic balance approach are validated by the numerical integrations and the experimental data. The investigation reveals that there coexist hardening and softening characteristics in the amplitude-frequency response curves under sufficiently large excitations. The harvester with the coexistence of hardening and softening nonlinearities can outperform not only linear energy harvesters, but also typical hardening nonlinear energy harvesters.

References listed at the end of the paper:
References listed at the end of the paper:

- Nonlinearities can outperform not only linear energy harvesters but also typical hardening nonlinear energy under sufficiently large excit.

- Reveals that there coexist hardening and softening characteristics in the amplitude balance approach are validated by the numerical integrations and the experimental data. The investigation model. The two approaches yield the same results. The amplitude continuation technique. An incremental harmonic balance approach is also developed for the lumped parameter to analyze the system, and the resulting algebraic equations are numerically solved by adopting an arc-length continuation technique. An incremental harmonic balance approach with alternating frequency/time domain progress for piezoelectric mechanical systems. Mech. Syst. Signal Process. 37, 223–235 (2016)


Tian-Chen Yuan (1), Jian Yang (2) and Li-Qun Chen (1)

(1) Shanghai Institute of Applied Mathematics and Mechanics, Shanghai University, Shanghai 200072, China
(2) School of Urban Railway Transportation, Shanghai University of Engineering Science, Shanghai 201620, China


ABSTRACT: A lumped parameter transversevibration model of a composite plate harvester is analyzed via harmonic balance approaches. The harvester is mainly composed of a piezoelectric circular composite clamped by two steel rings and a proof mass on the plate. The lumped parameter model is a 1.5 degree-of-freedom strongly nonlinear system with a higher order polynomial stiffness. Harmonic balance approach is developed to analyze the system, and the resulting algebraic equations are numerically solved by adopting an arc-length continuation technique. An incremental harmonic balance approach is also developed for the lumped parameter model. The two approaches yield the same results. The amplitude-frequency responses produced by the harmonic balance approach are validated by the numerical integrations and the experimental data. The investigation reveals that there coexist hardening and softening characteristics in the amplitude-frequency response curves under sufficiently large excitations. The harvester with thecoexistenceof hardening and softening nonlinearitiescan outperform not only linear energy harvesters but also typical hardening nonlinear energy harvesters.

References listed at the end of the paper:


(No appropriate papers in Vol. 35, No. 5, October 2019)

Hao Li, Xiaoyan Liang and Weibin Song (Department of Mechanics, School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, China), “Buckling-controlled two-way shape memory effect in a ring-shaped bilayer”, Acta Mechanica Sinica, Vol. 35, No. 6, pp 1217-1225, December 2019

ABSTRACT: Shape memory polymers (SMPs) usually have a one-way shape memory effect. In this paper, an easy-operating method to realize a two-way shape memory effect was demonstrated in a ring-shaped bilayer structure where the two layers are SMPs with different thermal transition temperatures. By designing specific thermomechanical processes, the mismatched deformation between the two layers leads to a morphology change of ring-shaped bilayer structures from a smooth ring to a gear-like buckling shape under cooling and a reversible recovery to the smooth shape under heating. Such a morphology change is ascribed to occurrence and
recovery of thermoelastic buckling. This method was validated by finite element simulation. We experimentally investigated the influence of pre-strain on buckling, and it was found that both the buckling occurrence and recovery temperature vary with pre-strain. Furthermore, considering a ring-shaped SMP-SMP bilayer structure, finite element analysis was conducted to study the influence of film thickness and modulus ratio of two layers on buckling behavior. The results showed that the critical buckling wavelength was greatly influenced by film thickness and modulus ratio. We made a theoretical analysis that accorded well with the numerical results.

References listed at the end of the paper:


H. Li (1,2), Y. G. Zheng (2), Y. X. Zhang (1), H. F. Ye (2) and H. W. Zhang (2)
(1) Science and Technology on Reactor System Design Technology Laboratory, Nuclear Power Institute of China, Chengdu 610200, China
(2) International Research Center for Computational Mechanics, State Key Laboratory of Structural Analysis for Industrial Equipment, Department of Engineering Mechanics, Faculty of Vehicle Engineering and Mechanics, Dalian University of Technology, Dalian 116024, China

“Large deformation and wrinkling analyses of bimodular structures and membranes based on a peridynamic computational framework”, Acta Mechanica Sinica, Vol. 35, No. 6, pp 1217-1225, December 2019

ABSTRACT: In this paper, the quasi-static large deformation, wrinkling and fracture behaviors of bimodular structures and membranes are studied with an implicit bond-based peridynamic computational framework. Firstly, the constant and tangential stiffness matrices of the implicit peridynamic formulations for the nonlinear problems are derived, respectively. The former is constructed from the linearization of the bond strain on the basis of the geometric approximation while the latter is established according to the linearization of the pairwise force by using first-order Taylor’s expansion. Then, a bimodular material model in peridynamics is developed, in which the tensile or compressive behavior of the material at each point is conveniently described by the tensile or compressive states of the bonds in its neighborhood. Moreover, the bimodular material model is extended to deal with the wrinkling and fracture problems of membranes by setting the compressive micro-modulus to be zero. In addition, the incremental-iterative algorithm is adopted to obtain the convergent solutions of the nonlinear problems. Finally, several representative numerical examples are presented and the results demonstrate the accuracy and efficiency of the proposed method for the large deformation, wrinkling and fracture analyses of bimodular structures and membranes.

References listed at the end of the paper:


50. 1933-1942 (2012)


Guangtao Wei, Yang Jin and Linzhi Wu (First author is from: Center for Composite Materials, Harbin Institute of Technology, Harbin, 150001, China), “Geometric and material nonlinearities of sandwich beams under static loads”, Acta Mechanica Sinica, Vol. 36, No. 1, pp 97-106, February 2020,

ABSTRACT: A new theory developed from extended high-order sandwich panel theory (EHSAAPT) is set up to assess the static response of sandwich panels by considering the geometrical and material nonlinearities simultaneously. The geometrical nonlinearity is considered by adopting the Green–Lagrange-type strain for the face sheets and core. The material nonlinearity is included as a piecewise function matched to the experimental stress–strain curve using a polynomial fitting technique. A Ritz technique is applied to solve the governing equations. The results show that the stress stiffening feature is well captured in the geometric nonlinear analysis. The effect of the geometric nonlinearity in the face sheets on the displacement response is more significant when the stiffness ratio of the face sheets to the core is large. The geometric nonlinearity decreases the shear stress and increases the normal stress in the sandwich core. By comparison with open literature and finite element simulations, the present nonlinear EHSAAPT is shown to be sufficiently precise for estimating the nonlinear static response of sandwich beams by considering the geometric and material nonlinearities simultaneously.

References listed at the end of the paper:


ABSTRACT: Pipes are often used to transport multiphase flows in many engineering applications. The total fluid flow density inside a pipe may vary with time and space. In this paper, a simply supported pipe conveying a variable density flow is modeled theoretically, and its stability and nonlinear vibrations are investigated in detail. The variation of the flow density is simulated using a mathematical function. The equation governing the vibration of the pipe is derived according to Euler–Bernoulli beam theory. When the internal flow density varies with time, the pipe is excited parametrically. The stability of the pipe is determined by Floquet theory. Some simple parametric and combination resonances are determined. For a higher mass ratio (mean flow mass/pipe structural mass), higher flow velocity, or smaller end axial tension, the pipe becomes unstable more easily due to wider parametric resonance regions. In the subcritical flow velocity regime, the vibrations of the pipe are periodic and quasiperiodic for simple and combination resonances, respectively. However, in the supercritical regime, the vibrations of the pipe exhibit much richer dynamics including periodic, multiperiodic, quasiperiodic, and chaotic behaviors.

References listed at the end of the paper:


ABSTRACT: In this paper, the nonlinear dynamic responses of a piezoelectric cantilever plate near the first-order and second-order natural frequencies under the action of electromechanical coupling are studied by experiments and finite element (FE) methods. The influence of different excitation frequencies on the dynamical characteristics of piezoelectric cantilever plates is analyzed with the fixed excitation amplitude. First, an experimental setup is built, including a carbon fiber cantilever plate attached to a macro fiber composite (MFC) sheet. Then, the electromechanical coupling excitations are subjected to the plate with different frequencies, which are chosen near the first and second-order natural frequencies of the plate. The piezoelectric cantilever plate has periodical motions under a lower frequency excitation, and the motions of the plate become more complex after another high frequency excitation added in the physical field. The experimental results show that the motion of the piezoelectric cantilever plate changes from stable to unstable with high–low coupled resonant frequencies. At last, the FE study is carried out to compare and verify the experimental results and the effects of isotropic and orthotropic materials on the accuracy of natural frequencies results are also compared.

References listed at the end of the paper:

ABSTRACT: On the basis of finite element analysis, an eigenvalue problem is performed to examine the vibrational characteristics of a hetero-nanotube made of carbon (C) and boron nitride (BN) nanotubes in magnetic and thermal environment. By incorporating the assumption of nonlocal elasticity theory, the size-dependent behavior of the considered structure is also taken into account. The obtained results demonstrate that the onset of the divergence and flutter instabilities may be postponed by exploiting a hetero-nanotube rather than a uniform one composed of carbon nanotube. Moreover, it is exhibited that, in the presence of fluid flow, the mode shape configuration of nanotubes may be different from those of classical modes and therefore the later one should not be utilized in the dynamic analysis of fluid-conveying tubes. Finally, it is shown that, as the temperature decreases, the natural frequencies of the system decrease in high temperature conditions and increase for the case of room temperature.

References listed at the end of the paper:

A topology optimization approach for designing the layout of plate structures is proposed in this article. In this approach, structural mechanical behavior is analyzed under the framework of Kirchhoff plate theory, and structural topology is described explicitly by a set of moving morphable components. Compared to the existing treatments where structural topology is generally described in an implicit manner, the adopted explicit geometry/layout description has demonstrated its advantages on several aspects. Firstly, the number of design variables is reduced substantially. Secondly, the obtained optimized designs are pure black-and-white and contain no gray regions. Besides, numerical experiments show that the use of Kirchhoff plate element helps save 95–99% computational time, compared with traditional treatments where solid elements are used for finite element analysis. Moreover the accuracy of the proposed method is also validated through a comparison with the corresponding theoretical solutions. Several numerical examples are also provided to demonstrate the effectiveness of the proposed approach.

References listed at the end of the paper:

the effect on failure behaviors caused by the imperfections of struts, face sheets and global shape. By geometrical imperfection of the specimen by the optical microscope. Numerical method is adopted to illustrate the effect on failure behaviors caused by the imperfections of struts, face sheets and global shape. By 


ABSTRACT: Additive-manufacturing process has substantially promoted the development of lattice structure and makes it possible to fabricate complex lattice sandwich structures. In-plane compression load always appears in engineering, such as in the primary structure of spacecraft. In order to reveal potential engineering application in future, this paper focuses on the lattice sandwich plate that is fabricated by additive-manufacturing and subjected to in-plane compression. Firstly, five failure modes are proposed for lattice sandwich plate under in-plane compression, including Euler buckling, shear buckling, face sheet dimpling, face sheet wrinkling and face sheet crushing. Secondly, an optimization method is proposed to obtain the optimum sizes, including the panel thickness, the length of rod, the size of rod cross-section, the inclined angle of rod and the wideness ratio of cell. Then, the in-plane compression experiment is operated after measuring the geometrical imperfection of the specimen by the optical microscope. Numerical method is adopted to illustrate the effect on failure behaviors caused by the imperfections of struts, face sheets and global shape. By
introducing these imperfection, numerical result can be well agreed with experimental result and explain the failure mechanisms mostly derived from the radius imperfection for the struts.

References listed at the end of the paper:


ABSTRACT: In this study, a finite element formulation based on the four-variable refined plate theory (RPT) is presented for forced vibration analysis of laminated viscoelastic composite plates integrated with a piezoelectric layer. To the best of the authors’ knowledge, this is the first time that the proposed approach is extended for study of the dynamic behavior of the smart viscoelastic plate. The utilized RPT which works for both thick and thin plates predicts a parabolic variation for transverse shear stresses across the plate thickness. Considering a linear viscoelastic model for the substrate material, the relaxation module is predicted by the Prony series. Using Hamilton's principle, the weak form equation is constructed and a four-node rectangular plate element is utilized for discretizing the domain. The Newmark scheme is employed for advancing the solution in time. A MATLAB code is developed based on the formulations and several benchmark problems are solved. Comparing the findings with existing results in previous studies confirms the accuracy and efficiency of the proposed method. The dynamic response of the smart viscoelastic plates under various electromechanical loads is investigated and the results show that the vibration can be passively controlled by adding and actuating the piezoelectric layer. The damping effects of viscoelastic parameters on the results are investigated, too.

References listed at the end of the paper:

D. E. S. Rodrigues, J. Belinha, L.M.J.S. Dinis and R. M. Natal Jorge, “Analysis of antisymmetric cross-ply laminates using high-order shear deformation theories: a meshless approach”, Acta Mechanica Sinica, Vol. 36, No. 5, pp 1078–1098, October 2020, ABSTRACT: For many years finite element method (FEM) was the chosen numerical method for the analysis of composite structures. However, in the last 20 years, the scientific community has witnessed the birth and development of several meshless methods, which are more flexible and equally accurate numerical methods. The meshless method used in this work is the natural neighbour radial point interpolation method (NNRPIM). In order to discretize the problem domain, the NNRPIM only requires an unstructured nodal distribution. Then, using the Voronoï mathematical concept, it enforces the nodal connectivity and constructs the background integration mesh. The NNRPIM shape functions are constructed using the radial point interpolation technique. In this work, the displacement field of composite laminated plates is defined by high-order shear deformation theories. In the end, several antisymmetric cross-ply laminates were analysed and the NNRPIM solutions were compared with the literature. The obtained results show the efficiency and accuracy of the NNRPIM formulation.

References listed at the end of the paper:


Aerostructural optimization is a keystone process to concurrently improve aerodynamic fidelity aerostructural gradient computation techniques with application to a realistic wing sizing”, AIAA Journal, Vol. 56, No. 11, pp 4487-4499, November 2018

ABSTRACT: Aerostructural optimization is a keystone process to concurrently improve aerodynamic performance and reduce the structural mass of an aircraft. However, gradient-based multidisciplinary design optimization is efficient only if the computation of gradients is fast and accurate. To this end, two high-fidelity
aerostructural gradient computation techniques are proposed for strongly coupled aeroelastic systems. In the specific context of this work, the focus is on design variables affecting structural stiffness only. Scalar objective functions like aerodynamic performance criteria are considered as well as a field of structural grid forces. The most intrusive technique includes well-established direct and adjoint formulations that require substantial implementation effort. In contrast, an alternative uncoupled nonintrusive approach is proposed that is easier to implement and yet capable of providing accurate gradient approximations. The accuracy of these methods is first demonstrated on the ONERA M6 wing test case. Their efficiency and applicability are then illustrated via a mass minimization problem applied to the Common Research Model. Both methods lead to very similar optimal designs, and the detailed analysis of results promotes the nonintrusive approach as a promising gradient computation alternative.


ABSTRACT: Modeling hydroelastic response of lightweight structures to water impact plays a pivotal role in the design of lightweight marine vessels and crew capsules. In contrast to the majority of studies that focus on water entry of wedge-shaped bodies, this study addresses the hydroelastic impact of cylindrical shells. A cylindrical shape allows for a systematic study of the interplay between bending and stretching during water entry. This study puts forward a mathematically tractable framework to study the rigid body motion and elastic deformation of cylindrical shells, free falling onto a quiescent water surface. Donnell thin shell theory is used to model the shell, and Wagner theory is adopted to determine the hydrodynamic loading as a function of the rigid body motion and structural deformation. Galerkin method is employed to cast the problem into a manageable system of coupled ordinary differential equations, which are then solved numerically. Model predictions are validated against experiments on shells with two thicknesses, detailing both the flow physics and elastic response through the cogent integration of direct acceleration measurement, high-speed imaging, and particle image velocimetry. The proposed framework and experimental dataset are expected to constitute the foundations on which to formulate new theories for lightweight composites and testing computational schemes.


ABSTRACT: This study describes the development of an integrated aerothermoelastic computational framework. The framework consists of a Navier-Stokes aerodynamic solver based on an Automatic Differentiation flow solver code; a finite element structural solver for moderate deflection of a composite, doubly curved, shallow shell with thermal stress; and a finite element thermal solver for heat transfer in composite shallow shells with nonlinear material properties. The solvers are loosely coupled using a partitioned scheme. An analytical approach is developed to determine the time accuracy and the so-called energy accuracy of a loosely coupled scheme, which serves as a guide for designing schemes having a high convergence rate. The aeroelastic and aerothermoelastic behaviors of two-dimensional and three-dimensional panels are investigated using the computational framework. The effects of the aspect ratio and boundary-layer thickness are found to have significant influence on the critical flutter parameter and the onset time of aerothermoelastic instability.


ABSTRACT: This paper presents a novel mixed one-dimensional formulation based upon Reissner’s mixed variational theorem for the accurate stress analysis of general multilayered beam problems. Carrera’s unified formulation is recalled to generate a class of theory of structure that assumes both displacements and stresses over the cross section of the beam. On the other hand, the finite element method is employed to obtain the governing equations in weak form using standard Lagrangian interpolation. Independent assumptions are taken for each layer of the laminated beam through a layerwise distribution of the unknowns, and the interlaminar continuity of the transverse stresses is imposed a priori by ensuring piecewise continuous fields in the thickness.
direction. A set of locally defined, hierarchical Legendre polynomials is chosen for the expansion of the variables over the cross-section surface, enabling the user to refine the model in particular zones of interest and to control the accuracy of the stress analysis through the polynomial order of the theory of structure. The numerical assessment of the proposed mixed elements for multilayered problems is carried out by comparison against benchmark solutions of the literature, including plate formulations and elasticity solutions. The free-edge problem is also addressed to show the three-dimensional capabilities of the model.

Technical Note: No abstract.

ABSTRACT: The supersonic aeroelastic stability of tow-steered carbon reinforced composite panels, in each layer of which the fibers follow curvilinear paths, is assessed. A structural model based on the Rayleigh–Ritz method, combined with the aerodynamic piston theory, is derived to represent the aeroelastic behavior of rectangular plates under different boundary conditions. In this model, the classical lamination theory, considering a symmetric stacking sequence and fiber trajectories described by Lagrange polynomials of different orders, is used. In addition, manufacturing constraints, which impose limitations to the feasible fiber trajectories, and the effect of in-plane loads are considered in the model. Using a multicriteria differential evolution algorithm, numerical optimization is performed for a variety of scenarios and aimed at increasing the flutter and linear buckling stability margins of tow-steered plates, considering the geometrical parameters defining the fiber trajectories on the layers as design variables. The results obtained for the different optimization scenarios are compared, having a composite plate with unidirectional fibers as the baseline and aimed at evaluating the benefits achieved by the optimum tow-steered plates. The results enable quantification of the stability improvements by exploring fiber steering, which has been shown to be beneficial, even in situations in which manufacturing constraints are accounted for.

ABSTRACT: High-speed flight vehicles operating in extreme environments are likely to undergo significant nonlinear dynamic deformation. The accurate response and life predictions of such structures require methods that enable direct time integration over long portions of flight trajectories, and also require the ability to resolve local stress concentrations. The approach proposed here takes root in displacement-based reduced order modeling to allow for direct time integration. The reduced order models (ROMs) are built using first a ROM constructed over the uncracked structure, whose global basis is augmented with localized enrichment basis functions that are constructed to capture the localized impact of a crack on the displacement field of the structure. The enrichment bases are built using a 3D generalized finite element model defined only in the region of the crack itself. Detailed stress information can also be extracted from the 3D fracture model. The proposed approach is demonstrated on a cracked flat cantilevered blade model, and the benefits of coupling the global basis functions and the localized enrichment bases are demonstrated.

ABSTRACT: This paper introduces a comprehensive analysis tool and framework for studying the structural dynamic and aeroelastic behavior of smart beams. It includes the theory behind the components of this comprehensive analysis tool and a verification of the proposed framework. This tool is used to study the aeroelastic behavior of a smart beam. This analysis is followed by a failure analysis in order to ensure the integrity of the structure under operation. This comprehensive analysis tool couples the variational asymptotic beam sections, geometrically exact fully intrinsic beam equations, and the circuit equation for smart materials. It takes into account the electromechanical coupling behavior of smart materials both in the cross-sectional
analysis and in the one-dimensional generalized beam theory.


ABSTRACT: The present paper aims to study the random static behavior of laminated composite and sandwich plates using nonpolynomial zigzag theories. The nonpolynomial zigzag theories are proposed earlier by the authors, which satisfy the transverse shear-stress continuity conditions at the layer interfaces including the traction-free boundary conditions on the top and bottom surfaces of the plate. These theories incorporate the realistic nonlinear distribution of transverse shear stresses across the thickness of the plate. A probabilistic procedure is developed using a $C^0$ stochastic finite element method that is in the conjunction of finite element method with a mean-centered first-order perturbation technique, to obtain the second-order statistics of deflections of the laminate. The problem is analyzed considering the material properties of laminated composite and sandwich structures to be random in nature while the other system properties are assumed to be deterministic. The stochastic results in terms of mean as well as standard deviation of the responses have been obtained for various combinations of geometric parameters, stacking sequences, span–thickness ratios, and boundary conditions and compared with those existing in the literature and Monte Carlo simulation approach.


ABSTRACT: The goals of this work are to 1) develop an optimization algorithm that can simultaneously handle a large number of sizing variables and topological layout variables for an aeroelastic wingbox optimization problem and 2) use this algorithm to ascertain the benefits of curvilinear wingbox components. The algorithm used here is a nested optimization, in which the outer level optimizes the rib and skin stiffener layouts with a surrogate-based optimizer, and the inner level sizes all of the components via gradient-based optimization. Two optimizations are performed: one restricted to straight rib and stiffener components only, and the other allowing curved members. A moderate 1.18% structural mass reduction is obtained through the use of curvilinear members. A global sensitivity analysis of the topology variables, with and without the effect of the nested sizing variables, is also presented.


ABSTRACT: Pursuing an alternative and effective numerical approximate method for structural analysis problems is always a demanding task for aerospace application. A natural element method is described in this paper. This method has the advantage of circumventing the difficulties of the mesh division and mesh dependency problems over existing finite element method methods. It also exhibits an automatic and optimal choice for the shape function and the imposition of essential boundary conditions as compared with other meshless methods, thus making it a robust method for solving mechanics problems such as buckling analysis and the free vibration of composite structures. The critical buckling loads and natural frequencies with their associated modes for several composite plates are determined, and the results are compared to the analytical solutions based on the first-order shear deformation theory. The proposed method is proved to have a good computational accuracy for composite plate analysis with various boundary conditions, thus demonstrating the fitness and flexibility of this approach and a promising perspective for solving structural analysis problems of composite structures.

ABSTRACT: Thermoplastic composites offer the potential for reducing the overall manufacturing costs of aircraft structures by allowing continuous production methods to be applied without the ancillary need for ovens or autoclaves by using in situ consolidation techniques. In the last 10 years, carbon-fiber/polyether-ether-ketone-based composites have become available with desirable combinations of strength, stiffness, and toughness properties. By combining the latest manufacturing techniques with these new materials and with new design methods, cheaper, lighter, and better-performing aircraft structures become a viable prospect. As such, a variable-stiffness unitized integrated-stiffener thermoplastic composite wingbox was developed, which was manufactured by laser-assisted automated tape placement with winding and in situ consolidation. The wingbox loads were determined by assuming its location to be at 85% of the wing semispan of a B737/A320-size aircraft. At this load, the wingbox was designed to buckle elastically. A full-scale structural test using a bespoke testing frame with representative bending moment and shear load was undertaken. Indeed, the wingbox buckled elastically at a load close to that predicted numerically. The current results highlight the potential advances that become possible in primary aerospace structures by combining fiber steering and in situ consolidation of carbon-fiber thermoplastic composites together with new blended, unitized structural concepts.

ABSTRACT: (none for a technical note)

ABSTRACT: Magnetic field and thermal loads are present in the operating environment of jet engine parts such as turbine rotors. Therefore, their influence on the burst velocity of rotors is worthy of investigation. The present paper addresses the analysis of rotational elastic instability in heterogeneous disks having variable thickness under magnetic field and thermal loading. Inclusion of the radial displacement in the centrifugal force indicates rotational instability at certain angular velocities. Closed-form expressions for the displacement and stresses are not possible due to variable material properties, thickness profile, thermal expansion, and conduction coefficients of the disk. The Complementary Functions Method is adopted as a numerical solution scheme. The results are obtained in terms of nondimensional parameters to achieve high accuracy with few collocation points. The burst velocities under influences of magnetic field and thermal loads are calculated. Distributed hoop stresses are also plotted against angular velocity for different magnetic intensity and temperature changes. It is concluded that magnetic field has a stabilizing effect on the rotating heterogeneous disk and the influence of thermal load is negligible in the rotational stability analysis.

ABSTRACT: In a traditional multidisciplinary design optimization loop for complex-shaped structures, the regeneration of structure geometry and its associated analysis grids may be unsuccessful or of poor quality, which will reduce the result validity and efficiency of multidisciplinary design optimization. In this paper, an improved multidisciplinary design optimization method based on parameterized free-form mesh deformation is proposed. Using this method, the analysis grid can be directly updated with high quality instead of regenerating the geometry model when design variables change during optimization. To achieve the mesh deformation of a blade in a single turbine stage, three-dimensional control volume needs to be constructed using two-dimensional control planes at different blade heights, where the control points in the two-dimensional control plane are arranged and parameterized according to the definition of profile design variables. The grids for both computational fluid dynamics and structural analysis are controlled by the same control volume to ensure grid consistency on the fluid-structure interface. Results for an example single turbine stage show that the proposed method can guarantee good controllability and high grid quality when updating design variables in optimization loop. Multidisciplinary design optimization for the single turbine stage is performed, and the optimization results indicate a significant improvement of isentropic efficiency and turbine blade fatigue life. Therefore, the proposed multidisciplinary design optimization method based on parameterized mesh deformation provides an efficient tool for the design of complex and high-performance engineering structures.

ABSTRACT: The paper presents the derivation of a modal nonlinear structural model and its coupling with a nonlinear aerodynamic model for static aeroelastic analysis of highly deformable configurations. The structural analysis, intended for geometrically nonlinear structures, computes the deformations of a beamlike structure by dividing it into a few segments. Large deformations are treated as the sum of large, rigid-body displacements of the segment plus small, elastic deformation within the segment. The latter are computed using a modal approach, where the natural modes of each segment are calculated with augmented large fictitious masses to improve the coupling between segments. The use of a modal method in a large-deformation case introduces difficulties in the application of compatibility equations, which are explained and addressed in the paper. The nonlinear aerodynamic model is an equivalent strip theory, in which each section is assigned a database of aerodynamic coefficients. Both the aerodynamic and structural models are suitable for beam-like wing structures and are highly computationally efficient. The numerical examples include three loading cases that validate the implementation of the methodology and demonstrate its use for static aeroelastic applications.


ABSTRACT: Different levels of structural modeling fidelity are evaluated against experimental results for the local aeroelastic stability boundaries of an internally pressurized circular cylindrical shell. Finite-element analysis is used to inform a modal approach taken to model the structural dynamics. Third-order piston theory is used to model the external and internal surfaces’ unsteady aerodynamic pressures. Results are used to drive model improvements of free-flight aerothermoelastic simulation in order to predict aeroelastic instabilities in a representative supersonic/hypersonic vehicle. The stability of a finite-element cylindrical structure when inclined to the flow is also considered to inform future work in which a cylindrical high-speed vehicle is required to perform maneuvers.


ABSTRACT: This paper evaluates the applicability of the stochastic method to membrane-wrinkling problems. The stochastic method is used to compute a conservative upper bound of structural responses for membrane-wrinkling problems based on measurements at selected points. An empirical tolerance limit, which is defined as the value that exceeds the possible structural responses for at least a proportion of $\beta$ among all values with a confidence level of 50% ($P_{\beta/50}$), was applied. The spatial distribution of the wrinkled-membrane distortion, presented by point-to-point variation in the out-of-plane displacement at various points on the membrane surface, was investigated through a wrinkling analysis based on shell theory. A practical method for computing a conservative upper bound of the wrinkled-membrane distortions based on measurements at selected points was then proposed and evaluated for the wrinkling phenomena in three membrane models: a rectangular membrane under shear and tension loadings, a stretched circular membrane with a rotating center hub, and a square membrane subjected to corner tension loads. The calculated upper bounds approximately enveloped the wrinkled-membrane profile, confirming that this method provides a new and simple statistical approach for estimating highly nonlinear wrinkling behavior.


ABSTRACT: Compared to straight fiber path laminates, variable-angle tow (VAT) laminates are known to redistribute the in-plane stress resultants for improving structural buckling response. The VAT laminates can also be used to improve the free vibration response by tailoring the structural elastic stiffness. This paper studies the prestressed vibration response of a stiffened, VAT laminated plate under a uniform end shortening. Because there are both spatially dependent stiffener and fiber path orientations for a stiffened, VAT laminated plate, a separate modeling of the plate and stiffeners is considered. This method avoids placing common nodes at stiffener–plate and stiffener–stiffener interfaces. This allows one to study mesh convergence for the plate and the stiffeners, separately. It also improves the efficiency and robustness of the finite element model. The finite element code based on the present method is verified extensively using examples that are either available in
literature or are analyzed using commercial software. Parametric studies show that, depending on the in-plane load and boundary condition, the VAT laminates with linearly varying (LV) fiber paths can increase the prestressed vibration fundamental frequency when compared to the straight fiber path laminates. Optimization studies found that using nonlinearly varying fiber paths, when compared to the LV fiber paths, causes a significant increase in the buckling load but only a slight increase in the case of free or prestressed vibration fundamental frequencies. The VAT laminates appear to mainly tailor the panel’s elastic stiffness for improving the prestressed vibration response for the stiffened plates with clamped edges. However, for the simply supported stiffened plate, the VAT laminates are mainly used to change both the elastic and geometric stiffness matrices for improving the prestressed vibration response.

ABSTRACT: This paper studies weight minimization of a composite flying-wing aircraft using bioinspired arbitrarily shaped spars and ribs, known as SpaRibs, for the internal structural layout design. A generalized mathematical model is developed to parameterize the shape of SpaRibs using a four-node nonuniform rational basis spline curve. Additionally, for reducing weight, composite structures and lift redistribution using multiple control surfaces are considered. A stacking sequence table is used to parameterize the wing laminate configuration with ply drops for flexible wing design. For the optimization problem including topology as well as discrete and size design variables, a bilevel programming optimization is employed by using a previously developed parallel particle swarm optimization and a gradient-based optimization, respectively, for the upper- and lower-level optimization problems. The upper-level optimization problem is employed to satisfy such design requirements as the flutter constraints for achieving a specific body freedom flutter mode. The lower-level optimization is used to optimize the control surface rotations to minimize the wing root bending moment, which is considered to be a surrogate for wing weight. Different internal structural layouts and flutter constraints are studied for comparison. Optimization studies show that using SpaRibs for aircraft wing box internal structural layout design can reduce the wing weight by 21.8% as compared to the base model and by 7.3% as compared to the wing box with traditional straight spars and ribs. The additional specific flutter result constraints lead to a 4.2% increase in the wing weight for aircraft design with SpaRibs as compared to the one obtained only with the lower bound on the flutter speed.

ABSTRACT: Problems related to mathematical modeling and optimal active control of pretwisted adaptive blade are considered. The blade is modeled as a rotating thin-walled composite beam embedded with anisotropic piezo-composite layers accounting for nonclassical effects, such as transverse shear and warping inhibitions. The linear-quadratic-regulator feedback control strategy is adopted to study the tailoring of piezo-actuators on vibration suppression. Control authority of piezoelectrically induced transverse shear and bending coupling is highlighted. Tailoring studies using the present model reveal that piezoelectrically induced transverse shear plays an important role on control effectiveness. In addition, the relations between the control authority and the elastic couplings, piezoelectrically induced actuation couplings, pretwist angle, and size and position of piezo-actuators are investigated.

ABSTRACT: Approximation errors due to using reduced-order, instead of full-order, models in the nonlinear flutter problem of variable-stiffness composite laminates (VSCLs) are qualitatively and quantitatively discussed. These VSCLs are made of composite laminates with curvilinear fibers. A third-order shear deformation theory (TSDT) and a p-version finite element are used to model the laminate and discretize its displacements and rotations. The VSCLs are subjected to a supersonic airflow and the aerodynamic pressure is approximated using the linear piston theory. The equations of motion of the self-excited vibrational system are
formed using the principle of virtual work. In this study, static condensation and/or a modal summation method are used to reduce the number of degrees of freedom of the full-order model. The equations of motion are solved using a method to calculate the amplitudes of limit-cycle oscillations (LCOs), and to study the dynamic responses, stresses, and damage indexes based on a failure criterion. Approximations are calculated for LCO amplitudes of VSCL plates with various boundary conditions, laminate thickness, and initial deflection (geometric imperfection). Viscous damping can have a major importance in this problem, and the approximation errors are discussed when viscous damping is included or excluded from the equations of motion.


ABSTRACT: This paper focuses on the vibration and damping analysis of three-layered sandwich cylindrical shells with stiff composite face layers and a viscoelastic core. The equations of motion and boundary conditions governing the free vibration are derived by using the Hamilton’s principle. Then, generalized differential quadrature method is used to solve these equations to obtain the natural frequencies and modal loss factors. Results are validated against the ones that already exist in the literature and performed finite element method analyses of current study. In addition, a parametric study is performed for a sandwich shell with carbon fiber–reinforced plastic face layers and a frequency-dependent viscoelastic core. A 10-parameter fractional derivative model is used to represent the viscoelastic behavior of the core layer. The effects of system parameters, that is, layer thicknesses, the orientation angle of the face layers, and the subtended angle on the vibration and damping characteristics of open cylindrical shells, are investigated in detail. The vibration and damping analyses of sandwich shells with frequency-dependent viscoelastic core are performed for the first time to the best of the authors’ knowledge.


ABSTRACT: Variable-stiffness laminates have lately drawn attention because they offer potential for additional structural performance improvements. In the optimization studies, laminate stiffness properties can be described efficiently by using lamination parameters, which is a well-established formulation for constant-stiffness laminates. However, ensuring manufacturability in the design of variable-stiffness laminates with lamination parameters is difficult. In this paper, a novel method for the design of variable-stiffness composite panels using lamination parameters is proposed. The method constrains the design space by controlling the magnitude and direction of change for the lamination parameters, and subsequently leads to a smooth change in the fiber angles. The method is used to maximize the fundamental frequencies of several panels as example cases. The solutions are calculated for various panel geometries and boundary conditions using the developed finite element analysis software. After finding optimal lamination parameter distributions, corresponding discrete fiber angles and fiber paths are retrieved, and the minimum radii of curvature are calculated. The results demonstrate that the proposed design method provides manufacturable smooth fiber paths while using the compact stiffness formulation feature of lamination parameters.


ABSTRACT: Composite laminate stiffened panels are often used in aircraft fuselage design because of their favorable properties. To assess the failure load of these thin-walled structures and to exploit their reserves, a reliable simulation capability for their postbuckling behavior is often necessary. To perform a realistic failure analysis and to accurately detect final collapse, material degradation should be considered. Global-local approaches are computationally efficient techniques to perform a progressive failure analysis and to examine localized damaged areas in detail. In this paper, a two-way coupling global-local approach is presented, including a combination of different damage modes, such as matrix cracking, fiber damage, and skin-stringer debonding. An accurate exchange of information concerning the damage state between global and refined local models is performed. From the global to the local model, the displacements are transferred through a
submodeling procedure. Afterward, the degraded material properties obtained from the local model analysis are returned to the global model with a special mapping technique that accounts for the different mesh sizes at the two levels. The two-way coupling procedure is applied to the progressive failure analysis of a one-stringer composite panel loaded in compression. Finally, the numerical results of the procedure are compared with experimental results.


ABSTRACT: (None given for Technical Notes)


ABSTRACT: This paper investigates the consistency and compatibility of various assumptions and strain measurements in a large displacements/geometric nonlinear analysis of beams and thin-walled structures. For this purpose, a refined beam model with enhanced three-dimensional accuracy is employed in a total Lagrangian scenario. This model is developed in the domain of the Carrera unified formulation, which allows expression of the nonlinear governing equations in terms of fundamental nuclei. These nuclei are independent of the theory approximation order; thus, low- to high-order theories of structures can be implemented with ease. Various numerical problems are addressed, and solutions are provided by using a classical finite element method and a Newton–Raphson linearization scheme. Given the intrinsic scalable nature of Carrera unified formulation, investigating the effects of the various nonlinear strain components is straightforward. It is demonstrated that the full Green–Lagrange strain tensor produces good approximation in case of large rotations, postbuckling, and nonlinear couplings. In contrast, approximations may be reasonable as moderate displacements and simpler problems (for example, slender beams under flexure) are considered.


ABSTRACT: The functional reconstitution technique is used for the first time to theoretically and a priori assess the numerical performance of Reissner’s Mixed Variational Theorem in the case of linear quadrilateral finite element, Generalized Unified Formulation, and composite materials. From the finite element discretization, the semi-complementary energy is reconstructed in integral form. Analytical expressions for the exact and spurious terms are obtained. Using the elasticity solution for a simply supported plate, it is numerically shown that these spurious contributions do not significantly alter the quality of the approximation of the total level of energy, with overall excellent computational performance. On the other hand, when the starting functional is the strain energy and the principle of virtual displacement is adopted, the finite-element-introduced additional terms and in particular the contributions associated to the transverse shear stresses are demonstrated to add a very large error, which is a priori proven to be eliminated with selective integration. The presented technique could be extended to analyze the performance of other finite elements (e.g., higher-order triangular ones) within Reissner’s Mixed Variational Theorem and Generalized Unified Formulation.


ABSTRACT: This work studies the instability (flutter) and poststability oscillations of an elastic shallow shell in a supersonic gas flow. The only available experimental results for flutter of a shallow shell with clamped edges are provided by Anderson. A comparison between theory and experiment is a novel and important contribution of this work. The nonlinear vibrations of a rectangular isotropic thin curved shell in supersonic airflow are studied to find the flutter speed and the limit cycle oscillations beyond the flutter boundary. Using the Galerkin method and the piston theory aerodynamic model for supersonic flow, the flutter and postflutter characteristics of the panel have been analyzed. Panel vibration frequencies and flutter dynamic pressure have been determined and compared with experimental results.

ABSTRACT: Light-activated shape-memory polymer (LaSMP) is a novel shape-memory material whose Young’s modulus can be manipulated with high-energy light irradiations. This study focuses on the frequency control of LaSMP-laminated simply supported thin plate by light-induced actuations. The governing equation of thin plate covered by LaSMP patch with arbitrary distribution is derived. The controlled frequency is solved numerically based on the Rayleigh–Ritz method and degenerates to an analytical solution of the fully laminated plate. The finite element method (FEM) is used to validate numerically solved analytical solutions, and FEM results are compared favorably with those solutions. Based on the numerical results of thin plate with partly covered LaSMP, the influences of LaSMP size and location on frequency control are investigated. The data suggest that the effect of frequency control is best when LaSMP is placed at the peak amplitude of the mode shapes with larger covering area. This study indicates that LaSMP can be a potential smart material for controlling frequency of thin plates by noncontact light actuations.

References listed at the end of the paper:

ABSTRACT: Accurate modeling of composite structures is important for their safe application under different loading conditions. To provide accurate predictions of three-dimensional (3D) stress fields in an efficient computational framework, in this study, a modeling approach that builds upon the recently developed Carrera unified formulation (CUF): a novel and efficient methodology to develop higher-order structural theories hierarchically via a variable kinematic approach. The concurrent multiscale framework consists of a macroscale model to describe the structural level components interfaced with efficient CUF micromechanical models. Such micromechanical models can take into account the detailed architecture of the microstructure with high fidelity. The framework derives its efficiency from the capability of CUF models to detect accurate three-dimensional-like stress fields at reduced computational costs. This paper also shows the ability of the framework to interface with different classes of representative volume elements and the benefits of parallel implementations. The numerical cases focus on composite and sandwich structures and demonstrate the high fidelity and feasibility of the proposed framework. The efficiency of the framework stems from comparisons with the analysis time and memory requirement against traditional multiscale implementations.


ABSTRACT: This paper presents a novel multiscale framework based on higher-order one-dimensional finite element models. The refined finite element models originate from the Carrera unified formulation (CUF): a novel and efficient methodology to develop higher-order structural theories hierarchically via a variable kinematic approach. The concurrent multiscale framework consists of a macroscale model to describe the structural level components interfaced with efficient CUF micromechanical models. Such micromechanical models can take into account the detailed architecture of the microstructure with high fidelity. The framework derives its efficiency from the capability of CUF models to detect accurate three-dimensional-like stress fields at reduced computational costs. This paper also shows the ability of the framework to interface with different classes of representative volume elements and the benefits of parallel implementations. The numerical cases focus on composite and sandwich structures and demonstrate the high fidelity and feasibility of the proposed framework. The efficiency of the framework stems from comparisons with the analysis time and memory requirement against traditional multiscale implementations.


ABSTRACT: This paper presents a computationally efficient concurrent multiscale platform to undertake the nonlinear analysis of composite structures. The framework exploits refined one-dimensional models developed within the scheme of the Carrera unified formulation (CUF), which is a generalized hierarchical formulation that generates refined structural theories via a variable kinematic description. The CUF operates at the macro- and microscales, and the macroscale interfaces with a nonlinear micromechanical toolbox. The computational efficiency derives from the ability of the CUF to obtain accurate three-dimensional (3-D)-like stress fields with a reduced computational cost. The nonlinearity is at the matrix level within the microscale, and its effect scales up to the macroscale through homogenization. The macrotangent matrix adopts a perturbation-based method to have improved performances. The numerical results demonstrate that the framework requires some 50% of the computational time and 10% of memory usage of traditional 3-D finite elements. Very detailed local effects at the microscale are detectable, and there are no restrictions concerning the complexity of the geometry.


ABSTRACT: Accurate modeling of composite structures is important for their safe application under different loading conditions. To provide accurate predictions of three-dimensional (3D) stress fields in an efficient computational framework, in this study, a modeling approach that builds upon the recently developed hierarchical Serendipity Lagrange finite elements (FEs) is employed. The approach provides layerwise (LW) and equivalent single-layer (ESL) models for analyzing constant- and variable-stiffness laminated beam structures. To enhance the capability of the ESL model, two zig-zag (ZZ) functions, namely, Murakami’s ZZ function (MZZF) and the refined ZZ theory function (RZT), are implemented. For constant-stiffness laminated and sandwich beams, the RZT ZZ function predicts the structural response more accurately than the MZZF. However, for variable-stiffness laminated structures, the applicability of RZT remains unknown and its accuracy is therefore tested within the present formulation. Results obtained are validated against 3D closed-form and 3D FE solutions available from the literature. For similar levels of accuracy, significant gains in
computational efficiency are achieved over 3D FE and LW models by using the ESL approach with RZT ZZ functions.

ABSTRACT: In the present research, thermally induced vibration of shallow spherical shells made of functionally graded materials is investigated. The thermomechanical properties of the FGM media are assumed to be temperature dependent. Based on the uncoupled thermoelasticity theory, the one-dimensional heat conduction equation is established. The top and bottom surfaces of the shell are subjected to several types of rapid heating boundary condition. Because of the temperature dependency of the material properties, solution of nonlinear heat conduction equation needs a numerical method. In the first step, generalized differential quadrature method (GDQM) is applied to discretize the heat conduction equation across the shell thickness. Afterward, the governing system of time-dependent ordinary differential equations is solved using the successive Crank–Nicolson scheme. The obtained thermal force and thermal moment resultants at each time step are applied to the equations of motion. The axisymmetric equations of motion, using the first-order shear deformation theory (FSDT) based on the Kármán type of geometrical nonlinearity, are derived with the aid of the Hamilton principle. Using the harmonic differential quadrature method, shell domain is divided into a number of nodal points, and differential equations are turned into a system of ordinary differential equations. To obtain the displacement components at any time, time marching scheme based on the Newmark method is implemented. The obtained highly nonlinear algebraic equations are solved by means of the Newton–Raphson method. Comparison studies are performed to validate the formulation and solution method of the present research. Various examples are illustrated to discuss the influences of effective parameters such as power law index in the FGM formulation, thickness of the shell, temperature dependency, shell opening angle, in-plane boundary conditions, type of thermal boundary conditions, and geometrical nonlinearity on thermally induced response of the FGM shell under thermal shock.

ABSTRACT: An analytical closed-form expression is derived for the shear correction factor of beams with annular cross sections. The beam theory is formulated using the variational asymptotic method, which uses inherently occurring small parameters to convert a variational statement from three-dimensional elasticity to an engineering beam theory without any ad hoc assumptions on the beam kinematics. Comparisons are made with existing solutions in the literature; then, the critical speeds of a rotor are shown to depend not only on the inclusion of transverse shear but also on the choice of the shear correction factor, establishing its importance. The motivation of this work is twofold: first, rotors that can be modeled as beams with annular cross sections are often encountered, and this expression for the shear correction factor can be readily incorporated into any rotor dynamics solver; and second, closed-form expressions, when available, always provide more insight into structural mechanics as opposed to numerical solutions.

ABSTRACT: The present work investigates the nonlinear bending and buckling behavior of carbon nanotubes (CNTs) using variational asymptotic method. Considering a CNT as a slender beam structure, an asymptotically-correct nonlinear continuum beam model is presented. Through the resulting nonlinear moment-curvature relationship, the model captures the phenomenon of ovalization of the cross sections and local buckling of the CNT, which arises due to their geometrical nature. Further studies are performed in order to explore the effect of CNT wall thickness on the nonlinear bending behavior of the CNT structure. It is shown that the continuum modeling approach can capture the ovalization and further localization of the CNT
deformation under bending. The study aims to provide a reduced-order modeling framework analyzing the inherent nonlinearities associated with the geometrical nature of CNTs.


ABSTRACT: Free vibration analysis of rotating composite strip with delamination is presented. The analysis is based on the framework developed using variational asymptotic method, which is used to reduce the three-dimensional (3D) composite strip with delamination problem into a two-dimensional (2D) cross-sectional analysis and a one-dimensional (1D) problem. This approach, in combination with the sublaminate method, delivers homogenized nonlinear cross-sectional stiffness of the delaminated strip with explicit delamination representation. For the purpose of free vibration study, only the linear cross-sectional stiffness obtained from zeroth-order analysis is used in the 1D problem. The 1D problem is set up by using the Hamilton’s principle to derive the dynamic equilibrium equations of motion of a rotating composite strip used in the determination of its natural frequencies. The approach presented is applied to composite strips of different layup configurations and delamination size to investigate their effect on the modal behavior of the strips. The efficacy of the results obtained from the model is validated in comparison with experimental data, other theories, and 3D finite element analysis. Apart from being computationally efficient, due to the closed-form analytical determination of the strip cross-sectional stiffness constants, the approach is capable of providing insight into the strip modal behavior by directly relating structural response with appropriate cross-sectional stiffness constants.


ABSTRACT: Most of the engineering structures are built using beams, plates, and shells as the structural elements, and in recent times using laminated composite structures is increasing drastically. The accurate analysis of laminated plate structures is an important responsibility; to this end, there are different ordered theories developed by the research community. The variational asymptotic method developed in a mathematically rigorous method practiced by Prof. Hodges and group to analyze laminated structures promises the accurate analysis. A review of the variational asymptotic method employed in the analysis of laminated plate structures is presented in this paper, along with the brief review on other plate theories. The solution strategies employed by the different plate theories are briefly reviewed. A flow chart or tree structure on different plate theories and different solution strategies are presented as a quick reference for the researchers. The possible research areas or problems to be addressed using the variational asymptotic method in conjunction with different solution strategies are briefly mentioned.


ABSTRACT: Unlike previous works, the present work implements the variational-asymptotic method to develop a generalized Reissner–Mindlin model for composite plates made of inhomogeneous and anisotropic materials. From a mathematical perspective, an equivalent two-dimensional plate model is first constructed through a dimensional-reduction procedure that involves the asymptotically correct energy functional up to second order in small parameters and with no specific restrictions on constituent materials. Next, to obtain a generalized Reissner–Mindlin plate model, a hybrid energy transformation procedure is applied from an engineering perspective. During this procedure, the unnecessary mathematical complexity of partial-derivative terms in the energy functional derived herein and obscure physical interpretations of mechanical boundary conditions in the plate modeling are systematically resolved. To evaluate the accuracy and capability of these procedures, three-dimensional recovery relations are established to predict the three-dimensional fields of the original three-dimensional structure. Several examples from the literature are presented to demonstrate the consistency and efficiency of the proposed approach.

ABSTRACT: A dynamic instability analysis of fiber reinforced composite cantilever beams has been carried out in this study. Both experimental and numerical studies are performed to estimate the flutter speeds. Three different types of composite beams [namely, glass fiber reinforced plastics, aluminum fiber reinforced (glass reinforced aluminum), and multifunctional carbon fiber reinforced composites] have been considered in the analysis. A graphite fiber reinforced polymer matrix composite laminate with dimensions of 320×75×12mm is used in the experiments. The fibers are oriented along 0 deg: that is, along the direction of major dimension of the laminate. The experiments are conducted on three such beams by clamping one end of the beam to a heavy steel frame and leaving the other end free. The natural frequencies, mode shapes, and structural damping characteristics of each beam are estimated using the modal analysis through the fast Fourier transform analyzer. Variation of the damping and the frequency with wind velocity for each beam is illustrated through the v−g and v−f plots. The modal assurance criterion is also verified. Experiments are further continued to perform a dynamic instability analysis by clamping the beam inside the test chamber of a low-speed suction-type wind tunnel. The beam response at various wind speeds is captured through an accelerometer mounted at the tip.

Based on the experiments, the flutter speed of the tested beams is estimated to be around 32m/s. A numerical analysis framework is developed using the ZAERO code to perform the modal and flutter analyses. Numerical results are compared to the experimental results and are found to be in excellent agreement. Therefore, the numerical framework has been further extended to carry out the flutter analysis of the multifunctional composite beams, such as glass reinforced aluminum and plastic lithium–ion battery embedded composite beams. The multifunctional laminated composite beams are observed to have better dynamic stability as compared to the glass fiber reinforced polymer composite beams.


ABSTRACT: In this paper, the stability analysis of the elastic columns subjected to seven different types of the nonconservative force is investigated on the basis of fully intrinsic beam equations. The generalized differential quadrature method is used for the discretization of the first-order intrinsic equations and corresponding boundary conditions. Altogether, four important boundary conditions—simply supported, clamped–simply supported, clamped-free, and clamped-clamped conditions—are considered. Furthermore, the effect of the combined action of an end-concentrated force and a distributed tangential follower force is investigated. To confirm the validity of the proposed intrinsic formulations, the present results are compared with those obtained from classical formulations. Our results reveal that the fully intrinsic formulation is a suitable framework to model nonconservative problems.


ABSTRACT: This study describes the development of an efficient aerothermoelastic computational framework and its application to the aerothermoelastic scaling law development. In the framework, a novel approach is developed for the reduced-order model of the fluid solver, which accounts for nonuniform temperature distribution and geometrical scales using simple analytical pointwise models. Subsequently, a new, two-pronged approach to aerothermoelastic scaling is presented. It combines the classical scaling approach with augmentation from numerical simulations of the specific problem. This enables one to obtain useful scaling information for important quantities that cannot be treated by the classical approach. Finally, the framework is applied to study the effect of flow orientation angle on panel flutter and the development of a scaling law for a hypersonic skin panel configuration.

ABSTRACT: In this paper, the aeroelastic stability of a tailored aircraft wing with different pretwist distributions is investigated. The structure of the wing is modeled using the geometrically exact fully intrinsic beam theory of Hodges, whereas the aerodynamic loads are simulated by an incompressible unsteady aerodynamic model. The governing nonlinear partial differential equations are discretized using a time-space scheme, and the stability of the system is sought by evaluating the eigenvalues of the linearized system. The wings have linear or quadratic pretwist distributions, and the effect of various twist angles on isotropic and tailored wings is investigated. In this study, the effect of pretwist is considered on both the aerodynamic and structural models. Moreover, the effect of wing structure taper ratio in conjunction with the pretwist is investigated. The preliminary results obtained for a wing modeled as a clamped-free beam are compared with those reported in the literature and excellent agreement is observed. It is concluded that the pretwist angle leads to mode coupling and also has a significant effect on the flutter speed of the wing. By pretwisting the wing, the flutter speed of the wing with respect to the clean wing increases until a specific twist value and then decreases. Moreover, adding the pretwist to the wing decreases the flutter frequency. Finally, results highlighting the effect of bend-twist elastic coupling and wing taper ratio in combination with the pretwist angle on the aeroelastic stability of the wing are provided.


ABSTRACT: A mechanism is proposed to suppress the nonlinear flutter and thermal buckling of composite lattice sandwich panels with tetrahedral truss core in supersonic airflow by means of the Winkler–Pasternak elastic foundation. The strain-displacement relations are evaluated according to the von Kármán large deflection and first-order shear deformation theories. The aerodynamic pressure acting on the sandwich panel is formulated by the supersonic piston theory. The nonlinear equations of motion of the structure are established by Hamilton’s principle in conjunction with the assumed mode method. By using the Winkler–Pasternak elastic foundation, an effective method for eliminating the nonlinear thermal buckling of the structure is presented. The natural frequencies of the sandwich panels are validated through comparing with the published results. The parametric investigations on the shearing layer and Winkler parameters are conducted. The influences of several parameters, including ply angle of laminated face sheets, and radius and material properties of the trusses on the nonlinear flutter, and thermal buckling behaviors are investigated. The numerical results attest that the nonlinear thermal buckling effect can be completely eliminated, and the nonlinear flutter of the composite lattice sandwich panels can be effectively suppressed by adjusting the elastic foundation parameters.


ABSTRACT: Hybrid composite materials, which contain more than one type of reinforcing fiber, have been gaining ever-increasing popularity. They can keep superior mechanical properties while greatly reducing the material cost. To fully explore the load-carrying potential, it is crucial to develop a series of corresponding optimization methods for hybrid composites design. In this paper, the concurrent patch optimization of hybrid composite plates is investigated, where fiber orientation, the stacking sequence, and material topology are optimized simultaneously. Discrete material optimization (DMO) is performed to optimize the hybrid composite plates, with the buckling load as the objective and the material cost as the constraint. Because the effectiveness of DMO has been demonstrated to perform the discrete variable optimization of composite structures. Furthermore, an innovative DMO framework based on proper orthogonal decomposition is established to reduce the computational cost, with the aim being to improve the optimization efficiency by
ABSTRACT: With the objective of identifying dominant deformation modes for clamped spherical sandwich shells of different geometries and materials, and especially that of Reissner’s parameter for a shell (RPS) = h/E2R2, the infinitesimal quasi-static deformations are analyzed by using a third-order shear and normal deformable shell theory and the finite element method. For spherical shells subjected to normal tractions on a major surface, the effects are delineated on strain energies (SEs) of the in-plane, out-of-plane, stretching, and bending deformations of the following ratios: span/thickness (a/h); radius of curvature/span (R/a); core to face-sheet thickness (h1/h); and face sheet’s elastic modulus along the fiber axis to that of the core (E/Ec), where h = 2h1 + h2. It is found that, for fixed values of other parameters, the proportions of SEs of bending to that of the total deformations, as well as of the transverse normal to that of the transverse shear deformations, increase with an increase in a/h or a decrease in the RPS. For RPS = 1.4, the SE due to bending deformations of the face sheets equals 29%; and, those due to transverse normal and shear deformations of the core are, respectively, 20 and 5% of the total SE. Thus, one should incorporate transverse normal deformations of the core in the shell theory for such problems. For fixed values of other parameters, the core’s in-plane deformations become more significant than its transverse shear deformations, with an increase in h1/h or a decrease in the RPS. The SE of the core’s in-plane deformations equals 30% of the total SE for RPS ≤ 0.01, suggesting a need to account for in-plane deformations of the core for such shells. The present results provide useful insights into deformation modes for spherical sandwich shells of different Reissner’s parameters.


ABSTRACT: An isogeometric analysis is used to simulate the vibration and buckling problems of functionally graded plates with curvilinear stiffeners and cutouts. The polynomial splines over a hierarchical T-mesh (PHT-splines) inherit the advantages of nonuniform rational B splines, such as capturing exact geometry, making the flexibility of refinement, reducing computational cost, and getting a higher calculation accuracy. Besides, the PHT splines overcome some drawbacks of the nonuniform rational B splines and make local refinement and free gap representation come true. Thus, using the PHT splines as the base of the isogeometric analysis, the local refinements near the cutouts and the connection areas between the stiffeners and plates are realized. The convergence and correctness of the method are verified by numerical examples. The influences of boundary conditions, the cutout radius, the plate thickness, the plate volume fraction exponent, and the stiffener cross-sectional size on the natural frequencies and buckling loads are also studied. The results show that the degradation of the vibration and buckling performances caused by defects in functionally graded plates can be avoided by adding appropriate stiffeners. Thus, certain vibration and buckling characteristics can be gained by changing the shape and size of the cutouts and stiffeners with no weight growth or even weight deterioration.


ABSTRACT: The dynamics of a two-material panel in supersonic flow is studied, with the aim of exploring the possibility of enhancing the stability of supersonic panels. The hybrid panel is longitudinally nonuniform and
consists of a host segment (HS) and a hard ancillary segment (AS). By taking into account the aerodynamic load, aerodynamic heating, and structural nonlinearity, the general nonlinear governing equations of the hybrid panel for different boundary conditions are derived based on Hamilton’s principle. With the use of linearized governing equation, the stability of the panel subjected to supersonic airflow is investigated via finite element method (FEM). By comparing the present results with previous ones regarding a uniform panel in supersonic flow, the reliability of the FEM model is confirmed. The effects of length, position, and material properties of the AS on the flutter and buckling stability boundaries are discussed. Results show that the stability of the current supersonic panel can be enhanced by choosing a proper AS position. This paper also proposes a consistency hypothesis relating the extreme solutions to the inherent function, which could enable us to efficiently achieve the optimized solutions of the mathematical formulations and physically explain the optimal AS position. Furthermore, it is shown that the inherent function for force balance equations corresponds to the potential energy of a mechanical system, and thus the consistency hypothesis could degenerate into the principle of minimum potential energy.


ABSTRACT: The nonlocal three-dimensional vibration analysis of rectangular plates is investigated within the framework of fractional calculus in the sense of the Caputo fractional derivative. To show the effect of the fractional derivative on nonlocality, the frequency spectra of the plates with different boundary conditions and symmetry modes are carried out for the different orders of the fractional derivative \(a\) and different values of the length scale parameter \(l\). The vibration analysis is obtained by the Ritz energy method, whereas Chebyshev polynomials are used as admissible functions. The results of the frequency spectrum demonstrate that the nonlocal effect decreases and the results get closer to the values of the classical frequencies as the order of the fractional derivative approaches the classical derivative \((a \to 1)\).


ABSTRACT: In this paper, a vertical drop test of a full composite fuselage section of a regional aircraft has been presented. This test was performed to investigate the structural response of a prototype of a composite fuselage section as well as the biomechanical response of the anthropomorphic dummies under a vertical crash loading condition. The research activity, carried out within the framework of Metodi di CERtificazione e Verifica Innovativi ed Avanzati (CERVIA) project, allowed collecting suitable amount of data for the assessment of the reliability of numerical models. The test article consists of a composite fuselage section with a diameter of 3445 mm and a total length of 4750 mm. It includes all main structural components, the passengers, and the cargo floor structure. Fuselage section has been also equipped with an aeronautical three-seat row. The accelerations, recorded in different locations, demonstrate that the structure is able to absorb a considerable impact energy amount, thus to mitigate the acceleration levels induced to the passengers.


ABSTRACT: In this research, a new analytical solution for finding the buckling loads of thin orthotropic rectangular plates with different boundary conditions is derived. The methods currently known in the literature for finding the buckling loads of plates are mainly numerical. Although some plates with specific boundary conditions have analytical solutions, a comprehensive analytical method providing analytical solutions that fit all possible combinations of boundary conditions is lacking. The solution method in this study is based on the development of a static solution for a plate. The physical meaning of buckling is the loss of stiffness, and it is found as the value of the in-plane loading intensity at which a zero force on the plate surface will generate infinite displacement. The solution is obtained in series form, and the coefficients are solved to match the edge.
conditions. The solution presented for this plate will fit different boundary conditions of the deflection, slope, shear force, and bending moment along the common edges of neighboring plates. Using this new method, exact buckling loads and the buckling modes of many new cases of classical boundary conditions are found (cases involving clamped, simply supported, guided, and free boundaries). Results are given for several stiffness ratios in both directions of the plate, as well as for unidirectional and several cases of bidirectional loading.

References listed at the end of the paper:


ABSTRACT: This study starts with defining generalized displacements. Together with the assumptions and shear-stress-free conditions, the in-plane displacements of a functionally graded (FG) plate are first mathematically assumed, and then orthogonally decomposed into three terms with the aid of a neutral surface. The generalized stresses are accordingly defined, and the constitutive relations are derived for an FG plate after the generalized strains are measured. The principles of virtual work (PVW) are eventually expressed for FG plate problems. Compared with the previous work in this field, due to the use of frame-indifferent generalized displacements, the in-plane displacements are physically interpreted as tension part, bending part, and high-order bending part. Because of the use of frame-indifferent generalized stresses and generalized strains, mutual
couplings of tension, bending, and higher-order bending are removed in the constitutive relations. More important, the lower-order theory of an FG plate is mathematically correlated with the higher-order theory from the viewpoint of PVW. With these fundamentals, finite element formulations are derived and two kinds of plate elements are constructed. Typical examples show that the elements can yield satisfactory deflection and rotation, whereas the high-order element can also capture the boundary effect of shear force at the clamped edge.

References listed at the end of the paper:
References listed at the end of the paper:


model the gradually changing mechanical properties in a truthful way, the coating is represented by 25 layers consisting of an aluminum core coated with functionally graded material. The elastic modulus and density are

https://doi.org/10.2514/1.J059002

Mindlin Plates with Variable Thickness

[28]

https://doi.org/10.1007/s10483


Applied Mechanics

[23]

[22]

Vol.

[21]

https://doi.org/10.1006/jsvi.1995.0410

Journal of Applied Mechanics

[18]

Journal

[12]

https://doi.org/10.1007/s11012

Part L Journal of Materials Design and Applications


ABSTRACT: This paper presents a theoretical investigation on the free vibration of a symmetric beam consisting of an aluminum core coated with functionally graded material. The elastic modulus and density are varied throughout the thickness of the coating material with both a polynomial and an exponential function, whereas a classical lamination theory is applied to determine the effective elastic modulus and density. To model the gradually changing mechanical properties in a truthful way, the coating is represented by 25 layers of
material, whereas each layer itself is homogeneous and isotropic. To obtain a numerical solution, the Timoshenko finite element model beam theory (which also takes first-order shear deformation effects into account) is used. For this purpose, a finite element code is written in MATLAB and the natural frequencies of the beam are found. A detailed parametric study is conducted to show the influences of the core thickness to beam height ratio ($h/L$), the beam span to height ratio ($L/H$), the exponential function and power law index $n$, and multiple boundary conditions on the natural beam frequencies. It was observed that the studied parameters had a significant effect on the natural frequencies.

References listed at the end of the paper:


ABSTRACT: Light-activated shape memory polymer (LaSMP) is a novel actuator with dynamic Young's modulus and strain when exposed to ultraviolet lights, which can be used in noncontact vibration control. This study focuses on the vibration control effect of LaSMP patches on hemispherical shells with free boundaries. An LaSMP strain variation model is presented with experimental verifications. Based on the strain model, the control forces of LaSMP patches on hemispherical shells are introduced. The FEM method is used to obtain natural frequencies of the free hemispherical shell by solid modeling in ANSYS and proved by comparing numerical results with analytical and experimental results. Using the modal expansion method, the LaSMP vibration control of hemispheres is investigated, and independent modal responses are presented and evaluated. The results indicate that LaSMP patch can control vibrations of hemispherical shells by reducing vibration amplitudes. And the control effect is better for low modal vibration, as the LaSMP-induced strain is relatively smaller. By establishing the relationship between LaSMP actuator forces and modal amplitude reduction, this study offers an analytical tool and procedure for future LaSMP application to vibration controls of flexible structures.

References listed at the end of the paper:

ABSTRACT: To alleviate the flexoelectric stress concentration, an elastic rectangular plate actuated by multiple flexoelectric actuators is evaluated in this study. A line electrode placed on top of a flexoelectric patch and coupled with a bottom surface electrode layer can generate an inhomogeneous electric field when a control voltage is applied, and consequently an internal actuation stress is generated. The objective is to explore the influence of the multiple actuator placements and optimal actuation locations. A multi-actuator mathematical model with any arbitrary actuators is derived. Case studies proved that the influence of actuator locations on the modal force is modal dependent. The optimal actuation location of mode (1,1) indicates all three actuators gathering in the middle of the plate. For mode (2,1), there were two sets of optimal locations located at the peaks of its mode shape, respectively. The multi-actuator method has significant advantages on actuation capability and can alleviate the stress concentrations caused by the single-actuator method.

References listed at the end of the paper:


The finite-element-implemented Koiter’s initial postbuckling analysis has not managed to convince commercial finite element code developers to incorporate it into their codes to benefit structural designers and analysts. Three key obstacles have been identified. With two of them being resolved recently, the present paper addressed the remaining one, namely, the efficient solution of the second-order perturbation equation. A closed-form solution is obtained, which is more computationally efficient than any approach adopted in the past. The closed-form solution is obtained mathematically rigorously, and in the meantime it is computationally efficient. 

The approach applies also to problems where buckling is of multiple modes. The solution procedure established in this paper has been verified and demonstrated through a structural application.

References listed at the end of the paper:

[2] Brush D. O. and Almroth B. O., Buckling of Bars, Plates and Shells, McGraw–Hill, London, 1975 (Fig. 5.18 on p. 186).

ABSTRACT: The dynamic response of thin-walled structures is driven by mass and stiffness distribution. As such, variable-stiffness (VS) composites offer opportunities to tune structural dynamic responses. To this extent, efficient analysis tools become increasingly important for structural analysis and design purposes. In this work, an efficient and versatile Ritz method for free vibrations and linear transient analysis of VS doubly curved shell structures is presented. VS shell structures are modeled as an assembly of shell-like domains. The shell kinematics is based on the first-order shear deformation theory, and no further assumption is made on the shallowness or on the thinness of the structure. The description of the shell is provided by a rational Bézier surface representation, and general surface geometries can be represented. Legendre polynomials are employed to approximate the displacement field, and penalty techniques are used to enforce displacement continuity and kinematical boundary conditions. Classical Rayleigh damping is considered, and solutions are obtained through the Newmark integration. The resulting model allows a wide range of configurations and load cases for multicomponent, VS composite structures to be solved, providing the same levels of accuracy as finite element analysis, yet with a reduced number of variables and simpler data preparation.

References listed at the end of the paper:


ABSTRACT: Nonsymmetric laminates are commonly precluded from composite design due to perceptions of reduced performance arising from in- and out-of-plane coupling. This coupling introduces warpage during cure—leading to raised stresses, together with diminished buckling and load carrying capacity. However, these reduced performance characteristics are rarely quantified and included in the design process; instead the symmetric-only paradigm remains pervasive at the cost of a significantly reduced design space. Warpage is largely driven by mismatch in the coefficients of thermal expansion between sublaminates located above and below the midplane and can be predicted by the classical laminate theory. Acknowledging that all symmetric laminates in multipart structures have build stresses from assembly, it is proposed that subsets of nonsymmetric laminates that translate to similar raised stress levels be considered for design. Challenging this symmetric-only design paradigm would permit greater design freedom and offer new routes to elastically tailor composite structures. Further analysis of structural performance is assessed in terms of reduced loading and buckling capacity.

References listed at the end of the paper:


ABSTRACT: We delineate effects of 1) face-to-core stiffness ratio (FCSR) and mass density ratio (FCDR) in square laminates and sandwich plates and 2) the fiber and transverse direction elastic modulus ratio E1/E2 in cross-ply laminates on the first 12 distinct frequencies found by analytically solving the three-dimensional linear elasticity theory equations and using an equivalent single-layer third-order shear and normal deformation plate theory (TSNDT). Whereas the elasticity equations for simply supported plates are solved by using Srivinas and Rao’s approach, the TSNDT equations are numerically solved by using weighted Jacobi polynomials and the Ritz method. We note that previous studies have generally compared only the fundamental frequency. For [0°/90°/0°/90°/0°] square laminates with a side-length/plate-thickness ratio of 100 (10), the maximum error in the TSNDT predicted first 12 frequencies is less than 0.4% (7%). For a FCSR less than 20, the maximum difference in predictions from the two approaches for the first six distinct frequencies is 5.4%. However, the FCDR has little effect on the difference between frequencies from the two methods. The frequencies and mode
shapes presented herein should help us better understand the dynamic behavior of laminated and sandwich plates and provide benchmark results for others to assess their theories.

References listed at the end of the paper:


Developments No. 35 savings by the proposed PCA method is applied to the design changes of the loads on the ribs are subjected to a reduction by principal component analysis (PCA). In both the subsystem proposed. The proposed method decomposes the wing level and rib optimization. The ribs are the subsystems of the problem. Each rib has a local set of design constraints points.,” Journal of Vibration and Acoustics, Vol. 141, No. 1, 2019, Paper 011018. https://doi.org/10.1115/1.4041216


ABSTRACT: A decomposition strategy for the structural optimization of a fiber-reinforced aircraft wing box is proposed. The proposed method decomposes the wing-box optimization into two levels: a system-level and a subsystem-level optimization. The ribs are the subsystems of the problem. Each rib has a local set of design variables and constraints. The loads on the ribs are the crushing loads caused by the bending of the wing. At the system level, the wing-box skins are optimized while accounting for the effect of the skin design on the loads applied to the ribs. The sensitivity of the rib mass to the applied loads is evaluated using the Lagrange multipliers of the optimized rib design. To enhance the numerical efficiency of the two-level optimization, the changes of the loads on the ribs are subjected to a reduction by principal component analysis (PCA). In both the wing-level and rib-level optimization problems, the level-set strategy for the optimization of composite structures, previously introduced by the authors, is employed. This method permits an advantageous use of coarse and fine finite element models employing a standard commercial finite element code. The proposed method is applied to the design of a composite horizontal tail plane. The accuracy of and the computational time savings by the proposed PCA-based reduction scheme are quantified.

References listed at the end of the paper:


ABSTRACT: The aim of this paper is to deal with the often-occurring mistake in the implementation of the Galerkin method, and its correction. It is shown that the flexural rigidity should be represented as a discontinuous function incorporating a unit step function. This leads to occurrence of the Dirac’s delta function and its derivatives when substituting the flexural rigidity into the governing differential equation.

References listed at the end of the paper:
using a specific literature framework, sub-conditions in classical nonlifting aeroelasticity of plates and shells. Here, within a wave-based finite element framework, sub- and supersonic aerodynamic models are introduced to analyze the effect of self-excited aerodynamic loading terms on the dispersive characteristics of structural waves. The method is validated by using a specific literature test case and is applicable on both isotropic and multilayered flat and curved
structures. The sound transmission is also computed under sub- and supersonic turbulent boundary-layer excitations: the effect of including or neglecting the aeroelastic coupling is discussed.

References listed at the end of the paper:


ABSTRACT: The increasing reliance of aerospace structures on numerical analyses encourages the development of accurate, yet computationally efficient, models. Finite element (FE) beam models have, in particular, become widely used approximations during preliminary design stages and to investigate novel concepts, for example, aeroelastic tailoring. Over the last 50 years, developments in hp-FE methods based on elements of variable size (h) and polynomial degree (p) have helped reduce the computational cost of numerical analyses. Concurrently, many structures, including aircraft wings and wind turbine blades, have gradually increased in length, slenderness, and complexity. As a result, modern blades and wings regularly operate beyond the range of linear deformation, requiring nonlinear analyses for which hp-FE methods are often not readily applicable. The aim of this paper is, therefore, to derive a corotational FE formulation for enriched three-, four-, and five-noded beam elements, suitable for nonlinear hp-FE refinement. To this end, the mathematical formulation is derived to incorporate enriched elements within the corotational FE beam framework. The proposed formulation is then validated against multiple nonlinear benchmark problems and an experimental case study.

References listed at the end of the paper:

and curved panel by varying either the Young's modulus or the thickness of the structure to increase the linear
Young's modulus or the thickness of the structure to increase the linear
a chosen mechanical response
a chosen mechanical response

ABSTRACT:


Sander van den Broek (1), Sergio Minera (2), Alberto Pirrera (2), Paul M. Weaver (2), Elco Jansen (1) and Raimund Rolfes (1)

(1) Leibniz University Hannover, 30167 Hannover, Germany
(2) University of Bristol, Bristol, England BS8 1TR, United Kingdom


ABSTRACT: The effect of stochastic variation in material and geometric properties on structural performance is important for robust design. Knowledge of such effects can be acquired by applying variation patterns to a structure using random fields through a Monte Carlo analysis. The output is postprocessed to show the correlation pattern between the stochastic variation of a structural property and a chosen mechanical response measure. The resulting patterns are used to identify areas most susceptible to variations, as well as areas that have the most potential to increase structural performance by varying the material parameter or geometry. By using these maps of local sensitivity to variations with respect to the structural response, it is possible to redistribute material properties or geometry to promote certain behavior. This is demonstrated on a flat plate and curved panel by varying either the Young’s modulus or the thickness of the structure to increase the linear

Sander van den Broek (1), Sergio Minera (2), Alberto Pirrera (2), Paul M. Weaver (2), Elco Jansen (1) and Raimund Rolfes (1)

(1) Leibniz University Hannover, 30167 Hannover, Germany
(2) University of Bristol, Bristol, England BS8 1TR, United Kingdom


ABSTRACT: The effect of stochastic variation in material and geometric properties on structural performance is important for robust design. Knowledge of such effects can be acquired by applying variation patterns to a structure using random fields through a Monte Carlo analysis. The output is postprocessed to show the correlation pattern between the stochastic variation of a structural property and a chosen mechanical response measure. The resulting patterns are used to identify areas most susceptible to variations, as well as areas that have the most potential to increase structural performance by varying the material parameter or geometry. By using these maps of local sensitivity to variations with respect to the structural response, it is possible to redistribute material properties or geometry to promote certain behavior. This is demonstrated on a flat plate and curved panel by varying either the Young’s modulus or the thickness of the structure to increase the linear

Sander van den Broek (1), Sergio Minera (2), Alberto Pirrera (2), Paul M. Weaver (2), Elco Jansen (1) and Raimund Rolfes (1)

(1) Leibniz University Hannover, 30167 Hannover, Germany
(2) University of Bristol, Bristol, England BS8 1TR, United Kingdom


ABSTRACT: The effect of stochastic variation in material and geometric properties on structural performance is important for robust design. Knowledge of such effects can be acquired by applying variation patterns to a structure using random fields through a Monte Carlo analysis. The output is postprocessed to show the correlation pattern between the stochastic variation of a structural property and a chosen mechanical response measure. The resulting patterns are used to identify areas most susceptible to variations, as well as areas that have the most potential to increase structural performance by varying the material parameter or geometry. By using these maps of local sensitivity to variations with respect to the structural response, it is possible to redistribute material properties or geometry to promote certain behavior. This is demonstrated on a flat plate and curved panel by varying either the Young’s modulus or the thickness of the structure to increase the linear

Sander van den Broek (1), Sergio Minera (2), Alberto Pirrera (2), Paul M. Weaver (2), Elco Jansen (1) and Raimund Rolfes (1)

(1) Leibniz University Hannover, 30167 Hannover, Germany
(2) University of Bristol, Bristol, England BS8 1TR, United Kingdom


ABSTRACT: The effect of stochastic variation in material and geometric properties on structural performance is important for robust design. Knowledge of such effects can be acquired by applying variation patterns to a structure using random fields through a Monte Carlo analysis. The output is postprocessed to show the correlation pattern between the stochastic variation of a structural property and a chosen mechanical response measure. The resulting patterns are used to identify areas most susceptible to variations, as well as areas that have the most potential to increase structural performance by varying the material parameter or geometry. By using these maps of local sensitivity to variations with respect to the structural response, it is possible to redistribute material properties or geometry to promote certain behavior. This is demonstrated on a flat plate and curved panel by varying either the Young’s modulus or the thickness of the structure to increase the linear

Sander van den Broek (1), Sergio Minera (2), Alberto Pirrera (2), Paul M. Weaver (2), Elco Jansen (1) and Raimund Rolfes (1)

(1) Leibniz University Hannover, 30167 Hannover, Germany
(2) University of Bristol, Bristol, England BS8 1TR, United Kingdom


ABSTRACT: The effect of stochastic variation in material and geometric properties on structural performance is important for robust design. Knowledge of such effects can be acquired by applying variation patterns to a structure using random fields through a Monte Carlo analysis. The output is postprocessed to show the correlation pattern between the stochastic variation of a structural property and a chosen mechanical response measure. The resulting patterns are used to identify areas most susceptible to variations, as well as areas that have the most potential to increase structural performance by varying the material parameter or geometry. By using these maps of local sensitivity to variations with respect to the structural response, it is possible to redistribute material properties or geometry to promote certain behavior. This is demonstrated on a flat plate and curved panel by varying either the Young’s modulus or the thickness of the structure to increase the linear
buckling load. In both of these variations the average property is set to remain the same as the original structure. Applying the redistribution increased the linear buckling load by up to 29%.

References listed at the end of the paper:


(No abstract with a Technical Note)
References listed at the end of the paper:


ABSTRACT: Unstable buckling leads to the failure of thin-walled cylinders under axial compression. Because of the manufacturing and loading imperfections, a significant variation was observed between experimental and theoretical buckling load. The current design ...


ABSTRACT: The numerical investigation of the stochastic aeroelastic characteristics of conventional and tow-steered composite laminates subjected to random uncertainties affecting the laminate fiber volume is addressed in the present paper. A computationally ...


ABSTRACT: This study presents the derivation and application of the modal rotations method (MRM), a novel framework for the computation of large deformations of complex wing-like structures using a modal approach. The method targets static analyses of slender structures, accounting for large-deformation nonlinearity. The
input for the analysis is linear modal finite-element-based data. However, the MRM uses modal rotation data, rather than deformation modes. The modal rotations are used for the solution of the nonlinear kinematic problem along with an iterative load-correction procedure that accounts for the geometric stiffening. The method is suitable for cases where the generation of an equivalent beam model is impossible or requires considerable effort, such as structures of multiple different sections, structures having abrupt geometrical changes, and lattice structures. The MRM is verified with three test cases. The first is a simple geometry, a one-dimensional symmetric beam loaded in one plane. The second and third test cases are three-dimensional built-up structures aimed to challenge the method with abrupt geometric changes, orthotropic material coupling, and nontrivial geometries. All test cases yield accurate results compared with nonlinear finite element analyses. Parametric studies present the dependency of the results on different computational parameters and the load magnitude.

References listed at the end of the paper:

ABSTRACT: Motivated by evident absence of studies on doubly curved closed nanocomposite shells under complex thermomechanical loading conditions, this paper presents an analytical investigation on the buckling and postbuckling behavior of the carbon-nanotube-reinforced composite toroidal shell segment surrounded by an elastic foundation, exposed to preexisting thermal loadings and subjected to axial compression, external pressure, and combined mechanical loads. Carbon nanotubes are reinforced into the matrix phase through uniform or functionally graded distributions. The material properties of the constituents are assumed to be temperature dependent, and the effective properties of the nanocomposite are estimated by an extended rule of mixture. Two temperature conditions and various situations of mechanical loads are considered. Basic equations are established within the framework of the classical shell theory taking into account the geometrical nonlinearity and surrounding medium-shell interaction. Multiterm solutions of deflection and stress function are assumed to satisfy simply supported boundary conditions, and the Galerkin method is applied to obtain nonlinear load-deflection relations from which buckling loads and postbuckling paths are determined. Numerical examples are carried out, interesting discussions are given, and beneficial and deteriorative effects of various factors are analyzed.
References listed at the end of the paper:
ABSTRACT: Nonlinear reduced-order models are being investigated for use as digital twins for advanced aircraft and spacecraft. In concept, the digital twin would be tuned to accurately describe the behavior of the vehicle, and then it would be updated as the vehicle is modified or ages. Unfortunately, the linear model correlation and validation techniques that are commonly used in the aerospace industry are not valid for nonlinear models, so a new set of tools is needed. This work presents an algorithm to update geometrically nonlinear reduced-order models using nonlinear normal modes as a correlation metric. The nonlinear normal modes serve as a strong metric to correlate the numerical models because they can be extracted from experiments, and they describe the dynamics of the nonlinear system over a range of amplitudes and are independent of the loading applied to the system. This paper presents a novel method of computing analytical gradients of nonlinear normal mode solutions with respect to system parameters using the multiharmonic balance method. The procedure is first tested using numerical simulations and then applied to tune the reduced-order model of a curved beam based on nominal blueprints and idealized boundary conditions to match a nonlinear normal mode that has been measured experimentally from a three-dimensional printed test specimen.

References listed at the end of the paper:


ABSTRACT: Damping characteristics of three-layered sandwich cylindrical shells with the focus on mode switching phenomenon are investigated in the present study. All layers of the sandwich cylinder are formulated based on the first-order shear deformation theory. Considering the von Karman strain displacement relations, the nonlinear equations of motion are derived through Hamilton’s principle. By separating the displacement components into previbration and vibration states and substituting in the obtained nonlinear equations of motion, the previbration equilibrium equations and vibration equations of motion are obtained. The acquired equations are solved by applying the generalized differential quadrature method. The method is validated by comparing the obtained results with those available in the literature. The effects of temperature, length-to-radius ratio, and radius-to-thickness ratio on the fundamental loss factor of sandwich cylindrical shells are examined at different boundary conditions. Also, variation of the fundamental loss factor of the sandwich shell with variation in the thickness of the constraining and core layers is investigated. The results show superior effect of the mode shape switching phenomenon on the fundamental mode loss factor variation. Temperature rise results in significant reduction of loss factor values. Depending on boundary conditions, the length ratios at which mode shape switching occurs may remain constant or change with increasing the temperature. Some new results are also reported to serve as benchmarks for future studies of such structures.

References listed at the end of the paper:


In this paper, the wing box of an aircraft is optimized using a level set topology optimization method and considering aerostructural coupling. A new level set method is developed where the design domain and the finite element analysis domain are represented by two separate meshes, and coordinates and sensitivities are transformed from one mesh to the other mesh using an isoparametric map. This method is applied to minimize the compliance and tip displacement of a tapered and swept wing box subjected to aerodynamic loads. The wing box is modeled using 1.47 million isoparametric hexahedral elements, whereas the skin (which is nondesginable) is modeled using shell elements. The results show that the optimizer exploits the aerostructural coupling properties and tailors the lift distribution to yield stiffer wing boxes. Moreover, the results also show that ignoring aerostructural coupling leads to suboptimal designs.

References listed at the end of the paper:


ABSTRACT: The focus of this investigation is on modeling uncertainties on the structural and thermal properties of heated structures and assessing their effects on the resulting temperature distributions and structural response. This effort is accomplished within the framework of reduced-order models (ROMs) of both the thermal (heat conduction) and structural (nonlinear geometric response) problems relying on the maximum entropy nonparametric approach. Uncertainties are introduced on both the heat conduction and the structural response problems. In the latter, it is in particular shown that the purely structural terms of the ROM governing equations and those associated with the structural–thermal coupling should be randomized jointly. Moreover, this can be done through the construction of a large matrix that includes all of these terms and is shown to be symmetric and positive definite. Several challenges in applying this approach are identified and resolved. Finally, the applicability of the methodology is demonstrated on the response of a simple panel subjected to an oscillating heating flux as an example of strongly coupled thermal–structural problems.

References listed at the end of the paper:


ABSTRACT: To allow an efficient preliminary design, a grid pattern or configuration optimization strategy is proposed for grid-stiffened composite structures under the constraint of sustaining the buckling resistant capability. This is achieved by first introducing a configuration vector for representing stiffeners in a grid unit, which is applicable for the description of iso-grid, ortho-grid X-grid, and bi-grid. The parametric equivalent stiffener model of the structure is derived by the smearing method, and the global and local buckling loads are calculated for the different grid configurations. The artificial bee colony algorithm was used as an optimizer to address the discrete design variable space, including a grid-unit size, height, and thickness of stiffeners that could be specified by designers or manufacturing requirements. Two test examples validated the effectiveness of the approach. The results suggested that both optimal and suboptimal solutions can be considered effectively as design options in the preliminary stage of design for such types of structures.

References listed at the end of the paper:


ABSTRACT: For fixed values of the areal mass density, product of the midsurface curvilinear lengths, and the choice from three unidirectional fiber (glass, graphite, or aramid) reinforced composites for facesheets, one- and two-core doubly curved sandwich shell’s geometries, fiber material, and fiber orientations for the facesheets are found that maximize the first failure load. Also determined are the locations of failure points and stress components significantly contributing to the failure, as well as the effects of uncertainties in values of material parameters on the failure load. The shell’s quasi-static and infinitesimal deformations are analyzed with a third-order shear and normal deformable plate/shell theory, in-plane stresses are found by using the plate theory deformations and transverse stresses using a one-step stress recovery scheme. The Tsai–Wu failure criteria, and honeybees inspired nest-site selection optimization algorithm are employed. Effects of uncertainties in material parameters are quantified by the Latin hypercube method and a statistical software, JMP. The predicted failure load and the failure point location agree well with their experimental values. It is observed that the first failure occurs in a core (facesheet) due to the transverse shear stress (in-plane transverse axial stress) exceeding its critical value. The methodology can be used to design the minimum weight optimal doubly curved multicore sandwich shells.

References listed at the end of the paper:


[34] Reissner E., Small Bending and Stretching of Sandwich-Type Shells, Massachusetts Inst. of Technology, Cambridge, MA, 1949.


ABSTRACT: Studying buckling behavior of large shell structures through full-scale test articles can be complex and expensive. Therefore, reduced-scale structures are often preferred for investigating buckling behavior. However, designing reduced-scale structures that are representative of the full-scale structure can be difficult. An analytical scaling methodology for compression-loaded sandwich composite cylindrical shells based on the nondimensionalization of the buckling equations is presented herein. The methodology was used to develop scaled configurations that show similar buckling responses to the full-scale baseline configuration. Finite element analysis results showed that both a baseline and a scaled configuration buckled similarly, when the nondimensional stiffness, defined as the ratio of the nondimensional load and nondimensional displacement, was matched between the different scale models. Limitations of the methodology are discussed and are believed to be a result of neglecting the flexural anisotropy and the transverse shear compliance. A preliminary material failure assessment for the different scales is also considered.

References listed at the end of the paper:


ABSTRACT: (None given)

References listed at the end of the paper:


ABSTRACT: Free vibrations of thick and skew quadrilateral laminates have been analyzed by using the Ritz method and a third-order shear and normal deformable plate theory (TSNDT) that does require a shear-correction factor. The weighted orthogonal Jacobi polynomials are employed as basis functions that exactly satisfy essential boundary conditions at the plate edges. An in-house-developed software is first verified by comparing computed frequencies with those either available in the literature or found by using the three-dimensional linear elasticity-theory-based finite-element-based commercial software ABAQUS. The method is applied first to find the lowest few (six in most examples) frequencies of isotropic cantilever plates of different skew angles and thickness-to-side length ratios. Subsequently, natural frequencies of laminated composite plates for various skew angles, thickness-to-side ratios, numbers of layers, and stacking sequences are compared with those obtained from converged solutions using either shell or brick elements in ABAQUS. It is demonstrated that the TSNDT/Ritz method provides highly accurate frequencies. Three-dimensional mode shapes are presented for a better understanding of the dynamic behavior of skew quadrilateral laminates.

References listed at the end of the paper:


ABSTRACT: Honeycomb sandwich panels are used in aerospace structures for their high stiffness-to-mass ratio. Reducing structural mass is critical in aircraft and spacecraft development due to its direct impact on payload capacity and operational costs. Typically, hexagonal honeycombs manufactured by cold expansion of periodically bonded strips of metal or foils of other materials are used for sandwich construction. With rapid development in additive manufacturing, other core shapes with higher specific stiffness can now be considered as an alternative. The authors of this paper had previously evaluated triangular cores to have higher or comparable specific moduli as compared with other two-dimensional core shapes. Further, the panels constructed using triangular cores had higher stiffness than traditional hexagonal core panels. To consider practical use of the triangular cores, elastic-plastic structural analysis is performed to evaluate the strength and failure of sandwich panel construction. Load bearing capacity of triangular core panels under three-point bending, in-plane compressive loading, and transverse shear loading is evaluated using finite element software ABAQS/Explicit. The comparison made between triangular core and hexagonal core sandwich panels having the same cell size and relative density showed that triangular cores outperform hexagonal cores for applications where in-plane loading is dominant, whereas, in terms of transverse shear and out-of-plane loading, triangular core panels tend to fail at lower loads and lower deflections.

References listed at the end of the paper:
independent, and parameter by experimental validation under actuation loads. This analytical model represents a robust, efficient, mesh account for stiffness discontinuities. A numerical validation is performed using finite element analysis, followed by experimental validation under actuation loads. This analytical model represents a robust, efficient, mesh-independent, and parameter-driven solution to modeling discontinuous plate structures. These traits make it


ABSTRACT: A parametrically driven structural model based on Mindlin—Reissner plate theory is developed to capture the three-dimensional deflections of a compliance-based morphing trailing edge device with severe structural discontinuities. The model is used to study the Fish Bone Active Camber (FishBAC) device, which is represented as a discontinuous plate structure that captures the step changes in stiffness created by the concept’s geometrical configuration. Courant’s penalty method is implemented in the form of artificial penalty springs to account for stiffness discontinuities. A numerical validation is performed using finite element analysis, followed by experimental validation under actuation loads. This analytical model represents a robust, efficient, mesh-independent, and parameter-driven solution to modeling discontinuous plate structures. These traits make it
useful for ongoing fluid–structure interaction analysis and optimization of the FishBAC concept and also for application to other complex composite structures.

References listed at the end of the paper:


ABSTRACT: (Not given for a Technical Note)


Correction Notice: This correction pertains to multiple errors in the original article when it was first published online [https://doi.org/http://arc.aiaa.org/doi/abs/10.2514/1.J055122]. The correct title should be “Efficient Optimization of Riblets for Drag Reduction over the Complete Mission Profile” as shown here, where “Riblets” replaces “Ringlets” in the original title. The value of “Relative error, % / number 1” in Table 5 should be changed from “-0.17” to “0.17”. The value of “Optimal self-adaptive riblet during the full profile” in Table 8 should be changed from “8.94” to “9.25”. The value of “Difference of average drag-reduction ratio between [S] and [F]” in Table 8 should be changed from “1.54 (20.8 decrease compared to [S])” to “1.53 (20.8 decrease compared to [S])”. The value of “Drag-reduction ratio at cruising condition [S] / London to Singapore” in Table 7 should be changed from “9.48” to “9.63”.


ABSTRACT: A plane vibration study of a sandwich thermal protection system insulation panel with a functionally graded core is conducted. The panel is assumed to be under plane-stress conditions and subjected
The theories and finite elements

Meshfree Boundary

Parameters

Materials Science and Engineering: B

Transform Method

with Soft Core

Improved Dynamic Stiffness Method

Flexible Element Free Galerkin Method

pp.

References listed at the end of the paper:


...To simply supported boundary conditions. The two-dimensional elasticity formulations are used to derive the equations of motion for each layer. The effects of the in-plane normal stresses as well as the shear stress are taken into consideration for all layers. Material properties of layers may vary through the transverse coordinate resulting in a pair of second-order coupled variable-coefficient governing differential equations. The governing equations are reduced to an uncoupled fourth-order differential equation, which is solved by the complementary functions method (CFM). The novelty of the present study includes the vibration analysis of functionally graded core sandwich beam using plane elasticity and implementation of CFM as the solution procedure. The influences of face sheets and core materials and the grading model on the free vibration behavior are studied. The solutions are compared with results available in the literature and those obtained from finite element software (ANSYS) for a three-layered isotropic panel to display the accuracy and efficiency of the presented method. The mode shapes dominated by vertical and horizontal displacements are also depicted. The method that is applicable for both symmetric and unsymmetric beams is shown to be accurate and efficient in the analysis of sandwich panels with a core graded in the thickness direction.


ABSTRACT: With regard to real-world engineering structures, an adjusting mean value called the self-adjusting mean value (SMV) is proposed for improving the efficiency and robustness of a maximum performance target point for evaluating the reliable performance of stiffened aircraft panel. A self-adaptive step size is presented using a merit function by a sufficient criterion, which is determined by using the results of the advanced mean value and the SMV. The abilities of the SMV are compared with several existing reliability methods through two nonlinear structural/mechanical examples. In particular, a practical aircraft panel example is investigated. Furthermore, the influence of self-adaptive parameters in the SMV is discussed on abilities the proposed SMV method for reliability analysis of aircraft panel example. The results demonstrate that the SMV is a robust algorithm for complex structural/mechanical examples, and it is slightly more efficient than the improved versions of reliability methods, which is significant for the reliability assessment of an aerospace structure.

References listed at the end of the paper:


References listed at the end of the Technical Note:


Google the string: “International Journal of Offshore and Polar Engineering”; click on one of the volumes/issues in the upper right-hand corner.

Atsushi Shibayama, Yoshinori Miyagawa, Naoto Kihara and Hideki Kaida (Central Research Institute of Electric Power Industry), “Response of RC walls subjected to tsunami debris collision by nonlinear finite element analysis”, International Journal of Offshore and Polar Engineering, Vol. 29, No. 1, March 2019 ABSTRACT: An experimental and analytical investigation of the response characteristics of reinforced concrete structures subjected to a tsunami wave pressure and debris collision force was performed, as well as verification of the applicability of numerical analysis. Even if the response of the material remained within the elastic range after a single collision, we found that plasticizing by receiving repeated collision forces was
possible. In addition, the nonlinear finite element analysis generally provided the experimental results such as the strain, residual displacement, and crack pattern of the reinforced concrete structure subject to wave pressure and collision force.


ABSTRACT: S-Lay installation of inline buckle arrestors in deep water can introduce plastic strain to girth welds. The welds are repeatedly loaded by large-strain cycles when traversing the stinger. A material-testing program was launched to assess the impact of this load sequence on the welds’ integrity. It is essential to establish the correct mechanism of crack growth caused by a limited number of sequential large-strain cycles. Segment specimens with increased specimen “daylight” length were tested. Fracture morphologies of ductile tearing and fatigue growth were distinguished; ductile tearing was identified only for the first load cycle, whereas subsequent cycles were dominated by fatigue crack growth.


ABSTRACT: Three-dimensional finite element (FE) analysis of axial–vertical interaction behavior of buried pipelines in dense sand is performed. The commercially available FE software package Abaqus/Explicit is used to accommodate large displacement and to avoid convergence problems. In addition, a user subroutine is utilized to capture the pressure dependent stress–strain behavior of dense sand. The numerical model is verified by comparing the results with experimental results available in literature. The effects of pipeline burial ratio, angle of attack, and pipeline surface roughness are discussed. A normalized axial–vertical interaction diagram is also proposed.


ABSTRACT: A rupture of buckled steel pipes on the tensile side of a cross-section is studied in this paper as the most plausible case of ultimate failure for the pressurized buried pipelines under monotonically increasing curvature. Finite element simulation of full-scale bending tests on two pressurized X80 pipes with different yield-to-tensile strength (Y/T) ratios were conducted. The Y/T ratio and internal pressure were identified as the crucial factors that have a coupled effect on the ultimate failure mode of buckled pipes. That is, the high values of Y/T ratio and internal pressure mutually trigger the rupture of buckled pipes on the opposite side of the wrinkling.


ABSTRACT: The aim of the present paper is to investigate the ultimate strength of stiffened panels under longitudinal thrust. A modified formula is proposed to express the ultimate strength as an equation of two dominant parameters, namely the plate slenderness ratio and the column (stiffener) slenderness ratio. Two undetermined coefficients $a$ and $\eta$ are introduced in terms of material yield stress and plate-stiffener stiffness ratio. To have a full verification of the proposed empirical formula, 221 finite element models of stiffened panels have been developed, and other researchers’ data have been collected for comparison. The proposed formula shows good agreement with the finite element method (FEM) results compared with other methods and can be directly used in the ship design.

Jieung Kim (Seoul National University) | Yongsan Kim (Seoul National University) | Sang-Yeob Kim (Ship and Offshore Technology Center, Korean Register) | Kwang-Min Lee (Hyundai Heavy Industries Co. Ltd.) | Young-Jae Sung (Hyundai Heavy Industries Co. Ltd.), “Experimental Study of Slosh-induced Loads on an

ABSTRACT: The present paper reports an experimental study on the effect of sloshing impact pressure on a small-scale liquefied natural gas (LNG) fuel tank of a container ship. LNG has recently gained attention as a ship fuel because it conveniently satisfies the existing and upcoming requirements for the emission of sulfur oxides, nitrogen oxides, particulate matter, and carbon dioxide. In this study, three-dimensional tank tests were conducted for various filling and motion conditions. The main objective of these tests was to determine the dynamic pressure on the tank walls. The measured pressure data were statistically analyzed, and sloshing-induced pressure values of the two different tanks were compared with respect to different aspects. From this study, the characteristics of sloshing load with respect to the filling condition and tank shape were systematically investigated. Test results were also qualitatively compared with the existing sloshing test data of a conventional LNG carrier.


ABSTRACT: Curved panels are widely used in the fore and aft side shells and circular bilge parts of container ships, which are subjected to complicated load combinations including axial compression, bending, and lateral pressure, particularly in the most critical hull girder vertical bending conditions. In this paper, the nonlinear structural behaviors and ultimate strengths of bilge panels are investigated by performing a series of finite element analyses, and interactions between the loads are also addressed. Meanwhile, variations in geometric parameters and structural scantlings are considered according to practical structural designs. Additionally, the effects of influencing factors such as initial deflections and geometric scantlings are investigated, and closed-form ultimate strength prediction formulae are proposed for curved stiffened plates. The results are representative and can be of reference values for structural evaluations and designs for similar structures.


ABSTRACT: Lightweight cellular materials can effectively improve the crashworthiness of thin-walled structures. To further investigate the potential of honeycomb-filled thin-walled structures, this paper proposed a novel functionally graded honeycomb (FGH) as filler. First, the finite element model of the functionally graded honeycomb-filled tube (FGHT) is established and validated via experimental results. Then, the key factors of FGHT for crashworthiness are identified. The results show that gradient pattern is critical to the crushing response. As for the overall energy absorption capability, we thoroughly examined the effects of gradient exponent n and the thickness range of honeycomb shells. Next, we conducted single and multi-objective optimisation, adopting genetic algorithm (GA) and non-dominated sorting genetic algorithm (NSGA-II), to seek the parameters that deliver overall crashworthiness performance. The Kriging surrogate metamodel was established to formulate specific energy absorption (SEA) and peak crushing force (PCF) in relation to the key parameters. The single objective optimisation revealed that, provided the same PCF, the SEA of FGHT is always higher than uniform honeycomb filled tube (UHFT); the Pareto front obtained from multi-objective optimisation also indicate that FGHT is generally more efficient than UHFT. This paper gives insights on the honeycomb-filled materials to achieve maximum crashworthiness performance.
References listed at the end of the paper:


ABSTRACT: An accurate material model plays a significant role in predicting the progressive damage of fibre-reinforced polymer (FRP) structures. A modified bilinear constitutive model is proposed to describe the stiffness degradation caused by the progressive intra-lamina damage, and has been embedded into the commercial software ABAQUS through the subroutine VUMAT. All coefficients, corresponding to various damage mechanisms, could be identified by specimen tests under typical loading conditions. As a case study, the compression test of a FRP composite tube is carried out and compared with the simulation results obtained by this model to verify the accuracy and versatility in predicting impact energy absorption and peak force as well as failure modes. Compared with other published simulation methods, the proposed model has better versatility, in which the progressive damage control coefficients are stable and insensitive to different types of FRPs.

References listed at the end of the paper:

tubes subjected to axial and oblique quasi static loading, Compos. Part B-Eng. 87 (2015), pp. 1–11.
22 J. Huang and X. Wang, Numerical and experimental investigations on the axial crushing resistance of composite tubes, Compos. Struct. 91(2) (2009), pp. 222–228.


ABSTRACT: The inversion processes of the proposed tubes under axial impact are simulated to investigate the detailed features of crushing process by using the explicit finite element FE code LS-DYNA. To validate the FE results, a new theoretical relation is developed. The validated FE model was then used for the parametric studies, to investigate the maximum crush distance and the effect of impact mass and the geometry parameters (i.e. wall thickness, foam density) on response of free inversion tubes under different strain rate loadings. Finally, a search algorithm combining Latin hypercube design (LHD) points and genetic algorithm is developed to carry out the multiobjective optimisation through the geometrical average method. The optimal design of the foam-filled free inversion tube demonstrates a significant improvement in the crashworthiness over the benchmark designs with the same loading conditions.

References listed at the end of the paper:


ABSTRACT: Thin-walled tubes have long been used as energy absorbing structures, owing to their high specific energy absorption (SEA) capacity. But, they are associated with substantial high values of peak crush
force (PCF). A high PCF results in a high deceleration pulse on the critical components and/or the passengers. This poses serious safety concerns. Even the use of triggers and grooves do not reduce the PCF considerably. To achieve improvement on the safety aspect, the research on the crashworthiness of the cellular truss structures was conducted in this paper. Finite element simulation model was developed by using ABAQUS/Explicit software and validated experimentally with structures fabricated through additive manufacturing. The truss structures were compared to the thin-walled tubes on the basis of their mass, SEA and PCF values. For an equal amount of energy absorption, the truss structures had a higher mass, the PCFs were lowered significantly. The PCFs decreased at a rate 1.5 to 4.5 times faster than the corresponding decrease in SEAs. The example of the crash box showed that the drop in PCF due to the use of truss structure resulted in a reduction of around 5g deceleration at the cost of 1 kg of additional mass.

References listed at the end of the paper:

ABSTRACT: An important, but insufficiently explored load case for sandwich composites is an impact by a small object. This contribution investigates sandwich panels exposed to such an impact event. The sandwich panels consist of carbon fiber reinforced face sheets and three different core structures, among them two types of aluminum foam and one Nomex honeycomb. The forces during the impact event were obtained by optically recording and analyzing the impactor trajectory. The impact deformation was evaluated using X-Ray computed tomography. An energy balance model, previously used for conventional low-velocity-impact cases, was applied to predict the peak force during impact dependent on the impact velocity, including the described data. The comparison to literature and the coherence of the model to the measured values demonstrated the suitability of the model for this load case. A systematic description of the influences of the sandwich composition on the impact behaviour was identified and qualitatively evaluated.

References listed at the end of the paper:
ABSTRACT: In this research, the effect of adding (inner or outer) transverse and longitudinal grooves on the energy absorption characteristics of cylindrical thin-walled tubes under quasi-static axial load", International Journal of Crashworthiness, Vol. 24, No. 1, 2019, https://doi.org/10.1080/13588265.2017.1367356


References listed at the end of the paper:

3. A. Alavi Nia and J. Haddad Hamedani, Comparative analysis of energy absorption deformations of thin walled tubes with various section geometries, Thin-Walled Struct. 48 (2010), pp. 946–954.
ABSTRACT: In vehicle accident reconstruction analyses, approaching with a two-dimensional method has its limits. In this study, the problems identified in calculating the collision speed with the three-dimensional crush volume established in the author's previous research were addressed and the reliability of its results has been improved. Regarding head-on collisions, curve fitting with a large amount of data from National Highway Traffic Safety Administration collision tests was effective in establishing optimal coefficients for various vehicle groups. Additionally, the video data from the recently conducted Insurance Institute for Highway Safety offset collision test was analysed, and based on the analysis results, the collision speed formula was newly established. This has allowed for more accurate speed calculation for offset collisions than using formulas established for head-on collisions.

References listed at the end of the paper:

- 4 Prasad AK. CRASH3 damage algorithm reformulation for front and rear collisions. 1990. (SAE Technical Paper; no. 900098), Warrendale, PA.


ABSTRACT: Crash box design has a substantial importance to reduce the fatalities in a frontal crash. In this study, four different types of multi-cell tubes, namely straight-circular, straight-square, tapered-circular and tapered-square geometries, are considered as energy absorbing components. For each type, seven different cell structures are designed, and the crushworthiness of these designs is assessed based on two different metrics: crush force efficiency (CFE) and specific energy absorption (SEA). When the thickness and the taper angle are fixed, the multi-cell design having the best performance is found to have 165% larger CFE and 237% larger SEA compared to the single-cell design having the worst performance. By varying the thickness, the CFE and SEA performances of the best design can be further increased by 5% and 7%, respectively. Similarly, by varying the taper angle, the SEA performances of the best design with varied thickness can further be increased by 4%.

Impact behaviour of several multi-cell straight and tapered tubes are investigated
All multi-cell models have larger CFE and SEA values than the single-cell models.

Tapered-circular tube has the best, straight-square has the worst crush performance.

CFE of the best multi-cell design is 177% larger than the worst single-cell design.

SEA of the best multi-cell design is 275% larger than the worst single-cell design.

References listed at the end of the paper:


ABSTRACT: The current research focuses on investigation of crashworthiness of the high-strength steel (HSS) columns filled with aluminium honeycomb. In this study, five variants of honeycomb thickness; Thickness-1, Thickness-2, Thickness-3, Thickness-4, Thickness-5 and six variants of honeycomb cell size; CellSize-1, CellSize-2, CellSize-3, CellSize-4, CellSize-5 and CellSize-6 are considered. Numerical analysis is performed for sandwich honeycomb separated by steel plates in HSS crash box and by inducing V-Notch triggers in the honeycomb. It was perceived that energy absorption (EA), specific energy absorption (SEA) and crush force efficiency (CFE) of Thickness-5 increased by 77%, 19% and 60% respectively compared to Thickness-1 and for CellSize-1, increased by 51%, 24% and 38% respectively compared to CellSize-6. Similarly, the crash box filled with V-Notch triggered honeycomb is increased by 10%, 17% and 4% respectively compared to crash box filled with regular honeycomb and 17%, 55% and 7% respectively compared to crash box filled with sandwich honeycomb.

References listed at the end of the paper:
ABSTRACT: In this paper, experimental studies of impact loading on honeycomb sandwich panels filled with polymer foam were investigated. The structural elements used in this research were aluminium plate, aluminium 5052 honeycomb structure and three types of polyurethane foam with densities 56.94 (foam1), 108.65 (foam2) and 137.13 (foam3) kg/m³. Failure mechanisms and damage modes, ballistic limit velocities, absorbed energies due to penetration, specific perforation energy capacity and some structural responses were analysed. The effect of foam-filling on ballistic impact response in these honeycomb sandwich panels was discussed. Also, it could be found that there was an increase in the dynamic strength of the sandwich structure when the honeycomb core was filled with foam. In addition, the findings demonstrated that the sandwich panels filled with the highest density foam (Type 3) had the highest ballistic limit velocity and specific absorbed energy. The specific energy absorption of this structure was 24% higher than the unfilled one.

References listed at the end of the paper:
(Cannot find them in this one case.)


ABSTRACT: In this article, an integrated analytical model is built to predict the damage and compressive strength of multi-layer composite laminates after low velocity impact (CAI). First, the low velocity impact process and the impact damage are simulated. Then, the state of damage is taken as the input for analysing the residual compressive strength. In order to validate these analytical studies, three kinds of multi-layer composite laminates mixed-formed by uni-directional layer HS160SF and woven layer HS220DF are tested good agreements between simulative and experimental results are obtained.

References listed at the end of the paper:

1. Choi HY, Chang FK. A model for predicting damage in graphite/epoxy laminated composites resulting from
ABSTRACT: This paper compares the crashworthiness characteristics of straight functionally graded strength (SFGS), tapered uniform strength (TUS) and classical straight uniform strength (SUS) tubes under axial crushing loading. Based on the numerical simulation, multi-optimisations are performed to optimise the crashworthiness of the SFGS, TUS and SUS tubes. Result of comparative study shows that the SFGS tubes are similar to the TUS tubes to some extent, since both of them have obviously larger CFE value, relatively good comprehensive crashworthiness and more predominant Pareto fronts than the traditional SUS tubes. Nevertheless, obvious differences between SFGS and TUS tubes exist. The relative differences of SEA and PCF for all the SFGS tubes are positive while that of the TUS tubes are negative. Finally, the comparison on Pareto fronts suggests that if the allowable tapered angle is big enough, it is better to employ the TUS tubes with relatively big tapered angle.

References listed at the end of the paper:

...
ABSTRACT: Experimental testing was conducted to study the mechanical behaviour and energy absorption characteristics of single- and bi-layer cups under quasi-static compressive loading. Bi-layer plates were fabricated by explosive welding or joined by adhesive and were formed by a deep drawing process to produce the cup. The tests were performed at a rate of 10 mm/min. The effect of geometric parameters and other apparatus parameters were considered in this study. Results from the experimental tests showed that the layer order of the bi-layer cup significantly influences energy absorption capacities of the cup such that the structures with stainless steel as the outer layer has total absorbed energy and mean crush force 8% and 14% higher, respectively, than those of cups with the aluminium outer layer. Furthermore, it was observed that cups fabricated by explosive welding displayed mean crush force and specific energy absorption 1.5 times greater than those fabricated with adhesive.

References listed at the end of the paper:

ABSTRACT: During the impact process, fuselage frame structures often experience severe crushing due to axial and oblique impact forces. To improve cabin safety, this paper developed an analysis and design algorithm to optimise 2D triaxially-braided composite (2DTBC) frame under dynamic crush-type load. The design methodology integrates three concepts coming from several different communities including numerical simulation, sensitivity analysis-based variable screening and reliability optimisation. Based on a continuous medium mechanics theory, a basic finite element (FE) model coupled with multiple failure modes is built at the macroscopic level previously. Afterwards, the Sobol’ global sensitivity analysis is performed to derive a design variable importance hierarchy. Finally, differential evolution (DE) algorithm is implemented to identify the optimum frame geometry that has maximum energy-absorption capacity. The investigation demonstrates that appropriate redistribution of shape parameters of the frame could enhance its design reliability and crashworthiness, and the higher number of design variables often performs better from the energy-absorption viewpoint.

References listed at the end of the paper:

probability distribution was used. The proposed function of the multi-tube (DD) under oblique loading. To validate the simulation and experimental results, two-parameter Weibull probability distribution was used. The proposed function of the multi-objective optimisation design (MOD)
process was based on the Finite Element Analysis results. The metamodels in were constructed to predict the crashworthiness criteria of specific energy absorption and peak crushing force under oblique impact loading. Also examined in the study were the MOD problems of the two structure types under multiple impact angles using the NSGA II algorithm. The findings from the study determined that the optimal full foam filled double circular tube had better crashworthiness under pure axial loading. While the optimal half foam filled, double circular tube had more space to enhance the crashworthiness under an oblique impact.

References listed at the end of the paper:

- Ahmad Z, Thambiratnam DP, Tan ACC. 2007 Effect of foam filling on the dynamic axial crushing of thin-walled conical tubes. 5th International Conference on Thin-walled Structures, Gold Coast, Australia, Queensland University of Technology.

ABSTRACT: An experimental and numerical investigation has been carried out to compare the ballistic performance and energy absorption characteristics of plate and hemispherical shells made of 1100-H12 aluminium against projectile impact. For direct comparison, the thickness (1 mm) and diameter (68, 100, 150 and 200 mm) of both the target were kept identical. With varying incidence velocity within the range of sub-ordnance velocity, two distinct shapes of nosed projectiles, ogive and blunt, were impacted normally at the centre and crown of the plates and shells, respectively. A pressure gun was employed to perform the ballistic test whereas the numerical simulations were carried out through commercial finite element code ABAQUS and a close correlation between the experimental and numerical findings was observed. The response of both the targets was investigated in terms of failure mechanics, global and local deformation, ballistic limit, residual velocity and energy absorption in plastic deformation against both the projectiles.

References listed at the end of the paper:

- Hibbit K, Sorensen. ABAQUS/explicit user's manual, Dassault systemes. 2007, Rahode Island, USA.

ABSTRACT: The main objective of this study is to investigate the effects of functionally graded thickness (FGT) patterns and cross-sectional shapes (i.e. circular, square and hexagonal) on crashworthiness performance of thin-walled tubes under multiple impact loading angles (0°–30°) by using the nonlinear explicit finite-element (FE) method. In order to show the efficiency of FGT tubes under different impact loading angles, the crashworthiness performances of the FGT tubes are also compared with their uniform thickness (UT) counterparts. At this point, the FGT and UT tubes are designed to have the same height, average cross-section area and weight. In addition, a multigene genetic programming (MGP)-based procedure is first time presented in literature for crashworthiness prediction of thin-walled structures under different impact loadings. To ensure the accuracy of the numerical models, the FE models are validated against both theoretical and experimental results in literature. The results demonstrated that the cross-sectional shapes, gradient exponents and impact loading angles effect the crashworthiness performances of thin-walled tubes, significantly. The simulation results showed that the FGT tubes have a superior crashworthiness performance compared to their UT counterparts especially at high impact loading angles due to the fact that FGT makes possible more folds to be formed and significantly increases the global buckling resistance of tubes. In particular, the SEA values of FGT tubes can reach 93% higher values than that of UT counterparts. The results also showed that the FGT tubes with square cross-section have generally lower energy absorption performance compared with circular and hexagonal ones. Especially, the square FGT tubes have up to 31% lower the SEA values than hexagonal and circular tubes. It is also revealed that the proposed MGP approach is able to predict the crashworthiness parameters with high accuracy.

References listed at the end of the paper:


ABSTRACT: This article concludes some of the important observation regarding quasi-static and dynamic crushing response of honeycomb structure carried out by authors and addressed in the literature. The behaviour of honeycomb structure has been reported through experimentation, mathematical and numerical models. The influence of cell wall thickness, node length, cell size and loading has been studied in detail leading to some important findings which have not been addressed earlier. The crushing responses of honeycomb structure have been studied in both out-of-plane and in-plane loading condition. Moreover, its bending behaviour has also been reported in few studies. Geometrical core configuration and geometric property like cell size, cell wall thickness and node length etc. play a defining role in administrating potential of honeycomb. Relative density was a vital property of honeycomb dependent on cell configuration and geometric properties. Facesheet material and thickness majorly effects the energy absorption capability of the core during dynamic projectile and impulsive impacts.

References listed at the end of the paper (155 references):


· Balawi S, Abot J. The Effect of Honeycomb Relative Density on its Effective Elastic Properties: A Theoretical and Experimental Study. ASME International Mechanical Engineering Congress & Exposition (IMECE); 2006.


...


ABSTRACT: A fluid–structure interaction analysis (FSI) should be performed to confirm the structural soundness of a fuel tank storing fuel against an external impact. In the past, FSI has been constrained from obtaining numerical results due to the requirement for excessive computational resources. Recent computer performance has been dramatically improved, enabling complex numerical analysis. In this study, numerical analysis of a crash impact test for an aircraft external auxiliary fuel tank is performed using FSI. Its purpose is to estimate the possibility of failure of the fuel tank mounted inside the composite container due to crash impact loads. As the numerical results, the fluid behavior inside the fuel tank is investigated and the validity of the load acting on the internal component is verified. Moreover, the structural soundness of the composite container is evaluated using a failure index and it of the fuel tank is evaluated based on equivalent stress.

References listed at the end of the paper:

- Bharatran G, Schimmels SA, Venkayya VB. Application of MSC/DYTRAN to the hydrodynamic ram problem. Structures Divisions, Wright Laboratory, Wright Patterson AFB; 2009.


ABSTRACT: Axial crushing behaviour of the polyurethane foam-filled aluminum cylindrical tubes with shallow spherical caps (combined thin-walled structures) is studied both experimentally and numerically. Non-linear dynamic finite element analyses were carried out to simulate the quasi-static tests. Satisfactory agreements were generally achieved between the finite element model and experimental deformed shapes, load–displacements, fold lengths and specific energy absorptions. Influence of important parameters such as semi-
apical angle, length of cylindrical and spherical caps, diameter and density of foam filler was discussed and the results highlight the advantages of using foam-filled shell of the combined geometry as energy absorber.

References listed at the end of the paper:


ABSTRACT: The drop test of a Boeing–737 fuselage section is modelled using a multibody (MB) with spatial plastic hinge method. The test is simulated in MADYMO to evaluate the structural interaction of the cabin with a stiff auxiliary fuel tank underneath the floor, in a severe but survivable impact condition. The fuselage ribs, cargo door frame, cargo door, and passenger floor with spar webs are modelled using a large number of bodies and universal joints with directional properties to allow for appropriate torsional and bending deformations. The contacts for the fuselage section are modelled using a Hertzian-based contact force model with dissipative damping. The simulation results from the MB approach show reasonably good agreement with those from the experimental test and from a detailed finite element (FE) model. This MB approach then could be a viable tool in modelling occupant and structural deformations for aircraft crashworthiness problems.

References listed at the end of the paper:

ABSTRACT: A comparative study of energy absorption characteristics and distortions between simple and multi-cell thin-walled tubes with various geometrics are examined. Energy has to disseminate to avoid damage and harm during collisions. To diminish the misfortunes from collision, thin-walled tubes are utilised to dissipate the kinetic energy by deformation. For this analysis, simple and multi-cell tubes with different sections were made from aluminium (Al 3003) sheet and then they are subjected to quasi-static axial crushing. From the results, the energy absorption capacity of various tubes were compared and it shows that multi-cell tubes have more noteworthy than that of simple tubes. Moreover, hexagonal multi-cell tubes were retained as most prominent for higher specific energy absorption. This type of columns was found to be effective one to improve the performance of crashworthiness.

References listed at the end of the paper:


ABSTRACT: This paper presents a modified calculation method for the crushing deformation of sheet metals, which is called the three-hinge-line method (THLM). Through developing the folding mechanism of a thin-walled square tube, the effect of the buckling curvature on thin plates is approximately considered by improving...
the original single hinge to three hinges, and a method for calculating the distance between the hinges is given. A program is designed for the solution of this problem. In addition to solving for the average force and energy, the deformation process and force-displacement curves are also included. The accuracy of the THLM can be checked by the finite element method (FEM). The good agreement between the methods shows that the compressive forces are predicted satisfactorily from the results of the proposed uniaxial crushing.

References listed at the end of the paper:


ABSTRACT: In this study, an experimental investigation into the crushing behaviour of one dimensional composite hexagonal cellular structure between two plates has been carried out. The materials have been used
to accomplish the studies are the plain weave E-glass fabric and the epoxy resin. The tested cellular structures are composed of 4 × 1 hexagonal cells with angles varied between 35° and 60°. Various crashworthiness parameters of the tested cellular structures such as crushing load capacity, energy absorption capability and force efficiency were computed and discussed. The crush failure modes of the tested rings were identified and analysed. Results showed that the hexagonal ring angle has a significant effect on the crush failure loads and energy absorption capability. Increasing the cell angle showed a decrease in energy absorption capability and load carrying capacity. Additionally, the cell angle has a remarkable effect on the failure sequence of the ring cells.

References listed at the end of the paper:


ABSTRACT: In the present study, a new analytical model is employed to investigate thin-wall grooved conical tubes under impact loading. In fact, by considering the groove that made on the wall structure, the effects of groove on the process of crushing and absorption ability have been investigated. Crushing of non-grooved cone has been compared with one grooved and then by considering different numbers of grooves and thickness, and variable gradient for cone’s wall is investigated under the axial impact loading. The number of grooves, thickness and cone’s wall gradient are the main variables in this paper. The results of current new model are compared with the finite element simulation results obtained by the ABAQUS code. A good agreement is observed between the analytical and numerical model results. Finally, absorption ability and more control of the process of crushing in conical energy absorbers are optimised by executing grooves on the cone’s wall. The initial peak load and mean axial crushing load are the main factors of the study, which showed that by increasing tension concentration at grooves, the initial peak load and the amount of absorbed energy will decrease, but the decrease in absorbed energy compared to reduction in initial peak load and control and more uniformity of absorber’s crushing can be ignored.

References listed at the end of the paper:


consistent with the case injury reports. The cardiac output during the accident was more intense than the flow rate and wall shear stress. The integrated model predicted aorta isthmus laceration and other injuries simulating left ventricle contraction. This model was further integrated with a human body model to reconstruct methods, aimed to study both kinds of mechanisms si

ventricular beating: a preliminary model for blunt aortic injuries in vehicle crashes”, 1986


ABSTRACT: Blunt aortic injuries are common and severe in motor vehicle crash accidents (MVCAs), but the injury mechanisms, which can be categorised as kinematics and hydrodynamics aspects, remain to be uncertain. In this study, a finite element model was developed for the aorta-heart system with fluid–structure interaction methods, aimed to study both kinds of mechanisms simultaneously. The aortic blood flow was generated by simulating left ventricle contraction. This model was further integrated with a human body model to reconstruct a real car crash case. The aorta-heart model was validated against ventricular volume, blood pressure, velocity, flow rate and wall shear stress. The integrated model predicted aorta isthmus laceration and other injuries consistent with the case injury reports. The cardiac output during the accident was more intense than the physiological output, proving the ability of current simulation approach to capture the blood flow modification by the thoracic compressive loadings during accidents.

References listed at the end of the paper:

· Alavi Nia A, Haddad Hamedani J. Comparative analysis of energy absorption and deformations of thin walled tubes with various section geometries. Thin-Walled Struct. 2010;48:946–954.
· Rahi A. Controlling energy absorption capacity of combined bitubular tubes under axial loading. Thin-Walled Struct. 2018;123:222–231.

ABSTRACT: The fuselage frame, an apron construction of the typical transport aircraft fuselage, manufactured with carbon fibre/epoxy 2D triaxially braided composites, hinders the crashworthy aircraft analysis and design for the complicated failure behaviour under transverse impact loading. To capture the intricate details, the crashworthiness performance is investigated and compared with different damage models including enhanced composite damage model, composite failure shell model and laminated composite fabric model. Based on the continuum damage mechanics and irreversible thermodynamics, the progressive failure behaviour is implemented to predict the damage behaviour. The damaged constitutive equations with damage state variables and Hashin’s criteria are adopted. Results show that the presence of non-physical parameters in the damage models make it challenging to predict the peak and post-peak responses using enhanced composite damage model and composite shell failure models. The laminated composite fabric model demonstrates good functionality to capture the failure sequences and the load response of the frame under transverse impact loading.

References listed at the end of the paper:

Crush tubes made of aluminium alloy H30 in WP condition and stainless steel SS304 grade are employed as frontal energy absorbing structures in road vehicles and they absorb crash energy by plastic deformation. Finite element analysis (FEA) is being used extensively in the early stages of design to study the method and magnitude of plastic deformation precisely ahead of prototyping and testing. Accurate definition of crush tube’s material including its post-yield and damage/failure behaviours forms a fundamental part of FEA for a realistic prediction of crush tube’s response to crash impact loads. Often, for the sake of simplicity or unavailability of data, it is a common practice in numerical simulations to ignore the damage criterion which leads to substantial differences between FEA predictions and experiments. Therefore, this article demonstrates the importance and effect of damage modelling in numerical simulation of crush tube’s material including its post-yield and damage/failure behaviours.

ABSTRACT: Crush tubes are employed as frontal energy absorbing structures in road vehicles and they absorb crash energy by plastic deformation. Finite element analysis (FEA) is being used extensively in the early stages of design to study the method and magnitude of plastic deformation precisely ahead of prototyping and testing. Accurate definition of crush tube’s material including its post-yield and damage/failure behaviours forms a fundamental part of FEA for a realistic prediction of crush tube’s response to crash impact loads. Often, for the sake of simplicity or unavailability of data, it is a common practice in numerical simulations to ignore the damage criterion which leads to substantial differences between FEA predictions and experiments. Therefore, this article demonstrates the importance and effect of damage modelling in numerical simulation of crush tube’s material including its post-yield and damage/failure behaviours.

References listed at the end of the paper:

ABSTRACT: In this article, the crashworthiness of a crisscross-reinforced square honeycomb under out-of-plane crushing was investigated theoretically and numerically. The square honeycomb is formed by the improved crisscrosses. The webs of the crisscross have variable thickness and unequal section length, which make the property of the honeycomb improved. An explicit formulation was deduced for predicting the mean crushing force. A finite element method based numerical analysis model was built to calculate the crashworthiness, and a surrogate model based multi-objective optimisation model was set up for designing the cross-sectional parameters including the thickness and the section lengths of webs. The theoretical prediction results have a good agreement with the numerical results, and the prediction formulation was further modified by the numerical results. The theoretical and numerical results showed the thickness of the crisscross webs greatly affect the crashworthiness. A square honeycomb with high specific energy absorption and low peak crushing force was obtained through optimising the cross-sectional parameters of the honeycomb. The specific energy absorption increases about 70% and the peak crushing force drop over 40% after the optimisation.

References listed at the end of the paper:

ABSTRACT: Energy absorbing structures are very important for safety reasons in automotive industries. Large portion of energy absorption depends on plastic deformation. Metallic frusta are extensively studied as plastic deformable energy absorbers. In this study, the experimental as well as numerical simulation are presented for metallic frusta with linearly varying wall thickness. Specimens are prepared from 6063 extruded solid aluminium shaft, annealed and tested under quasi-static compression. Two semi-apical angles viz. 5° and 10° along with thickness variation manner, resulting in four configurations of frusta are tested and analysed. Increasing the semi-apical angle increases the deformed mass efficiency within the studied range of angles. This also increases the compactness of the deformed material that leads to slight improvement of the specific energy absorption. Simulations are performed using Abaqus 6.14 commercial software. S4, S4R, C3D8R elements are used for modelling the frusta. Detailed analysis is done and results are presented. Among them the element S4R exhibits best simulation features. The simulation results are compared with the experimental results, and both are in good agreement. The best agreement between them is found to be when the frustum diverging and the thinning slope collaborate to initiate the collapse from the same side.

References listed at the end of the paper:

· Parsapour Alia Nia MA. Comparative analysis of energy absorption capacity of simple and multi-cell thin-walled tubes with triangular, square, hexagonal and octagonal sections. Thin-Walled Struct. 2014;74:155–165.
· Gupta PK. A study on mode of collapse of varying wall thickness metallic frusta subjected to axial compression. Thin-Walled Struct. 2008;46:561–571.

ABSTRACT: A combined experimental study and numerical simulation is performed to investigate the effect of core materials on low-velocity impact behaviour of sandwich panels. Dynamic responses of three types of corrugated sandwich panels with the same geometric configurations, which consist of the same CFRP (carbon fibre-reinforced plastic) face sheets, but the different corrugated cores including aluminium alloy, stainless steel and CFRP are investigated in the present research. Reasonably good agreement has been achieved by comparing impact force, energy absorption and failure modes between experimental results and numerical simulation predictions. The present research reveals that fracture stress and fracture strain of the core material have a significant influence on the performances of the sandwich panels under low-velocity local impact, sandwich panels with stainless steel core has the largest capability of load carrying and energy absorption. Conclusions presented in the present research would be used in the development of neoteric lightweight multifunctional smart structures.

References listed at the end of the paper:

ABSTRACT: As an energy absorber, circular tube with wide external circumferential grooves has excellent mechanical properties, and it has been defined as ‘Type B’ grooved tube. In the present work, a novel analytical model of ‘Type B’ grooved tube is proposed by considering the curvature of plastic hinge. In addition, the fitting equation of the maximum angular displacement of a thin-walled section is obtained. The theoretical methodology indicated that both the total energy absorption and mean crushing force depend on the geometric ratios $R/h$ and $h/t$. Based on axisymmetric assumption, a numerical model is established and the corresponding results are validated by a previous research. The theoretical and simulation results of total energy absorption and mean crushing force are compared with research results of previous studies. The conclusion shows that the present analytical model is more accurate to predict the energy absorption and mean crushing force of ‘Type B’ grooved tube under quasi-static condition. The energy absorption performance of ‘Type B’ grooved tube under quasi-static crushing can be improved by designing the thin-walled section as a stocky shape. Moreover, the model can also predict the response of ‘Type B’ grooved tube under dynamic condition when the strain rate sensitivity of material is introduced.

References listed at the end of the paper:

Ping Xu, Hui Zhao, Shuguang Yao, Quanwei Che, Jie Xing, Qi Huang & Kai Xu, “Multi-objective optimisation of a honeycomb-filled composite energy absorber for subway vehicles”, International Journal of Crashworthiness, Vol. 25, No. 6, pp 603-611, 2020, [https://doi.org/10.1080/13588265.2019.1626537](https://doi.org/10.1080/13588265.2019.1626537)

**ABSTRACT:** To meet the requirements of passive safety protection during vehicle collision, a honeycomb-filled composite energy absorber (HFCEA) was designed in this study. A finite element model was established and effectively verified using experimental data. To evaluate the effects of the outer tube thickness, diaphragm thickness and honeycomb strength on the specific energy absorption (SEA) and the undulation of the plateau force (UPF), a polynomial response surface method was employed. To optimise the crash performance of the structure, i.e. to maximise the SEA and minimise the UPF, a multi-objective particle swarm optimisation was performed. A critical honeycomb strength was determined, beyond which the composite structure loses its weight efficiency. The UPF could be
significantly reduced by increasing the honeycomb strength and reducing the outer tube thickness. This shows that the proposed composite structure can serve as an excellent crashworthy device for railway vehicles.

References listed at the end of the paper:


ABSTRACT: In this paper, groups of new homo-polygonal multi-cell tubes are introduced and investigated under both axial and oblique loads via studying the effect of cell growth on energy absorption characteristics. Finite element models have been developed and validated by experimental tests as well as a new developed theoretical procedure for multi-cell tubes. The new developed homo-polygonal multi-cell structures are investigated considering the effect of cell growth to find the most efficient topology. Different polygonal cross-sections including pentagonal, hexagonal and octagonal are considered while each cross-section has cells in corners form that have the same shape as their own cross-section. Obtained results point out that there is a distinct connection between cell’s size and absorbed energy and cell growth could affect the energy absorption characteristics in a perceptible manner. When cells start to manifest in tubes the peak crush force increases and then drops to its original value as cells reaches their maximum possible size. Acquiring the numerical data of all the structures, by using the COPRAS multi-criteria decision-making method, the best structure is distinguished. Next, the best thickness in the best impact angle of crush found using the relevant RSM as an optimisation method.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: The utilisation of fibre reinforced polymers (FRP) in the rehabilitation of steel structures increased in recent years. This article presents the advantages of using carbon fibre reinforced polymers (CFRP) in strengthening of the thin-webbed castellated beam (TCB). The performances of CFRP strengthened TCBs were analysed using finite element (FE) tool ABAQUS. Nonlinear FE analysis was carried out to find the optimum geometrical. Nine different designations of TCBs were arrived based on weld lengths, perforation sizes and strengthening technique (three each). Though all three techniques increased the strength considerably, the third one had much greater efficiency and was more suitable.

References listed at the end of the paper:


ABSTRACT: Modelling of plates with internal defects or cut outs is often an issue in the traditional isogeometric methods and hence extended isogeometric methods are developed. In order to reduce the computational cost involved in extended isogeometric methods based on weak form, a new extended isogeometric hybrid collocation–Galerkin method is proposed in the present paper. The natural frequencies of a homogeneous and functionally graded material plate with internal defects of varying gradient index, sizes and
shapes are obtained using the proposed method. The obtained results are compared and found to be in good agreement with the reference results.

References listed at the end of the paper:


ABSTRACT: An estimation of elastic-plastic stresses and strains is presented for mechanical components, using pseudo elastic analysis based on the deformation theory of plasticity. Analysis of two applications, one under proportional loading and other under non-proportional loading paths using pseudo elastic finite element method, is presented. A rectangular plate with a hole under tension loading and a rectangular plate fixed at one end under bending-tension non-proportional loading are considered for analysis. Pseudo Elastic finite element analysis for proportional loading uses elastic solutions and varies material properties for elements in plastic zone to estimate elastic-plastic solution. A finite element code is developed based on pseudo elastic analysis method. An attempt is made to extend pseudo elastic analysis to analyze bending-tension non-proportional loading problem. Both applications in consideration are assumed to be of Von Mises material and follow isotropic hardening rule with elastic-linear hardening material model. Non-linear analysis of the plate with a hole under proportional tensile loading and that of rectangular plate under bending-tension non-proportional loading are performed in ANSYS and results are compared for validation and are observed to be in good agreement with present analysis.

References listed at the end of the paper:


ABSTRACT: This work concerns with free vibration analysis of composite plate materials. Based on a transvers shear theory, the governing equations of the problem are derived. An indirect technique of moving least-square differential quadrature method is developed and employed to reduce the problem to that of eigenvalue one. Natural frequencies and mode shape functions of the composite are obtained. Validity of the developed technique is examined for regular and irregular plates with different boundary conditions. Accuracy and efficiency of the obtained results are achieved by comparing them with the previous exact and numerical ones. Further, a parametric study is introduced to investigate the effects of elastic and geometric properties on values of vibration field quantities.

References listed at the end of the paper:


ABSTRACT: Hygrothermal and mechanical buckling responses of functionally graded (FG) plates resting on Winkler–Pasternak’s foundations are presented in this paper using a refined quasi-3D model. The effects due to transverse normal strain and shear deformation are both included. The present model exactly satisfies stress boundary conditions on the upper and lower surfaces of the FG plate without using shear correction factors. It is assumed that the material properties vary according to a power law of the thickness coordinate variable. The hygrothermal buckling equilibrium equations are derived from the principle of virtual work for FG plates resting on Winkler–Pasternak’s foundations with simply-supported boundary conditions. Two types of thermal and hygrothermal loading, uniform thermal and hygrothermal rise, linear thermal and hygrothermal distribution through the thickness are considered. Numerical results are presented to verify the accuracy of the present study. The effects played by Winkler–Pasternak’s parameters, plate aspect ratio, side-to-thickness ratio, gradient index, and loading type on the critical buckling of the FG plates are all investigated.

References listed at the end of the paper:


ABSTRACT: Sandwich structures are widely used in aerospace and naval industries as they are light in weight and have high energy absorption capacities. Sandwich beams with soft core are the most commonly used structures in many applications. Analysis of sandwich beams is the key in its design and the development of new family of super convergent shear deformable finite elements are presented in this article. In this article, formulation of three different Super Convergent shear deformable finite elements with 4, 7, and 10 degrees of freedom respectively, for analysis of the sandwich beams with soft core are presented. The formulation considers the top, bottom face sheets and core as separate entities and are coupled by beam kinematics. The performance of these elements are validated by results available in the published literature. The article highlights the issues with the traditional elements for modeling sandwich beams and the advantages of the elements developed, in particular wave propagation analysis, are addressed in this article.

References listed at the end of the paper:


ABSTRACT: A three-dimensional finite element model is built to compute the motions of a pipe that is being laid on the seabed. Corotational beam elements account for geometric nonlinearity. The pipe is subject to contact, hydrodynamic forces, gravity, and buoyancy. New in this article is the addition of nodal moments due
to buoyancy and nodal correctional forces to compensate for a cross-sectional area mismatch. The results show a modest increase in accuracy due to these moments and a significant increase due to the correctional forces.

References listed at the end of the paper:
ABSTRACT: The variationally consistent methodology for generating state space models of 1D composite beams is evolved systematically and used to establish such models corresponding to different composite higher order beam theories. The state space form always yields the state vector in terms of generalized displacements and its associated generalized forces. It can handle arbitrary material coupling in a general manner and satisfy all the boundary conditions simultaneously. Numerical results of generally laminated beams under transverse loading using four warping functions of the normal and shear deformation theories for different boundary conditions are provided and compared with previous studies from the literature.

References listed at the end of the paper:

- M. Karama, K. S. Afzal, and S. Mistou.
- M. Touratier.
- K. Soldatos, and I. Elishakoff.
- M. Kara.
- J. F. Davalos, Y. Kim, and E. J. Barbero.
- E. Carrera.
- E. Carrera, and G. Giunta.
- V. Tahoun.
- V. Tahoun.
- V. Tahoun.


https://doi.org/10.1080/15502287.2019.1644394
ABSTRACT: This article presents the numerical solution of a system of linear fourth-order boundary value problems using a different amalgamation of non-polynomial splines. A novel approach was developed using quintic spline function together with exponential and trigonometric functions. Our method is convergent and second-order accurate. Numerical examples show that the method congregates with sufficient accuracy to the exact solutions. Our methodology has the advantages over some existing quintic spline method, direct method, and finite difference method.

References listed at the end of the paper:


ABSTRACT: Comparative structural performance of composite filled tubes under axial loading, is presented, by testing circular aluminium tubes of $D/t$ ratios 30.31 and 40.07 with $L/D$ three and four, filled with PU foam (density 150 kg/m). The specimens are tested for axial compression. FEA with ABACUS-6.14-3 software, showed good agreement between tests and simulation. Also, filling foam in metal tube as envelop, can enhance compressive strength of tube, as strength of foam filled tubes is higher than those of empty tubes. Finally, different composite filled tubes are compared with conventional materials with respect to strength-to-weight ratios, to suggest newly evolving building materials.

References listed at the end of the paper:


ABSTRACT: In this article, active control of geometrically nonlinear transient vibrations in laminated composite beams has been demonstrated using an advanced piezoelectric composite (PZC) layer as the active layer with a proper control strategy. A nonlinear mesh free (MF) model is derived for analyzing the dynamic characteristics of the laminated composite beams integrated with the PZC patch based on the element-free Galerkin (EFG) method within the framework of a layer wise beam theory considering transverse shear deformations. The Von Kármán type nonlinear strain–displacement relationships are considered for formulating the coupled electromechanical nonlinear MF model. Both in-plane and transverse actuation by the PZC layer have been taken into consideration for deriving the model. Various geometrical shapes of the PZC layers have been considered for the analysis to understand the geometrical shape dependency of the PZC layer in attenuating vibration in the structure. The numerical results indicate that the PZC layer significantly improves the dynamic characteristics of the laminated beams by suppressing the geometrically nonlinear transient vibrations induced in them. It has been also noticed that the irregular shaped PZC patches like triangular PZC patches perform better as compared to the regular rectangular PZC patches in alleviating vibration the structure.

References listed at the end of the paper:


ABSTRACT: A symbolic computation of a double scale asymptotic technique is used to derive a linear-elastic buckling theory for solids with periodic microstructure. From the stationary potential energy, equations are obtained for the classic homogenization problem, and for its extension to the buckling problem at macro, micro and mixed scales. The limitation to $\#Y$-periodic instability modes can be treated afterwards using a Floquet-Bloch theory. The symbolic procedure is worked out step-by-step and results are presented. The obtained equations present a theoretical framework for the topology optimization of structures and microstructures involving linear elastic buckling criteria.

References listed at the end of the paper:


ABSTRACT: Cellular materials, often called lattice materials, are increasingly receiving attention for their ultralight structures with high specific strength, excellent impact absorption, acoustic insulation, heat dissipation media, and compact heat exchangers. In line with emerging additive manufacturing (AM) technology, realization of the structural applications of the lattice materials appears to be becoming faster. Considering the direction-dependent material properties of the products with AM, by directionally dependent printing resolution, effective moduli of lattice structures appear to be directionally dependent. In this paper, we develop a constitutive model of a lattice structure, which is an octet-truss with a base material having an orthotropic material property considering AM. Case studies, simulations, and experimental validations are conducted on effective properties of octet lattice structures under uniaxial compression to validate the continuum model. The proposed model seems to be for good reason with the validations. New direction-dependent continuum models were proposed for the effective properties of octet lattice under uniaxial compression and tension.

References listed at the end of the paper:


ABSTRACT: A multi-fidelity model for beam vibration is developed by coupling a low-fidelity Euler-Bernoulli beam finite element model with a high-fidelity Timoshenko beam finite element model. Natural frequencies are used as the response measure of the physical system. A second order response surface is created for the low-fidelity Euler-Bernoulli model using the face centered design. Correction response surfaces for multi-fidelity analysis are created by utilizing the high-fidelity finite element predictions and the low-fidelity finite element
predictions. It is shown that the multi-fidelity model gives accurate results with high computational efficiency when compared to the high-fidelity finite element model.

References listed at the end of the paper:


ABSTRACT: The objective of this work is the elaboration of analytical and numerical procedures to investigate thermal buckling and vibration analyses of composite plates with thermal dependent material properties. Based on the homotopy and an asymptotic numerical method, a mathematical formulation that may account for various temperature dependent models is elaborated. Power series expansions of the displacement and the temperature are developed, and the finite element method is used for numerical solution. The effects of temperature dependent properties, structural geometry and boundary conditions on the thermal buckling and vibration are analyzed.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: Adopting an updated Lagrangian approach, a “general” and “exact” framework for the geometrically non-linear analysis of thin-walled framed structures are developed. The generality of such framework stands for the wide range of its applicability for different types of beam cross-sections, support conditions, and loading patterns including configuration-dependent behavior of applied moments; while the exactness stands for the utilization of a number of closed-form solutions of a class of torsionally loaded thin-walled beams to formulate a two-node element for spatial buckling analysis. The key in this formulation relates to the use of the “exact” solution for the displacement fields as opposed to the more conventional finite element approach in which polynomial/Lagrangian-type interpolation function is employed. Further, emphasizes are given to the effect of finite rotations in space on the non-linear kinematic descriptions as well as the configuration-dependent behavior of externally applied moment vector of the conservative/non-conservative type. Results obtained in a number of numerical simulations of beam assemblages subjected to different loading patterns illustrated the usefulness, robustness and fast convergence of the developed model in predicting the lateral torsional buckling.

References listed at the end of the paper:
ABSTRACT: In this paper, we provide comprehensive study of lightweight bilayer containment rings in gas turbine engines to contain a released blade. Three different materials were considered to form bilayer rings: aluminum foam, titanium, and Kevlar fabric. The effectiveness of the bilayer combinations is established through fundamental oblique impact studies on a planar target and blade shedding response of a fan disc. The effect of a gap between the two layers on its shock absorption and impact response is also evaluated. The results of our studies indicate that a bilayer aluminum foam-Kevlar ring with a gap offers greater energy absorption capability.

References listed at the end of the paper:

ABSTRACT: A domain-boundary element method for forced vibration analysis of fiber-reinforced laminated composite beams is introduced. Utilizing static fundamental solutions as weight functions in weighted residual statements, governing partial differential equations of motion are reduced to a system of four coupled integral equations. Domain discretization leads to a system of ordinary differential equations in time, which is solved by the Houbolt method. Developed procedures are verified through comparisons to analytical solution for isotropic beams. Parametric results illustrate elastodynamic responses of composite beams subjected to various loading types. It is shown that angle-ply laminates undergo higher displacements compared to cross-ply laminates.

References listed at the end of the paper:


ABSTRACT: A stochastic time-domain spectral element method (STSEM) is applied to sandwich beam structures. STSEM couples the computational efficiencies of the spectral stochastic finite element method and the time-domain spectral element method. A higher-order sandwich panel theory incorporating the core flexibility is considered for the analysis. The material properties are modeled as random fields and represented by the Karhunen-Loève expansion. The stochastic nodal displacements are expressed using the polynomial chaos expansion, and the expansion coefficients are computed by solving the spectral stochastic finite element equations. The computational efficiency of the proposed method is compared with Monte-Carlo simulation.

References listed at the end of the paper:
ABSTRACT: A semi-analytical model is proposed for the stress and displacement analysis of all-round simply supported functionally graded (FG) piezoelectric laminated plates in this paper. Material electric and elastic properties have been assumed to vary according to the exponential law as well as power law in the thickness direction, considering the Poisson’s ratio to be an invariant. Formulation part is based upon the theory of elasticity and numerical integration technique has been employed to obtain the solutions. Mathematical model developed is a set of mixed first order ordinary differential equations (ODEs), which has been validated by comparing the results obtained with exact solutions available in literature. Several examples have been addressed to ascertain the versatility of the model. Additional investigation has been carried out on FG piezoelectric plates and results provided for future reference.

References listed at the end of the paper:


ABSTRACT: Exploring lightweight sandwich structures with excellent load-bearing and vibration damping performances is one of the important topics in structural and functional applications. The aim of the present work is to design, fabricate novel metallic sandwich structures with Hourglass truss cores and investigate their modal characteristics and vibration isolation performances by comparing with the traditional pyramidal sandwich structure experimentally and numerically. It is shown that the natural frequencies of the Hourglass sandwich structures are much higher than that of the pyramidal sandwich structures under free-free boundary condition and equal relative density of the truss cores. The torsional modes and transverse bending modes of the Hourglass sandwich structures separately play a dominant role in lower and higher modes of vibration, which are opposite to the pyramidal sandwich structures. From the results of the acceleration frequency responses and vibration level difference (VLD), it is indicated that the Hourglass sandwich structures exhibit better vibration isolation performance than the pyramidal sandwich structures. Furthermore, experimentally validated finite element analysis (FEA) models are developed to study the influences of truss inclination angles and boundary conditions on the modal characteristics of the present sandwich structures. Some conclusions are summarized, which may be useful for understanding the vibration behavior of such kinds of lattice sandwich structures.

References listed at the end of the paper:

4 A. Vaziri, J.W. Hutchinson, Metal sandwich plates subject to intense air shocks, Int J Solit Struct, 44 (2007), pp. 2021-2035
7 L.L. Yan, B. Yu, B. Han, et al., Compressive strength and energy absorption of sandwich panels with aluminum foam-filled corrugated cores, Compos Sci Technol, 86 (7) (2013), pp. 142-148
13 J. Liu, X. Zhu, Z. Zhou, et al., Effects of thermal exposure on mechanical behavior of carbon fiber composite pyramidal truss core sandwich panel, Compos B Eng, 60 (60) (2014), pp. 82-90
17 Y.Z. Wang, Y.S. Wang, Active control of elastic wave propagation in nonlinear phononic crystals consisting of diatomic lattice chain, Wave Motion, 78 (2018), pp. 1-8
32 M. Xu, Z. Qiu, Free vibration analysis and optimization of composite lattice truss core sandwich beams with interval parameters, Compos Struct, 106 (2013), pp. 85-95
34 J.S. Yang, L. Ma, R. Schmidt, et al., Hybrid lightweight composite pyramidal truss sandwich panels with high damping and stiffness efficiency, Compos Struct, 148 (2016), pp. 85-96
35 B. Li, Z. Li, J. Zhou, et al., Damage localization in composite lattice truss core sandwich structures based on vibration characteristics, Compos Struct, 126 (2015), pp. 34-51
36 F.M. Li, X.X. Lyu, Active vibration control of lattice sandwich beams using the piezoelectric actuator/sensor pairs, Compos B Eng, 67 (2014), pp. 571-578
37 Z.G. Song, F.M. Li, Aeroelastic analysis and active flutter control of nonlinear lattice sandwich beams, Nonlinear Dynam, 76 (1) (2013), pp. 57-68
40 J.S. Yang, J. Xiong, L. Ma, et al., Vibration and damping characteristics of hybrid carbon fiber composite pyramidal truss sandwich panels with viscoelastic layers, Compos Struct, 106 (2013), pp. 570-580
41 J.S. Yang, L. Ma, K.U. Schröder, et al., Experimental and numerical study on the modal characteristics of hybrid carbon fiber composite foam filled corrugated sandwich cylindrical panels, Polym Test, 68 (2018), pp. 8-18
43 S.M. Ahmadi, S.A. Yavari, R. Wauthle, et al., Additively manufactured open-cell porous biomaterials made from six different space-filling unit cells: the mechanical and morphological properties, Materials, 8 (4) (2015), pp. 1871-1896


ABSTRACT: One type of submarine composite pipeline structure, with carbon steel-concrete-stainless steel (CCS) double-skin tube (DST), was introduced in this paper. This composite pipeline was expected to make optimal use of the three types of the materials, and provide significant structural and internal corrosion resistance. This study investigated the compressive and flexural behavior of the composite pipeline under internal content pressure and external hydrostatic pressure through finite element analysis (FEA). Finite element models were developed, where non-linear material properties of stainless steel and composite actions between constituent parts were considered. The models were verified through the comparisons between the numerically and experimentally determined results, in terms of load-deformation histories, failure modes and ultimate strength. Structural behaviors of the composite pipeline under pressures were compared with those without content and hydrostatic pressure. Parametric studies were carried out to investigate the effects of the outer carbon steel strength, inner stainless steel strength, concrete strength and hollow ratio on the compressive and flexural behaviors of the composite pipelines subjected to pressures.

References listed at the end of the paper:

6 Q.X. Ren, C. Hou, D. Lam, L.H. Han, Experiments on the bearing capacity of tapered concrete filled double skin steel tubular (CFDST) stub columns, Steel Compos Struct, 17 (2014), pp. 665-684, 10.12989/scs.2014.17.5.665


8 K. Uenaka, H. Kitoh, K. Sonoda, Concrete filled double skin circular stub columns under compression, Thin-Walled Struct, 48 (2010), pp. 19-24, 10.1016/j.tws.2009.08.001


15 Z. Tao, B. Uy, L.H. Han, Z Bin Wang, Analysis and design of concrete-filled stiffened thin-walled steel tubular columns under axial compression, Thin-Walled Struct, 47 (2009), pp. 1544-1556, 10.1016/j.tws.2009.05.006

16 O. Zhao, B. Rossi, L. Gardner, B. Young, Behaviour of structural stainless steel cross-sections under combined loading - Part I: experimental study, Eng Struct, 89 (2015), pp. 236-246, 10.1016/j.engstruct.2014.11.014

17 L.H. Han, X.L. Zhao, Z. Tao, Tests and mechanics model for concrete-filled SHS stub columns, columns and beam-columns, Steel Compos Struct, 1 (2001), pp. 51-74


29 American Concrete Institute, Building code requirements for structural concrete (ACI 318-11) and commentary, (2011), 10.1061/0262-5075(85)90032-6


https://doi.org/10.1016/j.marstruc.2018.10.003
ABSTRACT: A series of small-scale specimens of unstiffened and stiffened web girders were designed and tested by applying local imposed deformations by an indenter. These quasi-static experiments were to investigate the crushing behaviour of vertical stiffeners in web girders. Finite element (FE) models are established to calculate the crushing deformations and to analyse the energy absorbing mechanisms. Good agreement is observed between the numerical results and experimental measurements, leading to the conclusion that the FE model developed in the current investigation can be effectively used to predict the crushing behaviour of ship structures in stranding. It is concluded that the vertical stiffeners play an important role in the crushing resistance of the structures, especially have significant influence on the reaction force. Comparing with the unstiffened web girder, the maximum force measured in the tests increased by 17% and 64% in the stiffened...
webs with 2 and 3 stiffeners, respectively. Discussions on the effects of friction coefficient, the thickness of stiffener, and the determination of failure criterion using in FE simulations are also included.

References listed at the end of the paper:

2 L. Hong, J. Amdahl, Rapid assessment of ship grounding over large contact surfaces, Ships Offshore Struct, 7 (1) (2012), pp. 5-19
5 P.T. Pedersen, Ship grounding and hull-girder strength, Mar Struct, 7 (1) (1994), pp. 1-29
6 A. Mamontov, Measurement of bottom structure deformation due to grounding or beaching on an unimproved shore: a full-scale experiment, Nav Eng J, 129 (1) (2017), pp. 133-145
11 J.K. Paik, Practical techniques for finite element modeling to simulate structural crashworthiness in ship collisions and grounding (Part I: theory), Ships Offshore Struct, 2 (1) (2007), pp. 69-80
16 B.C. Simonsen, Ship grounding on rock - I. Theory, Mar Struct, 10 (7) (1997), pp. 519-562
31 J.K. Paik, Practical techniques for finite element modelling to simulate structural crashworthiness in ship collisions and grounding (Part II: verification), Ships Offshore Struct, 2 (1) (2007), pp. 81-85
ABSTRACT: The paper focuses on hull girder reliability and sensitivity analysis of an oil tanker and a bulk carrier in intact condition. After a brief review of the theoretical background concerning the reliability analysis, Turkstra rule, Ferry-Borges and Castanheta, Moan and Jiao load models are applied and compared to investigate the incidence on hull girder reliability of different load combination methods for ships in full load (sagging) and ballast load (hogging) conditions. Subsequently, sensitivity analysis is carried out to investigate the incidence on the hull girder failure probability of the main parameters affecting the still-water and vertical wave bending moment stochastic processes, namely the maximum still-water bending moment reported in the loading manual, the ship voyage duration, the shape parameter of the long-term Weibull distribution of vertical wave bending moment and the mean wave period. Two reference ships, namely the ISSC oil tanker and bulk carrier, are assumed as test case for reliability and sensitivity analysis, that are performed by Monte Carlo simulation based on a dedicated programme developed in Matlab MathWorks. Obtained results are discussed and some suggestions are provided to improve the effectiveness of reliability analysis.

Renhua Wang and R. Ajit Shenoi, “Experimental and numerical study on ultimate strength of steel tubular members with pitting corrosion damage”, Marine Structures, Vol. 64, pp 124-137, March 2019, 
https://doi.org/10.1016/j.marstruc.2018.11.006

ABSTRACT: Pitting corrosion can cause stress concentration and early onset of plasticity in the metallic structural components. This paper presents a comprehensive experimental and numerical study on the effect of pitting features such as pit shape and depth, pitting distribution and intensity on the structural performance of steel tubular members. The experimental investigations were carried out on tubular members with mechanically drilled pitting damage under axially loaded compression condition. The test results were applied to validate finite element (FE) models by comparing the load-shortening curves, ultimate loads and failure modes. The validated FE models were then used to simulate the random nature of pitting damage in terms of stochastic simulation. The results from the stochastic analyses show that random natures associated with pit shape, pit depth and pitting distribution can result in a great reduction and variation of ultimate strength, likely causing the transition of collapse mode. The experiments provide a modelling benchmark to validate FE models of the
tubular structures with random pitting corrosion for the ultimate strength assessment. The developed FE models are shown to be capable of replicating the pitted tubular members.

ABSTRACT: Operational safety requires that container ships are designed to endure extreme wave loads. This paper studies extreme panel stresses simultaneously measured at two different deck locations of a container vessel sailing in the North Atlantic between Canada and Europe. Ship panel stresses contain whipping part (transient vibratory response of the hull girder due to wave impacts occurring mainly in the bow area), the latter whipping phenomenon is inherently present in on-board stress measurements. It must be noted that measured hydroelastic vessel panel stresses include other complex non-linear effects as well, for example springing. In many practical situations it would be useful to improve accuracy of some statistical predictions extracted from a certain stochastic random process, given another synchronous highly correlated stochastic process that has been measured for a longer time, than the process of interest. The latter situation may happen if one on-board sensor malfunctioned, and it yielded data record much shorter than the neighboring well-functioning sensor. In this paper the latter issue of improving extreme value prediction has been addressed. In other words, this paper studies an efficient transfer of information between two synchronous highly correlated stochastic on-board stress processes. Two correlated ship panel stress processes at mid and aft deck locations were studied in order to test efficiency of the proposed technique of improving one process extreme prediction, based on the other. This paper intends to stimulate further research and fill the gap that is currently visible in the literature on the latter important topic.

ABSTRACT: The present paper addresses the mechanical behavior of tensile armor wires in a flexible pipe subjected to bending and longitudinal loads. An analytical model is formulated to evaluate the equilibrium state of a single armor wire on a frictionless torus surface by solving a consistent system of six nonlinear differential equations through the application of a perturbation technique. Cases studies are performed where the armor wire's responses to both tensile and compressive loads are discussed and compared with the results obtained from a numerical program. Under the circumstance of axial compression, two potential lateral buckling modes, global and periodic, are uncovered and their corresponding buckling limits are identified by establishing eigenvalue problems. While the global buckling limits are found conservative compared with the test data available in the literature, good agreements are observed for the estimated buckling limits regarding the periodic buckling mode.

Monir Takla (School of Engineering, RMIT University, Melbourne, Australia), “Non-symmetric bifurcation and collapse of elastic-plastic thick-walled cylinders under combined radial and axial loading”, Marine Structures, Vol. 64, pp 246-262, March 2019, https://doi.org/10.1016/j.marstruc.2018.11.009
ABSTRACT: Thick-walled cylinders, which are loaded by accidentally excessive internal or external pressure, axial force or both, may fail due to non-symmetric bifurcation modes with multiple axial and peripheral waves. These failure modes are most relevant to submarines, onshore- and offshore pipelines, vacuum containers, subsea structures, and pressure vessels. Continuum theory is adopted to analyze the bifurcation behavior of such cylinders, considering large elastic-plastic deformation with non-linear hardening. The presented general comprehensive solution is capable of calculating the loads and deformation at the onset of bifurcation for modes of any order in both axial and peripheral directions. As a case study, several bifurcation limit curves of different orders have been calculated using the proposed theoretical solution for a closed thick-walled long cylinder loaded radially and axially. The results are validated numerically by FEA simulations using commercial software. Limit curves of column buckling (first order) and section-collapse (second or higher order) modes of bifurcation are calculated using the proposed solution. The results demonstrate that adding tensile or compressive axial force to external pressure loading delays the occurrence of the section-collapse bifurcation mode.
On the other hand, adding external or internal pressure to an axial compression force, the axial strain at column buckling is also increased. The results also explain and quantify the transition between section-collapse and column-buckling bifurcation modes. While the presented results focus on different modes of non-symmetric buckling, the theory is also capable of calculating the axisymmetric and non-symmetric bulging as well as axial necking bifurcation modes. The presented solution offers deeper insight and substantial help to the designers of thick-walled cylindrical components of structures, particularly those subject to excessive external pressure, possibly combined with an axial force.


ABSTRACT: Unbonded flexible pipes consist of multiple subcomponents which interact through frictional contact. A full 3-D finite element analysis of unbonded flexible pipes is computationally expensive, and a more efficient approach for practical engineering purposes is required. This work presents a repeated unit cell (RUC) finite element model for analyzing flexible pipes subjected to combined constant tension and curvature. Periodic boundary conditions reduce the model size by taking advantage of the structural and loading periodicities, and by assuming uniform wire behavior in the armor layer. The RUC model is suitable for resolving the local tensile armor stress distribution and the global pipe response. A flexible pipe is studied with the RUC model for various tension-bending load configurations and the results have been compared with existing analytical models for validation. The study showed strong correlation between the RUC model and the analytical models, with some difference in the wire bending stresses. This difference can to some degree be explained by the difference in the wire kinematics assumptions. It is found that the proposed RUC model is a robust and computationally efficient approach for analyzing flexible pipes.


ABSTRACT: This study examined the buckling of spherical caps with four different geometric imperfections: local inward dimple, increased-radius, force-induced dimple, and linear buckling mode. The influence of imperfection amplitude, meridional position, and meridional extent on cap buckling was numerically explored and partially validated using experiments. The numerical and experimental data were well consistent. Results indicated that, in the case of small-sized imperfections, the linear buckling mode-shaped imperfection presented a relatively conservative cap buckling prediction compared with those of the other three imperfections. This finding contradicts previous findings that the force-induced dimple imprintation is the most unstable imperfection.


ABSTRACT: Water impact (slamming) is a strongly nonlinear phenomenon including significant fluid structure interactions. In the case of slamming with a small impact angle between the structure and water, the coupling between hydrodynamic pressure and the elastic responses of structures, known as hydroelasticity, matters. This has been studied extensively. However, when structures are subjected to violent water slaming in extreme sea states, large stresses may occur that exceed the material yield stress, causing large plastic flow and permanent damage. In such cases, the plastic responses of a structure will be strongly coupled with the hydrodynamic pressure, termed as hydro-plasticity. Hydro-plastic slamming has rarely been studied before.

This is Part I of a two-part companion paper. The paper advances the state-of-the-art of hydro-plastic slamming by formulating, for the first time, an analytical model coupling the hydrodynamic forces and the plastic response of rectangular beams and one-way stiffened panels. The studied scenarios are flat or nearly flat water impacts, which are critical for hydro-plasticity excitation. The impact angle between the water free surface and
the structure should preferably be no larger than 5°. Based on the proposed model, the governing non-dimensional parameters for hydro-plastic slamming are identified and discussed. Design curves for plate strips and stiffened panels against extreme slamming are developed. Part II - Numerical verification and analysis presents numerical verification and discussion of the analytical model by comparing with results from the multi-material Arbitrary Lagrangian Eulerian (ALE) simulations. The proposed analytical model does not require the challenging estimation of pressure history that is normally used in the design against slamming. Only the initial impact velocity is needed as the main input. The resulting non-dimensional curves may be utilized in rules and standards for the design of ships and offshore structures against extreme slamming loads.

Zhao long Yu, Jorgen Amdahl, Marilena Greco and Huili Xu (Department of Marine Technology, Norwegian University of Science and Technology, NTNU, Norway), “Hydro-plastic response of beams and stiffened panels subjected to extreme water slamming at small impact angles, Part II: Numerical verification and analysis”, Marine Structures, Vol. 65, pp 114-133, May 2019, https://doi.org/10.1016/j.marstruc.2019.01.003

ABSTRACT: An analytical model has been proposed for the response of beams and stiffened panels subjected to extreme flat or nearly flat water impacts in Part I of the two-part companion paper. The model aims to capture the significant hydro-plastic coupling between large plastic structural deformations and the hydrodynamic pressure. Governing non-dimensional parameters for the hydro-plastic slamming phenomenon were identified and discussed. This Part II paper verifies the analytical model proposed in Part I by comparison with the hydro-plastic slamming response of beams and stiffened panels using multi-material Arbitrary Lagrangian Eulerian (ALE) methods in LS-DYNA. Numerical modelling and settings with the ALE simulations are firstly validated by comparison against drop-test experiments of a rigid wedge and of an elastic plate. Then, water entry simulations of flat plates and stiffened panels are carried out, where structural deformations go into the plastic regime. The simulated scenarios cover different plate thicknesses/cross sectional dimensions of stiffened panels, and various initial water-entry velocities. The analytical model is discussed with respect to the fluid flow, structural deflections, the pressure history and the impulse. Validity of assumptions of the analytical model is also discussed. Potential applications and limitations are indicated. The proposed design curves are well suited to be utilized in rules and standards for designing against extreme water slamming.


ABSTRACT: Stiffened panel structure is one of the most commonly used structure type in ship and offshore engineering, aeronautics and astronautics and other fields. The basic joint type of stiffened panel structure is welding. One important factor affecting welding quality is mechanical boundary condition. The present work aims to obtain the influence of welding mechanical boundary condition on the residual stress and distortion of a stiffened-panel. Thermal elastic-plastic finite element method (FEM) is used to calculate the welding distortion and residual stress of a stiffened-panel under different mechanical boundary conditions. Welding distortion and residual stress at typical positions of the stiffened-panel are calculated. The results show that mechanical boundary conditions mainly affect the welding deformation and have little influence on the residual stress of stiffened-panels. Symmetric boundary condition can not only refrain localized deformation effectively but also decrease the overall bending magnitude of stiffened panels middle cross-section.


ABSTRACT: Interaction of sea or lake ice with vertically sided offshore structures may result in severe structural vibrations commonly referred to as ice-induced vibrations. With the surge in offshore wind developments in sub-arctic regions this problem has received increased attention over the last decade, whereas traditionally the topic has been mainly associated with lighthouses and structures for hydrocarbon extraction. It is important for the safe design of these offshore structures to have the ability to predict the interaction between
ice and structure in an expected scenario. A model for simulation of the interaction between a drifting ice floe and a vertically sided offshore structure is presented. The nonlinear speed dependent ductile and brittle deformation and local crushing of ice are considered phenomenologically. A one-dimensional sea ice dynamics model is applied to incorporate the effects of floe size, wind and current. The structure is modelled by incorporating its modal properties obtained from a general-purpose finite element software package. Alternatively, the model can be coupled to in-house design software for fully coupled simulations. Examples of application of the model to simulate dynamic ice-structure interaction are provided. Simulation results are validated with public data from forced vibration experiments, small-scale intermittent crushing and frequency lock-in, and full-scale interaction with the Norströmsgrund lighthouse. Effects of floe size and environmental driving forces on the development of ice-induced vibrations in full-scale are studied. It is shown that sustained frequency lock-in vibrations of the structure can only develop for very specific combinations of environmental driving forces and ice floe size. In all other cases, the ice floe slows down and comes to a stop, or accelerates to a drift speed which exceeds the range where frequency lock-in develops. This results in only a few cycles of vibration per interaction event, such as observed for the Norströmsgrund lighthouse in the Baltic Sea.


ABSTRACT: This paper presents experimental and numerical investigations into dynamic responses of aluminum foam core sandwich panels subjected to localized air blast loading. It mainly focused on the effects of face-sheet thickness and mass allocation on deformation responses and energy absorption characteristics. The specimen considered experienced several deformation/failure modes, including localized deformation of front face, large inelastic deformation of back face, core densification and fragmentation and debonding failure. Experimental results revealed that both the deformation/failure modes and permanent deformation are more sensitive to the variation of front face thickness relative to the one of back face thickness. The optimal mass allocation strategies for the reduction of deformation response are to distribute more mass to front face rather than back face, and to adopt a thick and suitable strength foam core. Numerical simulations reveal that the increase of front face-sheet thickness led to a remarkable decrease on total energy dissipation while the effect of back face thickness was negligible. The mass allocation strategy with a lighter front face could achieve superior capability in total energy absorption regardless of areal density. Moreover, allocating more mass from back face to foam core is an efficient means to further improve the panel energy absorption.


ABSTRACT: In the structural analysis of flexible pipes, the Finite Element Method (FEM) stands as a powerful and widespread tool. However, it is unfeasible to represent with detail in a Finite Element (FE) model all layers and components of a flexible pipe, since the calculation time would be unrealistic. Moreover, consistent numerical analyzes need support from experimental results. In this context, the development of a new strategy for the design of FE models of flexible pipes is placed. Using a commercial FE software, this text presents an innovative technique to represent helical layers, based on previous numerical contact studies. A space filling mesh scheme is introduced to model voids between wound wires. To assess this numerical approach, results obtained from three case studies are compared with analytical and experimental approaches found in the literature, highlighting advantages and drawbacks of the alternative strategy.


ABSTRACT: Concrete-Filled Steel Tube (CFST) columns combine the benefits of high ductility and tensile strength of steel with high stiffness and compressive strength of concrete. It can be used in marine structures.
This paper presents the mechanical performance of CFST columns strengthened by steel Reinforcing Bars (RBs) under axial compression. A series of experiments were carried out on 22 CFST columns using two different $D/t$ ratios and different patterns of RBs as parameters. Furthermore, different diameters and numbers of RBs were utilized. The RBs were either welded on the internal surface of the steel tubes or embedded within concrete as a reinforced concrete. Various patterns were used to enable a better understanding of the strengthened CFST columns performance. Moreover, the compressive loading vs. end shortening curves, failure modes, strength index and RBs contribution ratio were analysed. The design methods of the ordinary CFST columns (EC4, AISC, Han, Yu, and Liang) were modified and assessed against the experimental results to trace the suitable formulation for design purposes. According to the theoretical results, the analytical formulations of certain methods are acceptable for the analysis of reinforced and stiffened CFST columns.


ABSTRACT: Concrete Filled Double Skin Steel Tube (CFDST) columns which comprise two concentric steel tubes and shell concrete between them is a favourable member of composite columns family. The CFDST columns have the potential to offer equal or superior characteristics compared to the classical Concrete Filled Steel Tube (CFST) counterparts. Although CFDST columns have been the focus of experimental and numerical studies, there is limited knowledge on the contribution of the inner steel tube to the compression performance. Since the inner steel tube is the key member which motivates the deployment of the CFDST columns in the field, it is imperative to characterize its contribution. This paper conveys the findings of an experimental study which was conducted to explore the effect of the inner steel tube on the mechanical response of CFDST columns under axial compression. Two different $D/t$ ratios and concrete classes (normal strength and high strength) were utilized and in total sixteen specimens were tested to failure. To be able to analysis the impact of the parameters, failure modes, compression loading versus end shortening curves and the concrete-steel contribution ratios were detailed. The results show that the CFDST columns could attain greater performance over CFST columns when a proper configuration of the inner steel tube is used. Furthermore, the inner tube works consistently with the shell concrete and plays an important role in mitigating failure mode of CFDST even with high strength concrete (HSC). Finally, the prediction formulations were employed and examined against the test results to specify the convenient method for design processes.


Highlights
• The dynamic ultimate compressive strength of plates increases significantly as impact duration decreases.
• The plate thickness and material yield stress have little effect on the non-dimensional dynamic ultimate compressive strength.
• The empirical formula proposed in the present paper has been applied to the existing ship plates successfully. (There is no ABSTRACT)


ABSTRACT: An analytical model is proposed to investigate the local torsion and bending behavior of tensile armors in unbonded flexible pipes. The general expressions of torsion and curvature increments, including the effects of axial strain and twisting rotation of tendon cross-section, are firstly derived based on the generalized Frenet–Serret equations. Then the expressions corresponding to the strained helix assumption are obtained, which are further simplified by ignoring the twisting rotation. Afterwards, explicit expressions are given for axisymmetric case and tendon stick and slip states when bending is included. The developed model is finally verified with a finite element simulation. The results show that the model prediction of normal curvature increment is in good agreement with the numerical solution while the changes in torsion and transverse
temperatures, there has not been any study of the difference between the static strength of unreinforced and collar plate reinforced T/Y joints. Also, at elevated temperatures, the increase of the collar plate length and thickness significantly results in the increase of the initial stiffness. At the next step, a total number of 360 FE analyses were performed to investigate the structural behavior of T/Y-joints reinforced with collar plates at fire induced elevated temperatures. At the first step, a finite element (FE) model was developed and verified by results of six experimental tests carried out in the present author's previous study. Also, the FE model was validated using experimental data reported in available research works. At the next step, a total number of 360 FE analyses were performed to investigate the effect of elevated temperatures, dimensionless geometrical parameters (η, c, β, ϑ), and brace inclination angle (θ) on the initial stiffness, ultimate strength, and failure mechanisms. The joints were analyzed under axially compressive load and five different temperatures (20 °C, 200 °C, 400 °C, 600 °C, and 800 °C). Results showed that at elevated temperatures, the increase of the collar plate length and thickness significantly results in the increase of the initial stiffness. Also, at elevated temperatures, the ultimate strength of T/Y-joints reinforced with collar plate can be up to 254% of the ultimate strength of the corresponding unreinforced joint. Despite this significant difference between the static strength of unreinforced and collar plate reinforced T/Y-joints at elevated temperatures, there has not been any study on the initial stiffness and ultimate capacity of the T/Y-joints.
reinforced with collar plate at elevated temperatures. Also, there is no design equation for determining the ultimate strength of the collar plate reinforced T/Y-joints at elevated temperatures. Therefore, the results of the parametric study were used to develop a design formula, through nonlinear regression analyses, to calculate the ultimate strength of tubular T/Y-joints reinforced with collar plates subjected to axially compressive loading at elevated temperatures.


ABSTRACT: This paper reports experimental and numerical investigations on the ultimate strength responses of steel-welded, ring-stiffened conical shells when subjected to external hydrostatic pressure. Four small-scale shell models were fabricated from general structural steel by cold bending and arc welding. First, hydrostatic pressure tests were performed to investigate the collapse behaviour of the models. The influences of different parameters were also studied experimentally. Before the experiments, quasi-static tensile tests were performed to obtain detailed characterisation of the test model material. In addition, the initial imperfection of the shell and other as-built geometry parameters were carefully measured. The test was conducted using compressed water in a small-sized chamber and loaded to collapse. Three models with heavy stiffeners were failed by local buckling at the shell between the ring frames. Another model failed by the overall buckling of the adjacent frames together with the shell. The numerical computations were performed on the finite element code of ABAQUS FEA. The imperfection due to fabrication, such as initial out-of-circularity, and residual stresses due to welding are simulated. The quasi-static response was compared with the experimental load and plastic deformation curves. The numerical results revealed a close agreement between the collapse pressure prediction and failure modes of the simulation and the experiment.


ABSTRACT: This paper proposes a finite element (FE) modal approach to determine the critical loads and buckling mode shapes associated with the lateral buckling of the tensile armors in flexible pipes. This approach is based on pre-curved and twisted beam finite elements that are restrained to slide on the surface of a torus. The influence of the pipe's bending is addressed by assuming that the pre-buckling configuration of the tensile armors are geodesics or loxodromes of a torus and, moreover, friction effects are approximated using elastic springs. The proposed FE approach is employed in the classical buckling analyses of different tensile armors of several flexible pipes that have been previously studied in the public literature. The conducted analyses indicated that the buckling modes are sinusoidal and the pre-buckling configuration of the tensile armors in bent pipes affects their lateral buckling load. Moreover, friction between layers increases the lateral buckling resistance of the armor. Finally, comparisons with experimental and numerical results available in the literature indicates that the proposed approach is promising.

Jiwoon Yi (1), Soo-Chang Kang (1), Wonsuk Park (2) and Jinkyo F. Choo (3)
(1) Steel Structure Research Group, POSCO, 100 Songdogwahak-ro, Yeonsu-gu, Incheon, 21985, South Korea
(2) Dept. of Civil Engineering, Mokpo National University, 1666 Youngsan-ro, Chonggye-myeon, Muan-gun, Jeonnam, 58554, South Korea
(3) Dept. of Energy Engineering, Konkuk University, 120 Neungdong-ro, Gwangjin-gu, Seoul, 05029, South Korea


ABSTRACT: Abundant literature was dedicated to the numerical tracking of the yield strength of cold formed pipes throughout their forming process. However, the flattening process conducted on straps sampled from the formed pipe for tensile test as well as the residual stress developed after each stage were not considered in most studies. Therefore, a simulation-based finite element analysis program was developed to replicate the UOE forming of steel pipes and track the yield strength throughout the forming process and final flattening considering the residual stress. The accuracy of the simulation was validated through comparison with
experimental data for API 5L X70 steel pipe. In this study, the program is employed to examine the causes leading to the change in the yield strength at each forming stage. In addition, the effect of the thickness-to-diameter ratio (t/D) on the yield strength is evaluated. The consideration of the residual stress in the simulation enabled to find the existence of a critical range for beyond which further improvement of the yield strength cannot be achieved.

Gholamreza Gholipour, Chunwei Zhang and Asma Alsadat Mousavi (School of Civil Engineering, Qingdao University of Technology, Qingdao, 266033, China), “Nonlinear numerical analysis and progressive damage assessment of a cable-stayed bridge pier subjected to ship collision”, Marine Structures, Vol. 69, Article 102662, January 2020, https://doi.org/10.1016/j.marstruc.2019.102662

ABSTRACT: Despite many studies on barge collisions with girder bridges in the literature, this paper investigates the progressive damage behaviors and nonlinear failure modes of a cable-stayed bridge pier subjected to ship collisions using finite element (FE) simulations in LS-DYNA. The damages in the pier initiate with appearing of local shear failures in the slender columns during the ship collision stage and reach the severe cross-sectional fractures associated with the formation of plastic hinges which causes the combined shear-flexural failures during the free vibration phase of the pier response. In addition, an analytical simplified model with two-degree-of-freedom (2-DOF) is proposed to formulate the strain rate effects of the concrete materials as the dynamic increase factors in the global responses of the impacted pier. It is found that the analytical model is able to efficiently estimate the impact responses of the structure compared to those from the FE high-resolution simulations. Moreover, three different damage indices are proposed based on the pier deflection, the internal energy absorbed by the pier, and the axial load capacity of the pier columns to classify the damage levels of the pier. Finally, an efficient damage index method is determinant by comparing the calculated results with the damage behaviors of the pier observed from the FE simulations.

References listed at the end of the paper:

11. P. Yuan, I.E. Harik, Equivalent barge and flotilla impact forces on bridge piers, J Bridge Eng, 15 (2009), pp. 523-532
21 W. Fan, Y. Zhang, B. Liu, Modal combination rule for shock spectrum analysis of bridge structures subjected to barge collisions, J Eng Mech ASCE, 142 (2) (2016), Article 04015083
22 LS-DYNA 971, Livermore software Technology corporation, (2015) Livermore, CA, USA
28 W. Fan, W.C. Yuan, Numerical simulation and analytical modeling of pile supported structures subjected to ship collisions including soil–structure interaction, Ocean Eng, 91 (2014), pp. 11-27
32 T.V. Do, T.M. Pham, H. Hao, Dynamic responses and failure modes of bridge columns under vehicle collision, Eng Struct, 156 (2018), pp. 243-259
33 H. Jiang, J. Wang, M.G. Chorzepa, J. Zhao, Numerical investigation of progressive collapse of a multispans continuous bridge subjected to vessel collision, J Bridge Eng ASCE, 22 (5) (2017), Article 04017008
36 G.R. Consolazio, M.T. Davidson, D.R. Cowan, Barge bow force-deformation relationships for barge–bridge collision analysis, Transp Res Rec, 2131 (2009), pp. 3-14
38 LSTCLIS-DYNA keyword user's manual version 971, Livermore Software Technology Corporation, CA, USA (2016)
39 N. Jones, Structural impact, Cambridge University press, UK (2011)
40 European Committee for Standardization (CEN), Eurocode 1– actions on structures. Parts 1–7: general actions– accidental actions due to impact and explosions, (3draft), CEN, Brussels, Belgium (2002)
41 China Ministry of Railways (CMR), General code for design of railway bridges and culverts (TB10002.1-2005), China Railway press, Beijing, China (2005) [in Chinese]
42 Y. Cao, L. Luo, Y. Zhou, Ship collision protection device for Zhanjiang Bay bridge, 17th congress of IABSE, creating and renewing urban structures international association for bridge and structural engineering chicago (2008)
43 ACI 318-14, Building code requirements for structural concrete and commentary, American Concrete Institute, Farmington Hills, MI, USA (2014)
49 API, Recommended practice for planning designing and constructing fixed offshore platforms, Recommended Practice 2A–WSD, (twenty-first ed.), American Petroleum Institute, Dallas, TX, USA (2000)
52 T. Krauthammer, S. Shahriar, A computational method for evaluating modular prefabricated structural element for rapid construction of facilities, barriers, and revetments to resist modern conventional weapons effects. Report No. ESL-TR-87-60, Engineering and Services Laboratory Air Force Engineering and Services Center, FL, USA (1988)

Zhenkui Wang (1,2), G.H.M. van der Heijden (2)
(1) State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin, 300072, China

ABSTRACT: Pipelines exposed to high temperature and high pressure with a topographic step imperfection are susceptible to the phenomenon of upheaval buckling potentially leading to a hazard for the structural integrity of the pipeline. To analyse this problem we derive analytical upheaval buckling solutions and obtain the locations of maximum displacement and maximum axial compressive stress. We also analyse the typical post-buckling behaviour and its dependence on step height, axial soil resistance and wall thickness. The difference in behaviour between a pipeline with step imperfection and one with a symmetric prop imperfection is discussed. Our results show that a pipeline with a step imperfection is more prone to upheaval buckling than a perfect pipeline. For sufficiently small step heights the pipeline may suffer a snap-back instability under decreasing thermal loading, raising the possibility of hysteretic snap behaviour under cyclic thermal loading (for instance caused by periodic start-ups and shut-downs). The snap-back buckling disappears for large enough step height and the minimum critical temperature difference decreases with increasing step height and wall thickness or with decreasing axial soil resistance. The maximum compressive stress decreases with increasing step height and axial soil resistance or with decreasing wall thickness. A pipeline with step imperfection is safer than one with a symmetric prop imperfection.

References listed at the end of the paper:
1 D. Bruton, D.J. White, C.Y. Cheuk, M.D. Bolton, M. Carr, Pipe-soil interaction behavior during lateral buckling, including large-amplitude cyclic displacement tests by the SAFEBUCK JIP (OTC-17944-MS), Offshore technology conference houston, Texas (2006), pp. 1-10
2 H. Karampour, Effect of proximity of imperfections on buckle interaction in deep subsea pipelines, Mar Struct, 59 (2018), pp. 444-457
4 DNV-RP-F110, Global buckling of submarine pipelines structural design due to high temperature/high pressure, Det Norske Veritas (2018)
6 R.E. Hobbs, Pipeline buckling caused by axial loads, J Constr Steel Res, 1 (1981), pp. 2-10
7 A.D. Kerr, Analysis of thermal track buckling in the lateral plane, (1978)
12 R. Liu, H. Xiong, X. Wu, S. Yan, Numerical studies on global buckling of subsea pipelines, Ocean Eng, 78 (2014), pp. 62-72
16 Z. Wang, Y. Tang, G.H.M. van der Heijden, Analytical study of distributed buoyancy sections to control lateral thermal buckling of subsea pipelines, Mar Struct, 58 (2018), pp. 199-222
20 Z. Wang, G.H.M. van der Heijden, Y. Tang, Localised upheaval buckling of buried subsea pipelines, Mar Struct, 60 (2018), pp. 165-185
22 N. Taylor, V. TranProp-imperfection subsea pipeline buckling, Mar Struct, 6 (1993), pp. 325-358
23 P.T. Pedersen, J.J. Jensen, Upheaval creep of buried heated pipelines with initial imperfections, Mar Struct, 1 (1988), pp. 11-22
ABSTRACT: The aim of the present paper is to develop a simple theoretical method which can quickly calculate the nonlinear dynamic response of blast-loaded stiffened plates under a blast loading. The large deformation behavior of the stiffened plate is analyzed by using a singly symmetric beam model as representative of the stiffened plate. The material is assumed to be rigid-perfectly plastic, and the strain rate sensitivity is considered by using the Cowper–Symonds constitutive model (CS model). By Lee's extremum principle, the instantaneous
modes of nonlinear structural response are determined. A series of calculations are performed to investigate the influence of pulse intensity, pulse duration, plate thickness, stiffener spacing and material property on the displacement response. The obtained results are in good agreement with those of numerical simulations performed by software package ABAQUS, and then a definition for the cases when the simplified method proposed here can be used is provided.

Han-Baek Ju (1), Beom-Seon Jang (2), Junhwan Choi (1), Jung Kim (3), and Sang-Bae Jun (3)
(1) Department of Naval Architecture and Ocean Engineering, College of Engineering, Seoul National University, 1, Gwanak-ro, Gwanak-gu, Seoul, South Korea
(2) Research Institute of Marine Systems Engineering, Dept. of Naval Architecture and Ocean Engineering, Seoul National University, 1, Gwanak-ro, Gwanak-gu, Seoul, South Korea
(3) Samsung Heavy Industries, HSE Research, Seongnam, Kyounggi-do, South Korea


ABSTRACT: Ship-to-ship collision events can have severe consequences such as loss of life and environmental degradation. For this reason, modern ship designs are required to incorporate a double-hulled structure to prevent inner-hull damage from such events. Using the experimental or numerical method to analyze the crushworthiness of double-hulled ship structures entails much effort, for which reason neither method is easy to adopt at the early design stage. In this paper, an existing simplified method called Ito’s method is improved by a new buckling-and-contact-based expansion method. This method can be applied to double-hulled-structure or outer-hull-local-rupture failure mode. The perpendicular bow-to-side collision scenario is assumed for a conservative estimation of damage to a double-hulled structure. The method was verified in the present study by numerical ship collision simulations of several cases. The results for the buckling-and-contact-based expansion method and numerical simulation were similar for a blunt shape of striking body but different for a sharp shape.

M.F. Hassanein (1,2), Yong-Bo Shao (1), M. Elchalakani (3) and A.M. El Hadidy (2)
(1) School of Civil Engineering and Architecture, Southwest Petroleum University, Chengdu, Sichuan, 610500, PR China
(2) Department of Structural Engineering, Faculty of Engineering, Tanta University, Tanta, Egypt
(3) School of Civil, Environmental and Mining Engineering, Faculty of Engineering, Computing and Mathematics, The University of Western Australia, Australia


ABSTRACT: Concrete-filled steel tubular (CFST) columns are currently used in offshore structures and oil and gas drilling platforms, from which the external steel tubes become at risk due to the aggressive ocean climate and/or sea water. Therefore, the CFST columns in corrosive environment lose their excellent mechanical performances and safety as the thicknesses of steel tubes decrease due to corrosion. This has recently led to the introduction of the concrete-filled stainless steel tubular (CFSST) columns, which benefit from the stainless steel as a superior metallic corrosion resistant material. Accordingly, CFSST short columns have recently attracted the scientific community. However, circular CFSST slender columns have received very little attention. Currently, this paper provides a nonlinear finite element (FE) inelastic analysis for the axially-loaded circular CFSST slender columns to substitute the lack in their behaviour; especially when the relative cheap lean duplex stainless steel material (EN 1.4162) is utilised. The FE models are firstly validated by using the available test results in literature. This validation stage is, then, followed by a parametric analysis to explore the fundamental behaviour of such columns considering the most important factors. The paper divides the slender columns into intermediate length and long columns based on the type of the overall buckling that takes place, and then the behavioural differences between both types are clearly addressed. The obtained FE axial strengths are additionally compared with those predicted by the European (EC4) and American (AISC) specifications. Based on these comparisons, a formula, based on Eurocode 4, is suggested for the routine compressive design practice of these columns, which is found to fit well with the axial strengths of current slender columns which utilise the lean duplex stainless steel material.
ABSTRACT: As offshore hydrocarbon production moves towards ultra-deep water, flexible risers have to withstand the huge hydro-static pressure without collapse. They are designed with strong collapse capacities, allowing them to operate under the condition where their annuli are flooded by the seawater. However, initial imperfections can weaken the collapse capacity under such a flooded condition, triggering the so-called “wet collapse”. Two common initial imperfections, the carcass ovality and the radial gap between the carcass and pressure armor, would reduce the collapse strength of flexible risers significantly. Mostly, collapse analyses are performed through numerical simulations, which are less feasible for the design stage of flexible risers comparing with analytical models. To date, there are few analytical models available in public literature to predict the wet collapse pressure of flexible risers accounting for initial ovality and gap. To meet this demand, an analytical model is established in this paper to address these issues. This model is developed as a spring-supported arch, solving the collapse pressure with stability theories of ring and arched structures. This analytical model is verified by numerical simulations, which gives prediction results that correlate well with the numerical ones.

Zhenkui Wang (1,2), Yougang Tang (1)
(1) Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin, 300072, China
(2) Department of Civil, Environmental and Geomatic Engineering, University College London, London, WC1E 6BT, UK
ABSTRACT: Subsea pipelines exposed to high temperature and high pressure (HTHP) conditions is susceptible to lateral buckling. In order to control lateral buckling, engineered buckle initiators, such as sleepers, are introduced to initiate planned lateral buckles along the pipeline at specific locations in order to ensure that the stress in each lateral buckle remains acceptable. In this study, taking the interaction of adjacent buckles into account, analytical solutions of antisymmetric lateral buckling mode triggered by sleepers are derived. With the proposed formulations, the method to obtain the accurate locations of lateral displacement amplitude and maxima of bending stress is presented and discussed. And a detailed comparison between symmetric and antisymmetric mode of lateral buckling triggered by single sleeper is presented. Moreover, the influence of the sleeper spacing on controlled lateral buckling behaviour with the consideration of axial interaction between adjacent buckles is conducted. Finally, a detailed analysis about the influence of the sleeper height, lateral frictional coefficient and submerged weight of the pipeline on the controlled post-buckling behaviour is presented. Our results show that, for smaller sleeper friction or smaller sleeper height, the symmetric mode is more likely to happen, while the antisymmetric mode is prone to occur for larger sleeper friction and larger sleeper height. One effective method to reduce displacement amplitude and maximum stress is to decrease the sleeper spacing. The minimum critical temperature difference decreases with increasing sleeper height and increases with increasing lateral friction coefficient or submerged weight of the pipeline. And an alternative way to reduce the maximum stress is to reduce the lateral friction coefficient or submerged weight of the pipeline even though the displacement amplitude increases.

Ling Zhu (1,2), Lele Duan (3), Mingsheng Chen (1,2), T.X. Yu (3,4) and Preben Terndrup Pedersen (3,5)
(1) High Performance Ship Technology (Wuhan University of Technology), Wuhan, 430063, PR China
(2) Collaborative Innovation Centre for Advanced Ship and Deep-Sea Exploration (CISSE), Shanghai, 200240, PR China
(3) Departments of Naval Architecture, Ocean and Structural Engineering, School of Transportation, Wuhan University of Technology, PR China
(4) Department of Mechanical and Aerospace Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong
(5) Department of Mechanical Engineering, Technical University of Denmark, DK-2800, Lyngby, Denmark

ABSTRACT: When a ship navigates at sea, the slamming impact can generate significant load pulses which move up along the hull plating. The effect of the moving pressure has so far not been explicitly considered in the Rules and Regulations for the Classification of Ships. Based on a modal superposition method and the Lagrange equation, this paper derives analytical solutions to study the elastic dynamic responses of fully clamped rectangular plates under moving pressure impact loads. The spatial variation of the moving slamming impact pressure is simplified to three types of impact loads, i.e. a rectangular pulse, a linearly decaying pulse and an exponentially decaying pulse. The dynamic responses of fully clamped rectangular plates under the moving slamming impact pressure are calculated in order to investigate the influence of the load pulse shapes and moving speed on the plate structural behaviour. It is found that the structural response of the plate increases with the increase of the moving speed. The response of the plate subjected to a moving pressure impact load is smaller than the case when the plate is subjected to a spatially uniform distributed impact load with the same load amplitude and load duration. In order to quantify the effect of the moving speed on the dynamic load, a Dynamic Moving Load Coefficient (DMLC) is introduced as the ratio between the dynamic load factor for the moving impact load and that under the spatially uniform distributed impact load. An expression for DMLC is proposed based on analyses of various scenarios using the developed analytical model. Finally an empirical formula which transforms the moving impact loads to an equivalent static load is proposed.


ABSTRACT: This paper is the second of two companion papers concerning the ultimate hull girder strength of container ships subjected to combined hogging moment and bottom local loads. The nonlinear finite element analysis in Part 1 has shown that local bending deformation of a double bottom due to bottom lateral loads significantly decreases the ultimate hogging strength of container ships. In this Part 2, extending Smith's method for pure bending collapse analysis of a ship's hull girder, a simplified method of progressive collapse analysis of ultimate hogging strength of container ships considering bottom local loads is developed. The double bottom is idealized as a plane grillage and the rest part of the cross section as a prismatic beam. An average stress-average strain relationship of plate/stiffened plate elements employed in Smith's method is transformed into an average stress-average plastic strain relationship, and implemented in the conventional beam finite element as a pseudo strain hardening/softening behaviors. The extended Smith's method is validated through a comparison with nonlinear finite element analysis.

Kévin Brochard (1), Hervé Le Sourne (1) and Guillaume Barras (2)
(1) GeM Institute, UMR 6183 CNRS - ICAM, Nantes, France
(2) Direction Générale pour l’Armement / Naval Systems, Toulon, France


ABSTRACT: The work presented in this paper is focused on the development of a simplified method to study the structural response of a deeply immersed cylinder subjected to the primary shock wave generated by an underwater explosion. The proposed analytical model is based on the string-on-foundation method initially developed by Hoo Fatt and Wierzbicki, who converted the two dimensional boundary value problem of a cylindrical shell to an equivalent one-dimensional problem of a plastic string on a plastic foundation. This method has already been extended by the authors to study the shock wave response of an unstiffened cylinder immersed in shallow water. The present work focuses on deep-immersed cylinders subjected to both high hydrostatic pressure and explosion shock wave. The elastic deformation energy of the cylinder under hydrostatic pressure is first calculated and used to determine the initial conditions of the dynamic problem. Cylinder deflection and plastic deformation energy are then calculated for various immersion depths. When confronted to numerical results, the proposed model appears to underestimate the increase of deflection and absorbed energy with the immersion depth. A thorough analysis of the results post-processed from Ls-Dyna/USA finite element simulations highlights a new mechanism which is due to the action of hydrostatic pressure that continues to push inward the immersed cylinder. In order to improve the analytical model, a
correction factor on the hydrostatic pressure is introduced but it is finally concluded that a new mechanism dedicated to the late action of the hydrostatic pressure still needs to be developed.

Carlos Javier (1,3), James LeBlanc (2) and Arun Shukla (1)
(1) Dynamic Photo Mechanics Laboratory, Department of Mechanical, Industrial and Systems Engineering, University of Rhode Island, Kingston, RI, 02881, USA
(2) Naval Undersea Warfare Center (Division Newport), 1176 Howell St, Newport, RI, 02841, USA
ABSTRACT: An experimental and computational investigation was conducted to evaluate the underwater blast response of fully submerged carbon fiber composite plates after prolonged exposure to saline water. The material was a biaxial carbon fiber/epoxy composite with a [±45°] fiber orientation layup. The plates were placed in a saline water bath with a temperature of 65 °C for 35 and 70 days, which simulates approximately 10 and 20 years of operating conditions in accordance to Fick's law of diffusion coupled with Arrhenius's Equation and a reference ocean temperature of 17 °C. Underwater blast experiments were performed in a 2.1 m diameter pressure vessel. The composite plates were placed in the center of the vessel while fully submerged in water, and an RP-85 explosive was detonated at a standoff distance of 102 mm from the center of the plate. Two cases of fluid hydrostatic gage pressures were investigated: 0 MPa, and 3.45 MPa. Two high speed cameras were utilized for three-dimensional Digital Image Correlation, which provided full-field displacements and velocities of the composite plates during underwater blast loading. A third high speed camera captured the behavior of the explosive gas bubble. Moreover, the pressure fields generated by the explosive detonation and resulting gas bubble were recorded with tourmaline pressure transducers. A water diffusion study was completed which showed that the diffusion of water into the composites reached a point of complete saturation after 35 days of exposure. Quasi-static material characterization tests were performed before and after prolonged exposure to saline water. The properties obtained from quasi-static testing also served as material inputs for the numerical models. The quasi-static test results showed that the tensile modulus $E$, does not change with exposure to saline water, whereas the in-plane shear modulus $G$, decreases with saline water exposure. During blast loading, for the case of 0 MPa hydrostatic gage pressure, the gas bubble interacts with the composite plate substantially. In such an event, the out of plane displacement increased for saline water exposed plates when compared to virgin structures. For the case of 3.45 MPa hydrostatic gage pressure, the gas bubble does not visibly interact with the composite plate. In this case, the out of plane displacement for specimens exposed to saline water was similar to the virgin specimen. A fully coupled Eulerian–Lagrangian fluid structure interaction simulation was performed by using the DYSMAS code. The numerical simulations showed that the displacement of fully submerged composite plates is driven by the displacement of fluid, as well as the size of the gas bubble formed by the explosive rather than the peak pressure generated by the explosive. The numerical simulations were in agreement with the experimental findings in terms of pressure history and plate deformation.

Miguel A.G. Calle (1,3), Mika Salmi (2), Leonardo M. Mazzariol (3), Marcilio Alves (4) and Pentti Kujala (1)
(1) Marine Technology Research Group, Department of Mechanical Engineering, Aalto University, Tietotie 1C, 02150, Espoo, Finland
(2) Advanced Manufacturing and Materials Research Group, Department of Mechanical Engineering, Aalto University, Puumiehenkuja 5A, 02150, Espoo, Finland
(3) Engineering Modeling and Applied Social Sciences (CECS), Federal University of ABC, Av. dos Estados, 5001, Santo André, SP, 09210-580, Brazil
(4) Group of Solid Mechanics and Structural Impact, Department of Mechatronics and Mechanical Systems Engineering, Polytechnic School of the University of Sao Paulo, Av. Prof. Melo Moraes, 2231, Sao Paulo, SP, 05508-030, Brazil
ABSTRACT: Undoubtedly, the main advantage of the additive manufacture technology is to allow building miniature structural parts with a large degree of complexity such as to replicate structural details of real-scale marine structures. This work presents a new technique for reproducing the structural response of large-scale
thin-walled metallic structures when subjected to crushing loadings by using scaled-down additive manufactured models. This technique couples scaling laws for strain rate sensitive materials and a thickness distortion technique based on the structural collapse mode. In order to validate this coupled technique, the structural response of a large-scale crushing test of a web girder structure was experimentally replicated by using a 1/40 scale reduction model. The results and conclusions summarize the prospects and limitations of additive manufacturing of miniature complex marine structures for structural purposes and crashworthiness verification.

Y. Amini (1), M. Heshmati (2) and F. Daneshmand (3)
(1) Department of Mechanical Engineering, Persian Gulf University, Bushehr, 75169, Iran
(2) Department of Mechanical Engineering, Kermanshah University of Technology, Kermanshah, Iran
(3) Department of Mechanical Engineering, McGill University, H3A 2K6, Canada

“Dynamic behavior of conveying-fluid pipes with variable wall thickness through circumferential and axial directions”, Marine Structures, Vol. 72, Article 102758, July 2020,
https://doi.org/10.1016/j.marstruc.2020.102758

ABSTRACT: In addition to the traditional hollow circular sections used in marine structures, other hollow sections have attracted the attention of architects and design engineers due to their mechanical characteristics such as torsional rigidity and local strength against impact loading. The purpose of this study is to investigate dynamic response of pipes conveying fluid with variable wall thickness through both circumferential and axial directions. Pipes with variable wall thickness have different flexural rigidities about two different principal axes. This property allows these pipes to be oriented efficiently, meet various design requirements and resist the applied loads. The results of this investigation provide a better insight into the physics and dynamic behavior of non-circular pipes conveying fluid. Two different geometries are studied, (i) the pipe is assumed with a general non-circular cross section with variable wall thickness along the circumferential direction, (ii) both inner and outer boundaries of the pipe cross section are assumed to be circles whereas the wall thickness of the pipe along axial direction is varied with a specified function. The governing differential equations of the problem are derived using Timoshenko beam theory with the effect of shear deformation included in the formulation. The discretization of the problem domain is done using the finite element method. Consequently, a modal analysis is employed to calculate the critical flow velocities of the pipe with clamped-clamped end conditions. The effects of different cross sections on the critical flow velocity are investigated. The importance of Coriolis forces on the presence of coupled-mode flutter and re-stabilization point are also discussed for different values of mass ratio.

D. Fernández-Valdés (1), A.O. Vázquez-Hernández (2), J.A. Ortega-Herrera (1), A. Ocampo-Ramírez (3) and D. Hernández (4)
(1) SEPI-ESIME, Instituto Politécnico Nacional, Mexico City, Mexico
(2) Lloyds Register, Mexico City, Mexico
(3) Instituto Sanmiguelense, San Miguel de Allende, Guanajuato, Mexico
(4) NEO (Ocean Structures Laboratory), COPPE-Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

“FEM-based evaluation of friction and initial imperfections effects on sandwich pipes local buckling”, Marine Structures, Vol. 72, Article 102769, July 2020,
https://doi.org/10.1016/j.marstruc.2020.102769

ABSTRACT: Sandwich pipes have been studied as one option to overcome the high pressure problems in deep and ultra-deep waters. They have become a possible alternative solution for submarine infrastructure due to its thermal insulation capacity. This contribute to preventing the pipeline from clogging due to the difference in temperature between reservoir fluids and water at the bottom of the sea. The pipelines in ultra-deepwater are continually exposed to severe operating conditions, such as the effect of high levels of external pressure that can cause local deformation or even collapse of the pipe. Thus, a greater understanding of the mechanical behavior of sandwich pipes is required. This paper presents a FEM-based evaluation of friction and initial imperfection effects on sandwich pipes local buckling. The non-linear evaluation was carried out in FEM of local buckling of two sandwich pipes, with polypropylene and cement as filled annular material. The influence of initial imperfections and the degree of friction, between the annular material and the steel pipes, as well as geometric variations of the pipe were considered. The numerical simulations results indicate a capacity to withstand ultra-deep waters collapsing pressures, around 3000 m, either for polypropylene or cement filled annular material model. In addition, the results indicate that the collapse pressure is inversely proportional to the increase in annular thickness and directly proportional to the decrease in friction which have an impact and contribution on
the carrying capacity of the sandwich pipe. Further research will consider a design of experiments analysis of reported effects for different diameter-to-thickness ratios.

Hang Xie (1), Fang Liu (1), Haoyun Tang (2) and Xinyu Liu (1)
(1) School of Intelligent Manufacturing, Huanghui University, Zhumadian, China
(2) Navigation College, Dalian Maritime University, Dalian, China
ABSTRACT: Dynamic response of ship-hull structure under slamming has tracked widespread attention in the marine structural design. However, our understanding on the dynamic characteristics largely relies on the symmetrical slamming cases. This paper presented a preliminary numerical investigation on the dynamic response of a truncated ship-hull structure under asymmetrical slamming based on the uncoupled CFD-FE method. Asymmetrical slamming loads were predicted through combining the seakeeping analysis and CFD method. In there, three kinds of motions (vertical, horizontal and roll motions) of 2D ship sections were obtained through the seakeeping analysis and then the slamming pressure was predicted through simulating the water entry with various motions based on CFD method. The dynamic response was analyzed through finite element method. Numerical predictions including ship motions, slamming loads and dynamic analysis were validated against published experimental data and numerical calculations. The characteristics of asymmetrical slamming loads were analyzed showing obvious asymmetry in space, and the dynamic characteristic of the ship bow structure was further clarified through discussing the deformation and stress distribution. These results are useful for readers for better understanding the dynamic characteristics of the bow structure under slamming.

Junchang Ci (1), Shicai Chen (1), Hong Jia (2), Weiming Yan (1), Tianyi Song (1) and Kang-Suk Kim (3)
(1) Department of Civil Engineering, Beijing University of Technology, Beijing, China
(2) China Railway Urban Construction Group Co., Ltd, Hunan, China
(3) Korea Institute of Civil Engineering and Building Technology, Gyeonggi, 10223, South Korea
ABSTRACT: The concrete-filled double-tube (CFDT) columns have been proposed in recent years. The existence of inner steel tube can not only increase the confinement on core concrete, but also increase its fire resistance and anticorrosion performance. This makes it have a great application prospect in the field of ocean structure engineering. In this paper, the axial compression performance of square CFDT short columns is comprehensively analyzed. The specimens studied consist of an external steel tube (square hollow section) and an inner steel tube (circular hollow section), in which concrete is completely filled. The fine finite element (FE) method is used to simulate the performance of this column. Two constitutive models of confined concrete for square CFDT core concrete are proposed. In order to ensure the correctness of the model, the verification analysis of the model is carried out based on the previous experimental results, and the whole process of axial compression performance of CFDT columns is analyzed in detail. The concrete strength (math), width-thickness ratio (B/t), diameter-thickness ratio (d/t), diameter-width ratio (d/B) and yield strength (math) of square CFDT columns are compared and analyzed. The performance of CFDT columns with the same steel content is also analyzed, it is of great significance to improve the application of CFDT columns in marine environment or high temperature environment. Finally, new formulas for calculating the ultimate bearing capacity of CFDT short columns under axial compression are proposed. The results show that the new formulas can predict the strength of CFDT short columns well.

Renhua Wang (1), Haichao Guo (1) and R. Ajit Shenoi (2)
(1) Department of Civil Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
(2) Southampton Marine and Maritime Institute, University of Southampton, Boldrewood Innovation Campus, Southampton, SO16 7QF, UK
ABSTRACT: Locally pitted tubular members are usually considered as stub columns to assess the ultimate strength. However, it is not suitable for those with relatively larger slenderness ratios as their failure behavior is
more complex and closely related to corrosion features of localized pitting. This paper presents compressive column tests on locally pitted tubular members of a moderate slenderness ratio. Corrosion pits were artificially introduced on local surface of the members, forming corrosion patches with various corrosion features. A numerical modelling method was proposed to reproduce the test specimens. Localized pitting damage was proven to cause substantial declines in the load deformation capacity and ultimate strength, and have a significant effect on the failure mode. The failure of a pitted member is mostly initiated by local buckling after yielding occurs in the corrosion patch, concurrent with pitting closure, and even shear cracking of member wall due to the perforated pits. Moreover, shape change of the corrosion patch most likely results in the failure mode to alter from column buckling to local buckling or interactive buckling. The shape ratio of the corrosion patch is one of the critical factor to influence the ultimate strength of locally pitted members. The proposed modelling method is applicable for extensive stochastic simulations so as to develop an empirical formula and to clarify the probabilistic characteristics of ultimate strength.

Tianjiao Dai (1), Svein Sævik (1) and Naiquan Ye (2)
(1) Department of Marine Technology, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
(2) Energy and Transport, Sintef Ocean, Trondheim, NO-7052, Norway


ABSTRACT: The present paper addresses the stresses in dynamic steel tube umbilicals at the platform hang-off exposed to large motions corresponding to an extreme storm condition. Experimental tests were carried out by mounting fibre-optic Braggs inside steel tubes of a 9 m long umbilical specimen. Then the specimen was exposed to constant tension and dynamic curvature by means of a bellmouth and the stresses were measured. Realizing that the geometry of the umbilical cross section was too complex to apply full 3D modeling, a beam and penalty contact modeling procedure was applied to describe the extreme stress behavior. Then a simplified method was proposed to determine the contact stiffness which was further validated by full scale umbilical axial stiffness testing. As hoop contact interfaces between steel tubes and separation fillers were observed in the test specimen, a tailor-made contact element was formulated to facilitate hoop contact. Different modeling alternatives were used to investigate the hoop contact effect on the extreme axial stress and Coulomb friction stress range, which were further validated against measured dynamic axial stress. Good correlation was found by the combination of describing all contact interfaces and constraints due to the grooves in the inner sheath.


ABSTRACT: Localized pitting corrosion often occurs on marine and offshore structures in the form of patch corrosion with great uncertainties in the location, size and shape. The variation of corrosion features affects ultimate strength of tubular members significantly, but it is still not well understood. This paper presents a numerical study on tubular members of diverse slenderness ratios to clarify the localized pitting effect on ultimate strength. Numerical analyses were performed based on novel models of pitted members that were calibrated against benchmark column tests. Corrosion pits were randomly introduced on the local outside surfaces of members via stochastic simulation, forming corrosion patches varied in the location, size and shape. Numerical results obtained were regressed to propose a unified empirical formula to predict ultimate strength. It turned out that the shape of the corrosion patch has a significant influence on the ultimate strength. The shape change of the patch can alter failure modes of medium length columns. The reduction of ultimate strength is closely related to the shape ratio of the patch besides the volume loss of corroded material. The unified empirical formula incorporating the shape ratio and the volume loss shows a good ability to predict the experimental results.

ABSTRACT: This paper introduces a novel analytical method to predict the buckling collapse behaviour of a ship hull girder subjected to several cycles of extreme load. This follows the general principles of the established simplified progressive collapse method with an extended capability to re-formulate the load-shortening curve of structural components to account for cyclic degradation. The method provides a framework for assessing residual hull girder strength following a complex series of unusually extreme load events where the wave induced bending moment rises close to, or even surpasses, the monotonic ultimate strength. These load events may be sequential, such as might be caused by a series of storm waves, or they may occur as a collection of discrete events occurring over a longer period. The extreme cyclic bending amplifies the distortion and residual stress initially induced by fabrication in the flanges of the girder, which results in a deterioration of the residual ultimate strength. Validation is firstly completed through a comparison with previously published experimental work and secondly via comparison with numerical simulation on four ship-type box girders using the nonlinear finite element method.


ABSTRACT: The effects of non-symmetrical corrosion defects (about the major or minor axis of the ellipse) on the collapse modes and collapse pressures of subsea pipelines are studied using the Finite Element (FE) method. The corrosion defects are represented by a groove of a given length, width, and depth which is created by the “element death” technology. Parametric studies are conducted and the influences of corrosion location angle, length, width, and depth on the collapse pressure are discussed. Several significant and interesting results are achieved: (1) The collapse modes are mainly affected by the corrosion location angle, width, and depth; (2) The collapse pressure of a pipe may increase as the corrosion length, width, or depth increases when the corrosion location angle is small; (3) The longer the corrosion length, the larger the effect of corrosion location angle on the collapse pressure; (4) For collapses controlled by corrosion defect (0.3 ≤ h/t ≤ 0.7), the relationship between the collapse pressure and corrosion location angle follows a simple cosine function. For collapses controlled by the ovality (h/t < 0.3), the relationship can be expressed by the combination of straight-line and cosine function.


ABSTRACT: Rogue buckles may occur for unburied subsea pipelines operating under high temperature and high pressure conditions. Distributed buoyancy section (DBS) is often installed to trigger pipeline lateral buckling. Single distributed buoyancy section (SDBS) is normally adopted to trigger a symmetric lateral buckling mode. But in some cases, dual distributed buoyancy sections (DDBS) with a gap between them are utilised to trigger an antisymmetric lateral buckling mode. This paper concerns the behaviour of antisymmetric lateral buckling triggered by DDBS. First, the locations of the maxima of the deflection and bending stress are determined. Then, comparisons of the post-buckling behaviour between antisymmetric buckling mode, triggered by DDBS, and symmetric buckling mode, triggered by SDBS, are presented and discussed. The influences of the spacing between dual buoyancy sections and the parameters of the DBS on the buckled configuration and post-buckling behaviour are presented. Finally, the effects of the DBS on the minimum critical temperature difference, the maxima of the deflection and stress are discussed. The results show that the maxima of the deflection and stress of the antisymmetric mode are much smaller than that of the symmetric mode under the same operating conditions. During the design process, the spacing between dual buoyancy sections, the length and the weight ratio coefficient of the DBS should be determined in sequence.


ABSTRACT: This paper is dedicated to the comprehensive investigation on dented hemispheres under external hydrostatic pressure. A total of 20 stainless steel hemispheres are fabricated, which have a nominal radius of 60 mm and a nominal wall thickness of 0.76 mm. These fabricated hemispheres are divided into four groups
with five samples in each group. Wherein, three groups are dented using conical, spherical, and cylindrical indenters respectively, while the remaining group is designated as undented one. Both dented and undented hemispheres are hydrostatically tested into collapse to examine the effects of indentation on the collapse characteristics of hemispheres. Additionally, all tested hemispheres are semi-analytically and numerically evaluated based on the measured geometric data and tested material properties. The experimental, semi-analytical, and numerical results are compared in figures and tables.


ABSTRACT: In this previous study, a consistent theoretical formula was established in single hull structure, taking account of all the structural components affecting the load share of each member, in combination with the combined load effect of direct force from the longitudinal stiffener and shear force on the primary supporting member. What's more, it has been known qualitatively that the bending moment at the root of the web stiffener in double hull structure is less than that in single hull structure. However, the difference between double hull and single hull structures has not been achieved. In this study, the authors develop a theoretical formulation to represent the stresses at the root of the web stiffener due to the load from both the longitudinal stiffener and the shear force on the primary supporting member in the double hull structure. Then, the results calculated by the derived formulae are compared with the results obtained by finite element analysis, and good accuracy of the proposed formula was verified. Finally, the calculated stresses were compared between double hull and single hull structures. On one hand, the share of loading born by the web stiffener is almost comparable between the double hull and single hull structures. On the other hand, the bending moment at the root of the web stiffener is smaller in the double hull structure than in single hull structure, and therefore, the maximum stress is smaller.


ABSTRACT: Ice loads are important environmental loads that can influence the structural safety of ships during navigation in ice-covered waters. The identification of ice loads on ship hulls is the core of ice load monitoring. In this study, a new ice load identification model based on Green kernel and regularization methods is established. First, the forward model for ice load identification is developed through the discretised convolution integral of ice loads. Next, three commonly used regularization methods, including Tikhonov, truncated singular value decomposition, and least square QR-factorization (LSQR) are adopted to reduce solution errors. The LSQR method is thereafter selected as the optimal regularization operator, and its regular property is proved by numerical cases with ice-induced strains that contain noise. Finally, two load identification cases are conducted on an experimental rig to evaluate the feasibility of the model in ice load identification. The identified loads can determine the signal features of applied loads in the time domain with good accuracy. This identification model provides new insights for full-scale ice load monitoring.


ABSTRACT: Flexible pipes are key equipment for offshore oil and gas production systems, conveying fluids between the platform and subsea wells. The structural arrangement of unbonded flexible pipes is quite complex, encompassing several layers with polymeric, metallic and textile materials. Different topologies and a large amount of intricate nonlinear contact interactions between and within their components, especially because of the relative stick-slip mechanism during bending, makes numerical analysis challenging. This paper presents an alternative three-dimensional nonlinear finite element model that describes the response of flexible pipes subjected to combined axisymmetric and bending loads. To simulate the response of a flexible pipe under axial tension or compression combined with uniform curvature, an equivalent thermal loading is employed on the external sheath, which is modelled as an orthotropic thermal expansion material with temperature-independent

ABSTRACT: Steel fenders have been widely used to protect bridges from vessel collisions because of their relatively large plastic deformability and energy dissipation capacity. In the design of a steel fender, detailed finite element (FE) models are usually employed. However, detailed FE analysis involves complicated modeling and substantial computation time. This method is often not applicable, particularly during preliminary design iterations. For this reason, a simplified analytical method was developed in this paper with the aim to efficiently design steel fenders under vessel collisions. For primary individual members of steel fenders, the deformation mechanisms and models as well as participations during various collision scenarios were discussed in detail. By combining the contributions of primary members, a general analytical procedure was presented to rapidly estimate the force-deformation relationship of steel fenders under various bow impacts. For the fixed and floating steel fenders, several collision scenarios were simulated by FE models to verify the accuracy of the developed analytical method. The crushing resistances and energy dissipation capacities estimated by the developed analytical method were in good agreement with those obtained from the FE simulations. Based on the analytical method, an energy-based design approach was proposed for the efficient design of steel fenders. The developed design approach was demonstrated to be capable of predicting the crush depth and peak impact force of a steel fender with good accuracy.


ABSTRACT: The paper focuses on the ultimate strength of perforated platings with circular openings and manholes, eventually reinforced by ringed or carling stiffeners, in order to develop a comprehensive and rationale format, useful to assess the ultimate capacity of perforated plate panels under uniaxial compression. In this respect, a large number of FE simulations is performed by Ansys Mechanical APDL, in order to provide new design formulas for the ultimate strength of platings with circular openings or manholes and, subsequently, for perforated plate panels reinforced by local stiffeners. The design formulas are developed by properly varying the opening size and the scantlings of ringed or carling stiffeners, in order to provide a comprehensive set of design curves. Hence, the incidence of the opening longitudinal position on the ultimate capacity of perforated platings, without and with local stiffeners, is also investigated. Finally, the proposed equations are applied in a straightforward design example. Based on current results, the new design formulas allow a reliable assessment of the ultimate capacity of platings with circular openings or manholes and the incidence of local stiffeners on the plating ultimate strength, so providing a rationale design format that could be easily embodied in current Rules and guidelines.

References listed at the end of the paper:
3 J.M. Frankland, The strength of ship plating under edge compression, David Taylor Model Basin (1940), Report No. 469
6 W. Cui, Y. Wang, P.T. Pedersen, Strength of ship plates under combined loading, Mar Struct, 15 (2002), pp. 75-97
7 J.K. Paik, B.J. Kim, Ultimate strength formulations for stiffened panels under combined axial load, in-plane bending and lateral pressure: a benchmark study, Thin-Walled Struct, 40 (2002), pp. 45-83
11 V. Piscopo, A. Scamardella, Towards a unified formulation for the ultimate strength assessment of intact and pitted platings under uniaxial compression, Ocean Eng, 169 (2018), pp. 70-86
12 V. Piscopo, A. Scamardella, Comparative study between analytical and FE analysis for the ultimate strength assessment of pitted platings, Int Shipbuild Prog, 66 (1) (2019), pp. 3-15
13 V. Piscopo, A. Scamardella, Ultimate strength assessment of intact and pitted platings under biaxial compression, Eng Struct, 204 (11079) (2020), pp. 1-17
16 A. Campanile, V. Piscopo, A. Scamardella, Time-variant bulk carrier reliability analysis in pure bending intact and damage conditions, Mar Struct, 46 (2016), pp. 193-228
17 W.P. Vann, Compressive buckling of perforated plate elements, Proceedings of the 1st international specialty conference on cold-formed steel structures, 19-20 August 1971, University of Missouri-Rolla, Missouri, USA (1971), pp. 52-57
18 W. Yu, C.S. Davis, Buckling behaviour and post-buckling strength of perforated stiffened compression elements, Proceedings of the 1st international specialty conference on cold-formed steel structures, 19-20 August 1971, University of Missouri-Rolla, Missouri, USA (1971), pp. 58-64
19 D. Ritchie, J. Rhodes, Buckling and post-buckling behaviour of plates with holes, Aeronaut Q, 26 (4) (1975), pp. 281-296
28 DNV, Rules for classification of ships (2016)
30 ABS, Rules for building and classing – steel vessels (2019)
31 Ansys, User manual of Ansys APDL mechanical, Release, 18 (2017), p. 2
33 S. Zhang, A review and study on ultimate strength of steel plates and stiffened panels in axial compression, Ships Offshore Struct, 11 (1) (2016), pp. 81-91


ABSTRACT: In order to improve the combat effectiveness, stealth and safety of the marine structures, we design and fabricate the multilayer gradient composite lattice sandwich panels (MGCLSPs) to achieve excellent mechanical properties, vibration isolation characteristics and lightweight features of structures in the present study. The ideas of bionic gradients and material mixtures are incorporated in the design to improve the damping and vibration isolation behaviors of the MGCLSPs. The compression and hysteresis responses of the empty and polyurethane foam-filled MGCLSPs are investigated experimentally and numerically. It is found that the MGCLSPs have better energy absorption characteristics than the non-gradient panels, and the MGCLSP
specimen D1 which is positive gradient absorbs the most energy. The experimental results also show that the addition of polyurethane foam can enhance the strength and energy absorption characteristics of MGCLSPs.

References listed at the end of the paper:

7 H.N. Wadley, Multifunctional periodic cellular metals, Phil Trans, 364 (1838) (2006), pp. 31-68
8 L.L. Yan, B. Yu, B. Han, et al., Compressive strength and energy absorption of sandwich panels with aluminum foam-filled corrugated cores, Compos Sci Technol, 86 (7) (2013), pp. 142-148
9 W. Shen, B. Luo, R. Yan, et al., The mechanical behavior of sandwich composite joints for ship structures, Ocean Eng, 144 (2017), pp. 78-89
14 J. Liu, X. Zhu, Z. Zhou, et al., Effects of thermal exposure on mechanical behavior of carbon fiber composite pyramidal truss core sandwich panel, Composites Part B, 60 (60) (2014), pp. 82-90
18 Y.Z. Wang, Y.S. Wang, Active control of elastic wave propagation in nonlinear phononic crystals consisting of diatomic lattice chain, Wave Motion, 78 (2018), pp. 1-8
19 V.S. Deshpande, N.A. Fleck, M.F. Ashby, Effective properties of the octet-truss lattice material, J Mech Phys Solid, 49 (8) (2001), pp. 1747-1769
26 L. Che, G.D. Xu, T. Zeng, et al., Compressive and shear characteristics of an octahedral stitched sandwich composite, Compos Struct, 112 (2014), pp. 179-187
29 J.S. Yang, J. Xiong, L. Ma, et al., Vibration and damping characteristics of hybrid carbon fiber composite pyramidal truss sandwich panels with viscoelastic layers, Compos Struct, 106 (2013), pp. 570-580
31 S. Li, J.S. Yang, L.Z. Wu, et al., Vibration behavior of metallic sandwich panels with Hourglass truss cores, Mar Struct, 63 (2019), pp. 84-98
ABSTRACT: Corrosion wastage is one of the most important structural degradation phenomena of ageing ships and leads to severe consequences in reducing the strength of ship structures in all loading conditions during the service life. This paper investigates the effect of steel corrosion degradation on the ship structural crashworthiness in grounding numerically, considering the reduction of the thickness of structural components and the loss of material mechanical properties due to corrosion. Corrosion degradation causes the change of material properties, such as Young’s modulus, yield stress, ultimate tensile stress and fracture strain, which
determine the yielding, work hardening and critical failure strain of the material defined in an impact analysis. The mean values of accident statistics of grounding are considered to define the seabed shape and size. The objective of the paper is to develop a practical engineering assessment of the crashworthiness of ageing ship structures accounting for the corrosion degradation. The numerical analyses evaluate the reaction force and energy dissipation versus the ship damage during the grounding accident. The resistance of intact and corroded ship hulls is compared shown that, for example, the absorbed energy of the corroded ship hull decreases 33.8% with a wasted thickness of 2.0 mm in stranding. Also, some discussions are presented on the accuracy of numerical analyses.


ABSTRACT: Risk assessment is regarded as an effective tool for the design of ship structures, based on the safety level approach (SLA). However, there are gaps between the theoretical realisation of the approach and its practical application, such as the lack of specific risk analysis tools for different structural failure modes. Ship structures have various failure modes under different hazards (e.g., ultimate limit state, accidental limit state, and fatigue limit state). In an accidental limit state, structural failure is generally a casual process from local damage to overall hull collapse, and is affected by structural uncertainty factors and accidental random impacts. In this paper, a structural reliability analysis (SRA) model based on a Bayesian belief network (BBN) is proposed for the hull girder collapse risk after accidents. In this model, a BBN is used to represent the random states of variable risk events after accidents, as well as the dependencies between events; and a SRA is used to evaluate the failure probability of hull girders for each possible accident condition.

The hull girder collapse risk of a membrane liquefied natural gas (LNG) carrier after grounding is analysed using the BBN-SRA model. Compared with the conventional methods, the risk level obtained is more reliable, given that different possible accident conditions are considered using the new model. The extreme accidental condition of the LNG leak, and subsequent cryogenic impacts on the structural strength are also considered using the nonlinear finite element analysis (FÉA) method. In addition, the inverse inference and information updates of the BBN are confirmed to be useful as supports for decision making in risk-based designs and emergency rescue processes.

References listed at the end of the paper:
7 DNV, Classification Note 30.6, Structural Reliability Analysis of Marine Structures, DET NORSKE VERITAS (1992)
12 C. Fang, P.K. Das, Survivability and reliability of damaged ship after collision and grounding, Ocean Eng., 32 (2005), pp. 293-307

ABSTRACT: The residual ultimate strength of steel stiffened plates damaged with a crack and subjected to axial compression is determined by using the nonlinear finite element method. The numerical method is verified by comparing the finite element results with experiments made to investigate the influence of varying orientation, length and location of the crack. Under the gradual compression loading, the stress intensity factor is given to check the crack propagation before the structure collapses. The initial weld induced plate distortions have a significant effect on the residual ultimate strength including the measured data by tests and the buckling-type one. A series of analysis is performed to study the effect of the different boundary conditions of the longitudinal edge, different type of initial deformations and the different cracks.

References listed at the end of the paper:
ABSTRACT: During offshore installation, steel lined pipes are subjected to severe plastic bending, resulting in detachment of the thin-walled liner pipe from the outer pipe and eventually, the formation of local buckling in
the form of short-wave wrinkles that menace the structural integrity of the pipeline. The paper focuses on the mechanical behaviour of mechanically lined pipes subjected to monotonic bending, considering for the presence of low and moderate levels of internal pressure, aimed at preventing or delaying wrinkle formation, and improving structural performance. The problem is solved numerically, accounting for geometric non-linearities, local buckling phenomena and elastic-plastic material behaviour for both the liner and the outer pipe. Two types of lined pipes are examined, with and without mechanical bonding between liner and outer pipe referred to as tight-fit and snug-fit lined pipe, respectively. The results demonstrate that the bending performance of lined pipes, under low or moderate internal pressure levels, is significantly improved. The influence of initial geometric imperfections on liner pipe buckling is also examined, showing the imperfection sensitivity of bi-material pipe bending behaviour.

References listed at the end of the paper:
6 A. Hilberink, Mechanical Behaviour of Lined Pipe, Ph.D. thesis, Faculty of Civil Engineering, Delft University of Technology (2011)
8 A. Hilberink, A. Gresnigt, L. Sluys, Liner wrinkling of lined pipe under compression: a numerical and experimental investigation, ASME 29th International Conference on Ocean, Offshore and Arctic Engineering, American Society of Mechanical Engineers, Shanghai, China (2010), OMAE2010-20285

Amrit Shankar Verma, Nils Petter Vedik and Zhen Gao (First author is from: Department of Marine Technology, Norwegian University of Science and Technology (NTNU), Norway), “A comprehensive

ABSTRACT: For installing offshore wind turbines into deep waters, use of floating crane vessels is essential. One of the major challenges is their sensitivity to wave-induced vessel and crane tip motions, which can cause the impact of lifted components like blades and nacelle with nearby structures. The impact loads on fibre composite wind turbine blades are critical as several complex damage modes, capable of affecting the structural integrity, are developed. Planning of such installation tasks therefore requires response-based operational limits that consider impact loads on the blade along with their damage quantification. The research area considering the impact behaviour of the lifted blade is novel, and thus, the paper identifies vessel, blade and lifting parameters that determine impact/contact scenarios. Furthermore, for a case in which a lifted blade with its leading edge impacts the tower, a numerical modelling technique is presented in Abaqus/Explicit, and a comprehensive damage assessment of the blade and an investigation of the impact dynamics and energy evolution are performed. Sensitivity studies for two distinct blade designs and two different impact locations are considered. The results show that 7–20% of the impact energy is absorbed as damage in the blade, whereas the majority dissipates as rigid-body motions of the blade after the impact. The findings of the study highlight the requirement for advanced installation equipment, such as active tugger lines, to prevent successive impacts of wind turbine blades during installation.


ABSTRACT: A computational study of the flow over an axisymmetric submarine hull undergoing unsteady maneuvers is presented. The computational model is based on the Unsteady Reynold’s-Averaged Navier-Stokes equations, solved in body fixed coordinates using the Wilcox two-equation turbulence model. Static drift and dynamic sway simulations are performed on a hull geometry with a slenderness ratio of 8.5 and Reynolds number of 3.1 million, in strut-supported and unsupported configurations. Simulation results are compared with Horizontal Planar Motion Mechanism experiments at two reduced frequencies, k = 0.12 and k = 0.03. Simulated results for a strut supported hull are compared with experimental values to estimate simulation accuracy for static drift and dynamic sway. Simulation results for an unsupported hull demonstrate significant hysterisis of the hydrodynamic forces at k = 0.12, while at k = 0.03 the lateral force and yawing moment collapse towards the quasi-steady limit. Dynamic forces are decomposed in terms of the inviscid added mass and a viscous component which cannot be accounted for by the quasi-steady assumption and is attributed to flow history effects. The effect of flow history is further shown by visualisations of the wake vorticity. Finally, it is demonstrated that the presence of the support strut results in significant interference effects in all cases.


ABSTRACT: This paper derives an empirical formula for predicting the collapse strength of composite cylindrical-shell structures under external hydrostatic pressure loads as a function of geometric dimensions and layered angles, where the effects of initial manufacturing imperfections are implicitly taken into account. A series of experiments are undertaken on filament-wound-type composite cylindrical-shell models subjected to collapse pressure loads. A total of 20 composite cylindrical-shell models are tested to derive the empirical formula, which is validated by comparison with experimental data, existing design formulas of ASME 2007 and NASA SP-8700, and solutions of the nonlinear finite element method. It is concluded that the proposed formula accurately predicts the collapse pressure loads of filament-wound composite cylinders and will thus aid the safety design of composite cylindrical shell-structures under external pressure loads.

M. Erden Yildizdag, I. Tugrul Ardic, Murat Demirtas and Ahmet Ergin (First author is from: Department of Mechanical Engineering, University of California, Berkeley, CA, 94720, USA), “Hydroelastic vibration
ABSTRACT: This paper presents the hydroelastic vibration analysis of clamped rectangular plates, vertically or horizontally submerged in fluid by using isogeometric finite element and boundary element methods. The method of analysis is divided into two parts. In the first part, the dynamic characteristics of the structure, in vacuo conditions and in the absence of external forces, are obtained by NURBS-based isogeometric finite element method (IGAFEM). In the second part of the analysis, the fluid-structure interaction effects are calculated by using a NURBS-based isogeometric boundary element method (IGABEM) in conjunction with the method of images, in order to impose appropriate boundary condition on the fluid's free surface. By adopting the linear hydroelasticity theory, the fluid is assumed ideal, i.e., inviscid, incompressible and its motion is irrotational. The fluid-structure interaction effects are calculated in terms of the generalized added mass coefficients. In order to demonstrate the applicability of the proposed method, two different clamped rectangular plates were adopted for the calculations. The effects of the plate thickness and aspect ratio are also investigated. The predictions compare well with available numerical and experimental results found in the literature.


ABSTRACT: The residual ultimate strength of ship hull plates under uniaxial cyclic load is studied by numerical analysis using nonlinear finite element method. Strength behaviors of plate under cyclic loading are obtained and analyzed. The crack propagation from the low cycle fatigue damage is considered in present study. Three cyclic load cases are firstly analyzed and discussed in the assumption that fatigue crack propagation will not happen. Then accumulated residual stress and strain at the crack tip due to cyclic loads are studied when the fatigue crack is taken into consideration. The crack propagation rate is treated by a simple method based on the accumulated residual strain at the crack tip to improve computational efficiency in the numerical analysis. A typical relationship between the residual ultimate strength and number of cycles is established through the crack length. From the numerical results some significant conclusions are drawn to the residual ultimate strength of plates under uniaxial cyclic loads.


ABSTRACT: To ensure the structural capacity of plates with multiple openings subjected compressive loads and to find a better design solution, the strength of different structural configurations is analysed here. A series of experimental buckling collapse tests have been carried out for steel plates with multiple openings, of three different degrees of openings. Each degree of opening is represented by two groups of openings, to investigate the effect of possible design solutions aiming for the maximum compressive strength. The effect of corrosion wastage is also studied, where the specimens are naturally corroded. The effect of manufacturing defects as the initial imperfection on both compressive capacity and the final deformed shapes is also studied. Several relationships as functions of the degree of openings and remaining volume of the corroded plates with multiple openings are developed, and recommendations regarding the early design stage are provided.


ABSTRACT: An analytical solution is proposed to investigate the torsional dynamic response of a large-diameter pipe pile embedded in inhomogeneous soil. First, both the outer and inner soils are discretized into many annular vertical zones, and their radial inhomogeneity caused by the construction disturbance effect is considered by the gradual variedness of soil parameters in the radial direction. Meanwhile, the layered properties of the soil in the vertical direction are simulated by the distributed Winkler model. Then, the
analytical solution for the torsional dynamic response at the pile head is obtained by solving the pile–soil dynamic governing equations and its reliability is verified by comparing with the existing solutions. Finally, selected results for the complex impedance and velocity admittance are presented to examine the influence of the pile–soil parameters and the radial inhomogeneity of the soil on the torsional dynamic characteristics of the large-diameter pipe pile.


ABSTRACT: As water depths for oil and gas exploration and extraction increase, structures such as flexible risers, mooring lines, and umbilical cables are increasingly being used for subsea environments. Compared to conventional fixed-type structures and vertical risers, the dynamics of flexible risers is significantly more complex. In particular, the flexible structures may be prone to dynamic instabilities. The goal of the present paper is to provide a comprehensive study of the dynamics, stability, and vibration of flexible risers. We use Kirchhoff’s theory of an extensible, flexible rod that resists torsion to develop a set of nonlinear equations for the dynamics of risers. The resulting model incorporates drag and the effects of the fluid being transported internally. Using a nonlinear stability criterion, our analyses show the nonlinear stability of a simple catenary-type riser modeled either as an inextensible or extensible string. For the more advanced rod models, we use a linear stability analysis to show how the internal fluid being conveyed can destabilize certain static configurations.

Zheng Liang, Xin Lu and Jie Zhang (School of Mechatronic Engineering, Southwest Petroleum University, Chengdu, Sichuan, 610500, China), “Thermal vertical buckling of surface-laid submarine pipelines on a sunken seabed”, Ocean Engineering, Vol. 173, pp 331-344, 1 February 2019, https://doi.org/10.1016/j.oceaneng.2019.01.005

ABSTRACT: Submarine pipelines are the most viable way for transporting offshore oil and gas worldwide. However, it is easy to cause the vertical buckling in the process of work under the high temperature and high pressure. In this paper, the energy method was used to analyze and derive the relationship between the temperature and the buckling height during the thermal vertical buckling of the third-order mode of pipeline. Additionally, the finite element method was utilized to model and simulate the pipeline on submarine pit and trench respectively. From this investigation, it is found that the maximum circumferential stress and strain in mid-section of pipelines are larger than in left-section on submarine pit. On submarine trench, the maximum circumferential stress in mid-section is larger than in left-section but the maximum circumferential strain in mid-section is smaller than in left-section. The buckling height and length sharply increases with the increase of temperature or pressure whether on submarine pit or trench. With the increase of temperature, the stress of pipelines increases first and then decreases on pit but always enlarges on trench. With the increase of pressure, the stress of pipelines increases on trench, and the stress of pipelines in left-section increases but in the mid-section decreases. The length and depth of submarine pit and trench directly affect the shape of pipelines and size of the initial sunken imperfection. The friction coefficient has little effect on the buckling length, height and stress and the buckling deformation changes from third-order mode to fifth-order because the axial friction cannot balance the thermal axial force if the friction coefficient is too small. The buckling height, length and stress enlarges accompanied by the increase of diameter-thick ratio of pipelines and reducing the diameter-thick ratio in practice can effectively strengthen the ability of pipeline to resist buckling.


ABSTRACT: A riser conveys fluids from a subsea system to a host floater; however, oil and gas phases may alternate, increasing pipe's stress and damaging downstream facilities. This paper studies the nonlinear planar vibrations of a steel lazy wave riser excited by slug flow. The employed formulations comprise the Euler-Bernoulli beam model and the steady plug-flow model with a time-space-varying mass per unit length in the form of a rectangular pulse train. The equations are solved by a Runge-Kutta finite difference scheme and
frequency-response curves are constructed for effective tension, curvature, usage factor and fatigue damage. The results offer a useful insight of the slugging frequencies and slug lengths that may receive attention during the design of risers.


ABSTRACT: When transmitting highly corrosive offshore hydrocarbons, one economical approach is lining internally a thin corrosion resistance alloy (CRA) layer within an ordinary carbon steel pipe. Most commonly the liner is mechanically bonded to the outer pipe by mechanical expansion. The lined pipe is expected to make optimize usage of the two types of materials, providing significant corrosion and structural resistance. This study investigates full history interaction behaviors between the outer pipe and liner and the structural behaviors of the lined pipe under axial compression, through finite element analysis (FEA). Comprehensive finite element (FE) models are developed, where the manufacturing process, the non-linear material properties of stainless steel and the interactions between the constituent components are considered. The numerically determined failure modes, load-deformation histories and ultimate strengths are compared with those from tests. The interaction stress and axial loading histories of the specimen under axial compressions are studied, where the internal content pressure and external hydrostatic pressures are considered simultaneously. Confinement factor is suggested to ensure the structural reliability of the liner in engineering practice. Parametric studies are conducted to study the effects of the outer pipe strength, liner strength, outer pipe thickness and liner thickness on the structural behaviors of the axially loaded lined pipes.

Hui Liang, Yan Zhao and Qianjin Yue (State Key Laboratory of Structural Analysis for Industrial Equipment, Dalian University of Technology, Dalian, China), “Experimental study on dynamic interaction between pipe and rollers in deep S-lay”, Ocean Engineering, Vol. 175, pp 188-196, 1 March 2019, https://doi.org/10.1016/j.oceaneng.2019.01.030

ABSTRACT: Based on a substructure experiment, the pipe laying process of a deep S-lay case is reproduced in the laboratory, and the dynamic interaction between the pipeline and stinger rollers is investigated. As a key equipment component of the S-lay, a stinger is used to support the pipe weight and control the bending deformation of the overbend section. During the S-lay process, there exist a variety of strongly nonlinear mechanic behaviors, such as the contact interaction between the pipeline and rollers, plastic strain, and large pipeline deformation. Owing to these nonlinear behaviors, roller force, as the most important design loads for the S-lay, are often difficult to predict accurately during the design stage, by means of analytical or numerical methods. In contrast, model experiments are more accurate and reliable for solving this complex nonlinear mechanics problem. In this study, the static and dynamic substructure experiments of laying a 12 inch pipe into water at a depth of 3000 m are carried out with a length scale of 1:25. The experimental results indicate that the initial roller heights and amplitudes of the vessel motions have a significant effect on the distribution of roller forces, while the stinger provides sufficient length and curvatures for the deep S-lay case.


ABSTRACT: A Constrained Interpolation Profile (CIP) based multi-phase numerical viscous wave flume was constructed to investigate extremely nonlinear interaction between solitary waves and a submerged flat plate. Tangent of Hyperbola for Interface Capturing (THINC) scheme was employed to capture the free surface accurately. A total of 12 cases in constant water depth was investigated considering 4 incident wave heights and 3 submergence depths of the plate. Firstly, computational results of the solitary wave profiles, free-surface elevations, and hydrodynamic forces on a flat plate were validated against the published experimental data. Secondly, the evolution process of solitary waves interacting with the flat plate was shown for an intuitive impression. Thirdly, the influence of the incident wave height and submergence depth of the plate on the free-surface elevation and hydrodynamic forces was investigated. The pressure distribution at the time instant when
peak force occurred was then presented. Finally, the velocity and vorticity fields containing several strongly nonlinear and interesting phenomena were illustrated and discussed.


ABSTRACT: A modeling method based on the wave superposition method is studied in this paper. Different underwater acoustic propagation models are used in the near and far field. Taking the acoustic radiation field calculation of an elastic spherical shell as an example, the near and far field can be analyzed as a unified system, using this method. Many studies use FEM/BEM (finite element method/boundary element method) to calculate acoustic radiation fields of elastic structures, but only a few of these methods can be applied when considering finite ocean depth, seafloor reflection loss, and sound velocity profile. In this study, the Green function is calculated differently in the near and far field to significantly simplify calculations. The virtual source method is used to calculate the acoustic radiation field in the near field and source strength, while the normal mode method is used in the far field. The results are compared with those obtained using the COMSOL finite element software, which showed that this method was both computationally efficient and accurate. Based on numerical examples, the influence of sea surface, seafloor, and sound velocity on the acoustic radiation field of elastic structures in an ocean acoustic environment is quantitatively analyzed.


ABSTRACT: In this paper, a theoretical model for vortex-induced vibrations (VIVs) of a cantilevered pipe conveying fluid subjected to loose constraints is proposed and analyzed. The unsteady hydrodynamic forces associated with the wake dynamics are modeled by two distributed van der Pol wake oscillators. Taking into account the coupling between the structure and fluid, the full nonlinear partial differential equations of the flexible pipe are derived by using Hamilton's principle. The nonlinear partial differential equations for the pipe and wake are further discretized by the aid of the Galerkin's technique, resulting in a set of ordinary differential equations. These ordinary differential equations are further numerically solved by using a fourth-order Runge-Kutta integration algorithm. Via varying the internal and cross-flow velocities, the derived high-dimensional reduced-order model displays some interesting dynamical behaviors of the coupled system. Phase portraits, bifurcation diagrams, Argand diagram and oscillation shape diagrams are plotted, showing the existence of lock-in phenomenon and figure-of-eight trajectory. When the internal fluid velocity is small and below the critical value for flutter instability, the oscillation of the pipe is mainly induced by the cross flow. For internal flow velocity beyond the critical value for flutter instability, interestingly, the effect of low cross-flow velocity is not pronounced. For relatively high cross-flow velocity, both internal and external fluid flows can significantly contribute to the responses of the pipe. This work is expected to be useful for predicting the responses of marine oil-conveying pipes under the combined effects of internal and external fluid flows.


ABSTRACT: Axial pipe-soil interaction is crucial for prediction of pipeline walking, especially on a sloping seabed. In this study, a mechanical-actuator facility has been specially designed and utilized to simulate the axial pipe-soil interactions along a sloping sandy seabed. Based on dimensional analyses, an apparent axial anti-sliding coefficient is proposed to describe the anti-sliding capacity for pipeline walking on a sloping seabed under the fully-drained condition. Effects of the pipe surface roughness, the submerged weight ($G$) of the pipeline and the slope angle ($\theta$) of the seabed on the apparent axial anti-sliding coefficient are investigated experimentally. The experimental results indicate that, for a fixed value of the non-dimensional submerged pipeline weight, both the ultimate anti-sliding capacity and the corresponding mobilization displacement
increase with the increase of the slope angle of the seabed. There exist approximately linear correlations between the apparent anti-sliding coefficient and the examined seabed slope angle (-9\textdegree le \alpha le +9\textdegree) or the non-dimensional submerged pipeline weight (0.34 le G le 0.81). An expression for the apparent axial anti-sliding coefficient incorporating an updated wedging factor is finally deduced and validated with the present experimental results. This axial pipe-soil interaction model may help assessing the pipeline walking along subsea continental slopes.


ABSTRACT: Vibrations in ship and offshore structures owing to various ocean environmental loads and excitations of power systems become increasingly serious. In this paper, the flexural wave propagation and vibration attenuation characteristics in periodic bi-directionally orthogonal stiffened plates are investigated. The dispersion relations and the displacement fields of the eigenmodes of infinite periodic bi-directionally orthogonal stiffened plates are calculated by using the finite element method in combination with Bloch periodic boundary conditions. Numerical results show that periodic bi-directionally orthogonal stiffened plates can yield complete and directional flexural wave band gaps, in which the propagation of flexural vibrational waves is prohibited and flexural vibration suppression is dramatically achieved. With the introduction of bi-directionally orthogonal stiffeners, the flexural wave and vibration energy is confined in the four corners of the plate owing to the scattering effect of the bi-directionally orthogonal stiffeners. The transmission spectra for a finite periodic stiffened plate are numerically and experimentally achieved to verify the existence of the flexural wave band gaps and vibration suppression characteristics. Furthermore, the effects of geometrical parameters on the flexural wave vibration band gaps are carried out. The flexural wave band gaps and vibration attenuation properties can be artificially modulated by changing the geometrical parameters of periodic bi-directionally orthogonal stiffened plates.


ABSTRACT: The dynamic behavior of cylindrical shells with arbitrary boundaries is studied in this paper. Love's shell theory and Hamilton's principle are employed to derive the motion equations for cylindrical shells. A semi-analytical methodology, which incorporates Durbin's inverse Laplace transform, differential quadrature method and Fourier series expansion technique, is proposed to investigate this phenomenon. The use of the differential quadrature method provides a solution in terms of the axial direction whereas the use of Durbin's numerical inversion method generates a solution in the time domain. Comparison of calculated frequency parameters to that derived from the literature illustrates the effectiveness of the method. Specifically, convergence tests indicate that the present approach has a rapid convergence, the time-history response and the Navier's solution are in great agreement. Comparisons between time-history responses derived by two shell theories show that the results fit well with each other when the thickness-radius ratios are small enough. An analysis of the influences of boundaries on the time-history response of cylindrical shells indicates that the peak displacement is closely related to the degrees of freedom of boundaries. The influences of the length-radius ratios and the thickness-radius ratios on the peak displacement are further investigated.


ABSTRACT: This paper introduces a time-domain potential flow method for simulating fully nonlinear wave interaction with a fluid-filled membrane mounted on the seabed. The numerical method is based on a mixed Eulerian-Lagrangian method, which tracks the free water surface and the membrane using a Lagrangian method and solves the flow fields inside and outside the membrane using an Eulerian method. To remove the numerical
instability, a method that satisfies the no-flux condition on the membrane at any location and any time was developed to calculate the radial displacement of the membrane at every time step and a Fourier series expression for the radial displacement of the membrane was used to calculate the local curvature of the membrane accurately. Experimental results from an existing experimental study were used for model validation and verification. The response of the membrane and the nonlinear wave scattering were simulated. The simulation results show that the transmission coefficients of the fundamental waves, second harmonic free and locked waves approach zero when a resonant response of the membrane to waves occurs. Sample results of the simulated tension in the membrane and interior pressure are also included in the discussion.


ABSTRACT: The paper proposes a risk assessment methodology to be applied at the design selection phase of an oilfield development. The main objective of the approach is to support the decision makers in the selection process of the development concept of an oilfield based on risk considerations. The methodology assesses the risk level of a pipeline system identifying the pipeline groups contributing the most to the risk during the operating life of the system. The risk level of the pipeline systems at the design selection phase enables the decision makers to rank the alternative scenarios in terms of risks/expected losses. The proposed methodology is applied to four alternative oilfield development concepts according to the decision variables adopted for each production system. The results of the risk assessment methodology provide relevant knowledge on the weaknesses of the pipeline systems and subsystems, reducing the inherent uncertainties to develop an oilfield at the design phase. Furthermore, the methodology reduces the time and effort required to conduct a full Quantitative Risk Analysis (QRA) for all alternative design concepts.


ABSTRACT: Ice loads according to the various types of ice features depending on the location, time of year, and environmental conditions should be considered in the design stage of the ice-going ships. Normally, a ship follows a sea path covered with ice broken by an ice breaker. Therefore, it is important to estimate its performance in broken ice fields. In this study, a numerical simulation of an ice going ship navigating through broken ice field was carried out using the finite element method. Ice floes with random distributions of size, thickness and shape were modeled, and an efficient numerical simulation method for ice-sea, ice-structure, and ice-ice interactions was proposed for rapid computation. Important parameters, such as the drag force coefficient and the pressure-penetration relationship in interaction modeling were obtained based on the results of detailed analysis using the coupled Eulerian-Lagrangian method. The simulations were conducted under the same conditions as tests carried out in an ice model basin, and the results were compared.


ABSTRACT: This study aimed to investigate the fluid-structure interaction of a piezoelectric nanoplate using the analytical method. For the purpose of the study, nonlocal elasticity theory is employed for capturing the small-scale effects of the structure. The structure is modeled based upon several theories including classical plate theory, Mindlin plate theory, third-order shear deformation theory and six different types of modified shear deformation theory. These modified shear deformation theories deviate various nonlinear distributions for transverse shear stress along the thickness of nanoplate. Two new distributions for transverse shear stress are proposed for the first time in this article. The fluid is considered to be incompressible, inviscid and irrotational. Fluid velocity potential associated with bulging and sloshing modes are obtained with satisfying Laplace's equation and fluid boundary conditions. Governing equations of fluid-structure interaction are derived with Hamilton's principle and Galerkin approach is applied to solve them. After validation of the present study with
the available results in the literature, the effects of various parameters such as dimensions of fluid, nonlocal parameter and dimensions of piezoelectric nanoplate on the wet frequencies and mode shapes of the system are illustrated.


ABSTRACT: In this paper, a novel version of orthonormal polynomial series expansion method is developed to analyze vibrations of bottom hull panels due to moving impacting fluid loads. The initial phase of slamming is considered in the presented mathematical model, wherein, an elastic linear Euler-Bernoulli beam of uniform thickness mimics the bottom panel structural behaviour. The framework developed, suppresses the Gibbs phenomenon, and captures the beam deflection, flexural moment, and shear force by direct integration. The proposed solution exhibits a higher convergence rate, compared to the conventional method, in terms of the number of involved shape functions.


ABSTRACT: The state-of-the-art method for controlling temperature-induced global lateral buckling of a subsea pipeline is to engineer deliberate buckles at widely spaced locations. These buckles are engineered either by the installation process – i.e. `snake-laying` or by installing subsea structures known as buckle initiators at each intended buckle location. The pre-deformed pipeline is new alternative method that involves continuously pre-deforming the pipeline prior to installation onto the seabed. This pre-deformation causes a significant reduction in axial stiffness and therefore significantly increases the buckle initiation temperature. It also allows thermal expansion to be accommodated throughout the pipe length via expansion of the pre-deformed curvatures, rather than being concentrated at specific buckle locations. This paper presents the influence of two of the variabilities in a pre-deformed pipeline design on the buckling performance: the initial out-of-straightness and the lateral pipe-soil interaction. The results show that the concept of a pre-deformed pipeline is robust and the success of the scheme is not affected by these two uncertainties. The pre-deformed pipeline is shown to be a self-governing system where the maximum strain is self-limited at any location. Pipeline pre-deformation is therefore proven to be a cost effective, safe and valuable tool for controlling pipeline lateral buckling.


ABSTRACT: In this paper, a flexible pipe conveying variable-density fluid and simultaneously undergoing vortex-induced vibrations (VIV) is mathematically simulated and analysed. Resulting from multi-phase flows, the total fluid density inside the pipe may fluctuate temporally and spatially. This variable-density fluid is simulated with a mathematical model which obeys the conservation law of fluid mass. For the external VIV, the lift force caused by vortices shedding is modelled with a classic van der Pol wake oscillator. Based on the principle of Hamilton, the governing equations for the vibration of the pipe are derived. When only considering the fluctuation of the internal fluid density, the pipe is parametrically excited. The parametric resonances are determined with the Floquet theory. After this, the external VIV is taken into account and the influence from the internal varying fluid density on the VIV of the pipe is analysed in detail. When the internal fluid density fluctuates with different circular frequency, the vibrations of the pipe would become non-uniform or aperiodic. The root mean square displacement would increase or decrease. With the increase of the fluctuation amplitude of the internal fluid density, these phenomena would become more obvious. Nevertheless, the initial phase angle of the internal fluid density standing for the initial condition has seldom effect on the VIV of the pipe.


ABSTRACT:
A series of experiments have been conducted to investigate the dynamic response of stiffened panels. The uniaxial tension experiments and the dynamic experiments were conducted to obtain the material characterization. The falling weight experiments were conducted to study the dynamic response of the stiffened panels. A dynamic BWH criterion which combines the BWH criterion and the Cowper-Symonds model is proposed to evaluate the material failure. The scaled constant strain (CS) criterion can decrease the influence of mesh size and improve the accuracy of the simulations. These two different criteria are applied in the simulation models and the simulation results are compared with the experiments. The simulations of the experiments are carried out using the explicit solver of the finite element software package Abaqus. The dynamic BWH criterion is implemented in the numerical simulation using user material subroutine (VUMAT). The simulation results show that the dynamic BWH criterion is better consistent with the experimental results than the scaled CS criterion. Because the influence of stress state and strain rate on material failure has been considered in the dynamic BWH criterion. The formation mechanism of different fracture shapes of the stiffened panels is discussed.

ABSTRACT: Based on the existing structural and system reliability analysis methods, structural availability was recently proposed for the yield strength of beam elements subjected to external random loads. Structural availability has the potential to deal with the features of operation and the maintenance of structures, as well as structural integrity, in a quantitative manner. This paper reports another investigation on structural availability following previous research. Among the two different themes of this study, one is the structural availability estimation on the buckling strength of beams using the same method that was previously proposed for yield strength, and the other is to formulate a general failure model that covers structural deterioration over time and then to compute the structural availability based on the failure model by means of a numerical method, such as Monte Carlo simulation. Relevant examples are also included in this article. This study is expected to help further understand the feasibility of structural availability application in the actual design process and the risk-based design of structures.

ABSTRACT: Lateral soil resistance plays a significant role in lateral buckling, which is a main consideration in the design of subsea pipelines. In this study, a new lateral soil resistance model is proposed to describe the lateral resistance force-displacement relation. It shows a good agreement with existing test results. Based on the new lateral soil resistance model, analytical solution for the lateral buckling of subsea pipelines with initial imperfections is presented. The exact formula to determine the critical half-wavelength is also presented. The effects of initial imperfection parameters, soil properties and parameters, and lateral soil resistance models on critical force of lateral buckling are discussed. Results show that the capacity of subsea pipeline against lateral buckling increases with the increase of the initial half-wavelength, submerged unit weight of soil, and vertical load. It decreases with the increase of the initial imperfection amplitude, soil undrained shear strength, and breakout displacement. The critical forces of lateral buckling in and away from the buckled region both depend on the exact lateral soil resistance model and initial imperfection parameters.

Wei Shen (1), Yingjiang Zhao (1), Lun Li (1), Yu Qiu (1) and Enqian Liu (2)
(1) Key Laboratory of High Performance Ship Technology (Wuhan University of Technology), Ministry of Education, Wuhan, 430063, China
(2) University of Strathclyde, Glasgow, G40LZ, United Kingdom
ABSTRACT: Plate girders with web opening are commonly applied in marine structures for the demands of outfitting and light-weight. The presence of perforations will cause the structural discontinuity, stress concentration and declining of ultimate bearing capacity. In addition to the bending loading, the deck strong beam is often subjected to transverse loading, which belongs to the typical compression-bending biaxial
loadings. In this paper, the ultimate strengths of the perforated girders under compressive-bending loadings was investigated by experimental analysis and nonlinear finite element analysis. Meanwhile, the effect of welding-induced initial deflections, such as the shape of initial deflection and the magnitude of initial deflection, on the collapse behavior of plate girders with web opening was investigated thoroughly, by using numerical method in which the welding-induced initial imperfections are simulated properly. It is concluded that the initial imperfections and longitudinal load have important influences on the residual ultimate strength of perforated girder.

Zhiqi Li (1), Chen An (2) and Menglan Duan (2)
(1) College of Civil Engineering, Hunan University, Changsha, 410082, China
(2) Institute for Ocean Engineering, China University of Petroleum, Beijing, 102249, China


ABSTRACT: An analytical model is presented to evaluate the buckling pressure of pipes subjected to external/internal pressures. At firstly, a set of stability equations was solved mathematically and the elastic buckling solution was established. By introducing the inner plastic section and the middle non-linear elastic section, the analytical approach was then extended to the critical pressure evaluation of the thick pipes in non-elastic buckling and the effect of the initial ovality on the critical pressure is considered. Details of the analytical formulations and the required parameters are defined. The results are presented to show that the initial ovality has a significant influence on the bifurcation pressure and, however, its effect becomes trivial as the pipes become thicker. Compared to the plastic hinge approach, the proposed solution represents a lower critical pressure, which indicates that the pipes would collapse before the formation of the plastic hinges. Furthermore, some factors that affect the pressure capacity of the pipes are discussed, the results from the proposed analytical solution are compared with those of other solutions and experiments.

Zhao Jun Song (1), Ming Cai Xu (1), Torgeir Moan (2) and Jin Pan (3)
(1) School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Wuhan, China
(2) Department of Marine Technology, Norwegian University of Science and Technology, Trondheim, Norway
(3) School of Transportation, Wuhan University of Technology, Wuhan, Hubei Province, China


ABSTRACT: The collapse behaviours of ship structures are usually validated by testing their small scale models. For thin-wall structures, the scale models obtained by complete geometrical similarity might not be economical or practical in test. The present study aims to figure out an approach to determine the dimensions of small scale models, which have similar collapse behaviours and load carrying capacity with full scale prototypes. For this purpose, the partial similarity methods are used to design the dimensions of scale stiffened panels considering the influence of collapse modes, which could be employed for the experiment in laboratory condition. The proposed approaches assume that three principle parameters dominate the buckling behaviours of stiffened panels, including plate, column and torsional slenderness, which are considered as determinate variables in the analyses of partial similarity methods. The stiffened panels under uniaxial longitudinal compression are simulated by finite element method. The dimensional and similitude analyses of stiffened panels with flanged profiles and flat bars are also performed. The ultimate strength and collapse mode are compared between the small and full scale models. From the comparison, the small scale stiffened panels designed by the partial similarity methods could reasonably represent the collapse behaviours of full scale models.


ABSTRACT: Reinforced thermoplastic pipes (RTPs) can experience collapse under external pressure. The maximum external pressure that RTPs can resist before buckling collapse must be considered in engineering
practice. To predict the critical pressure of RTPs, a new analytical model is proposed by analyzing the hoop stress distributions of crushed rings. The model is made under the assumption that the maximum hoop stress equals the critical stress when pipes collapse. Different from the previously reported studies, focusing on axial compression, the critical stress of cylinders' buckling under crushing loads is formulated. With regard to the material anisotropy of RTPs, the equivalent stiffness method is applied to obtain the homogenized hoop elastic modulus in the proposed model. The effectiveness of the proposed model is verified by eigenvalue analyses on solid models and continuum shell models. Compared with numerical methods and Timoshenko and Gere (1961), the proposed model was found to give accurate critical pressures and hoop stress distributions. Furthermore, the optimal range for fiber’s winding angle is obtained, and the effect of thickness-radius ratios on critical pressure and the disproportionate motions of singularity points are also discussed.

Hao Qin (1), Lin Mu (1), Wenyong Tang (2) and Zhe Hu (3)
(1) College of Marine Science and Technology, China University of Geosciences, Wuhan, 430074, China
(2) State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
(3) Key Laboratory of Ships and Ocean Engineering of Fujian Province, Jimei University, Xiamen, 361021, China
ABSTRACT: With the enlargement of liquid containers, unexpected deformation and damage of the containers might happen. As a commonly used way to suppress intense sloshing, anti-sloshing baffles usually sustain liquid loads with a large wetted area. Therefore, it is necessary to investigate the structural response of the anti-sloshing baffles taking hydroelasticity into account to guarantee the structural safety. This paper presents a numerical study on the structural response of horizontal and vertical baffles of different configurations in a sloshing tank considering hydroelasticity. Two validations on the effectiveness of the numerical methods and convergence tests are conducted. Influences of baffle height and length of the horizontal and vertical baffles on the structural response are examined through a series of simulations, from which amplitudes, frequencies of different vibration components and energy ratio of the wetted natural vibration caused by hydroelasticity are obtained and analyzed. Additionally, possible structural resonances of the horizontal and vertical baffles caused by the periodic sloshing motion and hydroelastic effects are shown, indicating the necessity of considering hydroelasticity. Meaningful conclusions are drawn on the characteristics of structural response, the effects of baffle configuration and the occurrence of structural resonance of the baffle from a structural safety point of view.

ABSTRACT: Known as “shape sensing”, real-time reconstruction of a structure's three-dimensional displacements using a network of in situ strain sensors and measured strains is a vital technology for structural health monitoring (SHM). The inverse finite element method (iFEM) is a mechanics-based shape-sensing algorithm shown to be fast, accurate, and robust for usage as a part of SHM systems. In this study, a new eight-node curved inverse-shell element, named as iCS8, is developed based on iFEM methodology. The kinematic relations of iCS8 element are established through combining kinematics of solid shell together with kinematic assumptions of first-order shear deformation plate theory. The new weighted-least-squares functional of iFEM uses the complete set of section strains consistent with the iCS8 element, i.e., (1) coupled membrane-bending and (2) transverse-shear section strains. The iCS8 element accommodates a curvilinear isoparametric coordinate system, thus it can be effectively utilized to model cylindrical/curved geometries with a coarse discretization. This practical modelling capability can allow a relatively sparse placement of sensors, therefore providing an advantage for real-time shape sensing of curvilinear geometries. The high accuracy and practical utility of the iCS8 element is demonstrated for different cylindrical marine structures through examining coarse iCS8 discretizations with dense and sparse sensor deployments.

Qiang Zhang (1,2), Yu Zhu (1), Zhongmin Xiao (2), Wei Li (3), Wei Cui (1,2) and Qianbei Yue (1)
(1) School of Mechanical Science and Engineering, Northeast Petroleum University, Daqing, 163318, PR China
(2) School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, 639798, Singapore
(3) School of Petroleum Engineering, Northeast Petroleum University, Daqing, 163318, PR China


ABSTRACT: With the hypotheses of small deformation and Bernoulli-Euler beam, a gap element is introduced to describe the contact between the circular column and the external cylinder. The dynamic relaxation method is used to calculate the static equilibrium of the twisted column constrained by the cylinder. The post-buckling modes of a torsional column in a cylinder are investigated for the deformation configurations of one-point, two-point, three-point, and point-line-point contact. It is found that the end constraint has an effect on the length of the two suspended sections of helical buckling mode, but has no effect on the length of the continuous contact section in the middle. The relations have been derived among critical torque, post-buckling modes, lengths of each section, and loads (including shear, bending moment, and contact force). Finally, the torsional buckling has been investigated for sucker rods and drill pipes with lengths of 1 km. It is found that the helical buckling of multiple pitches occurs. The results of the current study provide theoretical guidance for the design of centralizer spacing in oil and gas engineering applications.

Muhammad Imran (1), Dongyan Shi (1), Lili Tong (2) and Hafiz Muhammad Waqas (1)
(1) College of Mechanical and Electrical Engineering Harbin Engineering University, Harbin, 150001, China
(2) College of Aerospace and Civil Engineering Harbin Engineering University, Harbin, 150001, China


ABSTRACT: The design of structures made of laminated composites greatly depends on the fiber orientation angle and the number of ply layers. In the present study design optimization of composite submerged pressure hull under 3 MPa hydrostatic pressure, which corresponds to 300 m depth, is carried out. The number of layers and orientation angles are optimized for layups [0/90/0], [10/-10/90/-10/10], [α/α], [α/α/α] and [α/α/α/α/α] using three unidirectional composite materials, Carbon/Epoxy, Glass/Epoxy, and Boron/Epoxy. The optimization process is carried out in ANSYS Workbench using a Genetic Algorithm. Minimizing the buoyancy factor is used as the objective function of the optimization. The constraints on the optimization process are Tsai-Wu and Tsai-Hill failure criteria and buckling strength factor. Optimization study is also conducted for one selected layup configuration using ABAQUS and ISIGHT. Additionally, a sensitivity analysis is also carried out to study the effect of various design parameters on the optimum design of composite submerged pressure hull.


ABSTRACT: By thoroughly considering the fluid-structure interaction, this paper aims to analytically analyze the free vibration of liquid sloshing in partially-filled two-dimensional flexible rectangular tanks. It is assumed that the fluid is compressible, irrotational and inviscid. Additionally, a closed-form formula is derived for estimating the fundamental natural frequency of this system by performing comprehensive curve fitting. Through various numerical examples, the correctness of authors’ exact solutions is corroborated, and the effects of different parameters on sloshing natural frequencies and mode shapes of the aforesaid fluid-structure system are assessed.

Xianzhong Wang (1), Enhui Xu (1,2), Chenban Jiang (2) and Weiguo Wu (2)
(1) Key Laboratory of High Performance Ship Technology (Wuhan University of Technology), Ministry of Education, Wuhan, 430063, China
(2) School of Transportation, Wuhan University of Technology, Wuhan, 430063, China
ABSTRACT: Vibro-acoustic behaviour of submerged double-walled cylindrical shells with general boundary conditions is analyzed by a precise transfer matrix method (PTMM), which is proposed by combining traditional transfer matrix method with precise integration method. Field transfer matrixes of both inner shell and outer shell are obtained accurately by PTMM respectively. The annular plates are simulated by two methods and exist in the form of point transfer matrixes. The dynamic models of double-walled cylindrical shells are established by assembling whole transfer matrixes. Based on the Helmholtz equation, the interlayer and external fluid loads are described to solve the Neumann boundary. The vibro-acoustic response of the double-walled cylindrical shell can be obtained by determining sound pressure coefficients. The free vibration and sound radiation of analytical models are comparing with numerical results and experimental results to verify the present method. The effects of the general boundary constraint stiffnesses on the free vibration and sound radiation of double-walled cylindrical shells are also discussed.

Do Kyun Kim (1), Hui Ling Lim (2) and Su Young Yu (1)
(1) Marine Offshore and Subsea Technology (MOST) Group, School of Engineering, Newcastle University, Newcastle upon Tyne, UK
(2) Ocean and Ship Technology Research Group (Department of Civil and Environmental Engineering), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

ABSTRACT: In the present study, a data processing technique was introduced to develop a closed form shape empirical formulation in predicting ultimate strength of structures. The proposed method was verified by applying a ship's stiffened panel as an applied example. In particular, a refined empirical formulation in predicting the ultimate strength of stiffened panel subjected to longitudinal compression was proposed. Recently, Kim et al. (2017) observed that the ultimate strength behaviours fluctuated in small value of column slenderness ratio and urged the need for a more accurate empirical formulation. In order for an accurate ultimate strength behaviour of stiffened panel to be obtained, a total of 10,500 cases of numerical simulation results using the ANSYS Finite Element Method (FEM) were employed by considering the relevant size change of stiffened panels including plate thickness, web thickness, flange thickness, height of web, and breadth of flange. The simulation results were processed, in the case of initial imperfection, only for average level of initial deflection to plate. On the other hand, initial distortion to stiffener elements and no residual stress by welding were considered in this study. A detailed data processing technique and detailed modelling procedures, i.e, the scenario selection, FE modelling, FE analysis, were documented. From the obtained data processing results by this study, we have found that four (4) important parameters, i.e., (math) are to be considered for the formulation of empirical formulation in predicting ultimate strength of stiffened panel under longitudinal compression (math). The proposed new empirical formulation revealed positive agreement with ANSYS FEM results (R² = 0.98 for overall case).

Xu Bai (1), Rongkeng Tang (1), Yingfei Zan (2) and Jinhua Li (3)
(1) School of Naval Architecture and Ocean Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
(2) College of Shipbuilding Engineering, Harbin Engineering University, Harbin, 150001, China
(3) Institute of Oceanographic Instrument, Qilu University of Technology (Shandong Academy of Sciences), Qingdao, 266061, China

ABSTRACT: Initial imperfections can greatly reduce critical buckling load of axially compressed thin-walled cylindrical shells. During the buckling process of a cylindrical shell, the total potential energy of cylindrical shell can be divided into a constant linear component and a square nonlinear component. In this study, based on deriving the buckling load of a perfect cylindrical shell under axial compression, the role of different stiffness
reductions in the evaluation of stable load carrying capacity was assessed with reference to the Reduction Stiffness Method (RSM). Then the influence of initial axisymmetric defects on stiffness of each part of compressed cylindrical shell was discussed. The mechanism by which axially symmetric initial imperfections affected the stability of axially compressed cylindrical shells was analyzed. The results show that (1) Initial axisymmetric defects affected the membrane stiffness of cylindrical shell. (2) The stability carrying capacity of axially compressed cylindrical shell was reduced. (3) The initial defect was amplified by the square of instability wavenumber of cylindrical shell. Hence, a small defect could have a significant influence on stability carrying capacity of axially compressed cylindrical shell. The results presented in this paper provide a useful reference for the design of axially compressed cylindrical shell structures.

Tian Xia (2), Ping Yang (1,2), Yueling Song (2), Kang Hu (2), Yi Qian (2) and Fan Feng (2)
(1) Key Laboratory of High Performance Ship Technology of Ministry of Education, Wuhan University of Technology, Wuhan, 430063, Hubei, PR China
(2) Departments of Naval Architecture, Ocean and Structural Engineering, School of Transportation, Wuhan University of Technology, Wuhan, 430063, Hubei, PR China


ABSTRACT: The present paper aims at making a research on the ultimate strength and post ultimate strength behaviors of hull plates under extreme longitudinal cyclic load. The cyclic load is controlled by displacement at the load edge of the plate to reach both ultimate strength and post ultimate strength stages. Two load patterns are considered for cyclic compressive and cyclic tensile-compressive load. The ultimate strength of intact plates in each cycle are found to be close to the unloading points of the previous cycle. It is found that not only the overall residual deformation but also the local residual stress and strain formed in cyclic loads will lead to a reduction of the ultimate strength of plates. Accumulated plastic damage and low-cycle fatigue crack damage arisen from the extreme cyclic load are discussed in present study. The combined effect of accumulated plastic damage and low-cycle fatigue crack damage on the ultimate strength and post ultimate strength as well as the load path of hull plates is obtained. It can be seen as a coupling effect of the two individual ones. The mechanical mechanism of strength behaviors in each condition of cyclic loading is analyzed.

I. Seyfipour (1,2), A. Walker (2) and M. Kimiaei (2)
(1) School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran
(2) Centre for Offshore Foundation Systems, University of Western Australia, Perth, Australia


ABSTRACT: Various factors influence the design of subsea pipeline subjected to high temperature and pressure operating loads. Cycles of operating shut-down and start-up have been shown to cause pipeline axial movement, which is called ‘walking’. Walking can influence pipeline performance and cause lateral deflection amplitudes at buckled zones as a result of walking and lateral buckling interaction. A novel cost-effective method for walking mitigation is investigated in this paper using of FE modeling to simulate the novel way of eliminating the occurrence of walking. The proposed technique for mitigating pipeline walking involves creating initial local lateral deformations along the pipeline via imposed local curvature during pipeline reel laying. The interaction between walking and lateral buckling is also explored for an example pipeline with initial local deformations imposed at regular small intervals along the pipeline. The effects of the residual curvatures on pipeline response to temperature and pressure loading are considered in this paper. The reduction in walking rate of subsea pipelines with different numbers of initial deformations is considered. Furthermore, a continuous snake-lay form of deformations is proposed as a very effective method for controlling walking and attaining virtually a zero value of incremental walking per cycle.

Fengyuan Jiang (1), Sheng Dong (1), Yuliang Zhao (1), Zexiao Xie (1) and C. Guedes Soares (2)
(1) College of Engineering, Ocean University of China, Qingdao, 266100, China
(2) Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisbon, Portugal

ABSTRACT: The response of pipelines to transverse impact loads by dropped objects is investigated experimentally and numerically. A series of experiments are carried out to examine the relevant effects, including the bed conditions (rigid or flexible seabed) and impact energy. A finite element numerical model is established to determine the dynamic response and it is validated against the experimental results, showing good consistency. An extensive parametric study is conducted, to examine the effects from various factors, including the velocity, weight and shape of dropped objects, pipeline wall thickness, concrete coating, internal pressure and free pipe span length. The effects of seabed flexibility, burial depth and soil properties on pipeline response are studied with a coupled Eulerian-Lagrangian method, able to simulate large deformation of the soil. Based on these analyses, the model applicability is validated and the research results give an insight to the effects of the various mechanisms on pipeline response, which provides a considerable reference for engineering design of submarine pipelines.


ABSTRACT: In this paper, the modified couple stress theory (MCST) is applied to study the effect of fluid surface waves on free vibration of a functionally graded (FG) microplate in interaction with bounded fluid. The bounded fluid is considered inviscid, irrotational, and incompressible. The fluid velocity potential which satisfies the boundary and compatibility conditions is applied to model the effect of bounded fluid. Assuming that the gradient of material properties varies through the thickness, the classical plate theory has been employed to obtain the frequency equations of the FG microplate; these equations are solved by Rayleigh-Ritz method to determine the natural frequencies. The frequencies are extracted for FG plates, homogeneous microplates, and FG microplates in vacuum and in interaction with bounded fluid. Where the microplate has been in interaction with bounded fluid, influences of microplate bulging and fluid sloshing are captured both simultaneously and separately. Effects of plate dimensions, fluid tank, fluid type, power law index, and length scale parameter on natural frequencies of the system are presented and discussed in details for various boundary conditions. Results show that fluid surface waves significantly affect the natural frequencies of high flexible microplates.

Fangqiu Li (1,2), Chen An (1), Menglan Duan (1) and Jian Su (2)
(1) College of Safety and Ocean Engineering, China University of Petroleum-Beijing, Beijing 102249, China
(2) Nuclear Engineering Department, COPPE, Universidade Federal do Rio de Janeiro, CP 68509, Rio de Janeiro 21941-972, Brazil

ABSTRACT: Vibration of a pipe conveying two-phase flow is a major concern in ocean engineering, and it is necessary to formulate a proper damping model to avoid excessive flow-induced vibration in pipes. While only a few studies have investigated the effects of damping model on dynamics of pipe conveying flow, in this work, we focus on the dynamic behavior of pipe induced by the gas–liquid two-phase flow using a combined damping model. The Generalized Integral Transform Technique (GITT) is employed to model the dynamic behavior of the pipe conveying two-phase flow, and the governing equation of vibration is transformed into a coupled system of second order ordinary differential equations in the time domain by GITT method. Parametric studies are performed to investigate the effects of damping ratios on the dynamic behavior of the pipe, and the results from this model have been verified against the existing experimental results. Besides, the dimensionless critical frequency of the pipe at which instability sets in has been predicted both in the real and imaginary part. Finally, a dimensionless structural parameter gamma-sub-0 that can govern the normalized stability envelope of the pipe is obtained. The proposed model for the dynamics of the pipe conveying two-phase flow with combined damping can be an important reference for the design and analysis of deepwater risers.
References listed at the end of the paper:

ABSTRACT: Shallow sea, especially the reflection and absorption of seabed, have significant influence on the vibroacoustic radiation and propagation properties of underwater structures. An FEM/BEM algorithm based on modal summation is adopted to calculate the modal source strengths and modal coordinate responses of a slender cylindrical shell, in which the Green function of sound field is obtained via virtual source chain model. Using the modal source strengths and modal coordinate responses obtained, the near/far field radiated sound pressure level (SPL) of the slender cylindrical shell in uniform shallow sea is calculated adopting the 3-parameter seabed model. By comparing the radiated power of all modal shapes, the modes with greater contribution can be acquired. Results show that seabed parameters have influence on the far field acoustic radiation of the slender cylindrical shell, mainly on the modal shapes with large grazing angle waves due to larger bottom loss; while the small grazing angle waves are less susceptible to the seabed and propagate much farther.

References listed at the end of the paper:

Chengfeng Li and Run Liu (State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin, 300072, China), “Numerical investigation into the effects of different initial imperfections on the lateral buckling of submarine pipelines”, Ocean Engineering, Vol. 195, Article 106752, 1 January 2020, https://doi.org/10.1016/j.oceaneng.2019.106752

ABSTRACT: Initial imperfections (out of straightness) constitute one of the key parameters impacting lateral buckling of pipelines as they influence both pre-buckling assessment and pipeline integrity assessment during the post-buckling stage. When adjacent imperfections exist in a submarine pipeline, the influence regularity of initial imperfections on the global buckling of pipelines will become more complicated. An elastic-plastic 3D-
Explicit numerical method is proposed to investigate the global lateral buckling of pipelines with single and double imperfections. Then, an investigation is conducted on the influences of the spacing, relative direction and relative size of double imperfections on the global buckling characteristics, such as the critical temperature rise, the buckling deformation amplitude and the buckling mode. Based on the limit state criteria of global buckling pipelines in DNVGL-RP-F110, the structural integrity of pipeline with different buckling modes is assessment. The results show that pipeline failure has a certain correlation with its buckling mode type. For pipelines with the same buckling mode type, the pipeline failure parameter is approximately linearly associated with the double-imperfection spacing.

References listed at the end of the paper:
2 L. Christensen, Analytical Linear Elastic Analysis of Lateral Buckling of "short" pipelines[C], International Society of Offshore and Polar Engineers (2005)
4 DNVGL-RP-F110, Global Buckling of Submarine Pipelines Due to High Temperature/high Pressure, Det Norske Veritas (2017)
5 J. Guan, P.R. Nystrøm, H.F. Hansen, Optimized solutions to control lateral buckling of pipelines with snaked-lay: theoretical and numerical studies, ASME 2007 26th International Conference on Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers (2007), pp. 219-227
7 Z. Hong, R. Liu, W. Liu, S. Yan, Study on lateral buckling characteristics of a submarine pipeline with a single arch symmetric initial imperfection, Ocean. Eng., 108 (2015), pp. 21-32
8 Z. Hong, R. Liu, W. Liu, S. Yan, A lateral global buckling failure envelope for a high temperature and high pressure (HT/HP) submarine pipeline, Appl. Ocean Res., 51 (2015), pp. 117-128
9 H. Karampour, F. Albermani, M. Veidt, Buckle interaction in deep subsea pipelines, Thin-Walled Struct., 72 (2013), pp. 113-120
10 G. Li, L. Zhan, H. Li, An analytical solution to lateral buckling control of subsea pipelines by distributed buoyancy sections, Thin-Walled Struct., 107 (2016), pp. 221-230
18 T. Sriskandarajah, S. Dong, S. Sribalachandran, R. Wilkins, Effect of Initial Imperfections on the Lateral Buckling of Subsea Pipelines, (1999)
29 Z.F. Zhang, Stability Analysis of In-Situ Submarine Pipeline, " Doctoral Dissertation, Tianjin University (2014)

ABSTRACT: Structural design often considers single beams instead of larger structures. To allow the single stiffener to be considered instead of the plate requires an assumption that the stress in the structure is carried through the stiffeners and not the attached plate, and therefore the stresses in each member do not interact. However, this assumption is not completely realistic so effective breadth has been developed to calculate an area of plate, carrying a uniform stress ensuring that the stresses are close to those in the larger structure. It is commonly used to design uniformly loaded structures such as ships, bridges and aircraft; allowing the replacement of complex and computationally expensive structural units with smaller monodimensional elements. Despite the effective breadth having been widely investigated for metallic structures specific derivations for composites are still limited, as they are still based on these original definitions. Almost every study that has been performed leads to the creation of a new formula but these studies tend not to compare back to the original larger structural units. This paper investigates the use of effective breadth for composite top-hat stiffened structures by comparing a number of definitions of effective breadth. It is shown that there is a wide variation in the different definitions and that comparison to realistic structural units is important, to ensure that the individual beams are replicating the behaviour of the full structure. The position of the stiffener is important, with intersection stresses calculated accurately but edge stresses giving poorer results, and a new formula is proposed to account for this.

Younseok Choi (1), Junkeon Ahn (2), Choonghee Jo (3) and Daejun Chang (1)
(1) Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon, 34141, Republic of Korea
(2) Plant Engineering Center, Institute for Advanced Engineering (IAE), Yongin, Gyeonggi-do, 17180, Republic of Korea
(3) R&D Center, LATTICE Technology Co., N28 Building, 291 Daehak-ro, Yuseong-gu, Daejeon, 34141, Republic of Korea


ABSTRACT: In this study, the design and strength of prismatic pressure vessels with new geometries for use as fuel tanks in LNG-fueled ships were assessed. The plate-stiffened prismatic pressure vessel had a rectangular cross-section unlike that of the conventional cylindrical pressure vessel; furthermore, its structure was capable of withstanding load by using a plate inside. ASME, and IGC/IGF codes were analyzed and the design procedure for a novel shaped pressure vessel was confirmed. A case study of an LNG fuel tank on a LNG fueled crude oil tanker was conducted. The design feasibility of the plate-stiffened prismatic pressure vessel was evaluated by conducting strength analysis at the design pressure and test vapor pressure. Furthermore, ultimate strength, dynamic acceleration, buckling, and thermal/fatigue analyses were conducted. As a result of the analyses, it was confirmed that a plate-stiffened prismatic pressure vessel could be used as a fuel tank in LNG fueled ships, according to the design regulations.

Xiangyuan Zhang, Yao Shi, Guang Pan and Qiaogao Huang (School of Marine Science and Technology, Northwestern Polytechnical University, 710072, Xi’an, China), “Study on the impact performance of sandwich hollow cylinders hitting water based on SPH method”, Ocean Engineering, Vol. 197, Article 106808, 1 February 2020, https://doi.org/10.1016/j.oceaneng.2019.106808

ABSTRACT: The impact performances of one monolithic cylinder and two sandwich cylinders during water entry are investigated by SPH method, which is validated by an existing experiment. The first cylinder is made of aluminum alloy (AL cylinder), the second cylinder is made up of polyurethane core and aluminum alloy layers (AL-PU-AL cylinder), and the third cylinder is made up of aluminum alloy core and polyurethane layers (PU-AL-PU cylinder). All the cylinders have the same size. The research shows that the stress levels and deformations of the cylinders are closely related to the impact forces and their inherent strengths and stiffnesses. The deficiency of the AL-PU-AL cylinder lies in its poor inherent strength and stiffness, resulting in the greatest stress level and deformation under the same initial conditions. The deficiency of the AL cylinder lies in its large impact force at the same initial velocity, which may lead to a high stress level. In contrast, the impact force and
inherent strength and stiffness of PU-AL-PU cylinder are moderate, contributing to a lowest stress level at the same initial velocity and a stress level slightly higher than that of AL cylinder at the same initial kinetic energy.

Hao Qin (1,3,4), Lin Mu (1,2,3,4), Wenyong Tang (5) and Zhe Hu (6)
(1) College of Marine Science and Technology, China University of Geosciences, Wuhan, 430074, China
(2) College of Life Sciences and Oceanography, Shenzhen University, Shenzhen, 518057, China
(3) Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou), Guangzhou, 511458, China
(4) Shenzhen Research Institute, China University of Geosciences, Shenzhen, 518057, China
(5) Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
(6) Ships and Ocean Engineering of Fujian Province, Jimei University, Xiamen, 361021, China
“"A Concurrent Multi-Process Refinement method applied in two-dimensional strong-coupled fluid-structure interaction problems”, Ocean Engineering, Vol. 197, Article 106912, 1 February 2020,
https://doi.org/10.1016/j.oceaneng.2019.106912

ABSTRACT: A Concurrent Multi-Process Refinement method for fluid-structure interaction (FSI) problems is developed and applied in a SIMPLE-based monolithic implicit method (SBMIM) initially presented by Hu et al. (2016). Concurrent Multi-Process Refinement method refines the computational domain of FSI simulations as several subdomains in multi-processes with multi-grid sizes and multi-time steps. Through file mapping, velocity and pressure data are transmitted between two processes using proper interpolations and time advance strategy. Numerical implementation and algorithm procedure of the method are explained in detail. Simulations of the liquid sloshing in a baffled tank are conducted to give an error estimation on different grid systems using the Grid Convergence Index (GCI). Simulations of the dam breaking flow slamming a vertical wall are conducted to verify the accuracy of present methods and to discuss the area selection of the localized FSI simulation. Simulations of the green water impact caused by freak wave are conducted to show the performance of this method in dealing with multi-scale ocean engineering problems and high-frequency structural vibrations. From results, it is seen that Concurrent Multi-Process Refinement method shows advantages in multi-scale FSI simulations using monolithic FSI methods and in predicting high-frequency structural vibrations, especially with low-cost computational facilities.

Qiang Zhang (1,2), Jiancheng Wang (1), Wei Cui (1,2), Zhongmin Xiao (2) and Qianbei Yue (1)
(1) School of Mechanical Science and Engineering, Northeast Petroleum University, Daqing, 163318, PR China
(2) School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, 639798, Singapore

ABSTRACT: In offshore oil and gas wells, the post-buckling transition of compressed pipe strings is a significant engineering problem to be addressed, particularly in horizontal wells. Many hypotheses exist in theoretical research, and it remains difficult to accurately measure the post-buckling mode in experimental tests. In the current study, the compressed pipe strings initially located at the bottom of horizontal wells were discretized into beam elements, and a gap element was introduced to detect the contact between the horizontal strings and the wellbores. The dynamic relaxation algorithm was used in finite element analysis to improve the weak points of the theoretical and experimental research. The calculation results show that the post-buckling transition exhibits nonlinearity. Based on the calculated post-buckling modes, the dimensionless critical loads for sinusoidal and helical buckling were identified. After sinusoidal buckling, it was observed that the compressed string was not in continuous contact with the horizontal wellbore, and two non-contact sections appeared near the string ends. These numerical results are beneficial for understanding the post-buckling behaviors of horizontal strings in wellbores.

Mingyang Li (1), Adnan Kefal (2,3), Burak Can Cerik (4) and Erkan Oterkus (1)
(1) Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow, UK
(2) Faculty of Naval Architecture and Ocean Engineering, Istanbul Technical University, Istanbul, Turkey
(3) Integrated Manufacturing Technologies Research and Application Center, Sabanci University, Tuzla, 34956, Istanbul, Turkey
(4) Department of Naval Architecture and Ocean Engineering, Inha University, Incheon, South Korea

ABSTRACT: The offshore industry has been using stiffened thin-walled steel cylindrical structures for decades, particularly as the columns of floating offshore installations. The floating offshore installations may be subjected to severe marine environmental conditions. Accidents such as collisions may also occur. Structural Health Monitoring (SHM) is a viable tool to maintain safe operation of offshore installations. Inverse Finite Element Method (iFEM) is one of the most powerful methods for SHM process. Hence, this study focuses on the application of iFEM methodology to thin-walled cylindrical structures representing the columns of floating offshore installations. iFEM methodology is verified by comparing its displacement results against reference finite element method (FEM) solution. After this verification, four different damage cases with different size, location and number of damages are considered. By using a newly introduced damage parameter and von Mises strain distribution iFEM accurately identified the correct damage locations and sizes. Therefore, it is concluded that iFEM can be used for structural damage prediction in offshore structures with high accuracy even if the number of the strain sensors is limited.

References listed at the end of the paper:
B.C. Cerik, Ultimate strength of locally damaged steel stiffened cylinders under axial compression, Thin-Walled Struct., 95 (2015), pp. 138-151
P.K. Das, A. Thavalingam, Y. Bai, Buckling and ultimate strength criteria of stiffened shells under combined loading for reliability analysis, Thin-Walled Struct., 41 (1) (2003), pp. 69-88
inverse finite element method using fiber bragg grating strains, Proceedings of 10th World Congress on Computational Mechanics, Sao Paulo, Brazil (2012) 

Qinghu Wang (1,2,3), Chonglei Wang (5), Jiameng Wu (1,2,3,4) and Deyu Wang (1,2,3) 
(1) School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China 
(2) Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China 
(3) The Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai, 200240, China 
(4) Marine Design & Research Institute of China, Shanghai, China 
(5) College of Shipbuilding Engineering, Harbin Engineering University, Harbin, 150001, China 

ABSTRACT: Taking a 10,000TEU container ship as the study object, a series of simplified global hull girder models with large deck openings are modeled and analyzed to investigate their torsional failure behaviors, including collapse modes and ultimate torsional strength. The objective of this research is to answer which mechanism the hull girder with large deck openings under torsion will collapse in and to figure out the decisive factor that is dominating the transformation between the warping failure and the shear failure mechanism. In addition, the ultimate torsional strength reduction curves of the hull girder with large deck openings are obtained to reveal the relationship of the ultimate torsional strength between the global hull girder and the single segment hull girder. Also, it is experimentally validated that the numerical models performed with nonlinear large deflection elastoplastic finite element analysis can well predict the torsional collapse behaviors and ultimate torsional strength of the test model.

Da Liu (1), Ruixiang Bai (1), Zhenkun Lei (1), Jingjing Guo (1), Jianchao Zou (1), Wen Wu (1) and Cheng Yan(2) 
(1) Structural Analysis for Industrial Equipment, Dalian University of Technology, Dalian, 116024, China 
(2) School of Mechanical, Medical and Process Engineering, Queensland University of Technology, Brisbane, 4001, Australia 

ABSTRACT: Compression-after-impact tests were used to investigate the impact resistance of composite panel with hat-stiffener filled with foam via good energy absorption. The low-speed impact tests were conducted on three different locations, and then fringe projection profilometry was used to measure the full-field deflection of composite panels during compression. The experimental results show that local buckling occurs during compression of the free-impacted panels, and material compression damage of the impacted panels is caused by impact damage. The residual compressive strength of the stiffened panels is different because of damage of the stiffened panels at different impact locations. Finally, finite element simulation was performed to analyze the damage propagation in the compression-after-impact and the effect on the ultimate failure. The strain history, full-field deflection and numerical simulation results are of reference significance for the impact resistance design of hat-stiffened composite panels.

ABSTRACT: Considering the limitation of current direct measurement method for ship damage identification, an indirect damage identification method based on dynamic parameters is taken into account. A 1500-ton ship simplified as the hull girder is taken as the research object. Artificial neural network method, the coordinate
modal confidence (COMAC) and modal curvature index are applied to identify the ship's damage under different conditions through numerical experiments. Migration matrix method is introduced to obtain the damage database. The damage identification accuracy of two indexes based on modal shapes is discussed. Results show that the neural network intelligent method based on frequency changes can well locate and quantify the damage of the ship structure. Damages were correctly located, and the average accuracy of damage severity reached 95.78%. For damage indexes based on modal shapes, COMAC requires less data to identify the damage and has high calculation efficiency, but there is a certain range of error. When used in conjunction with various modes of the index modal curvature, damage localization is relatively accurate. Both indicators based on modal shapes can reflect the damage degree to some extent, but can't accurately identify the specific extent of damage.

Yuan Lyu (1), Jiangan Sun (2), Zongguang Sun (1), Lifu Cui (2) and Zhen Wang (2)
(1) College of Transportation Engineering, Dalian Maritime University, Dalian, 116026, China
(2) College of Civil Engineering, Dalian Minzu University, Dalian, 116650, China
ABSTRACT: Based on potential fluid theory and soil model theory, this paper derived a simplified mechanical model for horizontal storage tanks considering soil-tank-liquid interaction (STLI), which can be used for seismic design of horizontal storage tanks. Then the paper studied the ground motion response of STLI and Non-STLI under different shear wave velocity. We find the seismic response of the horizontal storage tank is more severe after considering the STLI, and the main control targets such as the base shear force, overturning bending moment and sloshing wave height increase by 25%~58%. Moreover, the effects of soft and medium soft fields are more significant.

Jiangchao Wang (1,2), Xionghua Shi (1), Hong Zhou (3), Zhen Yang (4) and Jianfeng Liu (4)
(1) School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China
(2) Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai, 200240, China
(3) School of Naval Architecture and Ocean Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
(4) Shanghai Waigaoqiao Shipbuilding Ltd., Shanghai, 200137, China
ABSTRACT: Ultra large container ship as an essential role during international trade, is required for precision fabrication due to highly efficient TEU loading and unloading. In this study, two major structures, so called watertight transverse bulkhead structure and torsion box structure of ultra large container with 20000TEU were examined for out-of-plane welding distortion prediction and mitigation with measurement and computational analysis. Based on the welding inherent deformation theory, typical welded joints of two major structures were systematically classified with the different material, thickness, welding condition and joining form; and the relationships between welding heat input and inherent deformations were also presented. Elastic FE analysis with shell elements model and welding inherent deformation as input loading was employed for welding distortion prediction. Not only the distributions but also the magnitudes of predicted out-of-plane welding distortions of considered major structures have a good agreement comparing to the measurements. Furthermore, welding sequence influence was considered for dimensional precision controlling during the watertight transverse bulkhead structure fabrication, and welding groove optimization of thick plate was examined for out-of-plane welding distortion mitigation during the torsion box structure fabrication. Computational results show that welding distortions of both ship block structures can be significantly reduced for requirement of fabrication precision.

Ming-Song Zou, Shu-Xiao Liu, Ling-Wen Jiang and He Huang (China Ship Scientific Research Center, Wuxi, 214082, PR China), “A mixed analytical-numerical method for the acoustic radiation of a spherical double shell
ABSTRACT: This study presents a mixed analytical-numerical method based on the analytical method and the wave superposition method to predict the acoustic radiation of a spherical double shell immersed in the ocean-acoustic environment. Using the Green's function, the fluid structure coupled vibration as well as the near and far field acoustic radiations can be simultaneously analyzed. Different forms of Green's functions are utilized to deal with the near and far field distribution of sound pressure. To reduce the complexity of the computation, the image-source method is used in the near field while the normal mode method is adopted in the far field. The acoustic radiation fields of the spherical double shell in finite depth ocean-acoustic environment with positive and negative gradient sound speed profiles are calculated using the proposed method. Numerical results compared with results using the finite element method obtained by COMSOL verify that the proposed method improves the computational efficiency without losing computational accuracy. Further, taking the spherical double shell as an example, the effects of seabed, sea surface, and sound speed profile of seawater on the fluid structure coupled vibration, acoustic radiation, and sound propagation of underwater structures are analyzed. Some figures are also included to show these effects clearly. The main idea proposed in this paper can be applied to the integrated calculation of fluid structure coupled vibration and the near and far field acoustic radiations of arbitrary three-dimensional elastic floating bodies in the ocean-acoustic environment.

Zhaohui Hong (1) and Wenbin Liu (2,3)
(1) Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin, 300072, China
(2) Tianjin Port Engineering Institute Co., Ltd. of CCCC First Harbor Engineering Co., Ltd, Tianjin, 300222, China
(3) CCCC First Harbor Engineering Co. Ltd., Tianjin, 300461, China
ABSTRACT: Pipelines are widely used for transporting oil resources in offshore oil exploitation. As burying an entire deep-water pipeline is not possible owing to the large water depth, an on-bottom pipeline inevitably exhibits lateral global buckling deformation under high temperature and pressure in practice. Triggering several controllable mitigatory global buckling deformations by installing sleepers under pipelines is a more effective alternative to prevent cross-sectional failure caused by excessive buckling. While sleepers may trigger vertical global buckling and this risk must be verified before they are installed in practice. This study analysed the feature of lifting deformation for a pipeline laid on a sleeper. Nine influential factors of the variation in the lifting displacement were analysed. Based on the nonlinear relationship between lifting displacement and temperature difference, three key points and four relevant key parameters for describing the lifting displacement curve were proposed and calculated for the conditions of a pipeline with different combinations of influential factors. A back propagation neural network was trained to model the relationship between the locations of the three key points and the values of the nine influential factors. The error analysis indicated that the trained network can effectively predict the vertical lifting deformation and is suitable for a pipeline that experiences no lifting deformation. Based on the feature points predicted by the trained network, the approximate profile of vertical lifting displacement during the heating process can be described, and the assessment of whether the lifting displacement with the loading conditions in practice is allowable can be conducted.

ABSTRACT: A literature review is presented on the theoretical, numerical, and experimental progress made in the application of porous membranes and net-type structures to breakwaters and fish cages. Initially, a brief discussion on modelling approaches of the porous membranes and net-type structures associated with theoretical and numerical analysis are discussed based on the frequency domain and time domain. Further, the basic mathematical equations associated with different analytical and numerical models of flexible porous membranes and net-type structures are presented. Next, various types of physical models of the sea cages and net-type floating breakwaters for the dynamic analysis of sea cages and net-type structures with action of waves and uniform currents are surveyed in detail. Further, the comparisons of numerical and experimental of different
fish cage models associated with net-type structures are presented and results are discussed. Finally, conclusions of the present revision and useful recommendations in relation to future research developments and directions within the field of porous membranes and net-type structures are discussed.

Van Tuyen Doan (1,2), Bin Liu (1,3), Y. Garbatov (4), Weiguo Wu (1,3) and C. Guedes Soares (4)  
(1) School of Transportation, Wuhan University of Technology, Wuhan, 430063, China  
(2) Faculty of Shipbuilding, Vietnam Maritime University, Haiphong, Vietnam  
(3) Green & Smart River-Sea-Going Ship, Cruise and Yacht Research Centre, Wuhan University of Technology, Wuhan, 430063, China  
(4) Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico, Universidade de Lisboa, Lisbon, 1049-001, Portugal


ABSTRACT: The ultimate compressive strength of equivalent stiffened panels made of aluminium and steel is analysed numerically and compared. This equivalence is established based on the design formulations as defined by the Classification Society Rules. Novel web girders, with openings for passing pipes and cables, are designed, and their importance on the ultimate strength of stiffened plates is assessed. This type of structural configuration is often applied in the design of the ship decks and superstructures. A series of finite element analyses are performed in order to evaluate the ultimate compressive strength of the equivalent aluminium and steel stiffened panels employing different design solutions. The results have shown that the equivalent stiffened panels yield at the same compressive load, but the aluminium panels have higher ultimate strength than the steel panels. Finally, the effect of the openings on web girders, heat-affected zone and boundary conditions are discussed.


ABSTRACT: Under fatigue loading, crack damage shaped by stress concentration of pitting corrosion in the steel plate adversely affects the strength of ship structure. A nonlinear finite element study is carried out in this paper to investigate how coupled corrosion and crack damage influences the ultimate strength of ship plate. The parameters such as the length, angle and transverse position of cracks, corrosion density and depth and the plate slenderness ratio are taken into account in the present study. It is presumed that the crack is through-thickness and symmetrically distributed inside and on both sides of the corrosion pits, and no contact of crack faces occurs at the ultimate limit state. Reasonable crack gap and a shape of semicircular tip are employed based on numerical results. The crack propagation is not considered in this paper. It is found that the major crack impacts on the ultimate strength depend on the interactions between the length and location as well as the plate slenderness ratio. In addition, the effect of different corrosion factors can be attributed to the corrosion volume. When the crack and corrosion exist together in the plate, their reduction for the ultimate strength is less than their superposition when they exist alone. Moreover, the difference of these two reductions becomes larger as the crack angle increases. Based on numerical results, two mathematical formulas for predicting the residual ultimate strength of steel unstiffened plates with coupled corrosion and crack damage are proposed for longitudinal cracks, transverse and inclined cracks, respectively.

Yang Yang (1), Ruixin Huang (1) and Zheng He (2)  
(1) School of Naval Architecture & Ocean Engineering, Dalian University of Technology, Liaoning, China  
(2) School of Civil Engineering, Dalian University of Technology, Liaoning, China


ABSTRACT: Local discontinuities and stress concentrations from pitting corrosion on a component can significantly affect the mechanical properties and failure mode of a structure, even though the total mass loss from pitting is not prominent. To analyse these problems, experimental specimens are created from high-
Based on the numerical results, the reduction factors of the compressive ultimate strength of stiffened plates are in detail. Assuming that the stiffener is always perpendicular to the involved plate elements in the dent depth, dent size and dent angle, in association with the stiffened panel's ultimate limit state, were discussed investigated by using the commercial software ABAQUS. The influences of some important factors such as the dent depth, dent size and dent angle, in association with the stiffened panel's ultimate limit state, were discussed in detail. Assuming that the stiffener is always perpendicular to the involved plate elements in the dent-producing process, a simple formula is proposed to represent the lateral deflection of the stiffeners and the dent. Based on the numerical results, the reduction factors of the compressive ultimate strength of stiffened plates are

Ali Aghaei (1), Stefan Schimmels (1), Torsten Schlurmann (2) and Arndt Hildebrandt (2)
(1) Forschungszentrum Küste (FZK), Merkurstraße 11, 30419 Hannover, Germany
(2) Ludwig-Franzius Institute, Leibniz University of Hannover, Germany


ABSTRACT: This work presents a comprehensive numerical study of the impact of aeration and hydroelasticity on slamming loads and structural response of elastic plates during a water entry event. A numerical tool is developed with OpenFOAM and validated against experimental data from available benchmark tests. An extensive parameter investigation revealed that the structural flexibility of a plate exerts a noticeable effect on slamming loads for pure water entry cases, which almost completely disappears when the water is aerated. The effect of aeration on slamming loads is quite significant. With only 0.5 % air fraction, aeration can reduce substantially the peak slamming forces, but as the load duration increases at the same time the force impulse remains almost constant. The structural response, in terms of strain rates, reacts directly on the hydrodynamic loads for stiff plates, and exhibits resonating effects and less influence on aeration levels at higher flexibilities. This suggests that the structural performance in a slamming event must be carefully considered, and is only directly related to loads for very stiff structures. For this purpose, a new functional relation between peak impact forces/pressures and impact velocity in the presence of aeration is suggested within the present study.


ABSTRACT: A numerical method to compute the nonlinear Fluid-Structure Interactions (FSI) of yacht sails is presented in this paper. The inviscid lifting-line flow model is used by including a quadrature method to efficiently compute sail pressure loads. The structural calculation is performed with a quasi-static resolution by using a dynamic backward Euler scheme, in order to improve the computation convergence. A specific thickness sail approach is also proposed to make the FSI solving easier. The assembly of these flow and structural methods leads to a fast and robust strategy to compute nonlinear FSI on yacht sails, and the proposed approach is applied on a complex semi-rigid composite mainsail.

Lei Ao (1), Hao Wu (1), De-yu Wang (2) and Wei-guo Wu (1)
(1) Departments of Naval Architecture, Ocean and Structural Engineering, School of Transportation, Wuhan University of Technology, Wuhan, 430063, China
(2) Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China


ABSTRACT: The residual ultimate strength of stiffened plates with dent damage under compressive load was investigated by using the commercial software ABAQUS. The influences of some important factors such as the dent depth, dent size and dent angle, in association with the stiffened panel's ultimate limit state, were discussed in detail. Assuming that the stiffener is always perpendicular to the involved plate elements in the dent-producing process, a simple formula is proposed to represent the lateral deflection of the stiffeners and the dent. Based on the numerical results, the reduction factors of the compressive ultimate strength of stiffened plates are
expressed as functions of the relative dent depth and dent length. In addition, the relationship between the residual ultimate strength of the stiffened plates and the dent inclination is also presented by a cosine function.


ABSTRACT: An eccentricity imperfection may be occurred in the pipes due to the inappropriate manufacturing process. Hence, the dynamic behavior of such geometrically imperfect pipes is extremely required to be explored and compared with the perfect ones. This work investigates the stability and free vibration of fluid-conveying homogenous and functionally graded (FG) pipes with consideration of eccentricity as a geometric imperfection. Three different fluid-conveying pipes are investigated; (i) the homogenous pipe with an eccentricity imperfection, (ii) the FG pipe without imperfection or concentric FG pipe and, (iii) the fluid-conveying FG pipe with an eccentricity imperfection. The governing equations of the fluid–structure interaction system are derived by including the effect of shear deformation using the Timoshenko beam theory. The finite element method is applied to discretize the governing equations and solve the eigenvalue problem of a clamped-clamped pipe. Consequently, the complex modal analysis is used to obtain the natural frequencies and critical velocities of homogenous and FG pipelines with and without eccentricity imperfection. Finally, the effects of different magnitudes of eccentricity and power-law exponent on the critical fluid velocity are investigated. This investigation is expected to provide more insight for the applications of geometrically imperfect pipes in the pipeline systems.

Xia Tan (1), Hu Ding (1), Jian-Qiao Sun (2) and Li-Qun Chen (1)
(1) Shanghai Institute of Applied Mathematics and Mechanics, Shanghai Key Laboratory of Mechanics in Energy Engineering, School of Mechanics and Engineering Science, Shanghai University, Shanghai, 200072, China
(2) University of California, Merced, 95343, USA

ABSTRACT: High-speed flow pipes suffer from severe vibration problems. When the fluid velocity is higher than the critical value, the straight equilibrium configuration of the pipe will lose stability. What follows is the supercritical vibration of the pipe near the non-trivial static equilibrium configuration. This paper attempts to reveal multiple resonance responses of forced vibration of pipes in the supercritical regime. Based on Timoshenko beam theory, the nonlinear coupled partial differential equations are deduced. The non-trivial static equilibrium configuration causes the parameters to vary with space variable. The approximate responses of the pipe are obtained and verified numerically. The results show that the flow velocity near the critical value is more prone to cause severe vibration. Unlike in the subcritical regime, there are third-order super-harmonic resonance and second-order super-harmonic resonance in the supercritical regime. So there are more resonance areas in the supercritical regime. High flow velocity or large external excitation can aggravate the difference between the Euler-Bernoulli model and the Timoshenko model, and the relative error of two models varies non-monotonically. Even for slender pipes, the difference between the two models is still very clear. Therefore, the Timoshenko model is more necessary to analyze the vibration of the high-speed pipe.

Chong Ma (1), Kazuhiro Iijima (2), Masayoshi Oka (1)
(1) National Maritime Research Institute, Japan
(2) Osaka University, Japan

ABSTRACT: This paper highlights linear and nonlinear waves under the influence of surficial structural stiffness and inertia. The main focus is on the waves in a thin elastic plate floating on the water surface. A numerical simulation method, combining smoothed-particle hydrodynamics and the finite element method, is developed to predict the waves propagating in the thin elastic plate. For validation, the simulation results are compared to those obtained through a numerical method, based on the linear potential theory for linear regular
wave cases. When the incident wave amplitude was increased, the waves' nonlinearity was observed in the simulation results. The nonlinear waves' characteristics are elucidated through a mathematical solution derived in a similar manner to Stokes wave theory. A significant difference is confirmed through comparisons with the conventional, nonlinear, free-surface wave. The positive peak was higher than the negative peak due to nonlinearity in one frequency range, while it was the opposite in the other frequency range. The nonlinear wave's amplitude increased divergently at the frequency between the two frequency ranges. Overall, it is shown that the mathematical solution effectively explains the characteristics of the nonlinear waves in the elastic plate observed in the numerical simulations.


ABSTRACT: Stiffened plates with openings exist in ship structures such as longitudinal girders and side shell platforms etc. Different from intact structures, the ultimate strengths for such kind of structures have not been extensively studied yet. In this paper, experiments have been designed and carried out to investigate the ultimate strengths and collapse behavior of stiffened plates with openings, and attached structures are introduced with simplified square tubes, and corrosion caused degradations are introduced and simplified as perforations. Three experimental models are employed to study the effects of perforation distribution. Additionally, numerical studies have been performed with Nonlinear Finite Element Analysis (NFEA) and results match well with the experimental results, based on the measured initial deflections by laser scanning technique. Collapse shapes have also been compared and analyzed, and influences of different types of initial deflections and boundary conditions on ultimate strength have been investigated. The results shown in this paper can be helpful for understanding the mechanism of structural collapse, and provide reference for the ultimate strength experimental designs of such structures.

Farzaneh Ahmadi (1), Ahmad Rahbar Ranji (1) and Hashem Nowruzi (2)
(1) Department of Maritime Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
(2) Department of Mechanical Engineering, Babol Noshirvani University of Technology, Babol, Iran

ABSTRACT: Corrosion and cracking are two main reasons for failure of plates in ships and offshore structures. In the current paper, the ultimate strength of plates with pitting corrosion and a longitudinal crack is investigated under uniform in-plane compression using non-linear finite element method (FEM). Ultimate strength of cracked-pitted plates are predicted using proper artificial neural network (ANN) under different aspect ratio, thickness of plate, number of pits, crack length, and pit depth over thickness of the plate. Based on the numerical results, in rectangular plates, ultimate strength for pitted plate and cracked-pitted plate are almost the same, while in square plates when degree of pitting is low, negligible effect of longitudinal crack on the ultimate strength is detected. For thin plates, less influence of pit corrosion on ultimate strength reduction is observed in comparison to thick plates. Also, it is found that the arrangements of pits in the cracked-pitted plates on ultimate strength reduction is more influential than number of the pits. Finally, an equation is suggested to predict the ultimate strength of corroded plated with longitudinal crack using ANN's weights and bias.


ABSTRACT: The paper presents the results of the study of natural frequencies and the corresponding decrements of harmonic vibrations of rectangular plates located in air or on the free surface of the fluid. Using a specially designed experimental setup, the excitation of vibrations was carried out by the electromagnetic field. The measurements were taken with a Polytec PDV-100 digital laser vibrometer. The locations of points on the
surface of the plates, at which an electromagnetic force was applied and the vibration velocity was measured, were determined from the solution of the modal problem by the finite element method. The decrements of plate vibrations were experimentally found for different schemes of plate clamping, and dependences of decrements on the amplitude were determined. It was found that the decrement corresponding to one mode of vibration (bending or torsional) increases with an increase in the number of nodal lines. The obtained results showed that during the interaction of the plate with the fluid, this relationship could be disturbed sometimes.

Xudong Gao (1), Yongbo Shao (2), Liyuan Xie (1) and Dongping Yang (3)
(1) School of Mechatronic Engineering, Southwest Petroleum University, Chengdu, 610500, China
(2) School of Civil Engineering and Architecture, Southwest Petroleum University, Chengdu, 610500, China
(3) Technology Inspection Center, China Petroleum & Chemical Corporation, Dongying, 257062, China
ABSTRACT: The performance of API 5L X56 submarine pipes subjected to transverse impact is investigated through both drop weight impact tests and finite element simulations. To study the improvement of resistance to transverse impact for pipe-in-pipe specimens, corresponding single-layer pipe specimens under impacting load were also tested for comparison. From the experimental tests, the failure mode, the impact force-time history curve, the displacement-time history curve, the strain-time history curve and the impact force - displacement curve of all specimens were obtained. The pipe-in-pipe specimens are found to have superior performance to resist impacting loading compared to single-layer specimens because smaller global bending deformation and local indentation were observed in them. In addition, the cross-section deformation rate, \( R \), was proposed, and the local indentation length of the specimen was divided into three zones based on experimental observation and numerical simulation. A comprehensive comparison of the length and the depth of local indentation in the pipe-in-pipe specimens shows that the local indentation decreases and the impact resistance increases due to the presence of the inner tube. Finally, the post-peak mean force \( (P) \) and the energy absorption capacity \( (EAC) \) were used to evaluate the energy dissipation mechanism of different specimens. The results also indicate that the pipe-in-pipe specimens have better energy absorption performance.

ABSTRACT: A cantilevered pipe conveying fluid is a non-conservative system and loses its stability for a sufficiently high flow velocity. When a fluid-conveying pipe is involved as a structural element in a mechanical system (e.g., in oil and gas industry), it is often preferred to maximize the critical flow velocity in the pipe. This study focuses on the possibility of increasing the critical flow velocity of horizontal and vertical pipes conveying fluid by considering one or more additional masses and/or springs at various locations along the pipe. Galerkin method is used to solve the equation of motion of the problem derived based on the linear theory of elasticity and a plug flow model assumption. The results of the present study are compared with those available in literature. The results show a possibility of increasing the critical flow velocity for horizontal and vertical cantilevered pipes. It is observed that the critical flow velocity can be significantly increased by adding a spring and a point mass at specific positions depending on the mass ratio of the system.

ABSTRACT: In this study, the impact of gravity wave on a circular elastic floating permeable membrane is investigated using linear wave wave theory in both homogeneous and two-layer fluids. The matched eigenfunction expansion technique is employed to obtain an analytic solution of the boundary value problem. Further, the plane wave integral representation of Bessel and Hankel functions are applied to study the influence of porous structure in damping the far-field wave energy. In order to examine the effect of various physical parameters, heave force exerted on the membrane, deflection of the membrane, reflected and transmitted wave amplitudes, flow distribution around the structure and far-field energy dissipation are computed and analyzed.
for three different edge conditions such as (i) free edge, (ii) moored edge and (iii) clamped edge. The study reveals that the surface wave amplitude on the lee side of the structure decreases significantly in the presence of floating porous elastic membrane. Moreover, the membrane having clamped edge dissipates more wave energy as compared to that for moored and free edge conditions.

Fengyuan Jiang (1), Sheng Dong (1), Yuliang Zhao (1) and C. Guedes Soares (2)
(1) College of Engineering, Ocean University of China, Qingdao, 266100, China
(2) Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisbon, Portugal


ABSTRACT: Hooking of anchors or trawling gear in submarine pipelines can cause catastrophic consequences on life and property. To quantify the consequences of these events and thus to mitigate this risk and provide a reference for submarine pipeline safety design, the failure mechanism and response of pipelines subjected to hooking loads is investigated experimentally and numerically. The experiment is first carried out to give an initial insight into pipeline response and then is used for validation of the numerical approach. Then the validated numerical model is used for studying the effect of boundary conditions, wall thickness and internal pressure on pipeline response and failure mechanism. Finally, the pipe-soil interaction is modeled and the pipeline response considering embedment depth, soil properties and friction is studied. The results show that the pipeline failure pattern differs under different boundary conditions. With the increase in embedment depth, the ultimate hooking force increases due to the restriction from the soils. The soil strength and ultimate hooking force are in a nonlinear relationship. The effect of friction is less significant for soft clays.


ABSTRACT: This study presents a comparison between nonlinear finite element analysis (FEA) and the Smith method of Fujikubo et al. (2012). The objective was to compare the accuracy and computation effort of the two methods for a double-hull tanker under biaxial bending and various ship conditions: intact hull structure, collision-damaged hull structure, newly built condition, and ship hull aged due to corrosion. The results for the non-corroded and intact ship hull structures showed good agreement between FEA, the Smith method and IACS CSR-H for vertical bending loading conditions. For all other bending load combinations, FEA always gave lower ultimate bending moments than the Smith method. The differences between the two methods were larger for the corroded and damaged ship hull structure than for other conditions. Results from ultimate strength analyses of the collision-damaged hull structures showed that both methods captured the expected asymmetric ultimate strength response due to asymmetric damage. A residual strength index calculation showed that the reduction was larger for the FEA than for the Smith method. A procedure is proposed that combines results of a few FEAs with the advantages of the Smith method to generate accurate biaxial bending load interaction curves for different ship conditions.


ABSTRACT: Scale models are normally designed as alternatives to true ship structures in ultimate strength experiments. In this paper, a series of true ship hull girders of a 10,000 TEU container ship under different scale combinations of geometric length and plate thickness are modeled and analyzed to investigate the scaling characteristics of hull girders’ ultimate strength and collapse behaviors, aiming at developing a more precise scaling criterion of the ultimate strength between scale model and true ship. In addition, the reliability and applicability of the proposed scaling criterion has been validated by a series of simplified ship hull girder models, of which the numerical results have been validated by scale model experiments. Results show that, under different scale combinations of geometric length and plate thickness, the first order scaling law which is derived based on dimension analysis has significant errors in quantifying the converting process of the ultimate strength between scale model and true ship. Correspondingly, an empirically modified scaling criterion is
proposed in this paper to improve the accuracy of the converting process of the ultimate strength between scale model and true ship.

ABSTRACT: To ensure the dimensional accuracy of fillet welded structures of a cantilever beam, triangle reinforcement plate stiffeners (TRPs) are employed to prevent welding distortion. However, this increases the weight of a structure. In this study, an efficient finite element (FE) computation was used to solve the afore mentioned engineering problem. The inherent deformations of typical welded joints in a mock-up welded structure were estimated through thermal elastic plastic FE (TEP FE) analysis. Subsequently, welding distortion of the mock-up welded structure was computed via elastic FE analysis wherein the inherent deformation was applied as a mechanical load. Specifically, the inherent deformation of a bevel fillet welded joint was initially estimated, and its precision was verified. The computed Z-direction welding displacement of a flange plate in the mock-up welded structure was in good agreement with the measured values. Hence, it was evident that TRPs mitigated the welding deflection of the flange plate. A series of elastic FE computations showed that the Z-direction welding displacement of the flange plate in an actual welded structure does not increase. However, the total weight of the actual welded structure apparently decreases when the position and number of TRPs are optimized.

ABSTRACT: In this study, the collapse responses of thick-walled subsea pipelines with imperfections subjected to external pressure are studied using finite element (FE) method. First, the FE model of the imperfect thick-walled pipe is built and validated by experimental results from other publications. Then, different collapse responses are obtained by using the validated FE model. The collapse modes are analyzed and the interaction mechanism of the ovality and the thickness eccentricity affecting the collapse response is proposed. The effects of the ovality and the thickness eccentricity on the collapse pressure are discussed. Finally, a new collapse pressure formula which includes both the ovality and thickness variation is presented. The comparisons of collapse pressures from the proposed formula, FE model, and DNVGL-ST-F101 are performed. It is found DNVGL-ST-F101 underestimates the collapse pressure when the diameter-to-thickness ratio (DTR) is less than 20. In addition, the errors of collapse pressures predicted by DNVGL-ST-F101 are unstable. While the proposed formula can provide a pretty well prediction of collapse pressure for thick-walled subsea pipelines and the error is stable.

ABSTRACT: In this study, buckling analysis of cracked plates is performed by using peridynamics. A peridynamic Mindlin plate formulation is used and the numerical implementation is done using commercial finite element software, ANSYS. Critical buckling load is obtained by utilizing ANSYS Eigenvalue Buckling Analysis feature. Peridynamic results are compared against numerical and experimental results and a good agreement is obtained between different approaches. After verifying the formulation, it is utilised to investigate the effect of crack length, crack orientation and plate thickness on the critical buckling load values for a centrally and side-edge cracked plates subjected to clamped-free-clamped-free (CFCF) boundary conditions. Moreover, the effect of variable thickness on the critical buckling load is also examined.

ABSTRACT: Experimental and finite element analyses are performed to identify the buckling strength of a large-scale specimen of tourist submarine subjected to external hydrostatic pressure. The tourist submarines are designed with multi-windows, built up of structural openings, affecting the buckling and ultimate strength of their pressure hulls. The hydrostatic pressure experiment is conducted in a pressure chamber, recording the external pressure and the structural strains. The experimental structural response and permanent deformation show a good agreement with the finite element analysis performed by the ABAQUS finite element solver. The numerical analysis presents some aspects of particular relevance to the buckling failure behaviour of the submarine hull subjected to a uniform external pressure. Additional analyses are performed to investigate the effect of material properties, structural openings and reinforcing rings. The buckling and ultimate strength of the prototype submarines are also evaluated to explore the critical design aspects of internal and external ring stiffeners.


ABSTRACT: Lining internally a thin corrosion resistance alloy (CRA) layer within an ordinary carbon steel pipe provides one economical approach, when transmitting highly corrosive offshore hydrocarbons. The lined pipe is expected to make optimize usage of the two types of materials, providing significant corrosion and structural resistance. Existing studies mostly covered the lined pipe under bending, corresponding to the load case during Reel-lay procedure. The behaviour of the lined pipe under axial compression, which can be induced by thermal field when transporting hot hydrocarbons, however, has received much less attention. The present paper describes a series of laboratory tests performed on lined pipes, including tensile coupon tests of the outer and the liner materials, initial geometric imperfection measurements and lined pipes tested under axial compression. Results of the column tests were used to validate numerical models and employed for subsequent parametric investigations. Based on the results, design provisions DNV–OS–F101 and EN 1993-1-1 were assessed for lined pipes under axial compression and a buckling curve was proposed for lined pipes for the first time.


ABSTRACT: The present paper studies the dynamical behavior of the moving viscoelastic plate which is in contact with barotropic compressible viscous fluid with finite depth. The time harmonic lineal located forces act on the plate. The linearized Navier-Stokes equations are employed for describing the fluid flow, however, the field equations and relations of the theory of visco-elastodynamics are employed for describing the plate motion. The analytic-numerical method based on the Fourier transform is employed for the solution to the related mathematical problems. Under concrete numerical investigations the viscoelasticity of the plate material is described by Rabotnov's fractional exponential operators, and dimensionless rheological parameters are introduced which characterize the long-term values of the mechanical properties and the characteristic creep time of the plate material. The main aim of the numerical investigations is determination of how these dimensionless rheological parameters influence the frequency responses of the stress and velocities on the interface plane between the fluid and viscoelastic plate. Analyzing these results, corresponding conclusions are drawn. In particular, it is established that the character of the influence of the rheological parameters on the stress and velocities depends significantly on the vibration phase of the external forces.


ABSTRACT: The concept of “cyclic ultimate strength” of ship hull structures is proposed. In navigating in waves a ship is subjected to alternate bending moments in hogging and sagging conditions. The present study aims to demonstrate that the ship hull girder can experience a weaker ultimate strength under cyclic loading than under monotonically increasing bending moment as assumed in the conventional analysis. Nonlinear finite element method is employed, using the explicit LS-DYNA solver, to analyse the ultimate strength of a container.
ship hull structure subjected to monotonic and cyclic bending moments. The numerical analyses under cyclic loading consider the ratcheting effect and the Bauschinger effect in steel. The ship hull girder can break due to the plastic strain accumulation and alternating plasticity collapse when the cyclic external load is greater than the elastic limit but lower than the monotonic ultimate limit. The collapse modes of the hull girder under monotonic and cyclic loadings are compared to reveal their different failure principles.


ABSTRACT: In-situ soil properties exhibit natural spatial variability. In this study, the Karhunen-Loève (K-L) expansion method and the Coupled Eulerian-Lagrangian (CEL) method are integrated to simulate large deformation behavior of slopes with spatially varied shear strengths. The impact on pipelines induced by spatially varied landslides is investigated. The mean value of the maximum impact force is significantly larger than the deterministic value obtained for a homogeneous slope. The proportion of the maximum impact force from stochastic analysis that exceeds the deterministic value is much greater than 50%. This result shows that the deterministic study can significantly underestimate the damage of pipeline by a landslide if the spatial variability is not considered. The uncertainty of the impact force increases with the coefficient of variation (COV) of the undrained shear strength and decreases with the reduction of horizontal correlation length. By considering buckling failure and plastic yielding failure of pipelines, the failure probabilities are assessed and a pipeline design based on stochastic analysis for spatially varied slope is presented.


ABSTRACT: This paper examines the vibrational characteristic of a horizontal functionally graded (FG) rectangular plate submerged in fluid medium. Young’s moduli and mass density vary continuously in the thickness direction according to a simple power-law distribution in terms of the volume fractions of the constituents, while other properties are assumed to be constant. The fluid is considered to be ideal, incompressible, inviscid and irrotational, thus the effects of hydrostatic pressure and free surface waves are not taken into account. Governing equation for the fluid-plate system is derived based on the first-order shear deformation theory. The fluid velocity potential is derived from the boundary conditions for the plate-fluid system and is used to determine the added mass. To demonstrate the accuracy of the present analytical solution, a comparison is made with those reported in open literature. The influence of different parameters including interaction boundary conditions, power law index, metal-to-ceramic Young’s modulus, density ratios of the FG plate, thickness to length ratios, aspect ratios, fluid density and fluid depth on the nondimensional natural frequencies of FG rectangular plate are quantitatively examined and discussed in tabular and graphical forms.


ABSTRACT: The aim of this paper is to investigate the influence of model extension and boundary conditions on the buckling behaviour of aluminium integrally stiffened panels under uniaxial compressive loading. Two types of models with different extensions, the multi-span model and half-multi-half span model, are employed and combined with various boundary conditions, namely fixed, simply supported and symmetric boundary conditions. The fabrication related imperfections, such as initial deformations, material softening in heat-affected zone and residual stresses are simulated in the numerical analysis. The results show some new evidence of the effect of different model extension and boundary conditions on the numerical results for the ultimate strength of aluminium integrally stiffened panels, which also explains the discrepancy between the experimental data and numerical results of aluminium integrally stiffened panels with the same cross-section and span length. The configurations of model extension and boundary conditions are proposed for numerical simulations and experimental tests of aluminium integrally stiffened panels.
ABSTRACT: In order to control lateral buckling, buckle initiation techniques, such as distributed buoyancy section (DBS) are employed to trigger lateral buckles at planned locations. Dual DBSs with a gap between are sometimes employed as a buckled initiation method, which may trigger either a symmetric or antisymmetric mode. In this study, analytical models for symmetric mode triggered by dual DBSs are proposed, which are validated by comparing with test data. First, the buckled configuration and the post-buckling behaviour are analysed. Then, a detailed analysis is carried out to present the effect of dual DBSs on the characteristics of the buckling behaviour. Comparisons between symmetric and antisymmetric buckling mode triggered by the same dual DBSs are discussed. The results show that when dual DBSs are utilised as the buckle initiation technique, both the symmetric and antisymmetric mode can be triggered. Symmetric mode is prone to be triggered for relative small spacing between dual DBSs. The symmetric mode is more dangerous than antisymmetric mode except that the weight ratio coefficient is small enough. Therefore, during the design process, it's better to check the maximum stress of both symmetric and antisymmetric mode to ensure the integrity of the buckled pipeline.


ABSTRACT: A marine riser operated in deepwater could encounter harsh environmental conditions and exhibit complex vibration phenomena which require thorough investigation, especially using nonlinear geometric diagnosis. The aim of this paper was to propose a theoretical formulation for undertaking large amplitude vibration analysis of a deepwater marine riser conveying oscillatory internal fluid flow. The work-energy principle based on virtual displacement was utilized to formulate the riser mathematical model, accounting for internal strain energy and external work done. The geometric nonlinearity of the riser regarding extensible elastica theory was considered, which accounted for axial stretching and the large deformed curvature of the riser. The finite element method was utilized to form the equation of the motion system for solving numerical solutions. Based on Taylor's series expansion, the stiffness matrices with second-order nonlinear dynamic displacements of the riser were regarded in the equation of motion. The hydrodynamic ocean force modeled in terms of the squared riser velocity also yielded the nonlinear hydrodynamic damping matrix. The inertial force initiated by the pulsatile flow of transported fluid was taken into account as a harmonic oscillation representing the pump operation. Performing the Newmark time integration incorporated direct iteration on the equation of motion provided the nonlinear vibration response. A thorough parametric study was accomplished which investigated the influences of geometric nonlinearity, the forcing frequencies of a hydrodynamic wave, and an internal pulsatile flow on the large amplitude dynamic response characteristics of a deepwater riser.


ABSTRACT: The upheaval buckling of sandwich pipelines may cause damage to the core material in the buckle, and the changed pipe material stiffness makes such instability problems more complicated. In this paper, the complementary error function is selected to describe the reduction in the stiffness of the pipe material along the sandwich pipe buckle to propose a new buckling characteristic equation for the sandwich pipeline. Green's function for the differential equation for the deflection curve of the variable stiffness of a beam is utilized to portray the upheaval buckle configuration for a precise critical buckling axial force calculation. Three classical imperfection shape functions to account for possible undulations of the seabed or the furrow bottom are induced to modify the critical buckling axial force considering out-of-straightness effects.


ABSTRACT: The ultimate strength of six stiffened columns under axial compressive loading are studied by experimental and numerical methods. The web local buckling mode observed in specimens is analyzed based on the measured strain and displacement during the test. The effects of measured stress-strain curve and
elastic/perfectly plastic curve of material to the ultimate strength of specimens are investigated by numerical calculations. The simply supported boundaries at the loaded edges and free boundaries at unloaded edges were produced based on the horizontal test fixture. The initial geometrical imperfections were measured and tensile tests with different thicknesses were conducted to get the true stress-strain curve. The strain gauges and displacement meters were installed to analyze the failure modes and it indicated that the local web buckling occurred first and dominated the collapse. The ultimate strength calculated by numerical analysis reaches a good agreement with experimental results. The ultimate strength calculated with the elastic/perfectly plastic curve is approximately 10% larger than that with the true stress-strain curve. It indicates that the elastic/perfectly plastic material constitutive model will not always overestimate the ultimate strength as the non-linear property between the proportional limit stress and 0.2% proof stress of material would reduce the ultimate strength.


ABSTRACT: Porous structures have been widely applied in the coastal and ocean engineering. In the CFD (Computational Fluid Dynamics) simulations of interactions between waves and porous structures, the microscopic model establishment approach usually requires huge amounts of fine grids around the model boundary, thus causing a huge computational overhead. This paper establishes a CFD numerical model using a macroscopic approach to simulate the interaction between waves and a vertical porous plate. By analysing the pressure loss of the interaction above and adding it into the momentum equation as a source term, the macroscopic porosity simulation can be implemented without using huge amounts of fine grids around the perforations. A series of CFD simulations of wave interacting with a vertical porous plate are performed based on the established numerical model, and the corresponding tank tests are conducted. The effects of wave characteristics and porosity of porous plate on horizontal wave force and the reflection and transmission coefficients are analyzed. The results demonstrate that the established model is reliable for engineering analysis and thereby being of great significance for reference purpose in the CFD simulations of waves interacting with porous structures.


ABSTRACT: Due to ice floe impacts or iceberg collisions, the side structures of ships and offshore platforms operating in Arctic region may experience permanent deformations, which may have significant influences on their structural safety and working performance. To provide insight into the plastic deformations of plates, this paper investigates the nonlinear elastic-plastic responses of plates impacted by an ice wedge striker and an idealized rigid striker by both experimental and numerical methods. The ice material model based on a soil and concrete material model is used in ANSYS/LS-DYNA program to simulate the ice mechanical behaviour in an ice-plate impact scenario. Good correlation is obtained between the experimental, numerical and analytical results for plastic deformations of plate and collision forces. The comparisons of elastic-plastic responses of plate under these two strikers are conducted by both model tests and numerical simulations. Besides, a series of numerical calculations are carried out to study the differences of ice-plate impact and rigid striker-plate impact. The plastic deformations and energy absorption of plate, energy dissipation of ice damage are investigated. Moreover, for these specific cases studied, an energy absorption reduction factor (EARF) of plate under ice impact compared to rigid striker impact is proposed to estimate the structural damage, which provide some useful information for the design of ship plate against ice impact.


ABSTRACT: Subsea pipelines with a free suspended span segment may be subject to upheaval buckling under high temperature, which may lead to a failure mode such as local buckling, fracture and fatigue. Mathematical models are established to study the upheaval buckling behaviour of subsea pipelines with a free span segment. Then, the accurate locations of the maxima of displacement and stress are obtained. The buckled configuration
and the typical post-buckling behaviour and their dependence on free span length are analysed. Furthermore, a detailed analysis is presented for critical temperature difference, displacement amplitude and maximum axial compressive stress. Finally, the influence of touchdown on post-buckling behaviour during the process of upheaval buckling is discussed. The results show that the pipeline is prone to upheaval buckling when the free span length is large enough and the critical temperature difference decreases with increasing free span length. The displacement amplitude and the maximum stress within the span increase with the increase of the free span length before touchdown. However, after the pipeline touches the bottom of the free span, the maximum stress within the span decreases significantly compared to the case without touchdown, which becomes further smaller for smaller depth of the free span.

Ocean Engineering, Vol. 218, Article 108220 15 December 2020,


ABSTRACT: On the example of an orthotropic shell, the problems of the dynamics of thin-walled structures under aerodynamic loading are studied, taking into account the viscoelastic properties of material and geometric nonlinearity. The aerodynamic pressure is determined using the AA. Ilyushin's piston theory. Equations of motion relative to displacements are described by a system of integro-differential equations in partial derivatives. Using the Bubnov–Galerkin method, based on the polynomial approximation of deflections, the problem is reduced to a system of ordinary integro-differential equations, where time is an independent variable. Solutions of integro-differential equations are determined by a numerical method based on the elimination of the singularity in the relaxation kernel of the integral operator. Computational algorithms and applied programs have been developed to solve the problems on the nonlinear flutter for viscoelastic elements of an aircraft. The critical flutter speed for the viscoelastic orthotropic cylindrical shells is determined. It is established that an account of viscoelastic properties of shell material leads to a decrease in the critical flutter.

References listed at the end of the paper:
65 P.M. Oghibolav, To the statement of the problem of the flutter for shells and panels, Vestn. MGU, Mekh., 6 (1961), pp. 60-65
66 P.M. Oghibolav, M.A. Koltunov, Shells and Plates, Moscow State University Publishing House, Moscow (1967)
67 Weiwei Zhang, Zhengyin Ye, Chen'an Zhang, Aeroelastic analysis for supersonic missile based on computational fluid dynamics, J. Aircr., 46 (2009), pp. 2178-2183
69 Weiwei Zhang, Chuangjiang Gao, Yilang Liu, Zhengyin Ye, Yuewen Jiang, The interaction between flutter and buffet in transonic flow, Nonlinear Dyn., 82 (2015), pp. 1851-1865


ABSTRACT: Theoretical closed-form solutions and numerical results for nonlinear stability of the moderately thick functionally graded sandwich shells subjected to thermomechanical loadings are presented in this study. Two proposed material distribution models supported by elastic foundations are examined. The nonlinear strain field is deduced from the first-order shear deformation theory taking the stretching, bending and shear effects into consideration. The Bubnov–Galerkin procedure and harmonic balance principle are utilized to bring about the explicit algebraic expression for the shell static behaviors from governing equations derived from Hamilton's principle. Mechanical buckling loads and critical thermal rises for the shells in spherical, cylindrical, and hyperbolic paraboloid forms are obtained. The effect of geometry, elastic foundations, volume fraction index, material distribution models, buckling modes, and imperfections on the shell stability behaviors are considered in parametric studies. The yielding plateau in the thermal analysis of the spherical shells in case of temperature dependent characteristics is recognized for the first time. Verification studies are also conducted.
A. Alibeigloo, free vibration responses of the functionally graded plates are investigated. The effects of the temperature field, analytical solution is confirmed by comparing the present results with those available in existing literature. The graded in the thickness direction according to a simple power law distribution in terms of the volume power and varied in the thickness direction only. Material properties are assumed to be temperature into account. The temperature field considered is assumed to be a uniform bottom surfaces of the FG plate. Heat conduction and temperature higher order shear deformation theo.

ABSTRACT: This paper deals with free vibration of functionally graded material plates using eight unknown higher order shear deformation theory, simultaneously satisfies zero transverse shear stress at the top and bottom surfaces of the FG plate. Heat conduction and temperature-dependent material properties are both taken into account. The temperature field considered is assumed to be a uniform distribution over the plate surface and varied in the thickness direction only. Material properties are assumed to be temperature-dependent, and graded in the thickness direction according to a simple power law distribution in terms of the volume power laws of the constituents. Equations of motion are derived from Hamilton's principle. The accuracy of present analytical solution is confirmed by comparing the present results with those available in existing literature. The effects of the temperature field, volume fraction index of functionally graded material, side-to-thickness ratio on free vibration responses of the functionally graded plates are investigated.


ABSTRACT: This paper deals with free vibration of functionally graded material plates using eight-unknown higher order shear deformation theory in thermal environments. The theory is based on full twelve-unknown higher order shear deformation theory, simultaneously satisfies zero transverse shear stress at the top and bottom surfaces of the FG plate. Heat conduction and temperature-dependent material properties are both taken into account. The temperature field considered is assumed to be a uniform distribution over the plate surface and varied in the thickness direction only. Material properties are assumed to be temperature-dependent, and graded in the thickness direction according to a simple power law distribution in terms of the volume power laws of the constituents. Equations of motion are derived from Hamilton's principle. The accuracy of present analytical solution is confirmed by comparing the present results with those available in existing literature. The effects of the temperature field, volume fraction index of functionally graded material, side-to-thickness ratio on free vibration responses of the functionally graded plates are investigated.

References listed at the end of the paper:
1 A. Alibeigloo, Exact solution for thermo-elastic response of functionally graded rectangular plate, Compos. Struct., 92 (1) (2010), pp. 113-121
5 X. He, T. Ng, S. Sivashanker, K. Liew, Active control of FGM plates with integrated piezoelectric sensors and actuators, Int. J. Solids Struct., 38 (9) (2001), pp. 1641-1655
8 Y.-W. Kim, Temperature dependent vibration analysis of functionally graded rectangular plates, J. Sound Vib., 284 (3) (2005), pp. 531-549
11 Y. Lee, X. Zhao, K.M. Liew, Thermoelastic analysis of functionally graded plates using the element-free kp-Ritz method, Smart Mater. Struct., 18 (3) (2009), Article 035007
18 H. Matsunaga, Stress analysis of functionally graded plates subjected to thermal and mechanical loadings, Compos. Struct., 87 (4) (2009), pp. 344-357
20 M. Qatu, A. Leissa, Buckling or transverse deflections of unsymmetrically laminated plates subjected to in-plane loads, AIAA J., 31 (1) (1993), pp. 189-194
23 B.S. Shariat, M. Esfahani, Buckling of thick functionally graded plates under mechanical and thermal loads, Compos. Struct., 78 (3) (2007), pp. 433-439
34 X. Zhao, Y. Lee, K.M. Liew, Mechanical and thermal buckling analysis of functionally graded plates, Compos. Struct., 90 (2) (2009), pp. 161-171

Foozieh Morovat, Ali Mozaffari, Jafar Roshanian and Hadi Zare, “A novel aspect of composite sandwich fairing structure optimization of a two-stage launch vehicle (Safir) using multidisciplinary design optimization

ABSTRACT: In this article, a novel composite sandwich structure analysis of launch vehicle fairing is considered by a new multidisciplinary design optimization methodology. Among the most important roles of this method, in addition to the convergence of optimization process, is tackling with complicated composite structure discipline. The bidirectional coupling existing between composite structure and trajectory disciplines is one of the complex problems of this multidisciplinary design optimization method. Accordingly, multidisciplinary design optimization based on independent subspaces is employed using the fixed point iteration method to achieve the best convergence at system level and segregate the disciplines. Therefore, the two proposed subspaces overcome the difficulties of common mentioned multidisciplinary design optimization of launch vehicles as the main novelty of this study. The first subspace is a multidisciplinary design optimization which includes propulsion, aerodynamics, weight and trajectory disciplines. The second one includes the novel composite fairing structure optimization as the other single discipline optimization which is analytically and numerically considered as a compact problem and is regarded as the other novelty of this work.

In a case study, by applying the proposed architecture on Safir launch vehicle and considering propulsion, trajectory and also composite sandwich fairing structure design as the variables and then performing an optimization process, the Safir fairing mass is reduced from 100 kg to 57.8 kg. This causes the launch vehicle gross mass to decrease from 26 tons to 25.2 tons due to the payload nature of fairing. This 3% mass decrease of an operational launch vehicle, despite the preservation of mission performance, can be called an industrial novelty which leads to the cost reduction of space transportation. The proposed system engineering demonstrates the great importance of using multidisciplinary design optimization in complicated designs using independent subspaces to be employed for the design of future launch vehicles. It can also be a road map for future designers of space vehicles, especially those who want to consider structure optimization in the design loop of launch vehicles.


ABSTRACT: The exact three-dimensional (3D) shell model proposed in the present paper is able to perform the thermal stress analysis of simply-supported Functionally Graded Material (FGM) spherical and cylindrical shells, cylinders and plates. The model is based on the 3D equilibrium equations for spherical shells developed using an orthogonal mixed curvilinear coordinate system. The use of this reference system allows the investigation of cylindrical shells, cylinders and plates as particular cases of spherical shells by means of simple considerations on the radii of curvature. The 3D shell model uses a layer-wise approach and the exponential matrix method to calculate the general and the particular solutions through the thickness direction z. The system of second order differential equations in z is not homogeneous because of the thermal terms which are externally defined. The system is reduced to a group of first order differential equations in z simply redoubling the number of variables. The solution is in closed form in the in-plane directions α and β because of the hypotheses of simply-supported boundary conditions, harmonic forms for displacement and temperature fields, and isotropic behavior in the in-plane directions for functionally graded materials. In order to define the equivalent thermal load, the temperature profile through the thickness is separately defined by means of three possible ways. Using the hypothesis of temperature amplitudes imposed at the top and bottom external surfaces in steady-state conditions, the temperature profile can be: imposed as linear through the entire thickness direction, calculated by solving the 1D version of the Fourier heat conduction equation, or calculated by solving the 3D version of the Fourier heat conduction equation. The effects of different temperature profiles on the displacement and stress analyses of FGM plates and shells are here remarked. The first order differential equation system in z has not constant coefficients because of the presence of radii of curvature for shells and through-the-thickness variable elastic and thermal coefficients for the FGM layers. An appropriate number of mathematical layers is introduced to calculate the curvature influence for shells and the elastic and thermal material coefficients for FGM layers. Therefore, the system can be considered as differential equations with constant coefficients. The proposed results allow the evaluation of thickness ratio, geometry, lamination scheme, thickness material law and temperature profile effects in the related thermal stress analysis of single-layered and sandwich FGM plates, cylinders, spherical and cylindrical shells.

ABSTRACT: This paper performs nonlinear vibration analysis of metal foam circular cylindrical shells reinforced with graphene platelets. An improved Donnell nonlinear shell theory is employed to formulate the present model. The graphene platelet reinforced material properties are evaluated by the Halpin–Tsai equation. Different types of porosity and graphene platelet (GPL) distribution are taken into account. Governing equations are derived via Hamilton's principle and then they are transformed to ordinary differential equations using the Galerkin method. Afterwards, nonlinear frequencies of the system are solved by using the multiple scale method. Our findings demonstrate that GPL reinforced metal foam (GPLRMF) shells exhibit hardening-spring vibration characteristics. The nonlinear to linear frequency ratio of the shell closely relates to the porosity distributions and GPL patterns. The effect of geometrical size of graphene platelets on nonlinear vibration characteristics of GPLRMF cylindrical shells is also highlighted.


ABSTRACT: A multi-domain eXtended Ritz formulation, called X-Ritz, for the analysis of buckling and post-buckling of stiffened panels with cracks is presented. The theoretical framework is based on the First-order Shear Deformation Theory and accounts for von Kármán's geometric nonlinearities. The structure is modeled as assembly of plate elements. Penalty techniques are used to fulfill the continuity condition along the edges of contiguous elements and to satisfy essential boundary conditions requirements. The use of an extended set of approximating functions allows to model through-the-thickness cracks and to capture the crack opening and tip singular fields as well as the structural behavior within each single domain. Numerical results for buckling and post-buckling of cracked stiffened panels are compared with finite elements simulations and literature solutions, showing the accuracy and potential of the proposed approach.


ABSTRACT: The analysis on the nonlinear dynamics of the circular truss antenna is an important problem for its design and control since its large flexible structure. This paper investigates the nonlinear dynamic behaviors of a beam-ring structure modeling the circular truss antenna subjected to the periodic thermal excitation. Based on describing the displacements and the nonlinear strains of the beam-ring structure, the kinetic energy and potential energy are calculated for the system. Using Hamilton's principle, the nonlinear partial differential governing equations of motion and the boundary conditions are derived for the beam-ring structure. Applying Galerkin's approach, the nonlinear partial governing differential equations of motion for the beam-ring structure are truncated into a two-degree-of-freedom system of the ordinary differential equation including the quadratic nonlinearities. The four-dimensional averaged equation is obtained for the case of the primary resonance and 1:2 internal resonance by using the method of multiple scales. From the averaged equation, numerical simulations are presented to investigate the frequency–response curves and the influences of the thermal excitation on the nonlinear dynamic responses of the beam-ring structure. The numerical results demonstrate that there exist the complex nonlinear dynamic phenomena of the beam-ring structure. The finding phenomena of this paper are helpful for controlling the nonlinear vibrations of the antenna.

ABSTRACT: This paper presents an analytical study on the sound transmission loss characteristics of sandwich plate with different truss cores under external mean airflow. Three types of truss cores are considered, which include pyramidal core, tetrahedral core and 3D-kagome core. The sandwich plate is immersed in a mean airflow of velocity tangential to the acoustically deformed boundary and it is impinged by a plane sound wave in the incident acoustic field. By applying velocity continuity condition at fluid–structure interfaces, the coupling of fluid–structure interaction is described analytically. The validity and feasibility of the proposed theoretical model are verified by comparisons with numerical simulation results calculated by commercial finite element software (LMS Virtual.Lab). Based on the developed theoretical model, the influences of the truss core radius and height, different truss core types, external mean flow and material combination types on sound transmission loss are subsequently presented.


ABSTRACT: The dynamic response of cylindrical sandwich panels with aluminum foam core, hexagonal honeycomb core, and auxetic honeycomb core are compared numerically. A novel curved auxetic honeycomb core is designed, and the finite element models are built by employing ABAQUS–Explicit. To calibrate the numerical models, the experiments of sandwich panels with honeycomb core and aluminum foam cores are modeled. And the numerical results have a good agreement with the experiment data. The calibrated numerical models are used to simulate the dynamic response of cylindrical panels subject to external blast loadings. It is found that the cylindrical panels with auxetic honeycomb cores have a better performance than that with aluminum foam cores and hexagonal honeycomb cores in resisting blast loadings. A material concentration effect was observed in the auxetic honeycomb core due to the negative Poisson's ratio (NPR) effect. According to parameter studies, it is concluded that with the increase of curvature and face sheet thickness the blast-resistance of panels with both auxetic honeycomb core, hexagonal honeycomb core, and foam cores increased obviously, especially the panels with auxetic honeycomb cores. For the panels with auxetic honeycomb cores, increasing the back face sheet thickness can improve the blast-resistance performance more efficiently than increasing the thickness of front face sheet, which is opposite for the panels with foam cores and hexagonal honeycomb cores. Auxetic cores with a smaller unit cell aspect ratio and a smaller unit cell length ratio has a larger Poisson's ratio, and achieves better blast resistance performance. These simulation findings can guide well the theoretical study and optimal design of cylindrical sandwich structures subject to external blast loading.


ABSTRACT: In this article, the elastic buckling response of rectangular GLARE fiber-metal laminates with three different support types subjected to shearing stresses is investigated using the finite element method and eigenvalue buckling analysis. Using validated FEM models, the buckling coefficient-aspect ratio diagrams of eight GLARE grades are obtained and studied along with the diagrams of three UD glass-epoxy composites and monolithic 2024-T3 aluminum. It is found that the critical average buckling stress and the buckling load of the materials increases for increasing metal volume fraction. The effect of the fiber-volume fraction on the shear buckling strength of simply supported and clamped fiber-metal laminates is also studied. It is found that the variation of the fiber-volume fraction has a small influence on the behavior of the buckling coefficient-aspect ratio diagrams of two specific GLARE grades. Furthermore, an approximate method is proposed in order to estimate the new shear buckling strength of a GLARE plate when the fiber-volume fraction changes.

ABSTRACT: The fundamental frequencies and nonlinear dynamic responses of functionally graded sandwich shells with double curvature under the influence of thermomechanical loadings and porosities are investigated in this study. Two material models are considered. The continuity requirement of material properties throughout layers are fulfilled by newly introducing refined effects of two porosity types regarding the average of constituent properties weighted by the porosity volume fraction. The first-order shear deformation theory taking the out-of-plane shear deformation into account is employed to obtain the Lagrange equation of motions. The number of primary variables reduces from five to three after introducing the Airy stress function. The system of dynamic governing equations is obtained by utilizing the Bubnov–Galerkin procedure. The natural frequencies are analytically computed by solving eigenvalue problems, and the fundamental frequencies are acquired by further assumptions about the inertial force caused by the shell rotation variables. The nonlinear dynamic responses of the functionally graded spherical, cylindrical, and hyperbolic paraboloid shells under the influence of different geometry configurations, loading conditions, and porosity types and degrees are obtained by applying the fourth-order Runge–Kutta method. The numerical results are presented and verified with available studies in the literature. Although porosities are usually considered material defects weakening the structure performance, this study has proved clearly that porosities stiffen the shell structures to some extent.


ABSTRACT: Predicting both buckling load and mode shape of eccentrically stiffened panels correctly is of important and a rather challenging task. In this paper, a novel and efficient quadrature element formulation is developed to fulfill this challenging task. A high-order quadrature plate-stiffener element is proposed by assembling quadrature beam elements to the quadrature plate element via the displacement relations. Thus, the same plate mesh scheme can be used for buckling analysis of stiffened plate with different numbers of stiffeners located at arbitrary positions. Explicit formulations and solution procedures are given. Convergence studies are performed for stiffened plates with different shapes of cross-section of stiffeners and materials. A number of case studies are given. For validations, numerical results are compared with either existing solutions or finite element data. It is demonstrated that high accuracy can be achieved with relatively small number of nodes. Presented formulation is simple, straightforward, and reliable, which can allow a quick and accurate analysis of buckling behavior of eccentrically stiffened plates.


ABSTRACT: This study is dedicated to develop a mixed interpolated formulation for nonlinear analysis of plates and shells. Using Equivalent Single Layer (ESL) theory and the rule of mixture scheme, the authors present a formulation for analyzing Functionally Graded (FG) sandwich structures. To incorporate large displacements and rotations, and alleviate the shear and membrane locking phenomena, a mixed interpolation of strain fields, including in-plane and shear strains, is utilized. Analyses are based on an isoparametric 6-node triangular shell element. There are five degrees of freedom, including three displacements and two rotations at each node of this element. In order to validate the proposed formulation, some well-known benchmark problems are solved. Besides, the obtained responses are compared to the other available solutions, separately. Moreover, two other practical structures, including FG-sandwich plate and curved shallow panel, are considered to indicate the accuracy and high performance of the authors' approach.


ABSTRACT: Composite laminated plates are widely used in modern aerospace structures. Thus, pursuing an alternative and effective numerical approximate method for the analysis of composite laminated is always a demanding task for aerospace application. It is essential to determine the mechanical behaviors of those
structures. This paper demonstrates the applicability of a novel meshless method in solving problems related to aeronautical engineering. The natural element method combines the advantages of meshless methods and finite element approaches. By its properties, it overcomes most of difficulties such as the imposition of Dirichlet boundary conditions or problems related to the size of the support domain comparing to other methods. The Stress Concentration Factor is investigated regarding its diminishing effect, the critical buckling loads and natural frequencies with their associated modes were determined and the results were compared to the analytical solutions. The proposed method is proved to have a good computational accuracy for composite plate analysis and also exhibit an automatic and optimal choice for the shape function and the imposition of essential boundary conditions, thus demonstrating the fitness and flexibility of this approach and a promising perspective for solving structural analysis problems of composite structures.


ABSTRACT: In this article the effect of a rectangular cutout on the buckling behavior of a thin composite cylinder was investigated using numerical and experimental methods. To verify the finite element results, a limited number of tests was carried out on perforated and non-perforated glass/epoxy cylinders with [90/−23/23/90] layups. In the numerical analysis, linear and nonlinear approaches were employed to study the effect of initial imperfections on the buckling of the cylinders. Several key findings including the effects of cutout size and orientation, and the mutual effects of the cutout and initial imperfections on the buckling behavior were investigated in detail. In the presence of cutouts, the effect of initial imperfections on the buckling load is a function of the cutout size. In cylinders with rectangular cutouts, buckling analysis revealed that a rectangular cutout in the circumferential direction causes around 8% more reduction in the buckling load than the same cutout in the axial direction. Also, numerical findings illustrated that elastic stress concentration factors for the circumferential cutouts are much greater than those for the axial cutouts; thus premature failure around the cutout will trigger earlier buckling in the cylinder with circumferential cutouts.


ABSTRACT: In this paper, an integrated geometrically nonlinear aeroelastic framework to analyze the static nonlinear aeroelastic response of morphing composite wing with orthotropic materials has been developed. A flat plate/shell finite element, which can model plate-like wings, has been accommodated to model composite/corrugated panels to investigate effects of different laminate orientations and corrugations. A corotational approach is used to consider the geometrical nonlinearity due to large deformation produced by wing morphing. An unsteady vortex-lattice method is implemented to couple with the structural model subject to the large deformations. A homogenization method is also implemented to model corrugated panels as equivalent orthotropic plates. Individual structural, aerodynamic, and corrugated panel models, as well as the complete nonlinear aeroelastic framework, are verified. Numerical studies explore the static aeroelastic responses of a flat wing with composite/corrugated panels. This work helps to understand the nonlinear aeroelastic characteristics of composite/corrugated wings and demonstrates the capability of the framework to analyze the nonlinear aeroelasticity of such morphing wings.


ABSTRACT: The energy absorption characteristics of sandwich panels with aluminum plate as facesheet and metal hexagonal honeycomb as the core are investigated under quasi-static punch loading using two flat nose and spherical projectiles, experimentally. Failure modes are classified as plastic hinges, facesheet wrinkling, debonding of the adhesive layer between the facesheet and core, facesheet tearing, out of plane core crushing, in-plane core folding, core tearing and detachment from the support. Furthermore, the article examines the
influences of six parameters including honeycomb wall thickness, sandwich core thickness, facesheet thickness, aspect ratio, adhesive layer between facesheet and core and existence of bottom facesheet. The results show that the increase in core thickness improves the energy absorption parameters of sandwich panel better than the increase in the facesheet thickness. Specific absorbed energy is increased linearly by increasing the honeycomb core thickness while it seems that the mentioned parameter has a meaningless dependence on the facesheet thickness. In addition, a 12 percent quota of adhesive layer between top facesheet and core is indicated in the energy absorption capacity of a sandwich panel for both flat nose and spherical projectiles, while its effect on the value of maximum force is 17% using flat nose projectile and 25% using the other one. Despite the major influence of the existence or non-existence of the bottom facesheet on the sandwich failure modes, its absorbed energy changes less than 3.5 percent; yet other parameters such as specific energy absorption and peak load are more dependent on the existence or non-existence of the bottom facesheet. Finally, keeping the honeycomb wall less thick improves the energy absorption characteristics of the sandwich panel.

Giuseppe Petrone, Giacom Melillo, Aurelio Laudiero and Sergio De Rosa (Laboratory for Promoting experience in Aeronautics Structures, Department of Industrial Engineering - Aerospace Section, University of Naples Federico II, via Claudio 21, 80125, Napoli, Italy), “A statistical energy analysis (SEA) model of a fuselage section for the prediction of the internal sound pressure level (SPL) at cruise flight conditions”, Aerospace Science and Technology, Vol. 88, pp 340-349, May 2019, https://doi.org/10.1016/j.ast.2019.03.032

ABSTRACT: Comfort plays an increasingly important role in the interior design of airplanes. In general, comfort is defined as ‘freedom from pain, well-being’; in scientific literature, indeed, it is defined as a pleasant state of physiological, psychological and physical harmony between a human being and the environment or a sense of subjective well-being. Cabin noise in passenger aircraft is one of the comfort parameter, which creates straightaway discomfort when exceeding personal thresholds. In general the cabin noise varies by the seat position and changes with flight condition. It is driven by several source types, which are transmitted through different transfer paths into the cabin. In the forward area the noise is mainly dominated by the turbulent boundary layer described by pressure vortexes traveling along the fuselage surface. In this paper evaluation of the Sound Pressure level, for the medium-high frequency range, of an aircraft fuselage section at different stations and locations inside the cabin has been performed numerically by using Statistical Energy Analysis (SEA) method. Different configurations have been considered for the analysis: from the “naked” cabin (only primary structure) up to “fully furnished” (primary structure with interiors and noise control treatments) one. These results are essential to understand which are the main parameters affecting the noise insulation. Furthermore the Power Inputs evaluation has been determined to see the contribution of each considered aeronautic component on the acoustic insulation. Finally, the effect of a viscoelastic damping layer embedded in the glass window has been evaluated.


ABSTRACT: This paper presents automatically generated higher order curved triangular meshes around airfoil design using MATLAB code. This work shows a valuable basis for the finite element procedures involved in evaluating aerodynamic performances. Finite element method (FEM) effectively solves all computational fluid dynamics problems around the airfoil and for that region around the airfoil that has been discretized with unstructured curved triangular elements. Meshes have been formed on the basis of subparametric transformation created for the curved triangular element obtained from the nodal relations of parabolic arcs. This scheme can be used to obtain the output data of node coordinates, element connectivity and boundary values for all discretized elements over the airfoil design. A spectacular work done on linear triangular element meshing over a domain by Persson and Gilbert Strang is the basis of present meshing scheme. The proposed meshing scheme presents a refined higher order (HO) curved triangular discretization of few airfoil designs namely NACA0012, NACA0015 and NACA0021 inscribed inside a circle. The approach of the suggested meshing scheme described in this paper can be applied to numerous aerospace applications such as computing pressure gradients, understanding atmospheric nature study, evaluating laminar viscous compressible flow around the airfoil shape, etc. The element and nodal information gained from this discretization is useful for the numerical solutions of FEM and for the aerodynamic portrayal. This paper is aimed at the innovative discretization scheme which can
be extended to all kinds of NACA airfoil designs. We have provided the MATLAB code AirfoilHOmesh2d for HO curved meshing around an airfoil with a cubic order triangular element. The mathematical explanation of this along with the description and implementation of it on few airfoil designs is described. The flowchart of the MATLAB code for cubic order meshing over airfoil design has been provided. This implementation supports many applications in an aerodynamic performance that have been elaborated in this paper. Two applications for the analysis of potential flow around airfoil and computation of pressure coefficient (C_P) on the surface of the airfoil design have been performed. It has been verified and found that the present HO curved meshing technique efficiently gives converging solution.


ABSTRACT: This paper aims to investigate the nonlinear buckling and post-buckling of eccentrically oblique stiffened sandwich functionally graded double curved shallow shells resting on elastic foundations in thermal environment. The shells are reinforced by functionally graded eccentrically oblique stiffeners with deviation angles. Two types of sandwich functionally graded double curved shallow shells with the differences of distribution of functionally graded face sheets and homogeneous core are considered. Material properties of the sandwich shells and stiffeners are assumed to vary continuously and smoothly in the thickness direction according to Sigmoid power law. The formula of force and moment resultants and the nonlinear equilibrium equations are established based on the improved Donnell theory and Lekhnitskii’s smeared stiffeners technique. The analytical displacement solutions are chosen based on the trigonometric forms satisfying the boundary conditions. The value of critical buckling loads and the load – deflection curves of the shells are obtained by using the Bubnov – Galerkin method. In numerical results; effect of geometrical parameters, elastic foundations, temperature increment, compressive load and oblique stiffeners on the critical buckling loads and post-buckling load – deflection curves of the shells are studied specifically. The obtained results are also compared with others from literature to validate the accuracy of the present method and approach.


ABSTRACT: A fluid-structure model based on Mindlin-Reissner plate theory and linearized incompressible potential flow theory is used to study the aero-hydroelastic stability of panels of arbitrary planforms. A finite-element procedure is developed to reduce the continuous system to a finite flow-structure system, which is solved in the frequency domain. The finite element method is crucial for the study of panels of arbitrary geometry and circumvents difficulties with the assumed mode shape approach. This paper is the first finite-element formulation of a fully coupled fluid-structure model of the aero-hydroelastic panel stability problem for incompressible flow. Circular, square, and triangular panels surrounded by a rigid baffle with different boundary conditions are studied. Eigenvalues of the system are surveyed as a function of the hydrodynamic loading at high and low density ratios. Critical flow velocity at divergence-onset and modal coalescence divergence or flutter are determined and compared for the three planforms. For simply supported or clamped panels of equal area and flexural rigidity, as the fluid velocity increases from zero the circular panel diverges first then the square and equilateral triangle, the later is the most stable. In order to compare the relative stability of the three geometries considered, a velocity ratio that consolidates divergence and flutter conditions for the three panels is introduced. Such a parameter offers a simple formula for the divergence velocity in terms of the panel geometry and flow and material properties, and is very useful to the designer in a wide range of engineering applications.


ABSTRACT: This paper presents the thermal and mechanical buckling behaviors of lightweight polymeric nanocomposite sandwich plates containing uniformly dispersed (UD) pores resting on two-parameter elastic foundations. The outer layers of the proposed sandwich plates were assumed to be made of functionally graded (FG) carbon nanotube (CNT)-reinforced polymeric nanocomposite. For nanocomposite layers, the considerable
effect of cluster formation of randomly-oriented CNTs was considered and material properties were evaluated through Eshelby-Mori-Tanaka (EMT)'s approach with the definition of cluster state. Furthermore, the first and third order shear deformation theories (FSDT and TSDT) of plates were employed to define the total energy function of sandwich plates. The governed buckling equations were facilitated using a mesh-free method. The effects of porosity, nanofiller characterizations, elastic foundation coefficients, sandwich plate dimensions and boundary conditions on buckling behavior were explored. The obtained results showed that porosity considerably improved thermal buckling behavior; however, it reduced the critical mechanical loads of sandwich plates. Moreover, adding CNTs into outer layers simultaneously improved the mechanical and thermal buckling responses of sandwich plates.


ABSTRACT: Buckling and postbuckling behaviors of graphene platelet (GPL) reinforced dielectric composite beams are investigated through theoretical formulation. The effective material properties of the GPL reinforced composite (GPLRC) as required for structural analysis, i.e. tensile modulus, dielectric constant and Poisson's ratio are obtained by using effective medium theory and rule of mixture. Governing differential equations for the composite beam are established through Timoshenko beam theory, von Kármán nonlinear strain-displacement relationship and principle of virtual work. Governing equations are numerically discretized and solved by employing differential quadrature method (DQM), through which several parameters affecting the buckling performances are quantitatively identified. The results demonstrate there exists a critical GPL concentration, above which the electrical field significantly affects the beam's buckling and postbuckling behaviors. The dielectric beam's buckling performances are very sensitive to AC (alternating current) frequency within a certain range. Moreover, it is found the dielectric beam's buckling and postbuckling performances comprehensively depend on the concentration and aspect ratio of GPLs. The present work is envisaged to provide guidelines to develop GPL-based smart composites and structures.


ABSTRACT: In this research, the elastoplastic postbuckling response of moderately thick rectangular plates subjected to in-plane loadings is analyzed by a novel numerical approach. The influence of transverse shear deformation is taken into account via the first-order shear deformation theory (FSDT). Also, the elastoplastic behavior is captured based on two theories of plasticity including the incremental theory (IT) (with the Prandtl-Reuss constitutive relations) and the deformation theory (DT) (with the Hencky constitutive relation). Moreover, it is assumed that the material of plate obeys the Ramberg-Osgood (RO) elastoplastic stress-strain relation. First, the matrix formulations of strain rates and constitutive relations are derived. In the next step, according to Hamilton's principle, the weak form of governing equations is derived which is then directly discretized using the variational differential quadrature (VDQ) technique. The discretization process is performed by accurate matrix derivative and integral operators of VDQ. Plates with various boundary conditions under uniaxial and equibiaxial compressions are considered. It is first indicated that the present results are in excellent agreement with the analytical solutions existing in the open literature. Thereafter, the influences of geometrical properties, boundary conditions, elastic modulus-to-nominal yield stress ratio and value of power $c$ in the RO relation on the elastoplastic postbuckling paths of plates are studied. Furthermore, several comparisons are made between the predictions of IT and DT.


ABSTRACT: This paper examines bending, buckling and free vibration behaviors of in-plane functionally graded (FG) porous microplates by means of isogeometric analysis (IGA) and modified couple stress theory (MCST). A hyperbolic shear deformation theory is used, which does not need a shear correction factor. To take into account size-dependent effect, the MCST is employed to analyze functionally graded porous microplates. The IGA meets continuous requirement by using B-Spline or Non-Uniform Rational B-Spline (NURBS)
functions. Various types of material distributions are assumed not only through plate thickness, but also in-plane material distributions. The effect of porosity on results is studied, while this parameter has not been paid attention yet for the analysis of in-plane and through-thickness functionally graded (FG) microplates. Furthermore, the effect of other parameters on the behaviors of microplates is investigated by several numerical problems. These parameters include boundary conditions, FG power index and material length scale parameter l.


ABSTRACT: A quasi-3D isogeometric thermal buckling analysis method for advanced composite plates such as functionally graded plates is presented. A new quasi-3D plate theory for the numerical analysis, which enables the normal deformations to be considered with only four unknowns, is introduced. A simple trigonometric normal shape function that is able to accurately express the through-thickness displacement while facilitating the numerical computation is developed. The refined quasi-3D theory is combined with the non-uniform rational B-spline (NURBS)-based isogeometric analysis (IGA) which satisfies the C1-continuity of the displacement field required by the proposed theory to resolve the thermal buckling issue. Several numerical examples which entail buckling analysis of diverse types of functionally graded plates including the one with a complex cutout under different temperature gradients through the thickness are simulated to validate the quasi-3D isogeometric approach, and to explore the thermal buckling response of functionally graded plates. The present quasi-3D IGA is concluded to be accurate and effective numerical method, and significance of including the thickness expansion effects in the thermal buckling assessment of functionally graded plates is confirmed.


ABSTRACT: This paper investigates the possibility to improve the dynamic response of complex aeronautical structures using variable angle-tow composites. The study has been performed using an innovative numerical approach developed in the framework of the Carrera Unified Formulation able to study laminates with curvilinear fibres whose trajectories can be arbitrarily defined. Refined kinematic structural models have been used to deal with the complex behaviour of such structures. Several cases have been investigated in order to validate this approach and the results have been compared with those from classical modelling approaches. Simple beam models and complex wing structures, have been considered. The effects of different fibres-paths have also been studied and compared. The results confirm that an appropriate tow lay-up can be used to improve the performances of wing structures, i.e. innovative design solutions can be achieved.


ABSTRACT: In this paper, a nonlinear analytical formulation of the forced vibration of the hard-coating cylindrical shell is developed to investigate the nonlinear resonant characteristics of the shell. The strain dependence of hard coating and the elastic constraint with continuous variable stiffness are considered in the formulation. In order to fully introduce the effects of the strain dependence of hard coating on the resonant characteristics with base excitation, a novel analytical method is presented to determine the equivalent strain of hard coating according to the principle of equal strain energy density. The nonlinear governing equations of motion and the admissible displacement function are derived based on the Love’s first approximation theory and the Gram-Schmidt orthogonalization process. A unified Newton-Raphson iterative solution method is employed to solve the nonlinear resonant frequency and response of the shell. As an example to demonstrate the feasibility of the developed analytical model, the forced vibration of the cylindrical shell coated with NiCoCrAlY + YSZ hard coating is implemented numerically and experimentally. Moreover, the influences of the storage modulus, loss modulus and thickness of hard coating on the forced vibration characteristics of the hard-coating cylindrical shell are analyzed in detail.

ABSTRACT: In this work analytical damped free-vibration and frequency response solutions are obtained for the analysis of composite plates structures embedding viscoelastic layers. On the basis of the Principle of Virtual Displacements, Layer-Wise models related to linear up to fourth order variations of the unknown variables in the thickness direction are treated. Analytical solutions using the Navier procedure are presented for the analysis of isotropic, cross-ply composite and simply-supported plate structures. The modelization of multilayered structure materials takes into account the composite material properties and the frequency dependence of the viscoelastic material. Various external loads are considered: closed form solution for bi-sinusoidal pressure, constant distributed pressure and concentrated loads. Several analyses are carried out to validate and demonstrate the accuracy and efficiency of the present formulation for the study of viscoelastic plates, taking into account different laminating sequences and different plate aspect ratios.


ABSTRACT: In the present, based on geometrical nonlinearity in von Karman sense and classical thin shell theory (CLT), the vibrational analyses of conveying-fluid functionally graded carbon nanotube reinforced composite (FG-CNTRC) cylindrical shells with piezoelectric layers in thermal environment are taken into account by an analytical approach. The uniform and functionally graded CNTs are used to reinforce through the thickness of the shell. The fluid flow in the shell is mentioned as non-viscous, incompressible, isotropic and irrotational. Furthermore, piezoelectric layers are bonded onto the outer surface of the cylindrical shell to act as an actuator. The equations of motion are derived by using the CLT, von Karman nonlinearity theory, the fluid velocity potential and then solved by Galerkin’s technique. Moreover, the fourth-order Runge-Kutta method is used to resolve the differential equations. The fundamental frequencies, responses of nonlinear vibration as time histories and bifurcation diagram are studied in this paper. Furthermore, the effects of CNT volume fraction, piezoelectric actuator, thermal environment, geometrical parameters, elastic medium and the fluid flow velocity are carefully analyzed. The obtained results that are validated with those of other studies can be used as benchmark solutions for an analytical approach serving in further research.


ABSTRACT: Mode localization in the airflow direction can be observed in aeroelastic structures. On the contrary, can the aeroelastic stability of the structure be enhanced if the geometric sizes and material properties vary along the airflow direction? The present study mainly solves this problem. The mode localization phenomenon in panel flutter in supersonic airflow is displayed. Three arbitrary thickness functions according to the flutter mode are taken into account. Their panel flutter behaviors show that although the consistency between the variation of thickness and flutter mode can increase the flutter bound slightly, the increments are limited. Consequently, a novel strategy for passive control of the panel flutter is proposed by the optimal axially functionally graded (AFG) design of the panel. By investigating the sensitivity of each element in the aerodynamic stiffness matrix to the aeroelastic stability of the structure, the optimal thickness and Young's modulus functions are given out. Simulation results show that the optimal AFG design in this study can suppress the flutter essentially. It can increase the flutter bound of the structure by changing the flutter modes rather than only makes a slight extension on the original basis. Moreover, the designed thickness and Young's modulus are reasonable and applicable.


ABSTRACT: An inflatable aerodynamic decelerator with a membrane aeroshell is a promising key technology in the reentry, descent, and landing phases of future space transportation. The membrane aeroshell is generally deformed by the in-flight aerodynamic force; however, the effects of the deformation on the aerodynamic
heating are unclear. Here, we investigated aerodynamic heating for an inflatable reentry vehicle, Titans, in the hypersonic regime using flow field simulation coupled with structural analysis. Thermochemical nonequilibrium flows around the Titans with a deformed membrane aeroshell were reproduced numerically for an angle of attack (AoA) values between 0° and 40°. The maximum displacements of the membrane aeroshell by deformation at the AoAs of 0° and 40° were 6.7% and 6.6% of the diameter of the Titans, respectively. The difference in heat fluxes between the deformed and rigid shapes was a remarkable 188.8% for a 0° AoA owing to the considerable changes in the front shock wave shape. Meanwhile, it was indicated that membrane deformation at an AoA of 40° insignificantly affected the peak heat flux value on the inflatable torus because the considerable change in the shock wave shape observed for the case of 0° AoA did not occur. It was found that local wrinkles on the membrane aeroshell were formed by deformation, thus causing the heat flux to increase owing to an increase in local temperature gradient on the surface.


ABSTRACT: The present paper deals with three dimensional nonlinear geometrically and elastoplastic analyses of thick functionally graded plates with nonlinear strain hardening. The boundary conditions are assumed to be general. The plate consists of ceramic (SiC) and metal (Al) phases varying smoothly through the thickness. The effective elastic material properties are obtained by Mori-Tanaka scheme where the plastic behavior of the FG plate is described by the von-Mises yield criterion, nonlinear isotropic strain hardening and the Prandtl-Reuss constitutive equations in combination with the TTO model. The governing equations are obtained from the incremental theory of plasticity in conjunction with the Green-Lagrange nonlinear kinematics. In order to investigate the nonlinear elastoplastic response of the FGM, the nonlinear graded finite element method is developed from three-dimensional continuum concepts that admit arbitrarily large displacements and rotations. This formulation has been implemented and the effect of material gradient index, boundary conditions and thickness-to-length ratio on the nonlinear elastoplastic analysis of the FG plate as well as the development of plastic zone are presented and discussed.

Mostafa Esmaeilzadeh (1) and Mehran Kadkhodayan (2)
(1) Department of Mechanical Engineering, Mashhad Branch, Azad University, Mashhad, Iran
(2) Department of Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

ABSTRACT: The principal purpose of this study is investigating the dynamic analysis of porous bi-directional functionally graded (FG) plates reinforced by eccentrically outside stiffeners and subjected to a moving load with a constant velocity. The materials are assumed to be graded in two directions and their effective properties are computed by the rule of mixtures. The FG plates are assumed to have both even and uneven distribution of porosities over the plate cross-section. Using appropriate kinematic relations, the displacements of the plate mid-plane are compatible with those of the stiffeners. The governing differential equations of porous bi-directional FG plates are derived through Hamilton's principle based on the first order shear deformation theory (FSDT) and Von Karman relations for large deflections. Moreover, dynamic relaxation method with kinetic damping (K-DR) coupled with Newmark integration technique are used to solve the plate's time-varying nonlinear equations. The effects of some numerical aspect ratios such as volume fraction, boundary conditions, porosity coefficients and distribution patterns and the existence of stiffeners on dynamic behaviors are investigated. The results show that the stiffness of the porous bi-directional FG plates is highly improved with the aid of eccentric stiffeners; hence, better dynamic behaviors are provided.


ABSTRACT: This paper focuses on the free vibration of circular and annular three-dimensional graphene foam (3D-GrF) plates under various boundary conditions. The Chebyshev-Ritz method is developed to solve the
present problem. Different types of foam distribution are considered and the effective elastic modulus and mass density vary along the thickness or radial directions of the plates. The Kirchhoff plate theory is employed to derive the energy equations of the 3D-GrF plates. The numerical results show that the developed method has good accuracy and stability for analyzing free vibration problem of circular and annular 3D-GrF plates. It is also found that the increase in foam coefficient leads to the decrease in natural frequencies of 3D-GrF plates. Among different types of foam distribution, the 3D-GrF-I results in the highest natural frequency while the 3D-GrF-II corresponds to the lowest natural frequency of circular and annular 3D-GrF plates for most cases, depending on the specific boundary condition and foam coefficient. Moreover, the foam coefficient, the boundary condition, and the foam distribution interact with each other and have coupled effect on free vibration characteristics of 3D-GrF plates.

Korosh Khorshidi and Mahdi Karimi (Department of Mechanical Engineering, Faculty of Engineering, Arak University, Arak, 38156-88349, Iran), “Flutter analysis of sandwich plates with functionally graded face sheets in thermal environment”, Aerospace Science and Technology, Vol. 95, Article 105461, December 2019, https://doi.org/10.1016/j.ast.2019.105461

ABSTRACT: This paper presents an analytical model for flutter analysis of sandwich plates with functionally graded face sheets in the thermal environment. The material properties of the face sheets are supposed to be temperature-dependent by a nonlinear distribution satisfying one-dimensional heat equation, and vary according to power law distribution in terms of the volume fractions along the thickness of the plate. The vibration of the sandwich plate is modeled on the basis of different plate theories including Mindlin theory, classical theory, exponential theory, third-order theory, sinusoidal theory, hyperbolic theory and fifth-order theory. Modified shear deformation theories applied herein are capable of considering inertia effects and transverse shear stresses. First order piston theory is utilized to model the aerodynamic load due to supersonic flow. The coupled governing equations are derived using Hamilton’s principle and, Galerkin approach is applied to obtain vibrational characteristics and critical dynamic pressure of the system. Some comparisons with available results in the literature are performed to validate the present modeling, and excellent agreement is observed. Our attention is focused on analyzing the effects of different parameters such as thickness ratio, aspect ratio, thermal load, the thickness of face sheet and power law index on dynamic stability of the sandwich plate.

Dong Li and Bao-Zong Huang (College of Sciences, Northeastern University, Shenyang 110819, China), “Secondary buckling and failure behaviors of composite sandwich panels with weak and strong cores under in-plane shear loading”, Aerospace Science and Technology, Vol. 95, Article 105463, December 2019, https://doi.org/10.1016/j.ast.2019.105463

ABSTRACT: The secondary buckling and failure behaviors of composite sandwich panels (CSPs) subjected to in-plane shear loading are studied via a self-developed quasi-conforming finite element method. The influences of key material and geometry parameters on postbuckling and failure behaviors are investigated. Numerical results show that (1) postbuckling failure is dominated by the ratio of two strengths, i.e. the through-thickness shear strength of the core and the transverse tensile strength of the lamina. In addition, two constant thresholds for this strength ratio exist in the relationship between the load bearing capacity of CSPs and the ratio, which can be used to define “weak” or “strong” core and the status of postbuckling load bearing capacity (PLBC); (2) local failures of the core and face sheets (FSs) can lead to a drastic decrease in the local stiffness of CSPs, a singularity of the tangent stiffness matrix and the occurrence of secondary bucklings of CSPs; (3) secondary bifurcation identification, branch switching and convergence improvement are all necessary to obtain reasonable paths during the path-following.


ABSTRACT: The dynamic modeling and free vibrations of rotating functionally graded (FG) tapered cantilever beams with hollow circular cross-section are studied in this paper. To capture the additional dynamic stiffening terms, the axial shrinkage of the beam caused by the transverse displacement is considered. The dynamic equations of the system governing stretching motion, flapwise bending motion, and chordwise bending motion are derived via employing assumed modes method and Lagrange’s equations. Based on the first order
approximate coupling (FOAC) dynamic model, natural frequencies and mode shapes of the beam system are calculated by solving eigenvalue problem of the deduced dimensionless vibration equations. Influences of the angular speed, the hub radius, the slenderness ratio, the ratio of hollow radius to the root radius, the taper ratio, and the functional gradient index on natural frequencies are studied. Frequency veering and mode shape interaction are discussed when the bending-stretching mode coupling effect of the beam is considered.

Masoud Babaei (1), Mohammad Hadi Hajmohammad (1) and Kamran Asemi (2)
(1) Department of Mechanical Engineering, Imam Hossein University, Tehran, Iran
(2) Department of Mechanical Engineering, Islamic Azad University, Tehran North Branch, Tehran, Iran

ABSTRACT: In this paper, natural frequencies and dynamic response of thick annular sector plates and cylindrical panels made of saturated porous materials are investigated for the first time. The structures have been modeled using 3D elasticity theory. Distribution of porosity along the thickness is considered in three different patterns, which are symmetric nonlinear, nonlinear asymmetric and uniform distributions. The relationship between stress and strain is based on the Biot constitutive law instead of simple Hook's law. Finite element method based on Rayleigh–Ritz energy formulation and Newark methods are used to solve the governing equations. The effect of different boundary conditions and various parameters such as porosity and Skempton coefficients, slenderness ratio, sector angle and different distribution of porosity on natural frequencies and transient responses have been studied.

References listed at the end of the paper:
1 L. Hromadová, Thermal Pressurization of Pore Fluid During Earthquake Slip, Comenius University, Bratislava, Eslovaquia (2009)
5 B. Karami, M. Janghorban, A. Tounsi, Nonlocal strain gradient 3D elasticity theory for anisotropic spherical nanoparticles, Steel Compos. Struct., 27 (2) (2018), pp. 201-216
20 M.H. Hajmohammad, A. Farrokhhian, R. Kolahchi, Smart control and vibration of viscoelastic actuator-multiphase nanocomposite
21 F. Zare Jouneghani, et al., Free vibration analysis of functionally graded porous doubly-curved shells based on the first-order shear
29 T. Belica, M. Malinowski, K. Magnucki, Dynamic stability of an isotropic metal foam cylindrical shell subjected to external
pressure and axial compression, J. Appl. Mech., 78 (4) (2011), Article 041003
30 P.H. Cong, T.M. Chien, N.D. Khoa, N.D. Duc, Nonlinear thermomechanical buckling and post-buckling response of porous FGM
31 A.B. Rad, M. Shariyat, Three-dimensional magneto-elastic analysis of asymmetric variable thickness porous FGM circular plates
with non-uniform traction and Kerr elastic foundations, Compos. Struct., 125 (2015), pp. 558-574
32 K. Magnucki, M. Malinowski, J. Lewinski, Optimal design of an isotropic porous-cellular cylindrical shell, ASME 2006 Pressure
Vessels and Piping/ICPVT-11 Conference, American Society of Mechanical Engineers (January 2006), pp. 345-352
33 F. Tornabene, A. Liverani, G. Caligiana, FGM and laminated doubly curved shells and panels of revolution with a free-form
34 B. Saafai, R. Moradi-Dustjerdi, K. Behdinar, F. Chu, Critical buckling temperature and force in porous sandwich plates with CNT-
35 K. Gao, W. Gao, B. Wu, D. Wu, C. Song, Nonlinear primary resonance of functionally graded porous cylindrical shells using the
method of multiple scales, Thin-Walled Struct., 125 (2018), pp. 281-293
36 Y.H. Dong, L.W. He, L. Wang, Y.H. Li, J. Yang, Buckling of spinning functionally graded graphene reinforced porous
37 J. Zhao, F. Xie, A. Wang, C. Shuai, J. Tang, Q. Wang, Dynamics analysis of functionally graded porous (FGP) circular, annular
38 T. Belica, K. Magnucki, Dynamic stability of a porous cylindrical shell, PAMM: Proceedings in Applied Mathematics and
Mechanics, Vol. 6, No. 1, WILEY-VCH Verlag, Berlin (December 2006), pp. 207-208
39 A.B. Rad, Static analysis of non-uniform 2D functionally graded auxetic-porous circular plates interacting with the gradient elastic
40 D. Shahsavari, M. Shahsavari, L. Li, B. Karami, A novel quasi-3D hyperbolic theory for free vibration of FG plates with porosities
41 M.R. Galean, A. Mojahedini, Y. Taghavi, M. Jabbari, Free vibration of functionally graded thin beams made of saturated porous
42 F. Zare Jouneghani, R. Dimitri, M. Bacciocchi, F. Tornabene, Free vibration analysis of functionally graded porous doubly-curved
43 P.T. Thang, T. Nguyen-Thoi, D. Lee, J. Kang, J. Lee, Elastic buckling and free vibration analyses of porous-cellular plates with
44 D. Chen, J. Yang, S. Kitipornchai, Buckling and bending analyses of a novel functionally graded porous plate using Chebyshev–
45 Fouad Bourada, Abdelmoumen Anis Bousahla, Mohamed Bourada, et al., Dynamic investigation of porous functionally graded
46 J. Zhao, Q. Wang, X. Deng, K. Choe, R. Zhong, C. Shuai, Free vibrations of functionally graded porous rectangular plate with
47 Y. Yue, G. Jin, X. Ma, H. Chen, T. Ye, M. Chen, Y. Zhang, Free vibration analysis of porous plates with porosity distributions in
48 H.A. Atmame, A. Tounsi, F. Bernard, Effect of thickness stretching and porosity on mechanical response of a functionally graded
49 H. Li, F. Pang, H. Chen, Y. Du, Vibration analysis of functionally graded porous cylindrical shell with arbitrary boundary restraints
piezoelectric FG porous plates reinforced by graphene platelets, Compos. Struct., 214 (2019), pp. 227-245
51 S.A. Yahia, H.A. Atmame, M.S.A. Houari, A. Tounsi, Wave propagation in functionally graded plates with porosities using various
52 X. Quan, K. Sok, A. Wang, C. Shuai, J. Tang, Q. Wang, A general vibration analysis of functionally graded porous structure
elements of revolution with general elastic restraints, Compos. Struct., 209 (2019), pp. 277-299

Zahra Shafiei (1), Saeid Sarrami-Foroushani (1), Fatemeh Azhari (2) and Mojtaba Azhari (1)
(1) Department of Civil Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran
(2) Department of Civil Engineering, Monash University, Melbourne, VIC 3800, Australia

ABSTRACT: With the development of nanotechnology, research activities on carbon nanostructures have increased rapidly. In recent years, due to the extraordinary mechanical properties of graphene sheets, there has been a growing interest in investigating the mechanical response of these carbon nanostructures. In this article, the modified couple-stress theory (MCST) is first employed to study the free vibration and mechanical buckling of single-layered graphene sheets (SLGSs). To this end, SLGS is modeled as a nanoplate and the two-variable refined plate theory (TVRPT) is adopted to extend the finite strip method (FSM) formulation. The natural free vibration frequency and mechanical buckling loads of the sheet are then obtained by solving the proper eigenvalue problems. Mechanical buckling and free vibration of multi-layered graphene sheets (MLGSs) are also investigated considering the effects of van der Waals (vdW) bonds between the layers. Modified couple-stress theory is applied to consider the small-scale effects of the graphene sheets. The results obtained by the proposed method are validated against those available in the literature. Finally, a comprehensive parametric study is performed to investigate the effects of different parameters such as loading schemes, nanoplate dimensions and boundary conditions.


ABSTRACT: Several multilayered physically-based plate theories are derived under different limiting assumptions on displacement, strain and stress fields, either in displacement-based or mixed Hu-Washizu and Helinger-Reissner form, and assuming different layerwise functions. Their features are reminiscent to those of theories published in the literature, or are entirely new. The present study aims to evaluate how different forms of description of the transverse normal deformation and stress affect accuracy. At the same time, the purpose is also to see if a much broader degree of generalization of what characterizing currently available physically-based zig-zag theories can be achieved through a redefinition of coefficients obtained by imposing the fulfillment of physical constraints, namely interfacial stress compatibility and local equilibrium equations across the thickness through use of symbolic calculus tool. Besides calculating exactly quantities, this tool enables users to choose representation form and zig-zag functions as desired, keeping fixed the d.o.f. to five. Challenging benchmarks with strong layerwise effects are considered, for which an accurate description of the transverse normal deformation effect is important. They include distributed/localized step loading and different boundary conditions. Effects of constraint stresses at supports are accounted for. Numerical results show that whenever the whole set of physical constraints is enforced across the thickness to redefine coefficients, the choice of the representation form and of zig-zag functions is immaterial and more importantly, accurate results are obtained with few variables and a low expansion order of solutions. Otherwise results are sensitive to the choices made.

W. Zhang (1), Y. Niu (1) and K. Behdinan (2)
ABSTRACT: A new dynamic model of the rotating tapered cantilever cylindrical panel with the graphene coating layers is developed to investigate the vibration characteristics of the rotating pretwisted tapered blade. It is assumed that the graphene platelets (GPLs) are randomly oriented and uniformly dispersed in the top layer and the bottom layer of the rotating pretwisted composite tapered blade. The modified Halpin-Tsai model is used to estimate the effective Young's modulus. The rule of the mixture is used to calculate the effective Poisson's ratio and mass density. Based on the Green strain tensor, an accurate strain-displacement relationship is acquired. The effects of the centrifugal force and Coriolis force are considered in the formulation. The Chebyshev-Ritz method is utilized to obtain the natural frequencies and mode shapes of the rotating pretwisted composite tapered blade with the graphene coating layers. The accuracy of the proposed model is validated through several comparison studies with the results of the present literatures and ANSYS. The free vibration characteristics are analyzed by considering different material and geometry parameters of the rotating pretwisted composite tapered cylindrical panel with the graphene coating layers, such as the graphene platelet (GPL) geometry, GPL weight fraction, taper ratio, length-to-radius ratio, pretwist angle, presetting angle and rotating speed. The frequency veering and the mode shape shift phenomena are found in the rotating pretwisted tapered cantilever cylindrical panel with the graphene coating layers.


ABSTRACT: Auxetic lattice cylindrical shell consisting of re-entrant lattice cell has superior mechanics performance due to negative Poisson's ratio (NPR). In this work, finite element models were established and finite element method (FEM) was adopted to explore the deformation behaviors and energy absorption of re-entrant auxetic lattice cylindrical shells and the SILICOMB lattice cylindrical shell in different crushing velocity. Result indicated that the deformation behaviors of auxetic lattice cylindrical shells are expressed as NPR mode, and different deformation behaviors (‘Z’ mode, ring mode, diamond mode and mixed mode) of lattice sandwich cylindrical shells are mainly determined by the ratio of the core wall thickness to the skin. The SILICOMB lattice cylindrical shell has better performance than the conventional hexagon honeycomb lattice cylindrical shell when crushing under high velocity. Meanwhile, the SILICOMB sandwich cylindrical shell has the best performance on the specific energy absorption among these four configurations and the maximum increment is 20.77%. The design of the auxetic and the SILICOMB cylindrical shells may provide a new idea which can be applied in practical application as impact resistance structures on aerospace.

Reza Kolahchi (1), Shun-Peng Zhu (2), Behrooz Keshtegar (3,4) and Nguyen-Thoi Trung (3,4)
(1) Institute of Research and Development, Duy Tan University, Da Nang 550000, Viet Nam
(2) School of Mechanical and Electrical Engineering, University of Electronic Science and Technology of China, Chengdu 611731, China
(3) Division of Computational Mathematics and Engineering, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
(4) Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam


ABSTRACT: Dynamic buckling optimization in laminated truncated nanocomposite conical aircraft shell in moisture and temperature environments as well as magnetic fields is considered in this article. The structural layers are hybrid nanocomposite consist of polymer, carbon nanotubes (CNT) and carbon fibers based on
Halpin-Tsai model. Utilizing theory of Mindlin, the final equations are solved and derived by method of Bolotin and differential quadrature method (DQM). In the optimization process utilizing improved meta-heuristic algorithm basis Grey Wolf optimization (GWO), the instability and frequency of the structure are utilized to define the subjective and objective functions. The GWO is improved using an adjusting randomly process with normal distribution. The main contribution of this study is maximizing the inequality and frequency constraint to control its instability. In the optimization procedure, the cone semi vertex angle, moisture and layers number change are optimized and the temperature influences, carbon fiber volume percentage, magnetic field and CNT radius are considered. The outcome shows that the proposed improved GWO may provide better abilities to search the global conditions compared to GWO because of rising flexibility to study optimum conditions of this complex problem. It is observed that the optimum frequency of system without retrofitting by CNTs is lower than the case of (math).

Qiang Gao (1), Wei-Hsin Liao (1) and Liangmo Wang (2,3)
(1) Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Shatin, Hong Kong, China
(2) Department of Automotive Engineering, School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, Jiangsu, China
(3) School of Mechanical Engineering, Wanjiang University of Technology, Ma’anshan, China


ABSTRACT: Auxetic structures with negative Poisson's ratio have been widely studied due to their unique mechanical properties, especially the dynamic properties under low-velocity impact. In this paper, the dynamic properties of an excellent candidate for engineering application, double arrowed honeycomb (DAH), are analyzed thoroughly. The deformation patterns of the DAH under high and low velocity impact are compared, which shows there is a great difference between them. Analytical models for predicting the dynamic strength at the crushing/supporting end of DAH are developed based on cellular collapse mechanism. It shows that the crushing strength rises with the increase of the relative density and impact velocity. Numerical simulations are also performed to verify the accuracy of the analytical models. It is found that there is good agreement between the analytical and numerical predictions for the dynamic characteristics. Also, the energy absorptions of the DAH are also thoroughly studied based on the analytical models.

Hu Liu (1), Han Wu (2) and Zheng Lyu (1)
(1) School of Mechanical and Aerospace Engineering, Nanyang Technological University (NTU), Singapore 639798, Singapore
(2) Institute of Solid Mechanics, Beihang University (BUAA), Beijing 10002, China


ABSTRACT: In this paper, the nonlinear dynamic response of a FG multilayer beam-type nanocomposite reinforced with graphene nanoplatelet (GNP) by considering the initial geometric imperfection is investigated on the basis of nonlocal strain gradient Euler-Bernoulli beam theory. Four patterns of GNP distribution incorporating the uniform distribution (UD) and O-, X-, and A- FG pattern distributions are taken into account and the effective elastic properties of the beam-type nanocomposite are evaluated in the framework of Halpin-Tsai scheme. The first-order vibrational mode is employed to represent the initial geometric imperfection of the nonlinear FG beam-type nanocomposite. Correspondingly, the nonlinear amplitude-frequency response of the imperfect FG multilayer beam-type nanostructures subjected to the excitation resonance is analyzed with the aid of multiple scale method. Firstly, the present model is validated with a comparison of two previous works. Then, a comprehensive investigation is conducted to evaluate the effects of GNP distributed pattern, weight fraction of GNPs, geometric imperfection amplitude, boundary condition, excitation amplitude, nonlocal and strain gradient size scale parameters on the nonlinear frequency-response of FG multilayer beam-type nanostructures. The current work is beneficial for the application of GNP as reinforcement to enhance mechanical performances of nanostructures.

Kang Gao (1,2), Duy Minh Do (1), Ruilong Li (3), Sritawat Kitipornchai (4) and Jie Yang (1)
computational domain by using the geometric transformation based singular convolution. The discretization plate buckling and boundary conditions of the problem are transformed from the physical domain into a square computational domain using discrete singular convolution (DSC) method. Related governing equations of skew plate. By using the transformation rule, quadrilateral plate field is mapped into a square domain in the computational space using discrete singular convolution (DSC) method. Related governing equations of skew plate buckling and boundary conditions of the problem are transformed from the physical domain into a square computational domain by using the geometric transformation based singular convolution. The discretization

ABSTRACT: In this paper, the free vibrational behavior of composite conical shells stiffened by bevel stiffeners is investigated using experimental, analytical and numerical techniques. The smeared method is employed to superimpose the stiffness contribution of the stiffeners with those of shell in order to obtain the equivalent stiffness parameters of the whole structure. Due to the specific geometry of the conical shell, the whole structure is converted to a conical shell with variable stiffness and thickness. The stiffeners are considered to be of beam-type which support shear load and bending moments in addition to the axial loads. The geodesic path is applied to the stiffeners. The governing equations have been derived based on the first-order shear deformation theory and using the Ritz method. In order to validate the analytical achievements, the experimental modal test is conducted on a stiffened cone. The specimen has been fabricated by a specially-designed filament winding setup. A 3-D finite element model was also built using ABAQUS software to further validate the analytical results and help with parametric study. Comparison of the results obtained from the three approaches revealed good agreements. The effects of the shell geometrical parameters and variations in the cross stiffeners angle on the natural frequencies have been discussed and investigated. The present achievements are novel and can be used as a benchmark for further studies.

O. Civalek (1) and M.H. Jalaei (2)
(1) China Medical University, Taichung, Taiwan
(2) Islamsahr Branch, Islamic Azad University, Islamshahr, Iran

ABSTRACT: This paper presents the first attempt to study the probabilistic stability characteristics of functionally graded (FG) graphene platelets (GPLs) reinforced beams by taking into account the multidimensional probability distributions, such as stochastic porosity and GPL distribution patterns as well as random material properties. For this purpose, a non-inclusive Chebyshev metamodel (CMM), which is implemented on deterministic analysis using discrete singular convolution (DSC) method with excellent computational efficiency and accuracy, is proposed and used to obtain both deterministic and probabilistic results including probability density functions (PDFs), cumulative density functions (CDFs), means and standard deviations of the critical buckling load. The present analysis is rigorously validated through direct comparisons against the results obtained by a direct quasi-Monte Carlo simulation (QMCS) method and those available in open literature. The influences of material properties, porosity distribution, GPL dispersion pattern and boundary condition on probabilistic buckling behaviour of the FG-GPL beam are comprehensively investigated. The global sensitivity analysis is also conducted. The results suggest that the critical buckling load of the FG-GPL beam is most sensitive to porosity distribution, followed by porosity coefficient and GPL weight fraction.

M. Zarei (1), G.H. Rahimi (1) and M. Hemmatnezhad (2)
(1) Faculty of Mechanical Engineering, Tarbiat Modares University, P.O. Box 14115-143, Tehran, Iran
(2) Faculty of Mechanical Engineering, Takestan Branch, Islamic Azad University, Takestan, Iran

ABSTRACT: This paper presents the first attempt to study the probabilistic stability characteristics of functionally graded (FG) graphene platelets (GPLs) reinforced beams by taking into account the multidimensional probability distributions, such as stochastic porosity and GPL distribution patterns as well as random material properties. For this purpose, a non-inclusive Chebyshev metamodel (CMM), which is implemented on deterministic analysis using discrete singular convolution (DSC) method with excellent computational efficiency and accuracy, is proposed and used to obtain both deterministic and probabilistic results including probability density functions (PDFs), cumulative density functions (CDFs), means and standard deviations of the critical buckling load. The present analysis is rigorously validated through direct comparisons against the results obtained by a direct quasi-Monte Carlo simulation (QMCS) method and those available in open literature. The influences of material properties, porosity distribution, GPL dispersion pattern and boundary condition on probabilistic buckling behaviour of the FG-GPL beam are comprehensively investigated. The global sensitivity analysis is also conducted. The results suggest that the critical buckling load of the FG-GPL beam is most sensitive to porosity distribution, followed by porosity coefficient and GPL weight fraction.
process is achieved via the DSC method together with numerical differential and two-different regularized kernel such as regularized Shannon's delta (RSD) and Lagrange delta sequence (LDS) kernels. The accuracy of the present DSC results is first verified via exiting results in literature. Then, some parametric studies have been presented to show the effects of CNT volume fraction, CNT distribution pattern, geometry of skew plate and skew angle on the shear buckling responses of FG-CNTR composite skew plates with different boundary conditions. Some new results related to critical buckling of FGM and CNT reinforced composite skew plate have been presented which can serve as benchmark solutions for future investigations.

Ali Heidari Soureshjani (1), Roohollah Talebitooti (1) and Mostafa Talebitooti (2)
(1) Noise and vibration control research Laboratory, School of Mechanical Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran
(2) Department of Mechanical Engineering, Qom University of Technology, Qom, Iran


ABSTRACT: This paper investigates the free vibrational behaviors of joined composite sandwich conical-conical shells under external lateral pressure. The corresponding equations are derived based on the first order shear deformation theory (FSDT). Herewith, free vibration equations are extracted via applying Hamilton's principle and considering initial mechanical stresses solved by static equilibrium equations. To establish the continuity of two conical shells, compatibility of displacements and stress resultants are satisfied at the junctions. The generalized differential quadrature (GDQ) method is adopted to discretize the governing equations for each conical segment, together with related boundary and continuity conditions in a meridian direction. In order to verify the results as well as representing the convergence of the presented approach, some pieces of case studies are accomplished. These studies provide a better exhibition of lateral pressure, cone angles and shell thickness influences on the free vibration of joined composite sandwich conical shells with various boundary conditions. Then, the effect of four different types of materials which are more applicable in pressurized environments such as underwater and submarine structures, i.e. polyetheretherketon (PEEK), polycarbonate (PC), solid propylene (SPP), and high density polyimide foam (HDPF) are investigated for the core layer. Critical buckling pressure in the present approach is obtained when the natural frequency takes the value of zero for the lowest pressure. Finally, the values of lateral pressure are selected considering the critical buckling pressure to avoid buckling occurrence.


ABSTRACT: To reveal the failure of carbon fiber reinforced composite (CFRC) anisogrid lattice cylinders, a multi-failure theory is proposed, including global buckling, local in-plane buckling, local out-of-plane buckling, Euler buckling and material failure. The global buckling is analyzed by Ritz buckling analysis through the equivalent continuum method and verified by the finite element modeling (FEM) covering different representative sizes and previous experimental results. A parametric analysis is performed to reveal the effects of the rib thickness, the rib height and the number of helical ribs and hoop ribs, on the critical load and failure modes. Failure maps are deduced to figure out the optimal route for lightweight design of the CFRC anisogrid cylinder. The theory will serve as a reference to design composite anisogrid lattice cylinders with high specific strength and stiffness.

Huagang Lin (1), Chonghui Shao (2) and Dengqing Cao (3)
(1) Northwestern Polytechnical University, Xi’an, 710072, China
(2) Harbin Turbine Company Limited, Harbin 150046, China
(3) School of Astronautics, Harbin Institute of Technology, Harbin 150001, China

ABSTRACT: An analytical model for the nonlinear aeroelastic, flutter postponement and random response of the composite panel with shape memory alloy (SMA) in the coupled multi-fields is presented. One-dimensional thermodynamic model is adopted to describe the recovery stress generated by the SMA. Then the recovery stress is introduced into the stress-strain relation, and the von-Karman's large deformation theory, third-order nonlinear piston theory are employed to establish the motion equation of the panel subjected to the combined thermal, aerodynamic and noise loads, in which the noise excitation is simulated by the Gaussian White Noise. The distributions of the stress cycle block are described by using the rain-flow cycle matrix. A few comparisons for the recovery stress of SMA, buckling temperature and flutter pressure are performed to validate the established model. The suppression effect of the SMA on the flutter boundary, post-buckling and response of the system are highlighted. Considering the Thermal-Aero-Acoustic coupled field, the nonlinear dynamic characteristics and post-flutter behavior of the system are analyzed. Many new phenomena, mode jumping, snap-through response and intermittent jumping motion have been observed.

Behzad Kazemianfar, Meysam Esmaeili and Mohammad Rahim Nami (School of Mechanical Engineering, Shiraz University, Shiraz, Iran), “Response of 3D woven composites under low velocity impact with different impactor geometries”, Aerospace Science and Technology, Vol. 102, Article 105849, July 2020, https://doi.org/10.1016/j.ast.2020.105849

ABSTRACT: This paper deals with experimental and numerical investigations into the impactor shape effects on the low velocity impact behavior of 3D woven composites. The samples were made of E-glass fibers and unsaturated polyester resin. Conical, hemispherical and flat-ended impactors were used. The damage modes and areas of the specimens are inspected using microscopic and optical images. The finite element package ABAQUS is used to simulate the impact event. The contact force, displacement and dissipated energy of different impactors are compared. A good agreement between experimental and numerical results is observed. The results show that the blunter impactors produce greater damage areas and threshold loads. However, the damage initiation time is not dependent to the impactor shape. Besides, the damage intensity of the composites is greatly influenced by the impactor shape and z-fibers volume fraction.

Tao Liu (1), Xianheng Wang (1), Ximining Qiu (1) and Xinghua Zhang (2)
(1) Department of Engineering Mechanics, Tsinghua University, Beijing, 100084, China
(2) Institute of Microelectronics of Chinese Academy of Sciences, Beijing, 100029, China

ABSTRACT: Large size and high precision inflatable membrane antenna is a promising design for space-based structures. To accurately control its mechanical states, such as shape and stress, the parameter sensitivity of an inflatable membrane antenna is theoretically investigated in this study. Based on the developed analytical matrix model, the influence of loading conditions (pressure, pre-stress) and material properties (elastic modulus, Poisson's ratio) is evaluated, and the stability of inflatable membrane antenna is also demonstrated analytically. Using Taylor expansion, an explicit closed-form solution is obtained, which avoids solving the transcendental equations. The solution is verified by corresponding orthogonal experiment technique and numerical simulations. The research shows that the influence of the variation of the factors on the mechanical states of inflatable membrane antenna will not be amplified, and the ranking of the factors' weights is elastic modulus > pressure > Poisson's ratio > pre-stress.


ABSTRACT: In the present study, control of a Thin Walled Beam (TWB) wing-engine system is examined applying piezoelectric actuators to enhance the performance of aeroelastic response. The composite piezoelectric governing equations of motion including the structure and electric effects are derived applying Hamilton's principle. Piezoelectric composite plate equations are added to the composite host wing-engine
governing system of equations. The incompressible aerodynamic model based on Wagner's function is applied and the Ritz based solution methodology is employed. As a passive control approach, the effects of piezoelectric fiber angles are studied on the time domain response of the high-aspect-ratio wing-engine system. The linear quadratic Gaussian (LQG) control algorithm is applied as a closed-loop active control strategy to enhance the flutter response characteristics of the composite wing-engine system. Numerical results firstly, demonstrate the effectiveness of the active control strategy based on piezocomposite actuator on suppressing the flutter response of the composite wing-engine system and secondly, prove the effect of piezocomposite actuator location and fiber angle orientation on the closed-loop control performance.


ABSTRACT: This paper studies wave propagation in functionally graded metal foam plates reinforced with graphene platelets (GPLs), where various types of porosity and GPL distribution are taken in account. The Halpin–Tsai model is employed to express the material properties of metal foam plates reinforced with GPLs. The governing equations of wave propagation in metal foam plates are derived by Hamilton's principle together with different plate theories, upon which wave dispersion relations in plates are achieved. Then, the validation of proposed model is examined by comparing the natural frequencies calculated in present study and those from literature. Finally, the effects of porosity and GPL distributions, porosity coefficient, GPL volume fraction and geometry on wave dispersion relations are evaluated.


ABSTRACT: This paper investigates the flutter characteristics of graphene nanoplatelet (GPL) reinforced laminated composite quadrilateral plates using the element-free IMLS-Ritz method. The modified Halpin-Tsai model and rule of mixture are employed to predict the effective material properties including Young's modulus, mass density and Poisson's ratio. The energy functions of GPL reinforced composite (GPLRC) quadrilateral plates are obtained by the first-order shear deformation theory (FSDT) and first order piston theory. Based on the IMLS-Ritz approximation, the discrete dynamic equation of GPLRC quadrilateral plates is derived. The accuracy of the IMLS-Ritz results is examined by comparing the natural frequencies with those obtained from published values. A comprehensive parametric study is carried out, with a particular focus on the effects of weight fraction, distribution pattern, total number of layers, geometry and size of GPL reinforcements and geometric parameters of quadrilateral plates on the flutter boundary of GPLRC quadrilateral plates.


ABSTRACT: Pyrotechnic separation devices have been widely used in various missions of spacecraft in order to separate the structural parts with high reliability. Although they afford advantages of cost-effectiveness and high reliability, pyrotechnic separation devices generate an intensive dynamic response called pyroshock, which can lead to fatal damage to the mounted electronic equipment. Previous studies have attempted to resolve these issues with a shock isolator. However, these studies have limitations such as possible dynamic instability in low frequency and complexity in design. In the present study, a novel design of the sandwich insert is proposed to achieve enhanced shock attenuation without a shock isolator. Static-load tests were conducted to validate the structural performance of the shock-absorbing insert. In order to observe the attenuation performance, shock propagation and response experiments were carried out with consideration that the inserts were utilized to connect parts and to mount devices on the panel. In addition, swept sine vibration tests were carried out to investigate the dynamic response in low frequency. The shock-absorbing insert reduced propagating shock for the joint structure, and the shock response of the mounted equipment was significantly attenuated. The novel shock-absorbing insert saves space and is dynamically stable, and furthermore has the ability to protect the
small electronic equipment, which is mounted on the honeycomb sandwich panel, from severe shock. These advantages make it a suitable insert for space structure application for connecting parts or mounting equipment.


ABSTRACT: This paper investigates the influence of linear and nonlinear distribution of nanofillers on the vibrational behavior of nanocomposite plates using a layer-wise formulation model. Two separate kinds of nanocomposite plates are considered in this study; multilayer functionally graded carbon nanotube-reinforced composite (FG-CNTRC) plates, and multilayer functionally graded graphene platelets reinforced composite (FG-GPLRC) plates. The carbon-based nanofillers are assumed to be either uniformly dispersed or functionally graded across the plate thickness direction. Those distributions can be in linear or non-linear form. The governing equation is obtained employing the first order shear deformation theory (FSDT). The rule of mixture is used to calculate the effective elastic modulus for the CNTRC plate, while for the GPLRC plate, the modified Halpin-Tsai micromechanics model is employed, however, the mass density and Poisson's ratio are determined by using the rule of mixture for both types of nanocomposite plates. A validation study is carried out in order to take an idea on the degree of precision of our results comparatively with those available in the literature, thereafter, a parametric study was performed focusing on the (i) effect of total number of layers for (ii) linearity and non-linearity cases of nanofillers distribution, (iii) nanofillers weight fraction and distribution types, (iv) plate length/width and width/thickness ratios, and (v) boundary conditions on the natural frequencies of the FG-CNT and FG-GPL reinforced composite plates. The results indicate that changing the nanofillers distribution patterns from a uniform to non-uniform way using the proposed layer-wise formulation model can remarkably increase or decrease the effective stiffness of the plate structures.


ABSTRACT: For the first time, three-dimensional (3D) temperature-dependent thermo-elastoplastic bending analysis of functionally graded (FG) skew plates subjected to combined thermal and mechanical loads is presented. A novel truly meshless approach based on the local moving Kriging method is formulated and employed for this purpose. The method utilizes a new correlation function in which the shape parameter does not affect the quality of the moving Kriging interpolation (MKI) shape functions. The von-Mises isotropic hardening theory and the Prandtl-Reuss flow rule are used to describe the plastic deformation. The obtained results are compared with the other existing 3D analytical and numerical results and an excellent agreement is observed. Various numerical examples are provided and the effect of significant parameters including material gradient, skew angle, thickness ratio, and boundary conditions on the nonlinear bending responses of FG skew plates is also studied. Results illustrate that the present meshless approach can provide highly accurate and stable results in the 3D thermo-elastoplastic bending analysis of FG skew plates.


ABSTRACT: An effective method is proposed to investigate the influences of the boundary relaxation on the supersonic flutter and thermal buckling characteristics of composite laminated panels. The relaxed boundary of the panel is simulated by a set of springs, and the degree of the boundary relaxation is evaluated by adjusting the stiffness of the boundary constraint springs. By employing the characteristic polynomial series as the admissible functions, the Rayleigh-Ritz method is used to calculate the natural frequencies and mode shape functions of the composite laminated panels with relaxed boundary. The supersonic piston theory is employed to determine the aerodynamic loading. The equations of motion of the structure are established by Hamilton’s

ABSTRACT: This paper introduces a semi-analytical approach integrated with Monte Carlo simulation for stochastic buckling analyses of porous functionally graded plates arising due to the inevitable source-uncertainties of geometrical configurations and material properties. Analytical derivations based on the classical plate theory in conjunction with three-variable refined shear deformation theory are carried out first leading to closed-form solutions for buckling loads and thereby, the closed-form equations are exploited to conduct the comprehensive stochastic quantification of buckling loads in a non-intrusive framework based on Monte Carlo simulation. The deterministic framework is validated with a separate finite element analysis before implementing it for stochastic analysis. The first-order and second-order perturbation theory integrated with the Taylor series expansion are utilized to derive closed-form expressions for the mean and variance of stochastic buckling loads which are compared with Monte Carlo simulation results. Sensitivity of stochastic buckling loads on individual and compound uncertainties are investigated to determine the relative importance of different uncertainty sources. Effects of plate thickness, volume fraction index, and degree of stochasticity variations on the probability distributions of the first three stochastic buckling loads are investigated for both uniaxial and biaxial load cases. The complete probabilistic descriptions presented in this paper assert that the overlapping areas in probability distribution plots corresponding to the consecutive buckling modes lead to the existence of non-unique critical buckling modes, which could potentially be crucial for analyses and designs of structural systems under an inevitable stochastic environment. This article convincingly demonstrates the importance of considering source-uncertainties in porous functionally graded structures including the critical loopholes for a buckling analysis in the presence of such uncertainties.


ABSTRACT: With the aid of an efficient meshless numerical solution and the reproducing kernel particle method, the feasibility for investigating the nonlinear vibrations of the carbon fiber reinforced composite rectangular plate with the random material properties is studied in this paper. A geometrically nonlinear mathematical model is established based on the classical plate theory. According to the derived governing equation of motion by using the principle of virtual displacement, the nonlinear vibration behaviors of the carbon fiber reinforced composite plates with various edge supports are investigated. The linear and nonlinear eigenvalues and corresponding eigenvectors are calculated iteratively by using the dimensionless amplitude. The stochastic meshless method is proved to have a good computational accuracy for the composite plate, and exhibits an optimal choice for the shape function and constraint of the essential boundary conditions. The useful conclusions are obtained regarding the effect of the material and geometrical parameters including the boundary condition, length-width ratio, plate length and carbon fiber content on the nonlinear responses in the framework of the meshless method.


ABSTRACT: The truss antenna based on the tetrahedral deployable mechanism has the advantages of good deployment stability, high stiffness, large folding rate and high profile accuracy. A new modular deployable antenna mechanism based on the 3RR-3URU tetrahedral symmetrical combination unit is proposed in the present study. It should be indicated that the construction method of the modular mechanism is proposed.
the projectile diameter and mass on the ballistic limit velocity were investigated. The study showed that the parameters such as the sandwich structure core, with velocity of the sandwich structures, so that the ballistic limit velocity of the sandwich structures with four revealed that, considering constant core mass and total thickness, the core layering increases the ballistic limit and 8 mm diameter. The impact velocity range was chosen from 188.7 to 322.6 m/s. The results ⁎ structures and four sandwich structures with four high face sheets (AL-1050) and also arrangements of these layers on the ballistic resistance of the structures under high-velocity impact were investigated experimentally and numerically. Three single-layer core sandwich structures and four sandwich structures with four-layer core were considered with a total fixed volume (90 * 90 * 63 mm). These structures were impacted by a hemispherical nose cylindrical steel projectile of 20 mm length and 8 mm diameter. The impact velocity range was chosen from 188.7 to 322.6 m/s. The results of this study revealed that, considering constant core mass and total thickness, the core layering increases the ballistic limit velocity of the sandwich structures, so that the ballistic limit velocity of the sandwich structures with four-layer core, with different arrangements of layers, compared to the single-layer core structure is 5 to 8 percent higher, on average. Additionally, experimental and numerical results are in good agreement. In this research, the effect of parameters such as the sandwich structure core, the thickness of the face-sheets, the projectile nose geometry, the projectile diameter and mass on the ballistic limit velocity were investigated. The study showed that the
removal of the core from the sandwich structure led to a 32% reduction in ballistic limit velocity. Increasing the thickness of the back face-sheet (with the constant total thickness of the two face-sheets) increases the ballistic limit velocity by more than 6%. Compared to flat nose projectile, the ballistic limit velocity of a hemispherical nose and conical nose projectiles are respectively 9.5 and 15.6% less. Considering a constant projectile mass, with an increase of 12.5 and 25% in its diameter, the ballistic limit velocity was increased by 6.5 and 14.4%, respectively, and by decreasing the diameter by 5 and 10%, the ballistic limit velocity dropped 7.9% and 13.5%, respectively. Assuming a fixed initial kinetic energy, the increase in the mass of the projectile also reduced the ballistic limit velocity, so that by increasing the 14 and 46.1% of the projectile mass, the ballistic limit velocity was reduced by 8.5 and 18.3%, respectively.

ABSTRACT: Analytical studies carried out on the vibro-acoustic response behavior of an isotropic plate under non-uniform edge loads subjected to steady-state mechanical excitation is presented. An analytical method based on the energy approach is used to calculate the buckling load . Free and forced vibration responses of the plate are obtained using an analytical method based on Reddy's third-order shear deformation theorem (TSDT) while sound radiation behavior is analyzed using Rayleigh Integral. Results revealed that is significantly influenced by the nature of non-uniform edge load. Similarly, natural frequencies reduce with an increase in axial compressive load due to a reduction in structural stiffness. Vibration and acoustic resonant amplitudes are affected by the intensity of the compressive load. Sound transmission loss reduces with an increase in compressive load magnitude and the effect is significant in the stiffness dominant region.

ABSTRACT: Auxetic cellular structures with outstanding mechanical performance and unique deformation characteristics have a variety of potential applications in aerospace, as ultralight load-bearing structures and vibration isolation structures. Herein, the in-plane compression behaviors of hybrid honeycomb metastructures, comprised of conventional and auxetic honeycombs, are systematically studied by using theoretical calculations, experimental characterization and numerical simulations. The theoretical formulae of elastic modulus and ultimate strength of the architected metastructure are derived by establishing stress analysis models. Three types of hybrid honeycomb metastructures are manufactured by selective laser melting (SLM) with 304 stainless steel. Finite element analysis is performed to unveil the deformation mechanism and failure modes. The theoretical prediction results of elastic modulus and ultimate strength are consistent with simulations and experimental results. In addition, the influences of panel and layer numbers on the mechanical behavior of hybrid honeycomb metastructures are discussed in detail. The results reveal that a hybrid metallic honeycomb metastructure, with stable and superior compressive properties, can be obtained by combining two types of cellular cells, i.e., conventional and auxetic honeycombs. These results provide a baseline for further research and development of novel metastructure designs.

ABSTRACT: Two innovative re-entrant hierarchical sandwich panels constructed by substituting the cell walls of re-entrant honeycombs with isotropic regular hexagon substructure (RHH) and equilateral triangle substructure (RHT) are proposed in this paper, and their crashworthiness performance has been investigated systematically. Based on the Euler beam theory, the Young's moduli of units of re-entrant hierarchical sandwich panels are derived. A comparison between the re-entrant hierarchical sandwich panels and re-entrant sandwich panel has been conducted to study their energy absorption ability. Furthermore, the parametric analysis based on numerical analysis has been carried out to discuss the effects of the gradient, arranged orientation of hierarchical sandwich cores and the impact velocities. Results show that both the two proposed sandwich panels
can greatly improve the in-plane stiffness and the energy absorption capacity, and the energy absorption mechanisms are discussed. In addition, the graded sandwich panels can effectively reduce initial peak force under quasi-static compression, and the configuration of large-medium-small (LMS) performs the best under high impact velocity. The cross-arranged cores can significantly improve the impact resistance ability of RHT sandwich panels. This work provides a new solution for designing lightweight sandwich structures.


ABSTRACT: The natural property of a three-axis attitude stabilized spacecraft is investigated by simplifying it as a rigid central body jointed with 4 solar panels in this paper. For the spacecraft composed of a rigid central body and flexible panels, the Rayleigh-Ritz method is employed to obtain global modes which are explicitly functions of space coordinates and are useful for the modeling of lower-order discrete dynamic equations and design of active vibration controllers for the system. The Gram-Schmidt process is used to construct a set of characteristic orthogonal polynomials as the displacement field of the solar panel. Lagrange multipliers are introduced to describe the constraint at joints. The characteristic equation of the whole system is derived through the Rayleigh-Ritz procedure. Then, natural frequencies and corresponding global modes of the spacecraft with jointed panels are obtained. Taking the natural frequency obtained from the finite element method as a reference value, the process of getting natural frequencies is validated by comparing results obtained with those from the finite element method. Moreover, an excellent convergence and high accuracy of the present method is demonstrated by a very good agreement between results from ANSYS and theoretical method proposed here. Finally, parametric studies on characteristics of the spacecraft are conducted. The interesting mode shift phenomenon is observed when parameters of the spacecraft are changed.


ABSTRACT: Using the ideas of variational differential quadrature and finite element methods (VDQ and FEM), a novel numerical approach is developed in this paper to investigate the postbuckling behavior of plates with arbitrary shape under the action of thermal load within the framework of higher-order shear deformation theory (HSDT). It is considered that the plates are made of functionally graded carbon nanotube reinforced composite (FG-CNTRC). By the proposed approach, the thermal postbuckling behavior of plates with arbitrary-shaped cutout can be modeled. The rule of mixture is utilized to obtain the effective material properties of nanocomposite which are considered to be temperature-dependent. To implement the proposed method that can be named as VDQFEM, the variational temperature-dependent formulation of problem is first developed. This formulation is presented using novel vector-matrix relations with the aim of utilizing in programming in an efficient way. In the context of VDQFEM, the space domain of plate is first transformed into a number of finite elements. In the next step, the VDQ discretization technique is implemented within each element. Then, the assemblage procedure is performed to derive the set of matricized governing equations which is finally solved by means of the pseudo arc-length continuation algorithm. One of the main novelties of present approach is proposing an efficient way based on mixed-formulation to accommodate the continuity of first-order derivatives on the common boundaries of elements for the used higher-order shear deformable plate model. Quadrilateral plate, skew plate, annular plate, square plate with rectangular hole and rectangular plate with circular hole under different boundary conditions including CCCC, SSSS, CSCS and CCSS (S: simply-supported, C: clamped) are considered in the numerical example. First, validation studies are presented in terms of critical buckling temperature of CNTRC rectangular plates with various CNT distribution patterns. It is shown that the proposed method has the advantages of standard VDQ technique including fast convergence rate, being locking-free and simple implementation. Moreover, it is capable of considering polygon and concave domains. Also, the effects of geometrical properties, volume fraction and distribution pattern of CNTs and temperature-dependency of material properties on the thermal postbuckling of plates are studied.

ABSTRACT: Auxetic structures exhibit negative Poisson’s ratio (NPR) and offer valuable enhancement of mechanical properties. This study presents a combined experimental and numerical investigation of the out-of-plane and in-plane performances of a recently proposed auxetic structure, re-entrant chiral auxetic (RCA), under quasi-static uniaxial compression. The popular hexagonal honeycomb and re-entrant honeycomb were also studied as benchmarks for comparison. Specimens were fabricated by fused deposition modelling (FDM) process. It was found that printing quality depends on the size and complexity of the printed structures. Deformation mode, stress-strain curves and energy absorption of the three types of structure were studied and compared. Specific energy absorption per unit volume, W-sub-v, and per unit mass, SEA, were calculated up to the strain at the onset of densification. Results show that the out-of-plane energy absorption of the proposed structure outperformed that of the other two benchmarks. In contrast, when comparing the energy-absorbing efficiency, the hexagonal honeycomb revealed the highest energy absorption efficiency of 65%, compared with 44% and 52% for the re-entrant and the proposed RCA structure, respectively. For the in-plane compression, the proposed structure exhibited a negative Poisson's ratio and demonstrated anisotropic mechanical performance.


ABSTRACT: This paper presents an analytical investigation on buckling and post-buckling of shear deformable sandwich toroidal shell segments with functionally graded core and homogeneous face sheets. The effective material properties of core layer are graded in the thickness direction according to a simple power law distribution in terms of volume fraction index. The shells are surrounded by an elastic foundation and subjected to axial compressive or thermal loads. Reddy's third-order shear deformation shell theory (TSDT) is used to established formulations. A new solution using Galerkin method for solving a governing system of four-partial differential equations is carried out to obtain closed-form expressions of buckling stresses and post-buckling curves. Two cases of bowed-out and bowed-in sandwich toroidal shells are considered. Effects of material, geometric parameters and elastic foundation on stability behavior of the shells is analyzed in detail. The difference between bucking stresses basing on TSDT and those basing on classical shell theory (CST) is also clearly shown in this study.


ABSTRACT: In this paper, an efficient Co finite element modeling based on higher-order nonpolynomial shear deformation theory (NPSDT) is proposed for dynamic analysis of folded laminated composite plate. The theoretical formulations are based on nine-noded Lagrange isoparametric finite element and inverse hyperbolic shear deformation theory (IHSDT) as NPSDT. The employed theory, IHSDT, assumes the nonlinear and realistic distribution of transverse shear stresses, and also satisfies the traction-free boundary conditions at the top and bottom surfaces of the plate. Hamilton's principle has been adopted to derive the system's governing equation. A penalty approach has been used to take into account the artificial constraints generated due to incorporation of Co Lagrange element. The free vibration pertaining to eigenvalue problem is solved using subspace iteration method. The transient analysis subjected to pressure load and vertical load is carried out using Newmark's direct integration scheme. The formulation has been validated with the available solution in the literature, and several novel solutions have been proposed to address the various practical aspects of folded plate. Numerical illustrations are presented to investigate the effect of various parameters such as crank angle, fiber angle, lamination scheme, fold location, and boundary conditions on the natural frequency and transient response of laminated composite plate.


ABSTRACT: In this paper, a meshless method has been developed to analyze stresses and deflections in an advanced smart lightweight sandwich plate (ASLSP) subjected to thermo-electro-mechanical loads. In ASLSP,
a passive sandwich plate consisting of a lightweight porous core and two graphene nanocomposite layers is integrated between two active piezoceramic faces. Moreover, functionally graded profiles have been considered for the dispersions of porosity and graphene in their corresponding layers. In the meshless method, MLS shape functions has been utilized, and essential boundary conditions are implemented using transformation approach. A version of Halpin-Tsai equations capable of capturing nanoscale effects of randomly oriented graphene is adopted to approximate the temperature dependent mechanical properties of graphene nanocomposite layers. The highly coupled governing equations are extracted by minimizing total energy function obtained from the estimation of displacement domain with Reddy's third order plate theory (called TSDDT). The influences of different aspects of ASLSP including loading, graphene content, porosity and geometric details have been studied on thermo-electro-mechanical stresses and deflections. It is observed that both graphene content and dispersion profile have considerable influence on ASL SP's deflections. Moreover, embedding pores in core layer offers a significant reduction in structural weight and a considerable stability in structural bending stiffness.


ABSTRACT: A new nonlocal model for free vibration and thermal buckling analysis of rotating temperature-dependent functionally graded (FG) nanobeams in thermal environment is developed by introducing an axial nonlinear second-order coupling deformation based upon the Eringen's nonlocal elasticity theory (ENET) and Euler-Bernoulli beam theory (EBT). Material properties of FG nanobeams are assumed to be through-thickness symmetric and the temperature distribution is uniform in the thickness direction. The Hamilton's principle is utilized to derive the governing equations and associated boundary conditions of the nonlocal rotating FG nanobeam model considering thermal, small-scale and centrifugal stiffening effects. The nonlocal governing differential equations are transformed into algebraic eigenvalue equations evaluating the vibration and buckling properties through the Galerkin method. The validity and accuracy of the present nonlocal model are verified by convergence and comparative studies. Numerical results are presented to investigate the influences of dimensionless angular velocity, hub radius ratio, temperature change, material gradient index, slenderness ratio and nonlocal parameter on the natural frequencies and critical buckling temperatures of rotating FG nanobeams. The obtained results clearly show that these effects significantly affect the thermal buckling and vibrational behaviors of rotating FG nanobeams.


ABSTRACT: In this study, the aeroelastic instability of a wing with an initial out-of-plane curvature is determined. The structural dynamics of the wing is modelled by using the geometrically exact beam equations, and the aerodynamic loads are determined using an incompressible unsteady aerodynamic model. The wing is considered to have initial out-of-plane curvature, and the effect of the curvature on the flutter velocity and flutter frequency of the wing is determined. Two curved wing cases are considered here. In the first case, the length of the wing is assumed to be constant and therefore, as the wing is curved, the projected area of the wing decreases. In the second case, the wing is assumed to have a constant projected area and therefore different curvature angles result from different wing lengths. When the wing is designed to have an initial out-of-plane curvature, the wing dynamics change, and therefore the aeroelastic stability of the curved wing is also affected. It is shown that as the initial curvature of the wing increases, initially the flutter velocity decreases but then increases, and finally a sudden jump occurs in the flutter velocity due to the change of the coupled modes contributing to flutter. Moreover, the flutter frequency also first decreases as the curvature of the wing increases, and then there is a sudden jump in the frequency, and from this point again the frequency decreases. Finally, results highlighting the importance of the initial curvature and the length of the curved segment on the stability velocity and frequency of the curved wing are presented.

Dang Xuan Hung, Tran Minh Tu, Nguyen Van Long and Pham Hoang Anh, “Nonlinear buckling and postbuckling of FG porous variable thickness toroidal shell segments surrounded by elastic foundation

ABSTRACT: The paper presents an analytical approach in investigating the non-linear buckling and post-buckling behavior of functionally graded porous (FGP) variable thickness toroidal shell segments surrounded by elastic foundation under axial compressive loads. The governing equations of non-linear buckling of FGP toroidal shell segments are obtained by using Donnell shell theory in conjunction with von Kármán nonlinearity and Stein and McElman assumption. The solution in terms of displacements, the closed-form expressions of buckling load and post-buckling load-deflection relation are obtained using the Galerkin method. Three types of porosity distribution are considered. This study found that the variation of porosity distribution as well as geometrical and foundation parameters have significant effects on the non-linear buckling and post-buckling behavior of the FGP variable thickness toroidal shell segments.


ABSTRACT: Stringer frame stiffened shell structures are frequently used as primary structures of aerospace applications. They show a high load carrying capacity combined with a low mass. The design is complex because of three reasons: Firstly, there exists a high number of design variables making the design of such a shell very demanding using numerical methods such as the finite element method. Secondly, such a shell can exhibit different local instabilities before failing globally. And thirdly, the calculation of the panel instability load is not fully possible yet, especially when using closed and therefore torsional stiff stringer stiffener. Within this paper, a novel approach for the calculation of the panel instability load of stringer frame stiffened shell structures with torsional stiff stringer under axial compression is introduced. The novelty is expressed in the consideration of transverse shear and prebuckling deformations. It is shown that in contrast to unstiffened shell structures both aspects cannot be neglected and have a significant influence on the buckling load. The classical smearing method is expanded and used in a consecutive utilization of the Ritz method to calculate the panel instability load. Geometrically non-linear finite element analyses are performed to validate the novel approach and establish a domain of applicability. The suggested approach delivers excellent results for the prediction of the panel instability load.


ABSTRACT: The dynamic buckling in viscoelastic carbon nanocones (CNCs) under the magnetic and thermal loads is considered in this article. This class of nano-structures has great application in nano-electro-mechanical system (NEMS) such as scanning probe microscopy. Structural damping influences are studied according to approach of Kelvin–Voigt. The viscoelastic medium around the CNC is assumed applying the model of visco-Pasternak. Utilizing the first order shear deformation theory (FSDT), Hamilton's principle, method of energy, the motion equations are determined where the influences of size are captured by higher order nonlocal strain gradient approach. Method of Bolotin and differential quadrature method (DQM) are utilized to solve the equations of motion in order to access the formation of dynamic instability region (DIR). The influences of different factors like, boundary conditions, nonlocal parameters, structural damping, magnetic field, viscoelastic medium, temperature changes along with CNCs semi vertex angle on the DIR are investigated. The outcomes show that with rising strain gradient parameter, the DIR will be occurred at high frequencies. It is furthermore found that the magnetic load has a positive influence on the DIR of the nano-structure.


ABSTRACT: In this paper, thermal buckling of functionally graded (FG) porous nanocomposite beams subjected to a thermal gradient are studied by generalized differential quadrature method (GDQM). We consider three different types of nanofillers dispersion patterns and porosity distributions. Materials parameters
vary along the thickness direction. Under Gaussian random field (GRF) scheme, the mechanical properties of closed-cell cellular solids are used. Thereby, the variation of Poisson's ratio as well as the relationship between porosity coefficient and mass density are determined. The elastic modulus of nanocomposite is obtained by applying Halpin-Tsai micromechanics model. In the course of this work, the accuracy and efficiency of the (GDQM) are validated. We studied the effects of weight fraction, dispersion pattern, geometry, and size of graphene platelets (GPLs), as well as porosity distribution, porosity coefficient, slenderness ratio and metal matrix on the thermal buckling of the nanocomposite beam. Our findings, contrary to what was expected, are somewhat surprising. According to our results, the graphene platelets (GPLs) performance is affected strongly by their geometry.


ABSTRACT: Sandwich structures have superior mechanical properties to be applied in civil, marine, mechanical and aerospace engineering fields. Auxetic structures with negative Poisson's ratio (NPR) can contract laterally when compressed axially to be excellent fillers for the sandwich structures to improve the energy absorption performance. In this work, a cylindrical sandwich filled with double arrowed auxetic structure is proposed. An analytical model is established to predict the dynamic responses of the sandwich structure under axial impact loading. The theoretical model is composed of three parts: energy dissipated due to the auxetic filler, the thin walled tubes, and their interaction. Numerical simulations are performed to validate the theoretical model and the results indicate that the theoretical model proposed is accurate to predict the crushing platform stress of the cylindrical sandwich under axial impact loading.


ABSTRACT: Composite sandwich panels with lattice truss cores have dramatic static and dynamic characteristics, which are widely used in aerospace industry. Owing to the inability to sustain localized loads of joining, valid inserts are required to enable the interconnection of the sandwich panels. The present study develops a novel boundary insert parallel to the facesheets for pyramidal lattice truss core sandwich panels. Analytical-mechanical models are addressed for the proposed boundary insert subjected to in-plane pull-out, in-plane shear as well as out-of-plane shear loads and experimental tests are carried out to characterize mechanical behaviors. Failure sequences and mechanisms are discussed comprehensively and good correspondence is obtained with analytical prediction. Finite element simulation models are developed for visualization of internal load distribution. Experimental results show that significant improvements in load capacities can be achieved by the developed boundary insert compared with the interconnection concepts for honeycomb sandwich panels.


ABSTRACT: This paper deals with impact test and numerical investigations on the crashworthiness of the typical sub-cargo fuselage section of a civil aircraft. The sub-cargo fuselage section with three-frame and two-span is designed and manufactured, and the 3.95 m/s impact test is conducted to research the failure modes and impact response characteristics for the upside-down sub-cargo fuselage section. The impact process is simulated by using the LS-DYNA finite element code. The impact velocity, displacement, and acceleration response are compared, and a good agreement between test results and numerical simulation results is observed. The energy absorption characteristics and impact load transfer path are further studied based on the verified finite element model (FEM). The results show that the impact phases are characterized by the bending and twisting of fuselage frames, the bending of middle stanchions and C-channel stanchions, the pull-off failure and shear failure of rivets, and the two plastic hinges formed at the joints of C-channel stanchions and fuselage frames. The fuselage frames and middle stanchions are the main energy absorption components. The impact load is transmitted along with the fuselage frames, middle stanchions, and C-channel stanchions to the cargo cross beams, and the area of middle stanchions is the most important energy absorption design area.

Abstract: In this paper a novel passive control method is explored for airfoil tonal noise reduction using localized flow-induced vibration of a short elastic panel flush mounted on suction surface of a NACA 0012 airfoil at low Reynolds number. The key idea is to provide local absorption of energy of natural instabilities evolving in the laminar boundary layer by self-sustained flow-induced vibration of a properly designed panel. The panel ultimately acts to weaken the aeroacoustic feedback loop responsible for airfoil tonal noise radiation. Perturbation evolution method with acoustic broadband excitation is utilized to assess the tonal noise reduction potential with various combinations of elastic panel design parameters and optimal resonating and non-resonating elastic panel configurations are determined. Subsequently, direct aeroacoustic simulation of airfoil flow with optimal panel configurations are carried out to uncover the mechanism of tonal noise reduction using localized flow-induced vibration in a quantitative manner. Extensive analysis of numerical results reveals that a resonating panel located just ahead of the sharp growth of boundary layer instability within the airfoil separation bubble provides the strongest reduction of flow instabilities and an overall tonal noise reduction up to 3 dB. Such significant noise reduction is achieved without any sacrifice in the original aerodynamic characteristics of the airfoil. The outcomes of the study evidently suggest that the proposed passive control method with a localized flow-induced panel vibration is effective in suppressing the fundamental mechanism responsible for tonal noise generation of airfoil flow, making it a promising approach for modifying the acoustics of existing aerodynamic or wing profile operating at low Reynolds numbers.


Abstract: This paper presents an analytical investigation on the nonlinear buckling behavior of graphene platelets reinforced dielectric composite (GPLRDC) arches with rotational end restraints under applied electric and uniform radial load. The effective materials properties of GPLRDC, including the elastic modulus and dielectric permittivity, are estimated by employing effective medium theory (EMT). The analytical solutions for nonlinear equilibrium, critical load of limit point buckling and bifurcation buckling of the GPLRDC arch are derived according to the principle of virtual work. The critical geometric parameters and electric voltage governing the buckling mode switching behavior are also identified and discussed. The effects of graphene platelets (GPLs) weight fraction, size and geometry, applied DC voltage, AC frequency, as well as geometry of the arch on the buckling behavior are examined comprehensively. It is found that the dielectric property of the GPLRDC has significant effects on the buckling behavior of the GPLRDC when the GPLs concentration exceeds the percolation threshold. The nonlinear buckling behavior of the GPLRDC is quite sensitive to the AC frequency within a certain range. Furthermore, the change of the applied voltage can switch the buckling mode and even the number of limit points of the GPLRDC arch.


Abstract: This paper presents the theoretical solution to the response of a square plate undergoing plastic deformation due to a generic localized blast pulse. A localized blast load function was assumed multiplicative of its spatial distribution and temporal pulse shape. The spatial distribution was representative of constant
pressure over the central zone, while exponentially decaying outside that zone. Considering an appropriate moment function and ignoring the membrane, transverse shear, and rotary inertia effects, the static plastic collapse was found, whereby the analysis was extended to the dynamic case by assuming a kinematically admissible, time-dependent velocity profile. The analytical model, which was validated against the numerical results obtained through ABAQUS hydrocode, showed close correlation in terms of the permanent transverse deflection profile. In order to consider the effect of temporal pulse shape, the results were formulated for rectangular as well as exponentially and linearly decaying pulses. For blast loads of high magnitude, the pressure load was replaced by an impulsive velocity. The calculations were simplified by utilizing the dimensionless form, and the results were corroborated with theoretical and experimental results from the literature. The model showed improvements in predicting the final deformation of square plates over previous models of simplified loading function.


ABSTRACT: In this study, a novel composite time integration method is proposed for more accurately and efficiently solving typical structural dynamic problems. In this method, the second-order accuracy is ensured for dynamic problems. First, the stability, accuracy properties, local truncation error, and global error are analyzed and compared with available state-of-the-art methods in the literature. Then, three sets of parameters are recommended and discussed, and optimization of these parameters results in a high accuracy and efficiency of the proposed method. Finally, three classical examples with high-frequency vibrations, where a large ratio of the time step size to the period is adopted, are presented to demonstrate the accuracy, efficiency, and applicability of the proposed method.


ABSTRACT: Four-point bending tests have been a staple in many structural engineering experiments as a reliable way of assessing the bending resistance of circular hollow sections, tubes, and cylindrical shells, and they continue to be widely performed. However, relatively little attention appears to have been paid to quantifying the effects of different boundary conditions on the test outcome. In particular, the restraint or freedom given to the cross section at the ends of a specimen to ovalize can have a significant impact when the specimen is in an appropriate length range. Ovalization is an elastic geometrically nonlinear phenomenon that is known to reduce the elastic bending resistance by as much as half in long tubes or cylinders. This paper presents a short distillation of some recent advances in understanding the buckling of cylindrical shells under uniform bending, identifying the strong influence of cylinder length on cross-section ovalization. A sample set of three-dimensional load application arrangements used in existing four-point bending tests was simulated using finite elements, allowing an assessment of the differences caused by prebuckling ovalization and its effect on the tested bending resistance. The study is limited to elastic behavior to identify the effect of ovalization alone in reducing stiffness without material nonlinearity. The outcomes demonstrate that maintaining circularity at inner load application points by appropriate stiffening has a significant effect. With freedom to ovalize, a significant reduction in stiffness occurs, leading to much lower bending resistance at buckling than may be achievable in practical applications.


ABSTRACT: This work studied the coupled stretching and bending deformations of a through-thickness nonelliptical elastic inhomogeneity embedded in an infinite matrix within the context of Kirchhoff isotropic and laminated plate theory. The matrix was subjected to uniform remote membrane stress resultants and bending moments, and was also subjected to a concentrated rotational moment at any position. Our analysis, based on complex variable methods, indicated that when the nonelliptical shape of the inhomogeneity is suitably designed and when three specific conditions on the remote loading are met for a given set of material and geometric parameters characterizing the composite: (1) the elastic inhomogeneity is harmonic, (2) the internal
A hysteretic shell finite element for the nonlinear, static, and dynamic analysis of structures is presented, formulated on the basis of classical theory of plasticity and finite deformation. The generalized smooth, rate-independent three-dimensional (3D) Bouc-Wen model is expressed in tensorial form incorporating the von Mises yield criterion and different types of nonlinear hardening laws. Based on this approach, a hysteretic shell finite element is derived in which the shell is considered as a number of fully bonded layers along the thickness. The elastic mixed interpolation of tensorial components with nine nodes (MITC9) element is extended by considering as additional hysteretic degrees of freedom the plastic strains, backstresses, and the variable yield stress. These are considered at the Gauss points of two faces and all interlaminar interfaces, the evolution of which is described by Bouc-Wen-type equations. Using this formulation, the effect of the nonlinear hardening on the response of a shell structure and in particular the phenomenon of ratcheting is investigated. The developed hysteretic shell element accounts for geometric nonlinear analysis and incorporates two constituent functionally graded materials. Numerical results are presented, demonstrating the efficacy, accuracy, and generality of the proposed approach.

ABSTRACT: This work aims at the unconstrained optimization of laminate plate problems by introducing a methodology that uses a decomposition method along with regularized Newton method. The framework is applied to fiber orientation optimization in laminated thin plates regarding the minimization of the maximum displacement of specific plate regions. First, the problem’s domain is divided into isotropic and remainder parts, with the latter grouping laminar anisotropic behavior. This leads to an evaluation of the gradient and Hessian of the objective function in such fashion that inverses are defined only at the first step of the procedure and they are related to the isotropic part only, although the Hessian is updated each step. The fiber orientation sensibility on a plate’s solution can be evaluated separately, leading to an analytic and straightforward way of deriving the first and second derivatives of the design variables. The $p^i_2$Rayleigh-Ritz Method is used to approximate the solution space and to determine the problem’s semianalytical response. The results obtained are discussed and compared to those found in the literature.

ABSTRACT: A statistical linearization technique is developed for determining second-order response statistics of beams with in-span elastic concentrated supports. The nonlinearities considered relate both to the support restoring forces, and to the assumption of relatively large beam displacements. A significant novel aspect of the technique is the utilization of constrained modes involving generalized functions in their definition; thus, shear-force discontinuities at the support locations can be readily accounted for. Overall, a set of nonlinear modal equations is derived and replaced by a set of equivalent linear ones based on an error minimization scheme in a mean square sense. This yields a set of algebraic nonlinear equations for the beam response second-order statistics, which can be readily solved in a computationally efficient manner via a simple iterative scheme. It is noted that the technique applies to an arbitrary number of supports yielding accurate and computationally efficient solutions for the second-order statistics of the response. Two illustrative numerical examples are considered for assessing the reliability and accuracy of the technique as compared with pertinent Monte Carlo simulation data. The latter are generated based on a boundary integral solution methodology in conjunction with a Newmark numerical integration scheme.

ABSTRACT: Laminated glass consists of at least two monolithic glass lites bonded together by an elastomeric interlayer. Existing mathematical models using the finite-difference method or the nine-node quadrilateral finite-element method were developed to numerically characterize the nonlinear behavior of laminated glass lites under bending and were benchmarked against available test data. The finite-difference solution was predicated on the well-known von Kármán equations, which are generally limited to the case of thin plates, while the nine-node quadrilateral finite element was predicated on the nonlinear Reissner-Mindlin plate formulation applicable to thick and thin plates but could result in a system of nonlinear equations that are computationally inefficient to solve. Therefore, a nonlinear four-node quadrilateral finite-element model for laminated glass based on the Reissner-Mindlin formulation is advanced. The assumed transverse shear strain fields method is employed to prevent shear locking and all the required stiffness terms are fully integrated. Hourglassing effects due to the reduced integration technique commonly used to prevent shear locking are mitigated and the stability of the numerical solution is preserved. The numerical solution obtained from the four-node element is in good agreement with available test data as well as the finite-difference solution.


ABSTRACT: Based on a literature review of the assumed kinematics in the so-called higher-order displacement-based shear-deformation theories, a generalization of this kinematics is first proposed and used to formulate variationally consistent field equations and boundary conditions for the bending and vibration of a flat plate of a rectangular platform. Second, attention is focused on displacement-based polynomial shear-deformation plate theories. It is shown that all the kinematics of polynomial third-order theories (3,0-order polynomial) proposed in the open literature are special cases of the present theory. Furthermore, it is concluded that the 3,0-order polynomial kinematics of all the theories is the same when the maximum transverse shear strain is used as generalized displacement coordinates. A deep analysis of the static and dynamic behavior of simply supported rectangular plates in cylindrical bending is performed in order to substantiate the general conclusion that all the 3,0-order polynomial displacement-based shear-deformation theories give the same numerical results, i.e., they are kinematically equivalent, although not all are statically equivalent.


ABSTRACT: Nonlinearity problems in engineering structures primarily involve material nonlinearity and geometric nonlinearity. Significant effort has gone toward developing accurate and efficient models and methods to simulate these nonlinear behaviors of structures. Although advanced hardware technology has greatly enhanced the computational performance of nonlinear analyses, many researchers still pay extra attention to developing more efficient numerical solution methods with the emergence of complex large-scale structures. The inelasticity-separated finite element method (IS FEM), as an efficient algorithm, is suitable for solving local material nonlinearity problems by keeping the global stiffness matrix unchanged throughout the whole computational process such that the Woodbury formula can be used as an effective tool. However, this procedure does not obviously improve the computational efficiency for structures with large deformation because widely distributed geometric nonlinearity commonly occurs throughout entire structures rather than in local domains. Furthermore, the global stiffness matrix, which is equal to the sum of the initial stiffness matrix and geometric stiffness matrix, changes in real time. This study proposes an efficient Woodbury-CA hybrid (WCH) method by incorporating the combined approximations (CA) method into the framework of the IS FEM to obtain the response of engineering structures with hybrid nonlinear behaviors (both material and geometric nonlinearities) under external loads. Within this framework, the solution of linear equations in the Woodbury formula, which is related only to the geometric nonlinear behaviors of structures, can be obtained by employing the CA method; two other global stiffness matrices, which are used to formulate the Schur complement matrices, are approximated as constant matrices for small periods of time. Additional error induced by these approximations can be eliminated by updating the global stiffness matrix when the optimal adaptive criterion (AC) used for evaluating the difference between the exact solution and approximate solution is not satisfied.
Additionally, the time complexity theory is used to evaluate the computational efficiency of the proposed method; the results show that the WCH method has outstanding advantages over the conventional finite element method (FEM). The proposed method is validated against the FEM results via two different numerical examples and has greater potential for solving local material and global geometric nonlinearity problems.

ABSTRACT: The stability and deformation of shallow tunnel faces are hard to predict, and the associated failure mechanisms are also indistinct to date. In this work, we incorporate the softening function and strain-dependent dilation model into a smoothed particle hydrodynamics (SPH) framework to simulate the collapse behaviors of shallow tunnel faces in cohesive–frictional soils under the open-face excavation condition. To this end, the stratum is modeled as a cohesive–frictional soil described by the elastoplastic constitutive model in combination with the Drucker–Prager yield criterion. Softening and strain-dependent dilation behaviors of soils are described by the softening function and the dilation model, which are incorporated into the constitutive model in the framework of the SPH method. For the deformation analysis, the effects of the cover depth variation on face extrusion and ground surface subsidence are investigated. For the face stability analysis, the impacts of the cohesion and the internal friction angle of surrounding soils on the safety factor of shallow tunnel faces are highlighted. Then, comparison is made between the results obtained from the present SPH method and those given by the finite-element method (FEM) and existing centrifuge model tests to verify the proposed SPH procedure. Ultimately, the main outcomes of the current work, including deformation features and safety factors of shallow tunnel faces, are presented.

ABSTRACT: In this work, monolithic and staggered schemes using a locking-free solid-shell element are proposed to analyze the behavior of thin-walled structural components subjected to combined thermal and mechanical loads. The enhanced assumed strain method, assumed natural strain method, and reduced integration with hourglass control are incorporated into the formulation of the eight-node solid-shell element to seek accurate predictions of the structural response of the elastodynamic systems. The thermal field (the solution of the heat conduction problem) is obtained using a standard eight-node solid-element formulation with full integration. Element formulations for monolithic, isothermal, and isentropic staggered schemes are presented. The use of different element formulations in the structural and thermal fields brings difficulties in implementing the isentropic scheme; hence, special efforts are made to preserve its convergence properties and numerical stability. Numerical examples demonstrate the accuracy and efficiency of the present locking-free solid-shell element in conducting large-deformation thermoelastic analyses of thin-walled structures. In particular, the isentropic scheme with only a one-pass strategy presents equal robustness but superior efficiency to the monolithic element in simulations considering weak, as well as strong, couplings.

ABSTRACT: Modeling errors that prevent the eight-node Mindlin plate finite element to behave correctly, namely shear locking and spurious zero-energy modes, can be explained using strain gradient notation. This notation is physically interpretable, and it allows for the sources of shear locking and spurious zero-energy modes to be clearly identified a priori. This means that spurious terms in shear strain polynomials are precisely identified as parasitic shear terms. Once this is done, such spurious terms are simply removed to correct the element model, resulting in a shear locking-free element. In order to avoid introducing spurious zero-energy modes, the analyst must recognize and retain the compatibility modes in the shear strain polynomials. As the study shows, compatibility modes can easily be confused with parasitic shear terms. Numerical displacement
and stress solutions from models containing parasitic shear terms revisit important locking effects. Further, solutions obtained using corrected models are qualitatively correct and have higher rates of convergence.


ABSTRACT: This study proposes a numerical method to solve the snap-through problem of elastic shallow inextensible circular arches. Specifically, the snap-through behavior of arches subjected to a downward load at a point along the span was systematically evaluated for variable elastic horizontal supports under unilateral displacement control. Through theoretical analysis based on a dimensionless formulation, the critical state of snap-through can be determined by embedding ordinary differential equations into the nonlinear unconstrained optimization. Then, critical stiffness lines for horizontal springs and snap regions with varying loading position were systematically analyzed to judge whether a snap-through phenomenon will occur. Parametric analysis was further carried out to investigate the influence of variable horizontal spring stiffness and different arch length on the overall deformation and the critical displacement of critical states. The results show that the critical stiffness increases with the decrease of arch length and the decrease of horizontal stiffness and arch length can both expand the snap region. This study highlights the important role of stiffness of supports in snap-through behavior control and provides a numerical method for more accurate evaluation of the snap-through behavior of arches under various supports and loading conditions in engineering applications.


ABSTRACT: This paper proposes a new symplectic transfer-matrix method (STMM) to solve the bending problem of nonuniform beams. The STMM is a hybrid method that combines the symplectic dual solution system and the traditional transfer-matrix method (TMM). It is first necessary to obtain the benchmark solution of uniform beams in a symplectic system. On this basis, this paper derives the transfer matrices under various nonuniform conditions and discusses the mathematical structure of these transfer matrices. After obtaining the global transfer equation, the equation is solved by changing its rows and columns. Three numerical examples are given to verify the correctness and applicability of the STMM. This paper proves that the transfer matrix in the symplectic system is a symplectic matrix in mathematics, whether it is a field transfer matrix, a point transfer matrix, or a global transfer matrix. The STMM reveals the mathematical property of the transfer matrix and provides a theoretical basis for the standardized application of the “transfer type” method in structural analysis.

C. M. Wang (1), W.H. Pan (2) and J.Q. Zhang (1)
(1) School of Civil Engineering, Univ. of Queensland, St. Lucia, QLD 4072, Australia
(2) College of Civil Engineering and Architecture, Zhejiang Univ., Hangzhou 310058, China

ABSTRACT: This paper is concerned with the optimal design of triangular arches of a given volume of material for maximum buckling capacity. The buckling criteria of triangular arches are derived analytically by using stability functions. Optimal designs of triangular arches with various vertical load positions, base support conditions, and apical joint conditions are obtained based on an optimization procedure involving two decision variables (arch height $h$ and cross-sectional area ratio $A_d/A_b$). Based on the optimization results, design recommendations for triangular arches against buckling are (1) the optimal height for triangular arches be taken as $h/L$ where $L$ is the span length of the arch, and (2) both members of the triangular arch are to take on the same cross-sectional area (i.e., $A_d/A_b=1$) when the arch has a rigid joint at the apical point, whereas the cross-sectional area ratio $A_d/A_b$ should be determined based on the optimality condition that both members should buckle at the same time when the arch has a hinge joint. By changing the base support condition from pinned-
pinned to fixed-fixed, the maximum buckling load of the optimal triangular arches is increased by about 2.05 times.

Chanachai Tangbanjongkij (1), Somchai Chucheepsakul (1) and Weeraphan Jiammeepreecha (2)
(1) Dept. of Civil Engineering, King Mongkut’s Univ. of Technology Thonburi, Bangkok 10140, Thailand
(2) Dept. of Civil Engineering, Rajamangala Univ. of Technology Isan, Nakhon Ratchasima 30000, Thailand


ABSTRACT: This paper concerned an analytical method to obtain exact solutions for displacements of submerged hemi-ellipsoidal shells. Based on the linear membrane theory, the membrane forces and strain components were defined in terms of the radius of a parallel circle. General solutions for normal and tangential displacements were established, which could be written in the simplest form when considered at the apex and equatorial points. To investigate the accuracy of the results, a finite-element modeling technique was used to verify the analytical solutions. The fundamentals of differential geometry and the principle of virtual work were used to develop the stiffness matrix for nonlinear finite-element procedures. This led to the numerical results for validation of the analytical solutions. The effect of shape ratios, thickness, and seawater depth on the forces and displacements of submerged hemi-ellipsoidal shells were also presented in this study.

Haitao Yu (1), Yuqi Sun (1), Pan Li (2) and Mi Zhao (3)
(1) Dept. of Geotechnical Engineering, Tongji Univ., Shanghai 200092, China.
(2) School of Rail Transportation, Soochow Univ., Suzhou, Jiangsu 215131, China
(3) Urban Security and Disaster Engineering, Beijing Univ. of Technology, Beijing 100124, China.

https://doi.org/10.1061/(ASCE)EM.1943-7889.0001817

ABSTRACT: In this paper, the dynamic response of underground rectangular fluid tank resting on an elastic foundation and subjected to arbitrary dynamic loads is developed in the form of analytical solution. The dynamic responses investigated are deflection, bending moment, and shear force of the tank. The underground rectangular tank is assumed to be a frame composed of horizontal and vertical beams resting on an elastic foundation. The mechanical resistance of elastic foundation is modeled using spring elements that account for soil resistance due to compressive strains in the soil. The fluid in the tank is assumed as inviscid and irrotational, and the influence of free-surface wave is ignored. An analytical solution of free vibration modes of empty tank (dry modes) is derived at first, and then the free vibration modes of fluid tank infilled with water (wet modes) can be obtained by the dry modes. Based on the wet modes, the explicit formulations of dynamic responses of the tank are finally obtained by the modal superposition method. The solutions for several cases, such as empty tank and fully filled fluid tank subjected to harmonic loads, are also discussed. Further parametric analysis is carried out to investigate the influence of the soil–structure relative stiffness ratio on dynamic responses of the fully filled fluid tank.

https://doi.org/10.1061/(ASCE)EM.1943-7889.0001831

ABSTRACT: Fluid-structure interaction (FSI) of earthquake shaking is a design consideration in the civil, nuclear, chemical, and mechanical industries. Preliminary sizing of structures and components in these industries will often use analytical solutions because there is insufficient information to warrant the analysis of numerical models. This study extends prior analytical work on seismic FSI of base-supported tanks in the 1980s to accommodate head-supported tanks with geometries similar to those proposed for new-build liquid (fluid)-filled advanced reactors. Analytical solutions are derived for flexible head-supported cylindrical tanks subjected to small-amplitude unidirectional horizontal seismic motion and address frequencies of lateral motions of the tank, hydrodynamic pressures, frequencies of waves, wave heights, and reactions at the head support. Solutions are presented for a range of tank dimensions and could be used for (1) preliminary design of head-supported cylindrical tanks and their supporting structures with idealized seismic input, and (2) verification of numerical models to be used for final seismic analysis, design, and probabilistic risk assessment.

ABSTRACT: Pipes conveying fluids are primary components in almost all industries. Internal surface attack is inevitable in pipes and can be crucial to their structural integrity and dynamic response characteristics. In this study, the dynamic response analysis of composite pipes with internal surface discontinuity is investigated in the presence of fluid flow. The equations of motion are obtained using the extended Hamilton’s principle and discretized using the wavelet-based finite-element method (WBFEM). The internal surface defect is allowed to occupy any length along the pipe span, while its cross section can vary both in radial and angular directions. The dynamic response of the defected pipe is obtained by integrating the equations of motion forward in time using MATLAB solver ODE45. The developed dynamic model has been validated using ANSYS and some benchmark results are presented to underline the influence of the internal surface defect on dynamic response of composite pipes conveying fluid.


ABSTRACT: In this paper, we establish a coupled damage-plastic constitutive model in the scheme of small deformation assumption, based on a continuum damage mechanics model proposed by Lemaitre, for the thin-walled circular steel tubes widely used in space structures. First, a new damage evolution law is developed for steel tubes. Then the isotropic damage-plastic constitutive model is created within the thermodynamics framework. In addition, the numerical integration algorithm for the proposed model is formulated based on the well-established operator split methodology and is implemented into ANSYS through the user-defined material subroutines. The uniaxial tension test and the spatial hysteresis experiment for thin-walled circular steel tubes are performed, which serves as calibration conditions for the new proposition. The model parameters are determined by the inverse optimization method and the least squares fitting method. Numerical results obtained from the proposed and Lemaitre model are compared with experimental data obtained by spatial hysteresis, and the predictive ability of both models is discussed in terms of the force-displacement hysteretic curves, the initiation and propagation of fracture, and the evolution of the damage variable. It is illustrated that the established model presents a good agreement with experimental observation. Furthermore, it performs a better prediction compared to Lemaitre’s model. Lemaitre’s model is able to predict the correct location for fracture onset but fails to capture the potential path of fracture propagation and the displacement at the fracture.


ABSTRACT: Effect of geometric nonlinearity on free vibration behaviour of a non-uniform in-plane inhomogeneous plate on elastic foundation is carried out with an emphasis on mode switching phenomenon. The formulation is semianalytic displacement based and it is carried out in two distinct steps. First, the static problem is solved to find out the unknown displacement field by using minimum total potential energy principle. Secondly, subsequent dynamic problem is set up as an eigenvalue problem on the basis of the known displacement field. The governing set of equations in dynamic problem is obtained by using Hamilton’s principle. In static analysis, unknown coefficient of the governing equations are solved using an iterative method, which is direct substitution with relaxation method. The dynamic problem is solved with the help of
intrinsic Matlab solver. The results of the present method are validated with existing data. Backbone curve corresponding to different combinations of system parameters are presented in non-dimensional plane. Mode switching is observed to occur in certain specific situation. The linear and nonlinear mode shapes are also furnished to support the presence of switching phenomenon.

References listed at the end of the paper:

ABSTRACT: The analysis of monolithic and sandwich plates is illustrated for those cases where the boundary conditions are not uniform along the thickness direction, and run at a given position along the thickness direction. For instance, a sandwich plate constrained at the bottom or top face can be considered. The approach relies upon a sublaminate formulation, which is applied here in the context of a Ritz-based approach. Due to the possibility of dividing the structure into smaller portions, viz. the sublaminates, the constraints can be applied at any given location, providing a high degree of flexibility in modeling the boundary conditions. Penalty functions and Lagrange multipliers are introduced for this scope. Results are presented for free-vibration and bending problems. The close matching with highly refined finite element analyses reveals the accuracy of the proposed formulation in determining the vibration frequencies, as well as the internal stress distribution. Reference results are provided for future benchmarking purposes.

References listed at the end of the paper:


https://doi.org/10.1515/clsi-2018-0017

ABSTRACT: In this article, free vibration of SingleWalled Carbon Nanotube (SWCNT) resting on exponentially varying Winkler elastic foundation is investigated by using Differential Quadrature Method (DQM). Euler-Bernoulli beam theory is considered in conjunction with the nonlocal elasticity theory of Eringen. Step by step procedure is included and MATLAB code has been developed to obtain the numerical results for different scaling parameters as well as for four types of edge conditions. Obtained results are validated with known results in special cases showing good agreement. Further, numerical as well as graphical results are illustrated to show the effects of nonuniform parameter, nonlocal parameter, aspect ratio, Winkler modulus parameter and edge conditions on the frequency parameters.

References listed at the end of the paper:


ABSTRACT: In the present paper, rotary inertia and small size effects on the free vibration response of single-walled carbon nanotubes are examined. The equations in motion and associated boundary conditions are obtained by using Hamilton’s principle on the basis of modified couple stress and Rayleigh beam theories. The size effect is taken into account by modified couple stress theory while the rotary inertia effect is considered by Rayleigh beam theory. The resulting equations are analytically solved by implementing Navier’s solution technique for pinned-pinned carbon nanotubes. Influences of slenderness ratio, length scale parameter and rotary inertia on the natural frequencies of single-walled carbon nanotubes are studied in detail.

References listed at the end of the paper:


ABSTRACT: The buckling of rotationally restrained micro-bars embedded in an elastic matrix is studied within the framework of strain gradient elasticity theory. The elastic matrix is modeled in this study as Winkler’s one-parameter elastic matrix. Fourier sine series with a Fourier coefficient is used for describing the deflection of the microbar. An eigenvalue problem is obtained for buckling modes with the aid of implementing Stokes’ transformation to force boundary conditions. This mathematical model bridges the gap between rigid and the restrained boundary conditions. The influences of rotational restraints, small scale parameter and surrounding elastic matrix on the critical buckling load are discussed and compared with those available in the literature. It is concluded from analytical results that the critical buckling load of microbar is dependent upon rotational restraints, surrounding elastic matrix and the material scale parameter. Similarly, the dependencies of the critical buckling load on material scale parameter, surrounding elastic medium and rotational restraints are significant.

References listed at the end of the paper:

2007 190, 185–195.


ABSTRACT: This paper contributes an analytical nonlinear morphing model for high-amplitude corrugated thin-walled laminates of arbitrary stack-up with a corrugation shape composed of circular sections. The model describes large deformations, the nonlinear relation between line force and global stretch, and the distribution of local line loads. The quarter-unit-cell approach together with assuming small material strains and a plane strain situation contribute to the model’s simplicity. It is explained how the solution procedure minimizes the force and moment residual of the equilibrium of cutting and reaction line loads by using Newton’s optimization method. Deformation results are verified by comparison with FEM simulation. The effects of laminate design and corrugation amplitude on deformations, line-force-stretch diagrams, and bending-curvature-stretch diagrams are presented and discussed.

References listed at the end of the paper:


[34] ANSYS Academic Research, Release 18.2.


Subrat Kumar Jena and S. Chakraverty (Department of Mathematics, National Institute of Technology, Rourkela-769008, India), "Differential quadrature and differential transformation methods in buckling analysis

ABSTRACT: In this paper, two computationally efficient techniques viz. Differential Quadrature Method (DQM) and Differential Transformation Method (DTM) have been used for buckling analysis of Euler-Bernoulli nanobeam incorporation with the nonlocal theory of Eringen. Complete procedures of both the methods along with their mathematical formulations are discussed, and MATLAB codes have been developed for both the methods to handle the boundary conditions. Various classical boundary conditions such as SS, CS, and CC have been considered for investigation. A comparative study for the convergence of DQM and DTM approaches are carried out, and the obtained results are also illustrated to demonstrate the effects of the nonlocal parameter, aspect ratio (L/h) and the boundary condition on the critical buckling load parameter.

References listed at the end of the paper:
ABSTRACT: Forced vibration of non-uniform axially functionally graded (AFG) Timoshenko beam on elastic foundation is performed under harmonic excitation. A linear elastic foundation is considered with three different classical boundary conditions. AFG materials are an advanced class of materials that have potential for application in various engineering fields. In the present work, variation of material properties along the longitudinal axis of the beam are considered according to power-law forms. Five values of material gradation parameter provides different functional variation and their effect on the frequency response of the system is studied. The present approximate method is displacement based and Von-Karman type of geometric nonlinearity is considered with rotational component to incorporate transverse shear. Hamilton’s principle is used to derive nonlinear set of governing equation and Broyden method is implemented to solve the nonlinear equations numerically. The results are successfully validated with previously published article. Frequency vs. amplitude curve corresponding to different combinations of system parameters are presented and are capable of serving as benchmark results. A separate free vibration analysis is undertaken to include backbone curves with the frequency response curves in the non-dimensional plane.

References listed at the end of the paper;

[2] Simsek M 2016 Buckling of Timoshenko beams composed of two-dimensional functionally graded material 2D-FGM having different boundary conditions Compos Struct 149 304–314
ABSTRACT: Based on the classical Kirchhoff hypothesis, the dynamic response and sound radiation of rectangular thin plates with general boundary conditions are presented in the paper, which may be useful for future researchers. Meanwhile, some interesting points are found when analyzing acoustic radiation characteristics of plates.

References listed at the end of the paper:


ABSTRACT: This article deals with free vibration of the variable cross-section (non-uniform) single-layered graphene nano-ribbons (SLGNRs) resting on Winkler elastic foundation using the Differential Quadrature Method (DQM). Here characteristic width of the cross-section is varied exponentially along the length of the nano-ribbon while the thickness of the cross section is kept constant. Euler–Bernoulli beam theory in conjunction with Eringen non-local elasticity theory is considered in this study. The numerical as well as graphical results are reported by using MATLAB codes developed by authors. Convergence of present method is explored and our results are compared with known results available in literature showing excellent agreement. Further, effects various parameters on frequency parameters are studied comprehensively.

References listed at the end of the paper:
Aditya Rio Prabowo (1) and Jung Min Sohn (2)
(1) Department of Mechanical Engineering, Sebelas Maret University, Surakarta 57126, Indonesia
(2) Department of Naval Architecture and Marine Systems Engineering, Pukyong National University, Busan 48513, South Korea


ABSTRACT: Ship collision appears as the most threatening loading accounting for structural casualties and numbers of casualties after impact on the target ship. In order to avoid such losses against collision, better safety during activities in maritime environment is demanded. Therefore, assessment of ship structure is needed to understand dynamic effect of the impact and quantify nonlinear behavior of local members. This study is conducted to achieve those aims by deploying nonlinear finite element analysis (NLFEA) to idealized ship collision event. Validation of the numerical method is performed by comparing results of a modeled collision case with various empirical calculations. Design for impact loading in main analysis considers side collision to main hull structure, which single side skin (SSS) and double side skin (DSS) types are modeled. Investigation is also directed to influence of the target members on the main hull to capacity of absorbed energy and characteristic of structural resistance. Analysis results indicate that good understanding is successfully obtained in terms of structural damage-energy relation. Confirmation of the current calculation using numerical calculation is also confirmed considering the modeled cases and empirical results agree well. Tendency of hull responses concluded that the longitudinal members contribute more to structural resistance against side collision. References listed at the end of the paper:

[17] Prabowo AR, Baek SJ, Cho HJ, Byeon JH, Bae DM, Sohn JM, 2017b. The effectiveness of thin-walled hull structures against...

Rahul Kumar (1), Aachche Lal (1), B. N. Singh (2), and Jeeoot Singh (3)
(1) Department of Mechanical Engineering, SVNIT Surat 395007 India
(2) Department of Aerospace Engineering, Indian Institute of Technology Kharagpur, West Bengal 721302, India
(3) Department of Mechanical Engineering, Madan Mohan Malaviya University of Technology, Gorakhpur, U.P, 273010, India


ABSTRACT: In the present work, new inverse hyperbolic higher-order shear deformation theory (IHHSDT) is proposed and implemented for buckling analysis and free vibration analysis of porous Functionally Graded Material (FGM) plate on the foundation. The proposed theory follows the approximately parabolic distribution of the transverse stresses through the plate thickness and satisfies the conditions of continuity and differentiability. Three different types of porosity distribution considered. Governing differential equations (GDEs) of the plate is developed in the framework of proposed theories by Hamilton’s principle. Multiquadrics radial basis function (MQ-RBF) based Meshfree method used for discretizing the GDEs. The result obtained by the present theory is validated with the three-dimensional elastic theory and other available solutions in the literature to ensure the efficacy and accuracy of the proposed theory. Numerical results obtained for buckling and free vibration for porous FGM plate resting on the foundation. Effect of grading index, porosity fraction, porosity distribution, the effect of foundation, and the span to thickness ratio have discussed. The secured results can consider as a benchmark for future studies.

References listed at the end of the paper:


Achchhe Lal and Kanif Markad (Mechanical engineering department, SVNIT, Surat, Gujarat, India), “Thermo-Mechanical Post Buckling Analysis of Multiwall Carbon Nanotube-Reinforced Composite Laminated Beam

ABSTRACT: In present paper, buckling analysis is performed over laminated composite beam incorporating multi walled carbon nanotube (MWCNT) polymer matrix and then reinforced with E-glass fiber in an orthotropic manner under inplane varying thermal and mechanical loads by finite element method (FEM). Aim of the study is to develop a model which accurately perform the buckling deterministic analysis of multi-walled carbon nanotube reinforced composite laminated beam (MWCNTRCLB) with the evaluation of material property by applying Halpin–Tsai model. Combined Higher order shear deformation theory and Pasternak elastic foundation based on von Karman nonlinear kinematics and Winkler cubic nonlinearity respectively, are successfully implemented. Through minimum potential energy principle, generalized static analysis is performed using FEM, based on interactive MATLAB coding. The critical buckling load and critical buckling temperature is presented under the action of inplane variable mechanical and thermal load, with different boundary conditions, beam thickness ratio and MWCNT aspect ratio, variation with MWCNT volume fraction and coefficient of thermal expansion, with and without foundation for linear and nonlinear cases. 

References listed at the end of the paper:

Hadi Sabermahany (1), Erfan Rasouli (2), and Massood Mofid (2)
(1) University of Tehran, Tehran, Iran
(2) Department of Civil Engineering, Sharif University of Technology, Tehran, Iran

ABSTRACT: Analysis of concrete shallow funicular shells of rectangular plan with simply supported boundary conditions under static loads is performed using the Ritz method. Double Fourier series with the unknown constant coefficients are assumed for the displacement components of the shell and their unknown coefficients are determined such that the potential energy of the shell becomes minimum. The solution is presented in a simple form and is suitable for practical applications. The responses of rectangular—plan concrete shallow funicular shells including deflections, strains, internal forces, internal moments and stresses could be easily determined using the proposed semi-analytical method. The Ritz method results are verified against the finite element method results.

References listed at the end of the paper:


Aditya Rio Prabowo (1), Jung Min Sohn (2), and Teguh Putranto (3)
(1) Department of Mechanical Engineering, Universitas Sebelas Maret, Surakarta 57126, Indonesia
(2) Department of Naval Architecture and Marine Systems Engineering, Pukyong National University, Busan 48513, South Korea
(3) Department of Civil Engineering and Architecture, Tallinn University of Technology, Tallinn, 10086, Estonia


ABSTRACT: Shipping time, cargo handling and quality as well as operational cost are main aspects of success in trading and shipping, which leads to high demand for ship safety. During freight shipping is conducted for various cargoes, the ship structure is subjected to numbers of loads, which several of them have been predicted during ship design. Nevertheless, incidental type in form of impact load can deliver massive blow to ship safety and cause immense loss. This phenomenon may be worse than initial condition if structure of chemical-oil carrier experiences impact, which possibly evokes environmental damage to maritime territory. This work is addressed to assess crashworthiness performance of structural part, i.e. bottom tank of chemical carrier. This part is one of center point of oil spill during occurrence of the impact load. The loading conditions are defined as configuration of interaction between ship structure and rock when the ship is stranded on shallow water. A
series of data observations produced by finite element analysis (FEA) provide a prediction regarding local member’s motions during the rock breaches lower parts of the bottom tank. Consequences of the plate towards failure are quantified to obtain effect of the selected impact loading conditions to directly involved (main) member and other affected local member.

References listed at the end of the paper:

ABSTRACT: Nonlinear flexural analysis of sandwich composite beam with multiwall carbon nanotube (MWCNT) reinforced composite face sheet and bottom sheet under the thermo-mechanically induced loading using finite element method is carried out. Solution of current bending analysis is performed using Newton’s Raphson approach by using higher order shear deformation theory (HSDT) and non-linearity with Von Kármán kinematics. The sandwich laminated composite beam is subjected to uniform, linear and nonlinear varying temperature distribution through thickness of the beam. The sandwich beam with MWCNT reinforced composite facesheet and bottom sheet is subjected to point, uniformly distributed (UDL), hydrostatic and sinusoidal loading. The two phase matrix is utilized with E-Glass fiber to form three phase composite face sheet and bottom sheet by Halpin-Tsai model. The static bending analysis is performed for evaluating the transverse central deflection of three and five layered sandwich composite beam. Transverse central deflection is measured by varying CNT volume fraction, uniformly distributed, linearly and nonlinear varying temperature distribution, thickness ratio, boundary condition, number of walls of carbon nanotube by using interactive MATLAB code.

References listed at the end of the paper:
“Investigation of structural performance subjected to impact loading using finite element approach: case of ship-container collision”, Curved and Layered Structures, Vol. 7, No. 1, pp 17-28, May 2020, Transporting mass products from one country to others is essential activities in industrial cycle. Ships are selected as reliable carriers for this objective considering traveling time and operational cost. During its operational, accidental events such as storm, high tide and bad weather may cause the products which are usually packed in freight containers fall into sea, and impacts the ship structure. In this situation, casualties on both involved structures can be detrimental. This work analyzes a series of ship-container collision in maritime territory in order to investigate resulting structural phenomena. The finite element approach is selected to solve the designed collision cases where the discussion is directed to selected crash-worthiness criteria. Impact speed between ship and container structures is chosen as the main parameter in the designed scenario by judging whether this parameter is a good representative of sea state. Overall results indicate that the indication for container rebounding after impact was high. It was followed by a significant increment of the internal energy after higher velocity, which was more than 5 m·s⁻¹, had been applied to the scenario. Quantification of specific structural performance suggests that approximately more than 80% of the damage occurs on the contacted area of the container structure.

References listed at the end of the paper:


[2] Prabowo A.R., Bae D.M., Sohn J.M., Cao B., Energy behavior on side structure in event of ship collision subjected to external...
parameters. Heliyon, 2016, 2, e00192. [https://doi.org/10.1016/j.heliyon.2016.e00192]


ABSTRACT: The study solves a system of finite difference equations for flexible shallow concrete shells while taking into account the nonlinear deformations. All stiffness properties of the shell are taken as variables, i.e., stiffness surface and through-thickness stiffness. Differential equations under consideration were evaluated in the form of algebraic equations with the finite element method. For a reinforced shell, a system of 98 equations on a 8×8 grid was established, which was next solved with the approximation method from the nonlinear plasticity theory. A test case involved computing a 1×1 shallow shell taking into account the nonlinear properties of concrete. With nonlinear equations for the concrete creep taken as constitutive, equations for the quasi-static shell motion under constant load were derived. The resultant equations were written in a differential form and the problem of solving these differential equations was then reduced to the solving of the Cauchy problem. The numerical solution to this problem allows describing the stress-strain state of the shell at each point of the shell grid within a specified time interval.

References listed at the end of the paper:


ABSTRACT: In this paper, non-linear transverse deflection, stress and stress concentration factors (SCF) of isotropic and laminated composite sandwich plate (LCSP) with and without elliptical cutouts subjected to various transverse loadings in hygro-thermal environment are studied. The basic formulation is based on second function-based shear deformation theory (SFSDT) with von-Karman nonlinearity. The governing equation of non-linear deflection is derived using C0 finite element method (FEM) through minimum potential energy approach. Normalized transverse maximum deflections (NTMD) along with stress concentration factor is determined by using Newton’s Raphson method through Gauss point stress extrapolation. Influence of fiber orientations, load parameters, fiber volume fractions, plate span to thickness ratios, aspect ratios, thickness of core and face, position of core, boundary conditions, environmental conditions and types of transverse loading in MATLAB R2015a environment are examined. The numerical results using present solution methodology are verified with the results available in the literatures. 

References listed at the end of the paper:


ABSTRACT: Due to their high numerical efficiency, homogenization models are often employed in the analysis of corrugated laminates. They are usually derived assuming periodic behavior in the corrugated direction and generalized plane strain in the out-of-plane direction, which corresponds to the assumption of infinite dimensions of the structure. As a consequence, any influences of edge effects are not mapped, although they can have a significant impact on the mechanical behavior of a given structure. The objective of this manuscript is to investigate the influence of boundary conditions - a combination of free-edges and clamping - on the structural stiffness of corrugated laminates. A total of six load cases are investigated which correspond to the line loads considered in the classical theory of laminated plates. The results of this parameter study allow the identification of several critical loading situations, where free edges can significantly alter structural stiffness. The given investigations hence contribute to the investigation of the validity range of homogenization models.

References listed at the end of the paper:


ABSTRACT: We present a simple methodology to design curved shell finite elements based on Nzengwa-Tagne’s shell equations. The element has three degrees of freedom at each node. The displacements field of the element satisfies the exact requirement of rigid body modes in a ‘shifted-Lagrange’ polynomial basis. The element is based on independent strain assumption insofar as it is allowed by the compatibility equations. The element developed herein is first validated on analysis of benchmark problems involving a standard shell with simply supported edges. Examples illustrating the accuracy improvement are included in the analysis. It showed that reasonably accurate results were obtained even when using fewer elements compared to other shell elements. The element is then used to analyse spherical roof structures. The distribution of the various components of deflection is obtained. Furthermore, the effect of introducing concentrated load on a cylindrical clamped ends structure is investigated. It is found that the CSFE3-sh element considered is a very good candidate for the analysis of general shell structures in engineering practice in which the ratio h/R ranges between 1/1000 and 2/5.

References listed at the end of the paper:


ABSTRACT: The present paper aims at studying the nonlinear ultrasonic waves in a magneto-thermo-elastic armchair single-walled (SW) carbon nanotube (CNT) with mass sensors resting on a polymer substrate. The analytical formulation accounts for small scale effects based on the Eringen’s nonlocal elasticity theory. The mathematical model and its differential equations are solved theoretically in terms of dimensionless frequencies while assuming a non-linear Winkler-Pasternak-type foundation. The solution is obtained by means of ultrasonic wave dispersion relations. A parametric work is carried out to check for the effect of the nonlocal scaling parameter, together with the magneto-mechanical loadings, the foundation parameters, the attached mass, boundary conditions and geometries, on the dimensionless frequency of nanotubes. The sensitivity of the mechanical response of nanotubes investigated herein, could be of great interest for design purposes in nano-engineering systems and devices.

References listed at the end of the paper:


ABSTRACT: This study aims to investigate the damping behavior of the fundamental mode of a foam-filled carbon fibre reinforced polymer composite (CFRP) tube when subjected to base excitations. In particular, expanded polystyrene (EPS) foam balls (with negligible mass) of different sizes are used as fillers in the tube and the enhancement in damping ratio of the fundamental mode w.r.t the empty condition is evaluated for different intensity of base excitation. Shake table tests are performed on cantilever CFRP composite square tubes filled with EPS foam balls of different sizes. From the recorded responses, frequency, mode shape and damping ratio of the fundamental mode w.r.t the empty condition is evaluated for different sizes and the enhancement in damping ratio is noted to be around 1.41x compared with the values corresponding to the empty condition. The results suggest that the bigger foam balls enhance the damping ratio significantly without altering the natural frequency owing to addition of dissipation in friction and impact generated through the sliding and collision of the balls while the tube is in motion.

References listed at the end of the paper:

researches presented at the...who are the organizers of the Workshop, desire to offer a scientific forum for disseminating the studies and the which had the advantage of increasing the inclusiveness of the event. With this special issue, the Guest Editors, siscoscienzadellecostruzioni.org). The pandemic emergency forced us to follow a completely new online forma...received two significant endorsements, from the IASS (www.iassstructures.org) and from the SISCO (www.siscoscienzadellecostruzioni.org).

This Special Issue is devoted to papers coming from a call principally addressed to the participants of the 1stItalian Workshop on Shell and Spatial Structures (https://sites.google.com/view/iwss2020/home) held on-line...h 2020 after the lockdown restriction due to the Covid-19 pandemic. The experience of the first IWSS (IWSS2020) was particularly innovative. It brought together the interests of the Italian and the international community devoted to the study and applications of shell and spatial structures. The IWSS received two significant endorsements, from the IASS (www.iassstructures.org) and from the SISCO (www.siscoscienzadellecostruzioni.org). The pandemic emergency forced us to follow a completely new online format which had the advantage of increasing the inclusiveness of the event. With this special issue, the Guest Editors, who are the organizers of the Workshop, desire to offer a scientific forum for disseminating the studies and the researches presented at the Workshop. The Guest Editors plan to promote a deeper and extended discussion


Introduction to the special issue: Advanced structural systems are more and more devoted to light, versatile, eco-sustainable structures. This goal can be achieved through the use of new materials and new approaches for structural optimization, form finding, design, and validation. Shell and spatial structures are representative of some of the most efficient structural systems in which the optimized use of materials is combined with effective structural forms and shapes. The ongoing development of analysis methods, design approaches and construction techniques of shell and spatial structures has resulted in an increasing interest from engineers, architects, and builders.

This Special Issue is devoted to papers coming from a call principally addressed to the participants of the 1st Italian Workshop on Shell and Spatial Structures (https://sites.google.com/view/iwss2020/home) held on-line the last June 2020 after the lockdown restriction due to the Covid-19 pandemic. The experience of the first IWSS (IWSS2020) was particularly innovative. It brought together the interests of the Italian and the international community devoted to the study and applications of shell and spatial structures. The IWSS received two significant endorsements, from the IASS (www.iassstructures.org) and from the SISCO (www.siscoscienzadellecostruzioni.org). The pandemic emergency forced us to follow a completely new online format which had the advantage of increasing the inclusiveness of the event. With this special issue, the Guest Editors, who are the organizers of the Workshop, desire to offer a scientific forum for disseminating the studies and the researches presented at the Workshop. The Guest Editors plan to promote a deeper and extended discussion
about the topics that have grown the widest interest during the online presentations. Through the publication of selected papers, this special issue has the goal of emphasizing the peculiarity of the IWSS and the contribution of this growing community in our country (Italy) that lives the dual spirit of the traditional Italian schools of theoretical and computational mechanics together with the development of the most innovative approaches for the structural design and optimized use of materials. The reading of the past history by a new perspective coming from today’s point of view is another important aspect that the Editors are willing to promote. It seems, even more evident, the necessity to analyze the building heritage with a particular attention to the beautiful realization of light-weight structures of the last century. All over the World and in Italy in particular the second half of the 20th Century coincided with a heroic era for concrete and steel constructions which today deserves to be safeguarded and recovered, with a particular focus on the pioneering calculation tools of the past and the fascinating use of materials and construction techniques.

This Special Issue intends to explore new directions in the field of shell and spatial structures with a particular interest on the Italian Community but looking, at the same time, at the most interesting and innovative results coming from all over the world. Topics include experimental and theoretical studies, analytical methods, design approaches, computational aspects, form finding procedures, structural optimization, manufacturing, historical reviews, topical surveys, testing and maintenance techniques. The aim of this Special Issue is to collect papers pertaining to the design, modelling, analysis, and other aspects of the technology of all types of lightweight structures. These may also include tension elements and membranes, framed and lattice structures, grid-shells and active-bending structures, shell roofs, tensegrity structures, pneumatic and inflatable structures, active and deployable structures, concrete, metal, masonry, timber and bio-inspired structures.

Luigi Fenu (1), Eleonora Congiu (1), Giuseppe Carlo Maran (2) and Bruno Briseghella (2)
(1) Department of Civil and Environmental Engineering and Architecture, University of Cagliari, Cagliari, Italy
(2) College of Civil Engineering, Fuzhou University, Fujian, China


ABSTRACT: Architects and engineers have been always attracted by concrete shell structures due to their high efficiency and plastic shapes. In this paper the possibility to use concrete shells to support footbridges is explored. Starting from Musmeci’s fundamental research and work in shell bridge design, the use of numerical form-finding methods is analysed. The form-finding of a shell-supported footbridge is introduced. Coupling Musmeci’s and Nervi’s experiences, an easy construction method using a stay-in-place ferrocement formwork is proposed. Moreover, the advantage of inserting holes in the shell through topology optimization to remove less exploited concrete has been considered. Curved shell-supported footbridges have been also studied, and the possibility of supporting the deck with the shell top edge, that is along a single curve only, has been investigated. The form-finding of curved shell-supported footbridges has been performed using a Particle-Spring System and Thrust Network Analysis. Finally, the form-finding of curved shell-supported footbridges subjected to both vertical and horizontal forces (i.e. earthquake action) has been implemented.

References listed at the end of the paper:

ABSTRACT: Venus and the Ocean Worlds are emerging areas of interest for space exploration, as they can potentially host, or have hosted, conditions compatible with life. Landers and probes for in-situ exploration, however, must deal with very high external pressure, due to the environmental conditions, often resulting in thick and heavy structures. Robust, reinforced shell structures can provide a lightweight solution for the primary structure. In this frame, the isogrid layout is already a standard in aerospace, especially for flat panels or cylindrical shells. In this paper, isogrid-stiffened hemispherical shells, or "geodesic domes", are described, focusing on the case of a Venus lander. Early design methods for both plain and geodesic domes subjected to external pressure are presented, providing design equations. Additive Manufacturing is identified as the key technology for fabricating metallic geodesic domes, due to the complexity of the internal features. Moreover, it allows to fabricate ports and integrated thermostructural systems in the same process, potentially resulting in improved performance or cost and schedule savings.

References listed at the end of the paper:
[14] NASA SP-8032, Buckling of Thin-Walled Doubly curved shells, 1969


Bellini C., Sorrentino L., Characterization of Isogrid Structure in GFRP, Frattura ed Integrità Strutturale, 2018, 46, 319-331
[29] MacDonald E. et al., Fabricating patch antennas within complex dielectric structures through 3D printing, J Manuf Process, 2018, 34 A, 197-203
[34] Li M., Lai C., Zheng Q., Han B., Wu H., Fan H., Design and mechanical properties of hierarchical isogrid structures validated by 3D printing technique, Mater Design, 2019, 168, 107664


Google the string: “ASCE Journal of Structural Engineering”, then click on the entry, “ASCE Journal of Structural Engineering | ASCE Library”, then, on the resulting screen, click on “ALL ISSUES”. 

ABSTRACT: Little research has been reported that investigates the effects of plate local buckling and postbuckling on the in-plane behavior and strength of steel arches, and hitherto there has been no corresponding design guidance available. This paper presents a numerical investigation of the structural behavior of steel arches, and proposes a strength design method against their in-plane failure by considering plate local elastic-plastic buckling and postbuckling coupled with global elastic-plastic buckling. The failure modes of pin-ended steel circular arches having a top section under a uniformly distributed radial load are analyzed by using a large deformation elastic-plastic finite-element formulation. It is found that plate local buckling significantly influences the in-plane failure mode and strength of a steel arch. The arch may fail owing to local elastic-plastic buckling of its plates, global elastic-plastic buckling of the arch, or coupled local and global elastic-plastic buckling. The failure mode is found to depend on a number of factors such as the height-to-thickness ratio of the plate components, the aspect ratio of the cross section, the rise-to-span ratio, and the slenderness of the arch, as well as the yield stress of the steel. It is also found that the most important factors that influence the strength of the arch are the normalized global slenderness of the arch and the normalized height-to-thickness ratio of the plate components of the cross section. A strength reduction coefficient for estimating the in-plane strength of arches is developed based on these two most significant parameters, and a corresponding strength design method is proposed.


ABSTRACT: Light-gauge metal sheeting is often used in steel building and bridge industries as concrete deck formwork. Besides providing support to the fresh concrete, the sheeting acts as a shear diaphragm and provides continuous lateral bracing to the top flanges of the beams to which they are attached. An adequate stability-bracing system must possess sufficient stiffness and strength to control deformations and brace forces. Strength requirements for shear diaphragms are currently not well established. A computational study was conducted to develop strength requirements for shear diaphragms bracing simply supported steel beams. Both end-fastener and sidelap-fastener connections were modeled in the study. To the best of the authors’ knowledge, this is the first study to quantify the stability-induced forces in sidelap fasteners. The effects of deck width and number of end and sidelap fasteners on brace forces were investigated. Expressions were developed to estimate the stability-induced brace forces in end-fastener and sidelap-fastener connections.


ABSTRACT: Concrete-filled stainless steel tubular (CFSST) columns have attracted increasing research interests in recent years; however, it seems that the behavior of this type of innovative column under cyclic loading has not been addressed sufficiently so far. This paper reports test results of 10 CFSST columns under constant axial load and cyclically increasing flexural loading. The main parameters varied in the experiments were axial load level, cross-sectional type, and concrete type. The influences of these parameters on strength, ductility, stiffness, and energy dissipation were investigated. It was found that CFSST columns exhibited excellent energy dissipation and ductility, even when the specimens were subjected to high axial loads. The hysteretic behavior of the tested CFSST columns was compared to that of their carbon steel composite counterparts reported in the literature. Several existing design codes were used to predict the ultimate strength and flexural stiffness of the test specimens, and some suggestions are proposed accordingly for designing CFSST columns.

ABSTRACT: An experimental study was performed to investigate the structural behavior of thin-walled rectangular concrete-filled tubular (RCFT) columns. This study mainly focused on the effects of a high-strength steel slender section on the overall eccentric compression capacity. The test parameters included the width-to-thickness ratio of steel plates, yield strength of steel plates, and use of stiffeners. Five specimens were tested under eccentric axial loading. In the slender-section specimens, despite early local buckling, significant postbuckling reserve strength developed. Consequently, the predictions of a current specification significantly underestimated the load-carrying capacity of the slender-section specimens. The specimens strengthened with vertical stiffeners exhibited enhanced strength and ductility, attaining the plastic capacity of the composite section. Furthermore, a design method of vertical stiffener was developed for high-strength steel RCFT columns.


ABSTRACT: Over the past two decades, there has been significant interest in research relating to concrete-filled tubes, and a corresponding penetration of this technology into practice. This paper aims to expound upon the effect of timber cores on the structural response of concrete-filled circular tubes under compression. A timber infill with different shapes and geometries surrounded by concrete and encased in a steel tube was employed. The effects of the combination of infill elements on the failure, axial capacity, ductility, and structural efficiency (weight versus capacity) are exhaustively set forth. For the specimens with the highest timber to concrete ratio, the capacity was enhanced by about two times the capacity of the hollow steel specimens. For these specimens a significant reduction in the total weight of the composite element was obtained relative to the fully concrete-filled specimens. These specimens showed the highest ductility among the other specimens. In addition, greater ratios of energy absorption to the mass were obtained for the specimens with different timber cores in comparison to the equivalent values for fully concrete-filled tubes, which is quite desirable in many practical scenarios. It is found that the use of timber as an inner core element in this new composite yields promising results in decreasing the weight and yet enhancing the capacity, ductility, and energy absorption, and can be a good alternative to double-skin concrete-filled steel tubes.


ABSTRACT: In this paper, a finite-element-based computational method is proposed for time-dependent structural stability analysis of a concrete-filled steel tubular (CFST) arch with uncertain parameters. Specifically, the targeted uncertainty includes the mercurial effects of the creep and shrinkage of the concrete core, which inevitably affect the structural performance of the CFST arch. The structural stability of the composite arch is systematically investigated under the influence of uncertain creep and shrinkage in a time-dependent fashion. The proposed computational scheme efficiently establishes the quantitative long-term stability envelope for CFST arches against uncertain viscoelastic effects. In order to demonstrate the effectiveness and efficiency of the proposed time-dependent structural stability analysis for CFST arches, practically motivated numerical examples are thoroughly investigated throughout this work.


ABSTRACT: Cold-formed steel shear wall with corrugated sheet steel sheathing is a newly proposed lateral force resisting system from recent research work. The advantages of noncombustibility, high shear strength and high shear stiffness enable this new wall system to be a feasible solution for low- and midrise construction at high wind and seismic zones. The design provisions for this new type of shear wall have not been developed in current design specifications. The initial phase of this research project involved the displacement-based testing of bearing wall and shear wall specimens under combined lateral and gravity loading. The phase two research, presented here, includes the nonlinear finite element analysis and the performance evaluation of a set of light framed steel buildings using the corrugated sheet sheathed shear walls. Incremental dynamic analyses were
performed on six archetype buildings and seismic performance assessment was evaluated. The results verify a
set of seismic performance factors \( R = C_{\Omega} = 6.5 \) and \( \Omega = 3.0 \) for the corrugated sheet sheathed shear wall systems.

Mehrdad Memari, Hussam Mahmoud and Bruce Ellingwood, “Stability of steel columns subjected to
earthquake and fire loads”, ASCE Journal of Structural Engineering, Vol. 144, No. 1 January 2018,
https://doi.org/10.1061/(ASCE)ST.1943-541X.0001909

ABSTRACT: Assessing the stability of steel building frames exposed to fire conditions is challenging because
of the need to consider the elevated temperature properties of steel, nonuniform heating of structural members,
and large deformational demands on the frames. This challenge is further intensified if the stability of the frame
is also influenced by the lateral forces of an earthquake that preceded the fire. Although there has been
significant progress recently in simulating the response of frames using finite-element methods, there is a need
for computationally efficient tools that would minimize the modeling effort and allow for accurate and rapid
assessment so that a large number of simulations can be conducted. To this end, the present study aims to
develop a framework for conducting a stability analysis of steel columns subjected to demands imposed by
lateral loading followed by fire. A nonlinear formulation is proposed to assess the stability of W-shaped steel
columns under multihazard loading scenarios. Results from the proposed formulation show good agreement
with available strength design equations of steel columns at ambient and elevated temperatures. This
computationally efficient tool can be used to investigate the effects of a wide variety of variables on the stability
of steel columns subjected to fire and fire following earthquakes.

Omar I. Abdelkarim, Mohamed A. ElGawady, Sujith Anumolu, Ahmed Gheni and Gregory E. Sanders,
“Behavior of hollow-core FRP-concrete-steel columns under static cyclic flexural loading”, ASCE Journal
of Structural Engineering, Vol. 144, No. 2, February 2018,
https://doi.org/10.1061/(ASCE)ST.1943-541X.0001905

ABSTRACT: This paper presents the seismic behavior of hollow-core fiber-reinforced polymer (FRP)-
concrete-steel (HC-FCS) columns comparable with the conventional RC column. The typical HC-FCS column
consists of a concrete shell sandwiched between an outer FRP tube and an inner steel tube. The HC-FCS
column represents a compact engineering system; the steel and FRP tubes act together as stay-in-place
formworks. The steel tube acts as a flexural and shear reinforcement. This paper studies three large-scale
columns—one RC column having a solid cross section and two HC-FCS columns. Each column has an outer
diameter of 610 mm (24 in.) and a shear span-to-diameter ratio of 4.0. The steel tube is embedded into the
reinforced concrete footing with an embedded length of 1.6 times the steel tube diameter, whereas the FRP tube
only confines the concrete shell and truncates at the top of the footing. The HC-FCS columns exhibits high
lateral drift reaching 15.2% and fail gradually due to concrete crushing and local steel tube buckling, followed
by FRP rupture. The reference RC column fails at a drift of 10.9% due to rebar fracture. Simple beam theory
overpredicts the flexural strength of the columns by an average of 9%.

Ahmed Elkady and Dimitrios G. Lignos, “Full-scale testing of deep wide-flange steel columns under multiaxis
cyclic loading: Loading sequence, boundary effects, and lateral stability bracing force demands”, ASCE Journal
of Structural Engineering, Vol. 144, No. 2, February 2018, https://doi.org/10.1061/(ASCE)ST.1943-
541X.0001937

ABSTRACT: This paper discusses the findings from 10 full-scale steel column tests subjected to multiaxis
cyclic loading. The columns use deep wide-flange cross sections typically seen in steel moment-resisting frames
designed in seismic regions. The effects of boundary conditions, loading sequence, local web, and member
slenderness ratios on the column hysteretic behavior are investigated. The test data underscore the influence of
boundary conditions on the damage progression of steel columns. Local buckling followed by out-of-plane
deformations near the plastified column base are the dominant failure modes in fixed base columns with a
realistic flexible top end. Twisting may occur only at drifts larger than 3% even when the member slenderness
is fairly large. The test data suggest that bidirectional loading amplifies the out-of-plane deformations but does
not significantly affect the overall column performance. The loading sequence strongly affects the column’s
plastic deformation capacity but only at story drifts larger than 2%. Above this drift amplitude, column axial
shortening grows exponentially and becomes a controlling failure mode. Measurements of the lateral stability
bracing force demands at the column top exceed the lateral brace design force specified in North American standards.

ABSTRACT: This research focuses on a new type of buckling-restrained brace (BRB) with replaceable steel angle fuses. The proposed BRB offers ease of postearthquake examination of fuse damage, convenient and prompt replacement of damaged fuses, and reuse of the buckling restraining elements. To investigate seismic behavior of the proposed BRB, seven brace specimens are tested. The test parameters varied in these specimens include fuse design, fuse material, debonding material, and loading protocol. Test results show that the proposed BRB can exhibit stable hysteretic behavior up to fairly high fuse strain levels. Failure modes of the specimens are found to be ruptures of the angle fuses, as expected. The compression strength adjustment factors and the cumulative plastic deformations of the specimens are found to satisfy the requirements specified by the current U.S. seismic design provisions for structural steel buildings. Moreover, the authors demonstrate that specimens repaired through fuse replacement remain satisfactory in following tests. Furthermore, rupture failures of the proposed BRB can be captured by the modified Park–Ang damage measure.

ABSTRACT: This state-of-the-art review provides an overview of the evolution of seismic design requirements for main steel building seismic force–resisting systems, as driven by new developments, the 1994 Northridge, California, earthquake, and changes in earthquake engineering practice in the United States. Important aspects of these systems in terms of ductility design and capacity design are highlighted. Recent developments in practice related to innovative systems are touched upon. The work presented here is intended to provide the reader with an appreciation of why the current seismic design requirements for steel structures are as framed, highlighting in the process several unresolved issues and inconsistencies that will require attention in future research. Implications of the Christchurch, New Zealand, rebuilding after the 2010–2011 earthquakes there for future U.S. seismic code development are also presented.

ABSTRACT: Quasi-static experiments were conducted to subject buckling restrained braces (BRBs) to a regime of relative end displacements demands to investigate if the BRBs’ end connections could be able to sustain the required displacement demands when installed in bidirectional ductile end diaphragm systems (EDS). The loading protocols included the bidirectional displacement histories to be applied to the specimens for the cyclic inelastic test and the uniaxial displacement histories for the low-cycle fatigue test caused by temperature changes. Two types of BRBs with flat end plates and unidirectional pinholes, namely BRB-1 and BRB-2, were designed and tested. Four specimens of each type of BRB were tested under combinations of different displacement protocols, and the resulting BRBs’ hysteretic behaviors were studied and compared. All the BRB specimens tested developed cumulative inelastic deformations of more than 200 times the BRB’s axial yield displacement. The specimens were able to sustain multiple years of severe temperature cycles in addition to meeting the seismic qualification test criterion. Ultimately, as expected, all BRBs failed in tension after extensive cycles of inelastic deformations. No undesirable end-plate failure or instability was observed. A recommended design procedure for the EDS with BRBs in both straight and skew bridges was developed based on these experimental results.

ABSTRACT: Historical earthquake events have demonstrated the destructive potential of postearthquake fire and the vulnerability of structural systems to such multiple events. Current well-established seismic design
provisions, however, require structural engineers to design structural systems to resist ground motions with no concerns regarding subsequent earthquake-induced hazards. This is primarily because efforts pertaining to developing design provisions addressing the response of building systems under both hazards are still lacking. The ramifications of ignoring the effect of both hazards in design codes could be substantial because of the increased potential for column failure as a result of residual interstory drifts caused by the preceding earthquake event, followed by the fire loads. To that end, the present study aimed to propose design equations to determine the nominal strength of W-shape steel columns subjected to fire following earthquake. The fire load effect was simulated through the application of nonuniform temperature profiles in the columns. The proposed equations account for the residual stress distribution in W-shape steel sections, initial out of straightness and out of plumbness, temperature-dependent material properties, nonuniform longitudinal temperature profiles, and residual interstory drift at the conclusion of an earthquake. The formulations can also accommodate various boundary conditions at column ends. The results clearly highlight the observable reduction in column strength under fire as a result of the preimposed lateral drifts. The results and the proposed equations can be used to quantify the potential for instability in steel columns when subjected to fire following an earthquake.

ABSTRACT: This paper presents the numerical investigation of the compressive behavior of cold-formed high-strength steel (HSS) tubular stub columns. The nominal 0.2% proof stresses of the high-strength steel are 700, 900, and 1,100 MPa. Experimental investigations have been conducted, and the numerical methodology has been verified against the test results in a complementary study. Parametric studies on the cold-formed HSS tubular stub columns were performed using the verified models, and additional data were generated to evaluate the structural performance of such compression members. The experimental and numerical results were then compared with the predictions from the design guidelines for square hollow sections (SHS), rectangular hollow sections (RHS), and circular hollow sections (CHS). The current codified slenderness limits and design methods were examined. Modifications to the design methods for resistances of SHS, RHS, and CHS stub columns against cross-sectional yielding or local buckling are proposed in this paper.

ABSTRACT: This paper presents a set of deployable origami tube structures that can create smooth functional surfaces while simultaneously maintaining a high out-of-plane stiffness both during and after deployment. First, a generalized geometric definition for these tubes is presented such that they can globally have straight, curved, or segmented profiles, while the tubes can locally have skewed and reconfigurable cross sections. Multiple tubes can be stacked to form continuous and smooth assemblies in order to enable applications, including driving surfaces, roofs, walls, and structural hulls. Three-point bending analyses and physical prototypes were used to explore how the orthogonal stiffness of the tubular structures depends on the geometric design parameters. The coupled tube structures typically had their highest out-of-plane stiffness when near to a fully deployed state. Tubes with skewed cross sections and more longitudinal variation (i.e., that had more zigzags) typically had a higher stiffness during deployment than tubes that were generally straight.

ABSTRACT: The present study investigated the effect of web distortion on the lateral torsional buckling strength of Gerber systems. Toward this goal, a number of modifications were introduced into two finite-element formulations for the distortional and nondistortional lateral torsional buckling analysis. The distortional formulation treated the web as a thin plate and the flanges as Gjelsvik members and captured load height effects. The nondistortional formulation was based on the Vlasov beam kinematics and enabled the enforcement of lateral restraints offset from the shear center while preserving the positive definiteness of the stiffness matrices. Both models were validated against shell finite-element solutions and then utilized to develop moment gradient coefficients for Gerber beams, assess the web distortional effects, and quantify the influence of various
lateral bracing scenarios on the elastic lateral torsional buckling strength. Unlike rolled simply supported beams in which web distortion was considered to be insignificant, the present study indicated that web distortion heavily influences the lateral torsional buckling strength of Gerber beams.


ABSTRACT: This paper proposes the use of an additional stiffening ring to prevent buckling of aboveground storage tanks (ASTs) under storm-surge inundation and presents an approach to obtain an optimal design for the additional ring. This study addresses the lack of methods to prevent storm-surge buckling of ASTs even though it has been identified as a common mode of AST failure. For this purpose, finite-element simulations were performed to study the effect of the proposed stiffening ring on the buckling response of ASTs. The critical surge height, i.e., the lowest surge height that causes AST buckling, is evaluated for a wide range of tank geometries, material properties, ring section moduli, and positions of the additional ring. The critical surge heights obtained from these simulations are used to obtain a multiparameter regression equation that can predict the critical surge height. The regression equation is further used to derive the optimal section property and the position for the additional ring as a function of tank geometry and material properties. In order to demonstrate the effect of the additional stiffening ring, the change in the critical surge height due to the installation of the additional ring is evaluated for five case-study tanks. The results show that installation of the additional stiffening ring can significantly increase the critical surge height of tanks. Furthermore, considering uncertainties from level of fill in the tank and geometric imperfections, fragility analysis for one of the case study tanks underscores the reduction in fragility, i.e., conditional probability of buckling failure given surge level, due to the additional ring.


ABSTRACT: This paper presents an experimental study and numerical simulation analyzing the seismic performance of low- and midrise cold-formed steel-framed buildings using shear walls sheathed with corrugated steel sheets with slits. A new testing method considering both lateral and gravity (vertical) load was used to investigate the behavior and strength of the cold-formed steel-framed shear walls. The test results indicate that the perforated shear walls demonstrate desirable ductility and initial stiffness with relatively high shear strength compared with nonperforated shear walls. To further study the seismic performance and determine the seismic performance factors, incremental dynamic analysis was performed of six building archetypes in which the new shear walls were installed. Seismic performance assessment was evaluated according to FEMA methodology. The results indicate that a set of seismic performance factors (R=Cd=6.5 and Ω=3.0) is appropriate for the perforated cold-formed steel-framed shear wall systems using corrugated steel sheathing. The proposed new shear wall can be used as a substitute for flat steel sheet or wood-based panels in Type I and II constructions in high wind and seismic regions. Detailed full-scale test results and nonlinear finite-element modeling results of this new lateral force resisting system are discussed and reported herein.


ABSTRACT: Steel beams are susceptible to large deformation and capacity reduction when subjected to elevated temperatures. Determination of collapse loads for structural steel members under fire is critical for realistic assessment of system vulnerabilities. Such determination, however, should be conducted within a probabilistic framework that allows for the integration of various uncertainties influencing the behavior. In addition, the assessment should address realistic fire exposure that arises due to typical fire scenarios. To date, evaluation of the collapse load of beams in the presence or absence of uncertainties under nonuniform temperature is lacking. This paper presents a new analytical formulation, based on virtual work, for calculating the collapse load of beams subjected to nonuniform longitudinal temperature distribution. Moreover, a new probabilistic framework is devised to generate fragility surfaces for beams under combined fire and applied loads. Randomness in load and resistance including applied mechanical loads, compartment ventilation,
ABSTRACT: A full-scale experimental study was carried out on a two-story steel frame to investigate the progressive collapse behavior of beam–column joints with cast steel stiffeners (CSS). The frame was divided into four vertical sections, and each section had a specific joint arrangement of (1) joints with CSS and (2) welded joints without stiffeners. Seven loads of increasing magnitude were applied to the frame. In each section, one of the columns had a device at the base that could be removed and replaced to simulate the failure and repair of this column; this column is referred to as an adjustable column. Strain changes and displacements were monitored during column removal. Moreover, three types of finite-element models were developed to simulate the test frame. The results showed that compared to a welded joint without stiffeners, joints with CSS reduced the strain change and deformation of the frame, as well as the dynamic strain magnification factor of strain change; concrete slabs played a significant role during the load redistribution in the sudden failure of the adjustable column.

Ju Chen, Man-Tai Chen and Ben Young, “Compression tests of cold-formed steel C- and Z-Sections with different stiffeners”, ASCE Journal of Structural Engineering, Vol. 145, No. 5, May 2019
ABSTRACT: This paper describes an experimental investigation of stub column tests of cold-formed steel C- and Z-sections with different stiffeners. The experimental program consisted of 30 fixed-ended column tests of 6 series of C-sections and 4 series of Z-sections. The configurations of stiffeners comprised simple edge stiffeners, simple lips with inward or outward return lips, and intermediate web stiffeners. The specimens were brake-pressed from high-strength zinc-coated grades G450 and G550 structural steel sheets. The material properties were measured through tensile coupon tests. The load-carrying capacities, load-end shortening responses, and failure modes of stub column specimens are presented and discussed in this paper. The test strengths and observed failure modes were compared with the design strengths and failure modes predicted by the Direct Strength Method. The comparison showed that the Direct Strength Method provides accurate and reliable design strength predictions for C- and Z-sections with different edge stiffeners but provides less accurate design strength predictions for C-sections with intermediate web stiffeners.

ABSTRACT: This paper presents experimental and analytical studies on the seismic behavior of beam-to-column connections with external diaphragms in the concrete-filled steel tubular (CFST) structures. Three cruciform joints between CFST column and H-shaped steel beam were tested subjected to a constant axial load on the column and a set of antisymmetrical cyclic loads at the beam’s tips to investigate the seismic behavior of the panel zone. A weak panel zone was specially considered in all three specimens to investigate the shear capacity of the panel zone. Key variables involved are the compressive strength of concrete and the axial load ratio. Three specimens all exhibited a shear failure in the panel zone due to local buckling. The strain distribution and load-displacement behaviors were discussed. In the analytical study, a computational model for the postbuckling shear capacity of panel zone was developed and checked for its applicability.

ABSTRACT: This study presents a simple yet efficient phenomenological hysteretic model for hollow circular steel (HCS) braces without a middle connection in concentrically braced frames (CBFs). The model is calibrated on the basis of the available experimental results and on a series of numerical simulations by finite-
element (FE) models, which are validated by existing experiments. The Miner linear cumulative damage theory based on the Coffin-Manson expression is used to represent the low-cycle fatigue deterioration of a brace subjected to cyclic loading. Furthermore, the cumulative yielding strength degradation is considered by a simplified formulation, which is defined as the cumulative fatigue damage. Comparisons of the hysteretic responses obtained by the proposed model with the results of the FE models show that this model can capture several failure modes of a brace during inelastic cyclic behaviors, such as yielding, inelastic postbuckling, strength degradation, and fracture due to low-cycle fatigue, as well as the fracture point. The cumulative dissipated energy of a brace is well-predicted by the model. In addition, this model takes much less computing time than the FE model and is therefore suitable for structural analyses. The model should be further examined to more precisely consider the effect of the local buckling of a brace with different cross-sectional geometries.


ABSTRACT: RC bridge columns that are at risk for collision loading must be designed for lateral impact load. Because bridge columns must also support axial loads, evaluating the residual axial capacity and collapse risk of impact-damaged columns is important. This study examined axial performance characteristics of RC columns using compression after impact (CAI) testing of twelve circular columns. As residual deformations caused by lateral impact loading increased, residual axial strengths were found to decrease. Additionally, damage modes induced by impact loading were found to have an obvious influence on residual axial capacity. Shear-dominated impact damage was observed to result in greater reduction of axial capacity than did flexure-dominated damage. Because the maximum load imposed during a collision is usually unknown, an assessment method based on the postimpact state (deformation and damage mode) is proposed and was demonstrated to be capable of predicting postimpact residual axial capacity. The effects of reinforcement ratio and axial load ratio on postimpact capacity were parametrically investigated, and an empirical formula derived from the results was developed for estimating residual strengths.


ABSTRACT: In this study, a total of 58 tests were performed on cold-formed lean duplex stainless steel (LDSS) tubular members under three different loading conditions of concentrated interior bearing forces. The loading conditions included interior-one-flange (IOF), interior-two-flange (ITF), and interior loading (IL). The loading conditions of IOF and ITF are specified in the US and Australian/New Zealand cold-formed stainless steel design specifications, and the loading condition of IL simulated the floor joist members positioned on a solid foundation subjected to concentrated bearing load. The cold-formed LDSS specimens were failed by web crippling. The test strengths were compared with the nominal strengths predicted by the international specifications for stainless steel structures. In addition, the strengths predicted by the North American specification for cold-formed carbon steel structures and those from the design equations proposed in the literature for cold-formed duplex stainless steel members were also compared with the test strengths. It was found that the nominal strengths predicted by the international specifications for stainless steel structures are conservative and reliable for cold-formed LDSS members under concentrated interior bearing loads. The predictions by the North American specification were generally unconservative and not reliable, whereas the predictions from the literature were generally less conservative and reliable compared with those predicted by the stainless steel design specifications.


ABSTRACT: This paper describes an experimental program carried out at the University of Sheffield to investigate the interaction of local and distortional buckling in cold-formed steel lipped channel beams. The channels were arranged in a back-to-back configuration and a total of six tests, including three different cross-sectional geometries, were completed. The specimens were tested in a four-point bending configuration with simply supported boundary conditions while being laterally braced at the loading points. The beams failed in the constant moment span by interaction of local and distortional buckling. The geometric imperfections of the channels were recorded before the test using a specially designed measuring rig employing laser sensors.
Pedro Borges Dinis and Dinar Camotim, “Proposal to improve the DSM design of cold-formed steel angle columns: Need, background, quality assessment and illustration”, ASCE Journal of Structural Engineering, Vol. 145, No. 8, August 2019

ABSTRACT: This paper presents a proposal for the codification of an efficient design approach based on the direct strength method (DSM) for cold-formed steel equal-leg angle columns with short-to-intermediate lengths, i.e., those buckling in flexural-torsional modes. Initially, the available experimental failure load data consisting of fixed-ended and pin-ended (cylindrical hinges) columns with several geometries (cross-section dimensions and lengths) and tested by various researchers are collected. These are used to show that the currently codified DSM design provisions are not able to handle adequately short-to-intermediate angle columns and that a specific DSM-based design approach is needed to estimate the failure loads of such columns. Then, the paper presents a brief overview of the structural reasoning behind the proposed DSM-based design approach. Next, the quality (accuracy and reliability) of the failure load estimates obtained with this design approach is assessed through the comparison with the aforementioned experimental failure load data and also a fairly large number of numerical failure loads previously obtained by the authors. This merit assessment includes the determination of the load-resistance factor design (LRFD) resistance factors concerning the failure-to-predicted load ratios. It is shown that the value recommended for compression members by the North American specification, \( \phi_c = 0.85 \), can also be adopted for short-to-intermediate angle columns designed with this DSM-based approach. Finally, the paper presents and discusses a few numerical examples that illustrate the application of the proposed design approach and provide evidence of its user-friendliness and advantages/benefits when compared with the currently codified one.

Hai-Ting Li and Ben Young, “Cold-formed high-strength steel tubular structural members under combine bending and bearing”, ASCE Journal of Structural Engineering, Vol. 145, No. 8, August 2019

ABSTRACT: This paper presents experimental and numerical investigations of cold-formed high-strength steel (CFHSS) tubular structural members under combined bending and bearing. A test program that contained 33 experiments was undertaken on square hollow sections (SHSS) and rectangular hollow sections (RHSs) with nominal yield strengths up to 900 MPa. The combined bending and bearing experiments were performed under the interior-one-flange bearing load case as per the North American Specification (NAS). Finite-element models were built and validated with the experiments; a parametric study was undertaken upon validation. The experimentally and numerically obtained results were compared with nominal resistances as per the NAS and European Code (EC3) to examine their applicability to CFHSS SHS/RHS members under combined bending and bearing. Overall, the comparisons reveal that the NAS provisions were generally conservative whereas the EC3 provisions were overly conservative. It is shown that the codified bending and bearing interaction formulas can be used for CFHSS SHS/RHS members, while more accurate predictions can be achieved using recently proposed bearing design rules.


ABSTRACT: In this paper, a total of 12 circular tubed steel-reinforced concrete (CTSRC) short columns with high-strength concrete are constructed and tested under axial compressive load. The main variables of the test include diameter-to-thickness ratio and yield strength of the steel tube, concrete strength, and the steel ratio of the profile steel. The failure modes, axial load-displacement curves, and ultimate axial load of the CTSRC columns are analyzed systematically. It can be determined from the test results that all specimens exhibited shear failure under concentric loading. However, the shear cracks around the concrete circumference were not connected throughout the entire section due to the presence of internal profile steel. Moreover, as a result of double confinement provided by the steel tube and profile steel, the ultimate concrete strength and ductility of the CTSRC columns were enhanced significantly, which led to a considerable improvement to the axial
capacity. Finite-element (FE) analysis is conducted on the CTSRC columns using ABAQUS software, and the results show that good agreement and satisfactory accuracy between the test observations and FE methods can be achieved. Therefore, the numerical simulation used in this study is relatively reasonable and accurate. Based on the effective FE model mentioned previously, extensive parametric analysis is performed, and a more accurate axial strength model is proposed. It is evident that good agreement of theoretical predictions and the test data from this paper and other relevant literature can be achieved using the proposed model.

ABSTRACT: This paper addresses the structural performance of a type of sandwich panels with lightly profiled thin steel skins filled with lightweight concrete. A series of experimental tests and numerical simulations were conducted on the composite panels subjected to concentric and eccentric compressive loads and flexural loads. Both results show that skin buckling is the governing criterion for the load carrying capacity of this structural component. Based on the contact buckling theory, practical formulas were developed for section capacity prediction of the composite panels. The experimental results, numerical simulation, and formula prediction results agree well with each other.

Lavan Sundararajah, Mahen Mahendran and Poologanathan Keerthan, “Numerical modeling and design of lipped channel beams subject to web crippling under one-flange load cases”, ASCE Journal of Structural Engineering, Vol. 145, No. 10, October 2019
ABSTRACT: Web crippling failure governs the behavior of thin cold-formed steel lipped channel beams (LCBs) used in floor systems. This paper describes a numerical modeling–based research study undertaken to investigate the web crippling behavior of LCBs under one-flange load cases and to develop improved design equations for possible inclusion in the cold-formed steel design standards. Finite-element models were developed to simulate the web crippling behavior of LCBs and their accuracy was verified using 36 web crippling tests of LCBs conducted under one-flange load cases using the new standard test method. A detailed numerical parametric study was then undertaken to investigate the web crippling behavior of LCBs using the verified finite element models of LCBs. This numerical parametric study provided an extensive web crippling capacity database and improved the understanding of the effects of key web crippling parameters such as inside bent radius, bearing length, and yield stress on the web crippling capacity. Using these results, new and improved web crippling design equations were proposed in this paper for LCBs under one-flange load cases. They include both unified web crippling equations and the direct strength method–based equations. This paper demonstrated the improved accuracy of the proposed equations and their potential for inclusion in the cold-formed steel design standards.

ABSTRACT: The concept and structural benefits of prestressing cold-formed steel beams are explored in the present paper. In the proposed system, prestressing is applied by means of a high-strength steel cable located within the cross section of the beam at an eccentric location with respect to the strong geometric axis. The internal forces generated by the prestressing are opposite in sign to those induced under subsequent vertical loading. Hence, the development of detrimental compressive stresses within the top region of the cold-formed steel beam is delayed and thus the load-carrying capacity of the beam is enhanced. Owing to the precamber that is induced along the member during the prestressing stage, the overall deflections of the beam are also reduced significantly. In the present paper, finite-element (FE) modeling was employed to simulate the mechanical behavior of prestressed cold-formed steel beams during the prestressing and vertical loading stages. Following the validation of the FE modeling approach, a set of parametric studies was conducted, where the influence of the key controlling parameters on the structural benefits obtained from the prestressing process was investigated. The parametric results were utilized to determine how the benefits obtained from the addition of the prestressed cable can be maximized, demonstrating the significant enhancements in the performance of the cold-formed steel beam that can be achieved.

ABSTRACT: Steel-concrete-steel (SCS) composite structures with bidirectional steel webs and ribs exhibit superior performance in capacity, rigidity, ductility, blast resistance, waterproofness, and construction efficiency compared with traditional engineering structures, making them especially suitable for megaprojects, such as submarine tunnels, nuclear shells, and offshore structures. The current design method is mainly an adaptation of reinforced concrete code, and studies to investigate the distinctiveness of the structure considering the composite action are needed. Seven bending tests were conducted and numerical models developed to study the bending behaviors of SCS composite structures. The major concerns were local buckling behavior and casting imperfection, which are rarely studied but of importance in practice. It was found that the biaxial strengthening effect due to lateral constraint plays an important role and should not be neglected especially in the tension flange, which typically offers an enhancement of about 15% in strength at the ultimate state. Based on the experimental, numerical, and theoretical analyses, suggestions are proposed to modify the current design method which clarify construction requirements considering local buckling and casting imperfection. These modifications have been proven to provide approximately 10% improvement compared with the experiments.


ABSTRACT: This paper proposes a scheme to improve the structural behavior of square concrete-filled steel tubular (CFST) columns, in which diagonal binding ribs are welded at all the four pairs of adjacent sides of the square tube. Thus, both the confinement from the stiffened square steel tube to the infilled concrete and local buckling behavior of the tube can be enhanced. The diagonal binding ribs made of perforated thin-walled steel plates can facilitate concreting and enhance the integrity of the columns. This kind of composite columns is called diagonal rib–stiffened square CFST columns in this paper. Nineteen specimens with the tube width:thickness ratios between 50 and 150 were tested under axial compression to investigate the effect of thicknesses, opening dimensions and opening shapes of the stiffeners. In addition, square CFST specimens without stiffeners and octagonal CFST specimens and square CFST specimens with longitudinal stiffeners on each tube face were also tested for comparison. Test results showed that the diagonal binding ribs can improve the composite effect effectively by cocarrying the axial compression force and confining both the steel tube and concrete. The diagonal binding ribs can increase load-carrying capacity by 10%–20% and ductility by 30% or more compared with the CFST specimens without stiffeners. The diagonal rib–stiffened square CFST columns also behaved better than the octagonal CFST specimens and square CFST specimens with longitudinal stiffeners. Finally, two calculating methods which well predict the axial load-carrying capacities of diagonal ribs stiffened square CFST columns are recommended.


ABSTRACT: This paper concentrates on the laterally flexural-torsional buckling analysis incorporating shear deformations for elastic steel circular arches having boundary rotational restraints under a localized uniform radial load, which has not been reported in the literature. The localized uniform radial load and elastic restrained boundaries produce complex nonuniform shear force, axial force, and bending moment in an arch, which need to be considered in the flexural-torsional buckling analysis of the arch. Therefore, the in-plane elastic analysis is carefully performed to derive exact prebuckling shear force, axial force, and bending moment based on which the analytical solutions of the critical value of localized uniform radial load for flexural-torsional buckling of elastic steel arches are derived. Comparisons show that analytical solutions agree extremely well with finite element results. The influences of various factors on the flexural-torsional buckling are studied. The localized loading segment length and/or the elastic stiffness of boundary rotational restraints are found to have significant influences on the flexural-torsional buckling load. The buckling load decreases with a decrease in the stiffness of the rotational restraints and with a decrease in the loading segment length. The influence of shear deformations on the flexural-torsional buckling load is also investigated, and the results show that shear deformations reduce the critical flexural-torsional buckling loads for arches with a medium and small slenderness ratio.

ABSTRACT: Structural insulated panels, commonly known as SIPs, constitute a panelized building system composed of external facer panels, such as oriented strandboard (OSB) sheets, bonded to a lightweight foam core. As the demand for SIPs increases as an alternative to light-frame construction in residential and light-commercial buildings, so too does the need for proper design requirements to satisfy regulatory agencies and building officials. This paper describes a combined experimental and analytical study whose objective was to investigate the structural behavior of OSB-faced SIPs subject to short-term axial loading. A total of 53 panels with varying types of foam core, thickness, and other construction details were subjected to concentric and eccentric loading. The test results indicated that the strength of SIPs was primarily influenced by the panel slenderness and the type of foam core. Reliability-based design expressions were developed for the ultimate limit state of SIPs subjected to short-duration concentric and eccentric axial loading. The results were also compared to current allowable stress design practices. In addition to presenting important test data for researchers, this paper presents a number of practical design recommendations to improve the performance of SIPs.

Sameh Ahmed (1) and Khaled Galal (2)
(1) Military Technical Research Center of Egypt, Cairo 11759, Egypt
(2) Civil, and Environmental Engineering, Concordia Univ., Montréal, QC, Canada H3G 1M8


ABSTRACT: A considerable amount of research studies have demonstrated the capability of metallic sandwich panels in dissipating blast loading energy. Metallic sandwich panels dissipate blast energy through large plastic deformation of the core and plates, making them more effective than a single metallic plate of similar density. This study numerically evaluated the effectiveness of using woven shapes as a new core topology in sandwich panels for resisting blast loads. The results of the proposed woven shapes were compared to honeycomb and folded shapes to examine their effectiveness in blast mitigation. Numerical models were developed using ANSYS Autodyn software and were validated using available data in the literature. Eleven panels were studied: three honeycomb panels, five folded panels, and three woven panels. The effect of changing the front layer’s thickness and the back layer’s thickness was investigated. A new scenario was investigated where the same sandwich panels were exposed to a second blast load following the first one. Finally, the effect of changing the charge weight was studied where parameter charts for the honeycomb topology, folded topology, and woven topology were developed. The results show that woven shapes achieved the best energy dissipation capability compared to the honeycomb and folded shapes. Moreover, woven shapes achieved less back layer deflection than the folded shapes and more back layer deflection than the honeycomb shapes.

Han Fang (1), Tak-Ming Chan (2) and Ben Young (2)
(1) Environmental and Mining Engineering, Univ. of Adelaide, Adelaide, SA 5005, Australia
(2) Dept. of Civil and Environmental Engineering, Hong Kong Polytechnic Univ., Hong Kong, China


ABSTRACT: This paper investigates the behavior of octagonal high-strength steel tubular cross sections under axial compression. Experimental investigations were conducted on cross sections with three nominal dimensions fabricated from different routes of welding or combinations of cold-bending and welding. Material properties and geometric imperfections of the cross sections were measured and are reported here. A total of 18 stub column tests were carried out; load-deformation histories and failure modes of octagonal high-strength steel tubular-section stub columns are presented and discussed. Nonlinear finite-element models were validated to replicate the stub column tests and subsequently applied to carry out parametric studies for further investigating the structural performance of octagonal tubular cross sections with various slenderness values under axial compression. The results from experiments and finite-element modeling are used to evaluate the applicability of codified cross-section classification limits and various existing design methods to octagonal high-strength steel tubular cross sections under axial compression. Modifications to the cross-section
classification limits and design methods are proposed to obtain more accurate predictions of cross-section classification and strengths of structures for efficient structural design.

Jia-Lin Ma (1), Tak-Ming Chan (2) and Ben Young (2)
(1) Dept. of Civil and Environmental Engineering, Tongji Univ., Shanghai 200082, China
(2) Dept. of Civil and Environmental Engineering, Hong Kong Polytechnic Univ., Hong Kong, China
“Cold-Formed High-Strength Steel Rectangular and Square Hollow Sections under Combined Compression and Bending”, ASCE Journal of Structural Engineering, Vol. 145, No. 12, December 2019, https://doi.org/10.1061/(ASCE)ST.1943-541X.0002446
ABSTRACT: High-strength steel is gaining more attention from engineers due to its high strength-to-weight ratio and cost effectiveness. However, the research on cold-formed high-strength steel (CFHSS) tubular members subjected to combined compression and bending is limited. This paper, therefore, presents an experimental investigation on this combined loading scenario, in particular at the cross-section level. The test specimens consisted of five square hollow section sizes and two rectangular hollow section sizes. The nominal proof stresses of the test specimens were between 700 and 900 MPa. A total of 51 short beam-columns were tested to investigate the behavior of CFHSS rectangular and square hollow sections subjected to combined compression and bending. A set of different initial loading eccentricities were adopted to attain a wide range of bending-to-compression ratios. The compression and bending capacities, load-deformation histories, and failure modes of the test specimens were reported. Based on the test results, the design methods described in American, Australian, and European codes were evaluated. Finite-element modeling methodology for CFHSS tubular beam-columns is also presented.

ABSTRACT: Designers favor laminated glass due to its inherent robustness. However, there is disparity between the various design codes currently available for laminated glass and the methods therein for calculating resistance to lateral-torsional buckling. This study examines the effective thickness methods found in some existing codes, which calculate the degree of composite action achieved by a laminated glass section subject to in-plane loading. These design methods are compared using relevant accompanying methods from the standards to calculate buckling loads and glass strength where appropriate to gain an understanding of how these methods are implemented in the industry. Results from the calculations are compared to published experimental data in order to assess the relative accuracy and range of applicability of each method. A parametric study is also undertaken, using results from a numerical model to predict the lateral-torsional buckling capacity of laminated glass sections with various geometries and properties. A significant range in results from the various design methods has been observed. It has also been found that some design methods give consistently nonconservative results.

Fei Lyu (1), Yoshiaki Goto (1), Naoki Kawanishi (2) and Yan Xu (3)
(1) Dept. of Civil Engineering, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan
(2) Dept. of Civil Engineering, National Institute of Technology, Toyota College, Toyota 471-8525, Japan
(3) Dept. of Bridge Engineering, Tongji Univ., 1239 Siping Rd., Shanghai 200092, China
ABSTRACT: Thin-walled partially concrete-filled steel tubular (PCFT) columns have come to be used as the piers of elevated-girder bridges widely in Japan because of their excellent seismic performance: strength, ductility, and energy dissipation capacity. To consider this excellent seismic performance in design, it is essential to provide an analysis method to assess the ultimate behavior of the thin-walled PCFT columns by considering the cyclic local buckling of the steel tube, the behavior of the confined infilled concrete with cracks, and the interface action between the steel tube and infilled concrete. Up to the present, the shell–solid element model analysis has been the only numerical method that can be used to consider these complicated behaviors of
PCFT columns in a direct manner. However, the use of this model requires unrealistically long computation time and often encounters numerical difficulty to obtain convergent solutions when applied to large structural systems such as the elevated-girder bridge systems with the multiple thin-walled PCFT piers. The objective of the present research is to propose a practical three-dimensional fiber-based model with a failure segment that is computationally efficient, yet accurate enough to assess the ultimate behavior of PCFT columns. This model was calibrated by an optimization technique, only referring to the in-plane hysteretic behavior of each single PCFT column calculated by the shell–solid element model analysis. The calibrated model is applicable to the seismic analysis of large structural systems with multiple PCFT piers under arbitrary multidirectional seismic accelerations. The accuracy and numerical efficiency of the proposed fiber-based model in the analysis of PCFT columns were confirmed extensively by the comparison to the shell–solid element model analysis results and the results of tests, such as cyclic loading tests and shake table tests.

Weeraphan Jiampeepreecha (1), Jirayut Suebsuk (1) and Somchai Chuicheepsakul (2) (1) Dept. of Civil Engineering, Rajamangala Univ. of Technology Isan, Nakhon Ratchasima 30000, Thailand (2) Dept. of Civil Engineering, King Mongkut’s Univ. of Technology Thonburi, Bangkok 10140, Thailand “Nonlinear Static Analysis of Liquid-Containment Toroidal Shell under Hydrostatic Pressure”, ASCE Journal of Structural Engineering, Vol. 146, No. 1, January 2020, https://doi.org/10.1061/(ASCE)ST.1943-541X.0002460

ABSTRACT: This paper presents a nonlinear static analysis of a liquid-containment toroidal shell subjected to linearly hydrostatic pressure, including the effect of constraint volume for the toroidal shell and internal compressible liquid. The geometry of the liquid-containment toroidal shell is defined as a circular cross section. The principle of virtual work was used to formulate the nonlinear finite-element model, including the fluid-structure interaction effect for the liquid-containment toroidal shell system. The formulation was written in an appropriate form in order to reduce the computation time. An iterative procedure was used to solve the nonlinear numerical solutions for the statically deformed configuration of the shell and changes in internal pressure. The numerical result from a commercial program was used to verify the proposed nonlinear finite element model. The effects of bulk modulus of internal liquid, initial internal pressure, sea water depth, thickness, and cross-sectional radius of the liquid-containment toroidal shell on the static displacement and internal pressure responses of the liquid-containment toroidal shell are investigated and discussed in this paper.


ABSTRACT: Special-shaped multicell composite concrete-filled steel tube (CFT) columns have been used in several super-high-rise buildings. However, research on special-shaped multicell CFT columns under low cyclic loading remains limited. Thus, seven 1/30-scaled specimens were designed for a low cyclic loading test. The parameters are four cross-section structures (i.e., the basic type, angle steel reinforced type, circular steel tube reinforced type, and simplified type) and three loading directions (i.e., the long axis, short axis, and 45°). The failure modes, hysteretic behavior, bearing capacity, ductility, and energy-dissipation capacity were analyzed. The results show that the angle steel and circular steel tube significantly increase the bearing capacity and energy dissipation. The circular steel tube has a better effect than the angle steel. The bearing capacity of the simplified-type specimens decreases but the ductility increases. When the loading direction changes from the long axis to the short axis, the ductility gradually increases, whereas the bearing capacity and energy-dissipation capacity gradually decrease. The optimized models of the fiber-based method (FBM) were proposed to predict the $N-M$ curves and $F-\Delta$ curves. The concrete constitutive relationship in the multicell CFT was proposed based on the separation model by analyzing the features of multicell CFT columns and was used in the optimized fiber-based method. The numerical simulation models were established using Abaqus to simulate the $F-\Delta$ curves for FBM models and test. The calculation results show good consistency with the test.

Song Hong Pham (1), Cao Hung Pham (1), Colin A. Rogers (2) and Gregory J. Hancock (1)
Subodh Kolwankar (1), Amit Kanvinde (1), Maha Kenawy (1), Dimitrios Lignos (2) and Sashi Kunnath (1)
(1) Dept. of Civil and Environmental Engineering, Univ. of California, Davis, CA 95616
(2) Dept. of Architecture, Civil and Environmental Engineering, Ecole Polytechnique Fédérale de Lausanne, Lausanne 1015 CH, Switzerland


ABSTRACT: Steel beam-columns subjected to cyclic loading (such as during earthquakes) may exhibit local buckling, which results in effective cross-sectional softening and localization of deformation. These phenomena are critical from the standpoint of performance and collapse assessment. Fiber-based elements are attractive for simulating beam-column response because they capture P-M interactions and the spread of plasticity and can be generalized to different cross sections from material-level calibrations. However, conventional fiber models typically employ softening constitutive material laws to represent local buckling. Without a regularizing length scale, this results in a nonelliptic boundary-value problem, leading to severe mesh dependence. A two-dimensional nonlocal fiber-based beam-column model is presented to address this issue for steel wide-flange sections subject to combinations of axial and cyclic lateral loads. The methodology includes the following elements: (1) a constitutive material model that is able to represent inelastic cyclic local buckling, (2) a nonlocal strain formulation that incorporates a physically based length scale, and (3) suggested practices for input selection and parameter calibration. Forty-two continuum finite-element models (encompassing a range of parameters including cross section, axial load ratio, moment gradient, and loading history) are constructed to inform as well as validate the presented methodology. The methodology simulates various aspects (load-deformation response, localized deformation, and column axial shortening) with accuracy and without mesh dependence. This is in contrast to conventional fiber models that exhibit severe mesh dependence. Limitations are discussed.
those composite members. The proposed equation quantifies the contribution of that strut to total strength as a function of shear span and accounts for the interactions between the steel tube and the concrete infill. The effectiveness of the proposed equation was compared with shear test data from the existing literature and was found to be safe; it accurately captures the contribution of the steel tube to the total strength and conservatively estimates that of the concrete.

Jiangang Wei (1), Xia Luo (1), Zhichao Lai (1) and Amit H. Varma (2)  
(1) College of Civil Engineering, Fuzhou Univ., Fuzhou, Fujian 350116, China  
(2) School of Civil Engineering, Purdue Univ., West Lafayette, IN 47907  
“Experimental Behavior and Design of High-Strength Circular Concrete-Filled Steel Tube Short Columns”,  
ASCE Journal of Structural Engineering, Vol. 146, No. 1, January 2020,  
https://doi.org/10.1061/(ASCE)ST.1943-541X.0002474  
ABSTRACT: This paper investigates the behavior of high-strength circular concrete-filled steel tube (CFST) short columns. An experimental database consisting of 87 tests conducted on high-strength circular CFST short columns was compiled, and gaps in the existing research were identified. A total of 20 tests were then conducted to address the gaps in the database. The test parameters were the diameter-to-thickness ratio of the steel tubes $D/t$, the yield stress of steel $F_y$, and the compressive strength of concrete $f'_c$. The tests indicated that the strength of high-strength circular CFST short columns increases with increasing $F_y$ and $f'_c$, but decreases with increasing $D/t$. All tested high-strength circular CFST short columns had acceptable ductility. Four of the specimens did not have any strength degradation, while the other 16 specimens retained at least 70% of their strength at strains of 5%. Results from the tests conducted in this research were combined with those from the compiled database; the combined results were used to evaluate the applicability of current design equations for estimating the cross-sectional strength of high-strength circular CFST columns. The evaluations indicated that the Japanese code provides the most accurate estimation.

Gabriel Sabau (1), Ove Lagerqvist (1) and Nancy Baddoo (2)  
(1) Dept. of Civil, Environmental and Natural Resources Engineering, Luleå Univ. of Technology, Luleå 971 87, Sweden  
(2) Steel Construction Institute, Silwood Park, Ascot SL5 7QN, UK.  
https://doi.org/10.1061/(ASCE)ST.1943-541X.0002529  
ABSTRACT: Flexural buckling is one of the main problems steel structures are faced with in ensuring an economic design. In Europe, the buckling resistance is calculated using an imperfection factor based on the section type, fabrication method, and steel grade. The current European design standards contain guidelines for the imperfection factor for sections made of steels with yield strength up to and including 700 MPa. However, the current design codes are based mainly on tests performed on steels with yield strength below 460 MPa. Therefore, the applicability of the methodology was reassessed. This paper reviewed the background documentation of the European flexural-buckling design methodology and discussed the current design practice described in the American National Standard. A total of 72 flexural-buckling experiments performed on cold-formed, hot-finished, and welded sections made of steel with yield strength in the range 690–960 MPa were collected and analyzed. Four models for estimating the resistance of high-strength steel struts subjected to pure compression were statistically evaluated based on the collected data. Finally, a recommendation for the estimation of flexural-buckling resistance of high-strength steel members is presented.

Julien Cravero (1), Ahmed Elkady (2) and Dimitrios G. Lignos (3)  
(1) Hydrology Meteorology and Complexity (HMCO)|Navier, Ecole des Ponts ParisTech, 6–8 Ave. Blaise Pascal, 77420 Champs-sur-Marne, France  
(2) Faculty of Engineering and Physical Science, Univ. of Southampton, Burgess Rd., Bolderwood Innovation Campus, B178/4017, Southampton SO16 7QF, UK  
(3) IIC, RESSLab, ENAC, École Polytechnique Fédérale de Lausanne (EPFL), GC B3 485 Station 18, CH-1015 Lausanne, VD, Switzerland

ABSTRACT: This paper presents results from an experimental evaluation on the pre- and post-buckling behavior of 12 steel wide-flange cantilever columns under axial load and lateral drift demands. The influence of several loading and geometric parameters, including the cross-sectional local web and flange slenderness ratios, applied axial load, and lateral and axial loading history on the performance of these columns is thoroughly examined. The test data indicate that cross-sectional local buckling is highly asymmetric in steel columns under variable axial load. A relatively high compressive axial load can significantly compromise the steel column seismic stability and ductility, but this also depends on the imposed lateral loading history. The AISC axial load–bending moment interaction equation provides accurate estimates of a steel column’s yield resistance. However, the same equation underestimates by at least 30% the column’s peak resistance, regardless of the loading scenario. Measurements of column flange deformation, axial shortening, flexural resistance, and lateral drift are combined in a single graphical format aiding the process of assessing steel column repairability after earthquakes. The test data suggest that current practice-oriented nonlinear component modeling guidelines may not provide sufficient accuracy in establishing both the monotonic and first-cycle envelope curves of steel columns. It is also shown that high-fidelity continuum finite-element models should consider geometric imperfections of proper magnitude, in addition to the steel material inelasticity, to properly simulate the inelastic buckling of wide-flange steel columns and generalize the findings of physical tests. Issues arising due to similitude are also discussed to properly limit steel column instability modes in future studies.

Bernard A. Frankl (1) and Daniel G. Linzell (2)
(1) Bridge Engineer, HDR, Lincoln, NE 68508
(2) Dept. of Civil Engineering, Univ. of Nebraska-Lincoln, Lincoln, NE 68508


ABSTRACT: Development and implementation of horizontally curved steel members, particularly curved plate girders utilized by the bridge industry for complicated site geometries, continue to occur, and material, analysis, and design advancements allow for more efficient and cost-effective cross sections, resulting in increasingly slender elements. A central byproduct of this enhanced efficiency has been the need to further investigate and mitigate possible global and local stability issues for very slender webs that are primarily loaded in shear. Classical work related to thin plate stability under shear forces was completed by a number of researchers, most notably consisting of work by Timoshenko published in the 1930s. This research produced an equation for the elastic, critical shear-buckling stress and utilized a coefficient, termed the shear-buckling coefficient, to account for plate aspect ratio and edge conditions. The work summarized herein focused on following Timoshenko’s approach to derive equations for simply supported, slender plates that explicitly accounted for horizontal curvature. Steps and assumptions used to derive these equations are presented in detail. A summary of the influence of horizontal curvature on variations of the derived shear-buckling coefficient over a range of geometric properties demonstrated that (1) the derived formulation is reduced to Timoshenko’s formulation for a flat plate; (2) the shear-buckling coefficient of curved plates is dependent on the curvature as well as the web slenderness ratio; and (3) the horizontal curvature could significantly influence the shear-buckling capacity for slender elements.

Nima Talebian (1), Benoit P. Gilbert (1), Cao Hung Pham (2), Romain Chariere (1) and Hassan Karampour (1)
(1) Griffith School of Engineering, Griffith Univ., Gold Coast Campus, Gold Coast, QLD 4222, Australia
(2) School of Civil Engineering, Univ. of Sydney, Sydney, NSW 2006, Australia


ABSTRACT: This paper first describes a finite element model using advanced analysis to determine the biaxial bending capacity of cold-formed steel storage rack upright sections. The model is found to accurately predict published experimental results with an average predicted to an experimental capacity ratio of 1.02. Second, the validated model is used to run parametric studies and analyze the biaxial response of slender, semicompact and compact unperforated storage rack upright cross sections. Analyses are run for local and distortional buckling
failure modes only. Nine biaxial bending configurations are considered per cross section and buckling mode. Results show that a nonlinear interactive relationship typically governs the biaxial bending of the studied uprights. This relationship is discussed and analyzed for the different failure modes and cross-sectional slenderness. The results from the parametric studies are used to verify the accuracy of different forms of published direct strength method (DSM) equations. They consist of the classical DSM equations and the use of inelastic reserve capacity in the DSM with and without using an extended range of the cross-sectional slenderness. Results show that for all investigated buckling modes, the DSM results in better predictions when the inelastic reserve capacity is considered. The appropriate form of the DSM to predict the biaxial capacity of unperforated cold-formed steel storage rack uprights is discussed.

Jie Wang and Adam J. Sadowski, “Elastic Imperfect Cylindrical Shells of Varying Length under Combined Axial Compression and Bending”, ASCE Journal of Structural Engineering, Vol. 146, No. 4, April 2020, ABSTRACT: This paper presents a comprehensive computational investigation of the elastic nonlinear buckling response of near-perfect and highly imperfect uniform-thickness thin cylindrical shells of varying length under combined uniform compression and bending. In particular, the elastic ovalization phenomenon in cylindrical shells of sufficient length under combined compression and bending was systematically investigated with finite elements for the first time. The study considered a representative range of practical lengths up to very long cylinders in which ovalization is fully developed under uniform bending and Euler column buckling controls under uniform axial compression. The imperfection sensitivity of the system was studied by introducing a single idealized axisymmetric weld depression imperfection at the midspan of the cylinder. The predictions permit an exploration of the nonlinear mechanics of the generally unfavorable interaction between bending and axial compression at the elastic nonlinear buckling limit state in thin long cylinders. The interaction is at its most unfavorable in cylinders where Euler column buckling is about to become critical, and is qualitatively very different from the favorable moment-force interaction at the reference plastic limit state of circular tubes. A simple closed-form algebraic characterization of the interaction is proposed considering both imperfections and ovalization.

Husam Alsanat, Shanmuganathan Gunalan, Keerthan Poologanathan, Hong Guan and Charalampos Baniotopoulos, “Fastened Aluminum-Lipped Channel Sections Subjected to Web Crippling under Two-Flange Loading Conditions: Experimental Study”, ASCE Journal of Structural Engineering, Vol. 146, No. 4, April 2020, ABSTRACT: Thin-walled members in structural systems are highly vulnerable to buckling instabilities, including web crippling. Aluminum alloy members are more prone to this kind of failure due to their relatively low elastic moduli. As shown in the existing literature, limited research has been performed to investigate the web crippling failure of aluminum members. This paper presents the details of an experimental investigation conducted to study the web crippling phenomenon of fastened (restrained flanges) aluminum-lipped channel (ALC) sections. Two loading conditions, end-two-flange and interior-two-flange loading, were considered. Two series of 40 tests were performed using roll-formed aluminum alloy 5052 H36 specimens with different web slenderness and load-bearing lengths. A comparison between the ultimate capacities of the web crippling tests and the predictions from the currently available design rules was performed. The results show that the current web crippling design rules are mostly unsafe and unreliable for fastened ALC sections. Thus, a modified equation is needed to closely and accurately estimate the web crippling strengths for fastened ALC sections under two-flange loading conditions. Furthermore, the effect of restrained flanges on the web crippling mechanism is discussed in detail. It was observed that fastening the flanges considerably strengthened the section web crippling capacity. Hence, a new prediction approach was developed to estimate the increase of the web crippling capacity due to flange restraining.

Man-Tai Chen and Ben Young, “Tests of Cold-Formed Steel Semi-Oval Hollow Section Members under Eccentric Axial Load”, ASCE Journal of Structural Engineering, Vol. 146, No. 4, April 2020, ABSTRACT: This paper describes the experimental study conducted on cold-formed steel semi-oval hollow sections (SOHS) under combined compression and uniaxial bending. Thirty-seven SOHS beam-columns with two different specimen lengths were compressed at various loading eccentricities in order to investigate the load-moment interaction relationship for each test series. The ultimate load-carrying capacities and full load-displacement responses are presented. It should be noted that the design of cold-formed steel semi-oval slender
Yu Bai and Chengyu Qiu, “Load-Dependent Composite Action for Beam Nonlinear and Ductile Behavior”, ASCE Journal of Structural Engineering, Vol. 146, No. 4, April 2020,
ABSTRACT: Ductile performance of beam structures often is achieved by material yielding or progressive failure of components. A new structural concept was developed and validated in this study to provide ductile responses of beam structures through load-dependent composite action resulting from the change in the modulus of shear connection. Layered beam specimens made from linear elastic fiber-reinforced polymer (FRP) members shear-connected by a nonlinear elastoplastic adhesive were tested to demonstrate this concept. Evidenced by the shear slip between the beam layers and the section strain distribution, the decrease in beam stiffness and thus the ductile load-displacement response originates from the reduced composite action between the beam layers. Recovery of the beam residual deformation after unloading occurred because of the nonlinear elastoplastic behavior of the adhesive. Finite-element (FE) modeling was conducted and well described the ductile load-displacement response and the change in composite action. Parametric studies were carried out to clarify the effects of adhesive modulus and strength on the load-dependent composite action and overall ductile performance. FE modeling was conducted to demonstrate the applicability of the concept for further engineering practice.

ABSTRACT: Generally speaking, steel beams are mechanically assembled with a concrete slab and stud shear connectors. The concrete slab works as a restraint against buckling instability such as lateral and lateral—torsional buckling of a steel beam. During an earthquake, the concrete slab is subjected to fully reversed stress. Previous studies have shown that the concrete slab begins to crack under tensile stress and that the composite effect is considerably degraded more than under compressive stress. The restraint effect therefore possibly degrades under negative bending. Eventually, beams have less than their expected lateral and lateral—torsional buckling strength. To alleviate this concern, cyclic loading tests were conducted on a component model of a composite beam subjected to in-plane displacement and out-of-plane rotation. Furthermore, the formulae for evaluation of the ultimate rotation strength and stiffness were constructed considering the influence of the stud specification and loading protocol.

Zhaochao Li, Fujian Tang, Yizheng Chen, Yan Tang and Genda Chen, “Elastic Buckling of Thin-Walled Liners Encased in Partially Grouted Pipelines under External Pressure”, ASCE Journal of Structural Engineering, Vol. 146, No. 4, April 2020,
ABSTRACT: In this study, the pressure-displacement equilibrium path and the elastic buckling pressure were formulated analytically for a thin-walled circular liner encased in a partially grouted pipeline–liner system. Numerical verification was conducted in the plane strain condition assuming a frictionless interface between the pipeline and the liner. Nonlinear equilibrium equations were developed to obtain the theoretical solutions by employing the principle of minimum potential energy and admissible displacement functions of the liner selected for different pipeline–liner contact conditions. The external pressure increases proportionally with displacement to an initial limit when the liner is not restrained by the pipeline, varies slightly to a lower bound due to geometrical nonlinearity, suddenly increases again to the critical buckling due to pipeline confinement, and finally decreases rapidly in the postbuckling stage. The confinement effect on the buckling pressure of the liner, defined by a ratio of the critical and initial pressures, decreases with an increase of void thickness between the liner and the pipeline. The analytical solution in critical buckling pressure differed from the numerical result.
by less than 6%. Both the analytical and numerical predictions were consistent with other available closed-form solutions in special cases.


ABSTRACT: Narrow width I-girder systems with relatively long lengths are susceptible to global lateral-torsional buckling, which is a mode that is not generally sensitive to the spacing between cross frames or diaphragms. This buckling mode can control the capacity of girder systems in a variety of structural systems ranging from bridge to building applications that use torsional bracing. Because of global instability, these systems can experience excessive deformation during construction, which severely compromises the safety or constructability of the steel girder systems. This paper documents an investigation into the elastic buckling behavior of these systems and considers many variables that impact this behavior during construction. This study included eigenvalue buckling analyses to determine critical buckling loads and large-displacement analyses on girders with initial imperfections. Load-deflection analyses indicated that the second-order amplification of both lateral and torsional displacements of the girder system is highly dependent on the shape and distribution of the imperfection. Although the “critical shape” imperfection is identified, the study also considers the likelihood of this shape occurring in practice by simulating the installation of torsional braces during erection. Although the girder system may initially possess an imperfection close to the “critical shape,” the installation of braces generally reduces the severity of the initial imperfection with respect to second-order amplification associated with global lateral-torsional buckling. Design recommendations are presented based on the inclusion of moment gradient modification factors and limits on the elastic global lateral-torsional buckling expression to control second-order effects in narrow girder systems.


ABSTRACT: This paper focuses on local buckling and axial compressive behavior of steel-plate composite (SC) walls. SC walls are comprised of a concrete wall sandwiched between two steel faceplates on the surfaces. The steel faceplates are anchored to the concrete core using stud anchors and (or) ties and connected to each other using ties. When subjected to axial compression, the steel faceplates can undergo local buckling between the anchor points. The local buckling and axial compressive behavior of SC walls depend on the faceplate slenderness ratio, reinforcement ratio, and strength of steel and concrete materials. A database of axial compressive tests conducted around the world is compiled and analyzed to evaluate the influence of various parameters on the local buckling and axial compressive behavior of SC walls. Experimental investigations are conducted on nine SC wall specimens with a wide range of faceplate slenderness parameters to further evaluate the local buckling and axial compressive behavior of SC walls. The test results are discussed in detail and added to the existing database. Using the enhanced database, a design equation is proposed to calculate the axial compressive strength of SC walls. A standard reliability analysis is performed to calculate an appropriate strength reduction factor (\(\phi\)) for the proposed equation.


ABSTRACT: Buckling analysis of spherical concrete domes constructed over prestressed concrete tanks subjected to gravity and earthquake load combinations is complex due to the sensitivity of spherical dome buckling to geometric imperfection, the effect of creep and shrinkage on amplifying the deflection of the dome (increasing the radius of curvature of the deformed dome and reducing the buckling resistance), and the geometric and material nonlinearity of the concrete dome. Study of imperfections has shown that imperfections that increase the average radius of curvature in an area the size of an elastic buckle have the highest impact in reducing buckling strength; thus, the problem of buckling of the concrete dome is reducible to the snap-through buckling of a shallow cap equal in size to an elastic buckle of the dome. In this paper, the buckling of a shallow cap subjected to gravity and seismic load combinations is determined using nonlinear geometry, material nonlinearity of concrete (accounting for softening and cracking in tension and microcracking and crushing in compression), and time-dependent creep and shrinkage of concrete. The analysis is performed in three steps: in the first step, the cap is analyzed for gravity loads; in the second step, the cap is analyzed for the effects of creep
and shrinkage strains; and in the third step, the earthquake load is applied until the snap-through buckling occurs. The analysis was carried out on a set of domes designed for gravity load combinations alone. These domes cover the extremes of size and rise of the domes that are currently constructed over prestressed concrete tanks. The results show that the majority of existing domes that are not in high-seismicity zones and are designed for gravity load combinations have capacity for earthquake loading. The results are also of value in the design of new domes for load combinations that include earthquake loading.


ABSTRACT: Concentrically braced frames (CBFs) are commonly used in steel building structures to rapidly increase structural stiffness, especially in high seismic regions. However, conventional buckling braces have been verified to typically provide low ductility due to premature failures of local buckling and fracture. An innovative steel brace with a novel mechanism was previously developed to improve the seismic performance of steel braces. This study performed an additional experimental investigation on a series of subassemblage naturally buckling brace (NBB) specimens along with knife-plate end connections to evaluate the slenderness effects, fabrication details of the channel segments, and batten dimensions on the hysteretic properties of NBBs. It was found that stocky NBBs provided more comparable strength backbone curves between tension and compression and later local buckling and fracture initiation compared to slender ones. A general numerical modeling approach was proposed and verified to accurately capture all yield mechanism as well as measured responses. An analytical parametric study covering a wide variation of features, dimensions, and steel grades was then performed to establish an estimation of the strength backbone curve of NBBs. The proposed model equations were found to accurately estimate the yield strength and initial and postyield stiffness of NBBs in tension and compression, respectively.


ABSTRACT: The grooved-type dissipater is an axial, metal hysteretic dissipative device. It is an alternative to the epoxy- or grout-filled buckling restrained fuse (BRF)-type dissipater. This device consists of a mild steel rod which has grooves milled into it to reduce the cross-sectional area to form the fuse. A thick-walled circular hollow section (antibuckling tube) covers the fuse length and prevents global inelastic buckling of the fuse in compression. The advantage of this device is that it consists of only two parts and does not require the use of expensive grout or epoxy filler. This paper describes a state-of-the-art device, presented formulations describing important geometric properties and discussed their engineering implications, presented experimental and numerical investigations undertaken to characterize the low-cycle fatigue life of the grooved dissipater, and obtained coefficients to model this phenomenon using either the Fatigue material in OpenSees or the well-known Coffin–Manson equation and Palmer–Milgren damage rule.

Ji-Hua Zhu, Zi-qi Li, Meini Su and Ben Young, “Design of Aluminum Alloy Channel Section Beams”, ASCE Journal of Structural Engineering, Vol. 146, No. 5, May 2020,

ABSTRACT: Aluminum alloy members of channel sections are widely used in lightweight structures, especially as pillars of curtain wall systems and brace and chord members in roof trusses. This paper presents both experimental and numerical studies on the behavior of aluminum alloy channel section beams. In this study, four-point bending tests under minor-axis and major-axis bending were carried out. The test specimens included plain and lipped channel sections of both 6063-T5 and 6061-T6 aluminum alloys. A finite-element (FE) model of the channel section beam was developed by using the FE package ABAQUS. The ultimate bending resistances and failure modes of the FE model were compared with the results from the bending tests. The validated model was employed for the parametric study to generate numerical simulation results. A total of 55 new experimental and numerical beam results were compared with predictions from existing aluminum alloy design specifications from the United States, Australia/New Zealand, Europe, and China. Additionally, two commonly used design approaches—the continuous strength method (CSM) and the direct strength method (DSM)—were applied to predict bending capacities for comparisons. A modified DSM approach for aluminum alloy channel section beams is proposed herein. Finally, reliability analyses were conducted to evaluate the aforementioned design methods. The results show that, in comparison with other considered design methods,

ABSTRACT: This paper highlights the challenges before researchers who are working to understand the postbuckling mechanics of a stiffened web panel, design of transverse stiffener, mechanics of end panel, and the overall behavior of a plate girder subjected to shear, in general. It describes how the tension-field theories evolved to provide a solution to predict the postbuckling shear resistance and what the impact was of these theories on the design of different girder components. In addition, the paper describes how and why these theories failed to explain the rational mechanics involved in the postbuckling shear resistance. It also presents the alternative explanations provided by researchers who do not agree with the significance of tension-field action. From the analysis of these theories, their alternatives, and the latest research about other contributing factors to shear postbuckling mechanics, many future areas of research emerged. Many such important future areas of research are highlighted in this paper. This paper also underlines the need for an improvement in code provisions related to finite-element analyses.


ABSTRACT: An experimental investigation was conducted to assess the performance of a new buckling-restrained brace (BRB) system for retrofitting seismically deficient reinforced concrete frames. The BRB consists of a ductile inner steel core bar designed to yield in tension and compression without buckling while controlling the response to seismic forces. The core bar is contained within a tubular steel section, which in turn is housed in a larger tubular steel section infilled with mortar, providing lateral restraint against buckling. Self-consolidating mortar is used as filler material between the two tubular sections to increase the buckling resistance. The inner core bar is connected to innovative end units that allow extension and contraction during tension-compression cycles while providing lateral restraint against buckling. The new BRB system has been verified experimentally using two large-scale reinforced concrete frames, one of which was tested as a reference nonretrofitted frame and then repaired and retested three more times after BRB retrofits, while the other was retrofitted and tested, forming the fourth retrofitted frame test. Tests demonstrated substantial increases in the lateral load and energy dissipation capacities of retrofitted frames with satisfactory drift control. Three different types of steel bars with different strength and elongation characteristics were considered. Among the three, stainless steel provided the best strength, stiffness, and ductility enhancements.


ABSTRACT: During earthquakes, I-shaped beams (I-beams) in a braced structure are subjected to the flexural moment synchronized with reversed axial forces transmitted from buckling restrained braces. A prior study used the modified width–thickness ratio to evaluate the rotation capacity of I-beams that failed by local buckling under alternating axial force. Generally speaking, I-beams in braced frames are designed with larger sections to resist severe stress conditions. The buckling mode might thereby be switched to web-shear buckling, leading to inaccurate estimation of the rotation capacity when using existing equations. For this study, a classification index of buckling mode is constructed considering axial force and plate interactions. Moreover, a novel index and formulas are proposed for evaluating the rotation capacity of I-beams under alternating axial forces, including buckling-mode transition effects.


ABSTRACT: The direct strength method (DSM) is a newly developed design method for cold-formed steel members due to its reliability and consistency. It has been well developed and incorporated in the North American Specification and the Australian/New Zealand Standard for the design of cold-formed steel members under compression, bending, and recently, in shear. To date, there are no DSM rules for the design of cold-
formed members under localized loading resulting in the web-crippling phenomenon. Recent literature has attempted to propose the DSM design equations for four localized loading cases including the interior one-flange (IOF), end one-flange (EOF), interior two-flange (ITF), and end two-flange (ETF) loading cases specified in the design specifications/standards. However, these proposed DSM equations were calibrated differently depending on the types of loading cases and geometric shapes of the cross-sections by varying coefficients and exponents in the DSM equations. In this paper, consistent and simplified DSM equations previously proposed by the authors are explained and calibrated for use in the design specifications/standards. They include new plastic mechanism models developed for determining the yield load and also cover the design of sections in the inelastic reserve range as observed. Detailed explanations of the yield load \((P_y)\) component and references to computing the buckling load \((P_{cr})\) component are given. A design example is also included.


**ABSTRACT:** Hollow structural sections (HSS) are used as columns in frame systems because of their ability to efficiently resist multiaxial loads. While the majority of previous studies of special moment frames (SMFs) focused on wide flange columns, HSS columns can provide a means of increasing the versatility of SMFs. In order to fully explore the use of HSS columns in SMFs, the collapse behavior of HSS columns subject to combined axial and lateral loading is computationally studied. Seventeen different HSS profiles are selected to cover a wide range of local and global slenderness ratios, including width-to-thickness ratio \((b/t)\), depth-to-thickness ratio \((h/t)\), and the global slenderness ratio about the weak axis \((L/ry)\). Detailed finite element studies show that the behavior of HSS columns is highly dependent on the local slenderness ratios and the level of initial applied axial load \((P/P_y)\). A regression analysis is performed leading to a proposed design aid for HSS columns along with updated highly ductile local slenderness limits. The proposed highly ductile limits suggest that the current AISC limits for HSS columns are conservative when considering the width-to-thickness ratio and potentially unconservative when considering the depth-to-thickness ratio.


**ABSTRACT:** Closed-form equations for the initial thermal postbuckling response of axially restrained elastic columns with six well-known sets of rotational and lateral end restraints are presented. These equations, which are consistent with the conventional beam-column (Euler–Bernoulli) theory, are based on the assumption that the column axial force remains constant at the buckling level in the postbuckling phase, i.e., the (additional) thermal axial extension because of the increased temperature above the buckling temperature is converted into the column’s lateral deflection via the bowing effect. The equations consider the effects of partial axial restraints as well as the degradation of elastic material properties with rising temperatures. To evaluate their accuracy, the postbuckling response predicted by these approximate equations is compared to the exact (elastica) solutions available in the literature and to the finite-element solutions. The results of these validation studies indicate that these relatively simple closed-form equations can predict, with a high degree of accuracy, the initial thermal postbuckling response of axially restrained columns with the various rotational and lateral end restraints considered in this paper.

Ali Mansouri, “Shear Strength of Concrete-Filled Steel Tubes Based on Experimental Results”, ASCE Journal of Structural Engineering, Vol. 146, No. 6, June 2020,

**ABSTRACT:** Experimental results provided in the related literature are used in the present study to develop a method for estimating the shear strength of circular concrete-filled steel tubes (CFSTs). This study benefits from using the findings of a significant number of experimental specimens with high diversity in terms of experimental details such as geometric dimensions, material specifications, test setups, as well as axial load. Within this method, the shear strength of the CFST member is considered to be the sum of the shear strength of the steel tube and that of the concrete core. The parameters supposed to affect the shear strength of the concrete include confinement factor, shear span ratio, and axial load ratio. A comparison between the results of the

**ABSTRACT:** In the present study, effects of panel shapes on wind-induced vibrations of solar wing system under various wind environments were investigated through conducting a series of wind tunnel tests. A scaled solar wing system with solar panels connected by cables was manufactured. Vertical displacements of four panels were measured using laser displacement sensors. The tests showed that the largest mean displacements occurred in low-turbulence flow for wind directions 40°–60°. For fluctuating displacement, boundary-layer and grid-generated flows showed buffeting vibration for all wind directions, but the values were much larger in boundary-layer flows. When the wind direction was greater than 40°, characteristic vibrations were found for low-turbulence flow, showing limited and instability vibration for a specific panel shape and wind direction. Mean and fluctuating displacements were highly dependent on panel shapes and wind environments.


**ABSTRACT:** An experimental study was conducted to investigate the mechanical behavior and residual capacity of concrete-filled steel tubular (CFST) columns subjected to a post-earthquake fire. Nine circular cantilever CFST columns, including two control specimens, were tested to investigate their post-earthquake fire resistance time. The residual seismic behavior and load carrying capacity of an additional four columns were also studied following post-earthquake fire. All specimens were first subjected to a reversed cyclic or simulated earthquake loading (to induce initial seismic damage) and were then heated to obtain the fire resistance time or were subjected to additional cyclic reversed loading after a post-earthquake fire. The experimental results indicate that the CFST columns generally performed well after a post-earthquake fire. Specimens with high compressive strength concrete exhibited longer post-earthquake fire resistance times, whereas the increase in tube wall thickness only had a marginal effect on improving post-earthquake fire resistance. More importantly, the presence of residual lateral drift at the end of the earthquake loading had a much more significant effect on the post-earthquake fire performance than specimens without residual deformation. Finally, it is recommended that the failure criterion for fire loading should possibly take into consideration lateral deformation limits during fire testing.

Zhaoyu Xu, Genshu Tong and Lei Zhang, “Stiffness Demand on Stiffeners of Vertically Stiffened Steel Plate Shear Wall”, ASCE Journal of Structural Engineering, Vol. 146, No. 6, June 2020,

**ABSTRACT:** Elastic buckling of steel plate shear walls (SPSWs) vertically stiffened by either flat-bar or closed-section stiffeners is studied first to determine the required bending stiffness on stiffeners. The torsional stiffness of the stiffener is found to increase the buckling stress and reduce the required bending stiffness. The proposed equation for the elastic threshold stiffness is related to the increment of the elastic buckling stress of stiffened SPSWs over that of unstiffened SPSWs. Comparisons with previous research on stiffened plates are presented. For moderately thick and stocky plates, elastic-plastic buckling stress is used to define the threshold stiffness. It is found that the threshold stiffness based on elastic-plastic buckling stress is less than that based on elastic buckling stress. Replacing the elastic buckling coefficients with elastic-plastic buckling coefficients, the proposed equation gives good predictions for elastic-plastic threshold stiffness. The findings of this study may be helpful in understanding the real demand on stiffeners in stiffened SPSWs.

Hui Fang (1), Renxia Wu (1), Liya Duan (2) and Yong Liu (1)
(1) School of Engineering, Ocean Univ. of China, Qingdao 266100, China
(2) Institute of Oceanographic Instrumentation, Qilu Univ. of Technology, Shandong Academy of Sciences, Qingdao 266100, China

were measured prior to testing. The experimental results showed clear evidence of interaction between the local buckling of their components. A 3JD, UK

The material properties of the test specimens were determined by local buckling of M6 bolts. Each built-up beam was composed of three or four plain channels with nominal thicknesses of 1.2 and 1.5 mm, which were joined together using M6 bolts. Each built-up geometry was tested with three different connector spacings. The specimens were designed to fail by local buckling of their components. Additionally, strut buckling of the channel comprising the top flange in between connector points was observed. The local buckling deformations and the beam deflections were recorded during the tests. The material properties of the test specimens were determined by means of coupon tests and the geometric imperfections were measured prior to testing. The experimental results showed clear evidence of interaction between the local buckling

Luca Possidente (1), Nicola Tondini (1) and Jean-Marc Battini (2)

(1) Dept. of Civil, Environmental, and Mechanical Engineering, Univ. of Trento, Via Mesiano 77, Trento 38123, Italy
(2) Dept. of Civil and Architectural Engineering, Royal Institute of Technology, Stockholm SE-10044, Sweden

ABSTRACT: The paper presents the development of a three-dimensional (3D) beam element for the analysis of steel structures in fire that properly accounts for the degradation of the torsional strength and stiffness owing to thermal exposure. The element is well-suited for the analysis of members that are subjected to significant torsional effects, as steel members with open cross-sections subjected to torsion, lateral-torsional buckling, and torsional buckling. The element is based on a corotational formulation and small strains assumption, while the local formulation was developed according to both the Timoshenko and Bernoulli beam theories. The stress-strain relationship and thermal expansion of steel were implemented according to Eurocode EN 1993-1-2 (CEN 2005). A comprehensive numerical analysis was performed and results for several case studies are presented in the paper to assess the performance of the 3D beam element. The outcomes indicated very good agreement when compared with shell-based models, highlighting promising capabilities of modeling steel structures in fire. Moreover, the proposed element showed more accurate results with respect to beam elements included into two commercial software, i.e., ABAQUS and SAFIR.

Francisco J. Meza (1), Jurgen Becque (2) and Iman Hajirasouliha (2)

(1) The Steel Construction Institute, Silwood Park, Ascot, SL5 7QN, UK
(2) Dept. of Civil and Structural Engineering, The Univ. of Sheffield, Sir Frederic Mappin Bldg., Mappin St., Sheffield S1 3JD, UK

ABSTRACT: This paper describes a comprehensive experimental program on cold-formed steel built-up beams with two different cross-sectional geometries. The work aimed to experimentally investigate the interaction between the individual components under increasing loading and to quantify the effect of the connector spacing on the cross-sectional moment capacity and the behavior of the beams. In total, 12 specimens were tested in a four-point bending configuration, with lateral restraints provided at the loading points in order to avoid global instabilities. The built-up specimens were composed of three or four plain channels with nominal thicknesses of 1.2 and 1.5 mm, which were joined together using M6 bolts. Each built-up geometry was tested with three different connector spacings. The specimens were designed to fail by local buckling of their components. Additionally, strut buckling of the channel comprising the top flange in between connector points was observed. The local buckling deformations and the beam deflections were recorded during the tests. The material properties of the test specimens were determined by means of coupon tests and the geometric imperfections were measured prior to testing. The experimental results showed clear evidence of interaction between the local buckling
patterns of the components, with the interaction being affected by the connector spacing and the type of geometry. However, the connector spacing showed a less significant effect on the ultimate capacity when failure was governed by local instabilities of the components.

Javier A. Avecillas and Matthew R. Eatherton (Dept. of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA 24061), “Controlling Out-of-Plane Buckling in Shear-Acting Structural Fuses through Topology Optimization”, ASCE Journal of Structural Engineering, Vol. 146, No. 7, July 2020, ABSTRACT: Shear-acting structural fuses rely on steel plates subjected to in-plane lateral displacements that dissipate energy through shear yielding or may have cutouts that result in shear or flexural yielding of ductile local mechanisms. However, the relatively high slenderness of the plates makes them prone to buckling, reducing the strength and energy dissipation capacity. The current study aims to facilitate local yielding mechanisms in shear structural fuses while resisting buckling. First, a genetic algorithm is implemented to find optimized topologies for structural fuses with a square domain and constant thickness. An objective function is formulated using the elastic shear buckling load obtained from a 3D eigenvalue analysis and the shear yield load obtained from a material nonlinear, but geometrically linear 2D plane-stress analysis. The ratio of shear yield load divided by shear buckling load is used as a way to control the amount of yielding expected before buckling. The set of new optimized topologies are interpreted into smooth shapes and analyzed using finite element models to evaluate their effectiveness. The finite element simulations show that the optimized geometries can resist buckling through inelastic displacement cycles with up to five times larger displacements than those that cause buckling in previously studied structural fuse shapes.

Hong-Song Hu (1), Hao-Zuo Wang (1), Zi-Xiong Guo (1) and Bahram M. Shahrooz (2) (1) College of Civil Engineering, Huaqiao Univ., Xiamen 361021, China (2) Dept. of Civil and Architectural Engineering and Construction Management, Univ. of Cincinnati, 765 Baldwin Hall, Cincinnati, OH 45221-0071. “Axial Compressive Behavior of Square Spiral-Confined High-Strength Concrete-Filled Steel-Tube Columns”, ASCE Journal of Structural Engineering, Vol. 146, No. 7, July 2020, ABSTRACT: A new type of concrete-filled steel plate (CFSP) composite shear wall that employs high-strength concrete (HSC) and square spiral-confined concrete-filled steel tube (SCCFST) boundary elements was proposed to reduce the core wall thickness of skyscrapers. Since the axial compressive behavior of the SCCFST boundary elements is essential to the overall seismic performance of the proposed composite shear wall, studies on square SCCFST members with HSC were first conducted to lay a foundation for further studies on the composite shear walls. Twelve SCCFST specimens and two conventional concrete-filled steel tube (CFST) specimens with the concrete compressive strength of 112 MPa were tested. The test variables included the amount and yield strength of the spiral and the ratio of the spiral-confined area to the total concrete area. The axial load capacities of the SCCFST specimens were essentially not increased, whereas the postpeak performances of the SCCFST specimens were significantly improved in comparison with the corresponding CFST specimen. The spirals in all the SCCFST specimens ruptured several times during the test, and each spiral rupture induced a considerable drop in the axial load of the specimens with high-strength spirals. The trend of the ductility of the concrete in SCCFST columns can be well captured by the spiral confinement index which reflects the effects of both the amount and strength of the spiral. Design expressions were derived based on the test results to determine the amount of spirals required for the boundary elements of the proposed composite shear wall using 110 MPa concrete.

Cheng Fang (1), Feng Zhou (1), Zhuoyue Wu (2) and Facheng Wang (3) (1) Dept. of Structural Engineering, Tongji Univ., Shanghai 200092, China (2) Fujian Provincial Institute of Architectural Design and Research, No. 1 Architectural Design Unit, No. 188 Tonghu Rd., Fuzhou 350001, China (3) Dept. of Civil Engineering, Tsinghua Univ., Beijing 100084, China “Concrete-Filled Elliptical Hollow Section Beam-Columns under Seismic Loading”, ASCE Journal of Structural Engineering, Vol. 146, No. 8, August 2020, https://doi.org/10.1061/(ASCE)ST.1943-541X.0002693 ABSTRACT: The seismic behavior of elliptical hollow section (EHS) beam-column members was examined in this study. A comprehensive experimental investigation was conducted on 14 concrete-filled and four bare steel EHS beam-column specimens under combined compression and cyclic bending. The main testing parameters
were tube wall thickness, axial load ratio, and bending direction. Among other findings, it was revealed that the bare steel specimens failed in local buckling, whereas the concrete-filled members exhibited more diverse failure modes, including local buckling, a fracture of the steel section following local buckling, and an abrupt fracture of the steel section with no evident local buckling. The failure modes largely depended on the bending direction. Due to the beneficial effects of material hardening and steel-concrete interaction, the moment resistance obtained from the test was consistently larger than the predicted plastic moment resistance. In addition, the specimens exhibited satisfactory ductility and energy dissipation performance, and both characteristics could be effectively improved by either increasing the compactness of the steel section or by applying the concrete infill. The strength, ductility, and energy dissipation characteristics of the specimens subjected to biaxial bending fell between the cases of major-axis and minor-axis bending. Based on the test results, the existing design methods for predicting the moment resistance of the considered members were evaluated. A preliminary design equation for ductility prediction was also proposed.

Song Hong Pham, Cao Hung Pham and Gregory J. Hancock (School of Civil Engineering, Univ. of Sydney, Sydney, NSW 2006, Australia), “Transverse Stiffener Requirements for Shear Postbuckling of Cold-Formed Steel Channels”, ASCE Journal of Structural Engineering, Vol. 146, No. 8, August 2020, https://doi.org/10.1061/(ASCE)ST.1943-541X.0002706

ABSTRACT: The enhanced shear strength of transversely stiffened shear panels compared to the strengths of the unstiffened has been well recognized in the Specification for Structural Steel Buildings (AISC 360) and the North American Specification for the Design of Cold-Formed Steel Structural Members (AISI S100). The requirements for the transverse stiffeners to secure such strength enhancement was similar in early versions of the two specifications, but the Specification for Structural Steel Buildings has recently adopted a whole new approach to reflect more closely the actual mechanistic behavior of stiffeners in the context of steel plate girders. The paper presents a series of shear tests on cold-formed steel beams with various transverse stiffener sizes followed by finite-element nonlinear collapse simulation to demonstrate the applicability of transverse stiffeners in the context of cold-formed steel members. The experimental series consists of six tests on 200-mm-deep C-shaped sections having angle intermediate transverse stiffeners screw-fastened to the web also reveals the conservatism of the transverse stiffener design rules in the AISI S100-16 specification. Based upon the experimental and numerical results, the paper recommends the adoption of the corresponding provisions taken from the AISC 360-16 specification.


ABSTRACT: The local instability of steel plates is the predominant seismic failure mode for steel bridge piers. However, the application of shell-based finite-element (FE) models in an engineering design presents significant difficulties, and existing simplified calculation methods have their own insufficiency. In this paper, single-column square-section steel bridge piers were studied to propose an equivalent hysteretic model for the fiber elements of steel piers that can consider the local instability behavior of steel plates. Using the length of the half-buckling wave at the bottom of pier as the length of effective damaged zone \((L_d)\), average stress–strain curves of the cross-section points over the \(L_d\) were extracted from the calculation results of a fiber-shell hybrid model. The two-surface constitutive model of material was modified by introducing the equivalent elastic modulus and skeleton curve and reducing the bounding surface radius to make the hysteresis and average stress–strain curves coincide. An equivalent hysteresis model for the fiber elements in the effective damaged zone was proposed, and the process for identifying model parameters was introduced. Using Q345qC structural steel as an example, regression formulae for equivalent hysteresis model parameters were established. Based on the comparison with calculation results of a hybrid element model, the improved fiber model can accurately calculate the seismic response of a structure under horizontal unidirectional or bidirectional earthquakes and significantly save calculation cost. The proposed equivalent hysteresis model can provide a method for calculating the elastoplastic seismic response with a high accuracy and good availability for the seismic design of steel piers under horizontal bidirectional earthquake actions.
Zhihua Chen (1), Jie Liu (1), Ting Zhou (1), Xiangyu Yan (2) and Xi Zhang (1)
(1) School of Civil Engineering, Tianjin Univ., 92 Weijin Rd., Nankai District, Tianjin 300072, China.
(2) Steel Structure Design Research Center, Tianjin Univ. Research Institute of Architectural Design, 92 Weijin Rd., Nankai District, Tianjin 300072, China.


ABSTRACT: In this study, five double-plate connected concrete-filled steel tube (CFST) composite columns were tested under a uniaxial eccentric compressive load. The test phenomena, load–axial displacement curves, strain analyses, and column curve analyses were examined. The effects of different eccentricities and loading directions were compared with respect to the double-plate connected CFST composite columns under uniaxial eccentric compressive load. ABAQUS 6.14-4 software was used to develop models of the double-plate connected CFST composite columns. Load–axial displacement curves and failure modes obtained from the finite element analysis (FEA) models and tests were compared in this study. The FEA results, which were in good agreement with the test results, can well simulate the uniaxial eccentric compression performance of double-plate connected CFST composite columns. Based on the superposition principle and calculation method of the slenderness ratio as per the Standard for Design of Steel Structures (GB50017-2017), the authors proposed a formula for the stable bearing capacity of the double-plate connected CFST composite columns. In addition, a new theoretical formula for the bearing capacity of the uniaxial eccentric compression specimen was proposed. A comparison between the calculated N–M correlation curves and the test and FEA results indicated that the calculation results exhibited good safety and can provide ideas for engineering design.

Mahmudur Rahman, Yoshiaki Okui, Masato Komuro, Muhammad Atif Anwer and Azusa Numata,

ABSTRACT: The strength of longitudinally continuous stiffened steel plates, exhibiting column-like behavior under uniaxial compression, was investigated at ultimate as well as serviceability limit states. Compressive strengths were determined from nonlinear elastoplastic FE analysis, where both material and geometric nonlinearity were taken into account. In the parametric analysis, the reduced slenderness parameter ($RR$) was varied from 0.4 to 1.4, and for each $RR$, thick plates and high-performance steels (SBHS) were considered along with thin plates and ordinary steels. The probabilistic distribution of the strengths was obtained through Monte Carlo simulation, in association with a response surface method. The response surface function comprises three independent variables, upon which the uncertainties in estimating the compressive strength of a certain stiffened plate depend, i.e., the residual stress, the initial out-of-plane whole-plate deflection, and the initial out-of-plane local deflection. Comparing the ultimate strength with a 5% non-exceedance probability indicates that the AASHTO, Canadian Code, and Japanese specification provides significantly conservative design, specifically for $RR > 0.8$. Based on the obtained probabilistic information, partial safety factors for each $RR$ were proposed, considering the mean value strengths as the nominal strengths, as an example.


ABSTRACT: The research presented in this paper aimed to investigate local buckling failure occurring adjacent to moment-resisting bolted connections in cold-formed steel back-to-back channel beams connected to a gusset plate through their webs. This failure is a result of a complex stress state originating from the transfer of both shear and bending moment through the web, combined with important shear lag effects. Experimentally validated finite-element models were used, accounting for material nonlinearity, geometric imperfections, and nonlinear bolt bearing behavior. The effects of the cross-sectional shape and thickness of the beam, the bolt group configuration, and the bolt group length were investigated. It was discovered that the detrimental effect of
local buckling exponentially decreases when a longer bolt group length is used, when the load is introduced at the connection with a smaller eccentricity relative to the centroid, and when the thickness of the beam is increased. The results of the investigation were employed to develop a practical design equation with a wide range of applicability. Finally, a reliability analysis was performed within the framework of various standards.


ABSTRACT: Lip stiffened flanges in cold-formed steel compression members may undergo local or distortional buckling depending on the slenderness of the flange and rigidity of the lip. In distortional buckling, the flange-lip assembly moves perpendicular to the flange. The decrease in stiffness (or depth) of the lip increases the vulnerability of such elements to distortional buckling. In the limiting case of zero lip depth, the plate behaves as an unstiffened element. Hence the behavior of the unstiffened element may be intuitively understood as the limiting case of distortional buckling of lip stiffened element as the lip depth tends to zero. In this study, experimental and numerical results are used to show that both elastic buckling and ultimate strength behavior of a uniformly compressed unstiffened element may also be represented as distortional buckling of the lip stiffened element of zero lip depth. In addition to the effective width method, the modified direct strength method equation developed for distortional buckling is also shown to accurately estimate the ultimate strength of uniformly compressed unstiffened elements.


ABSTRACT: Contrary to the large dataset of test results exploring the monotonic bending response of steel tubes, the corresponding dataset of cyclic bending tests remains very small. Seven compact and semicompact S355J2H cold-formed circular-hollow sections with diameter to thickness (D/t) ratios between 20 to 60, representative of piles used in piers and wharves, were brought to failure in three-point cyclic bending tests. Digital image correlation was employed to estimate average cross-sectional curvatures, and hence the critical bending strains, during local buckling at the midspan plastic hinges. These estimates were compared against those from two simplified localized hinge models and differed by up to a factor of two. A parametric study was performed with a validated finite-element model to ascertain the suitability of proposed design equations at predicting critical strains in piles with D/t from 20 to 60 under cyclic loading. Test and simulation data both show that critical buckling strains are lower under cyclic loading than under monotonic loading. This work can inform the future development of seismic design standards such as ASCE 61.


ABSTRACT: The strength of cold-formed steel beams with stiffened flanges may be controlled by distortional buckling. Buckling stress prediction methods have been developed for flanges under uniform compression. However, channel sections are commonly used where bending occurs about the minor axis with flanges under a stress gradient, such that the edges that are in compression and the flanges may experience distortional buckling. Current design specifications do not explicitly address this failure mode, which could lead to unsafe designs. This paper presents and verifies an analytical approach for distortional buckling stress prediction for flanges under a stress gradient. The approach is consistent with the design method used for flanges under uniform compression in the American Iron and Steel Institute (AISI) specification for the design of cold-formed steel members. This consistency facilitates a straightforward incorporation into the design specification.
The validated models. The numerical simulations indicated some parameters, including aspect ratio, axial load ratio, and CFT bottom reinforcing method, were examined using ductility ratio greater than 1.9% and a bending moment was predominately resisted by the CFTs. While the slender walls yielded due to flexural buckling, but rather conservative and scattered predictions when failure is by flexural-torsional buckling. Improved resistance predictions were achieved through application of a revised DSM-based approach.


ABSTRACT: High-strength aluminum alloys are emerging and gaining increasing prominence in structural engineering. The structural behavior and design of 7A04-T6 high-strength aluminum alloy equal-leg angle-section columns under axial compression are investigated in this study. Eighteen experiments on extruded high-strength aluminum alloy angle-section columns with various lengths were carried out. Complementary material tests and initial geometric imperfection measurements were also performed. The test setup, procedure, and results, including failure modes, load-carrying capacities, and load–end shortening responses, are fully reported. The test program was followed by a numerical study, where refined finite-element (FE) models were first developed and validated against the test results and then utilized to carry out parametric analyses covering a wide range of cross-section dimensions and column lengths. Finally, the load-carrying capacities obtained from the tests and numerical analyses were used to evaluate the accuracy of existing design provisions in European, Chinese, and American standards for aluminum alloy structures and the direct strength method (DSM). The results show that the existing design methods generally yield good capacity predictions for fixed-ended members failing by flexural buckling, but rather conservative and scattered predictions when failure is by flexural-torsional buckling. Improved resistance predictions were achieved through application of a revised DSM-based approach.


ABSTRACT: Experiments and finite element (FE) simulations were conducted on corrugated double-skin composite (Co-DSC) walls consisting of concrete-filled steel tubes (CFTs) and corrugated steel faceplates connected by tie bolts with concrete infill. Three specimens with different aspect ratios and one additional specimen with reinforcing sheaths at the bottom of CFTs were tested under combined axial and cyclic lateral loads. The specimens experienced a similar damage progress involving steel tubes and faceplates buckling and subsequent steel tube fracture. Both the steel tubes and faceplates experienced significant shear; however, the bending moment was predominately resisted by the CFTs. While the slender walls yielded due to flexure, the squat wall yielded due to both flexure resisted by the steel tubes and shear by the corrugated faceplates. All specimens experienced significant shear deformation and achieved a drift ratio capacity exceeding 1.9% and a ductility ratio greater than 3.2. FE models were developed and validated using the test data. The effects of major parameters, including aspect ratio, axial load ratio, and CFT bottom reinforcing method, were examined using the validated models. The numerical simulations indicated slender Co-DSC walls were more sensitive to the
axial load ratio. Moreover, using sufficiently thick reinforcing sheaths at the CFT bottom could effectively delay strength degradation. Equations for calculating the lateral strength of Co-DSC were provided.


ABSTRACT: The strength of thin-walled stainless steel columns has been investigated extensively over the last few years. The present paper presents the results of an extensive computational study of the buckling strength of lipped–channel section columns made of austenitic, duplex, and ferritic grades. The numerically computed strengths together with the available experimental data collected in the literature are compared to the current European and Australian/New Zealand standard (AS/NZS) codified predictions over the whole slenderness range. Minor and major axis buckling as well as flexural-torsional buckling are considered. A reliability assessment in the sense of both standards is then performed. The safety factor γm and resistance factor φc are computed per family of stainless steel. In conclusion, we advise the use of different European buckling column curves rather than the one currently adopted in the code and to make a distinction between the families of stainless steel. Besides, seeing the very good agreement found against the AS/NZS guidance, we propose that the factor η, currently being a linear expression in the European standard, be replaced by the AS/NZS expression with the proposed parameters for each stainless steel family.


ABSTRACT: This work provides a state-of-the-art report on the current knowledge concerning the structural behavior and design, by means of the Direct Strength Method (DSM), of steel equal-leg angle columns with short-to-intermediate lengths, that is, those buckling in flexural–torsional modes — although cold-formed columns constitute the main focus of the paper, hot-rolled columns are also addressed. The columns dealt with are either fixed-ended or simply supported – the latter designation includes columns with both cylindrically and spherically-hinged end cross-sections. Initially, numerical results concerning the mechanics underlying the buckling and postbuckling behavior of the previous angle columns are presented and discussed: (1) highlighting the main differences between the fixed-ended and simply supported column responses, and (2) evidencing the need for specific design procedures. Next, the paper collects the experimental and numerical failure load data available in the literature, reported by various researchers and dealing with cold-formed and hot-rolled fixed-ended and simply supported columns with several geometries (cross-section dimensions and lengths). Then, the paper presents the mechanical reasoning behind a recently proposed novel DSM-based design approach, as well as the main steps involved in developing and calibrating the corresponding strength curves. Finally, the merits of this design approach are assessed through (1) the estimation quality of the available failure load data, and (2) the evaluation of the associated Load and Resistance Factor Design (LRFD) resistance factors, which are compared with those currently recommended by the North American Design Specifications. The paper closes with an overview of the findings reported and a reference to future developments of this research effort.


ABSTRACT: The behavior and design of hot-rolled and cold-formed steel square and rectangular hollow section (SHS and RHS) columns, made of both normal- and high-strength material, are addressed in this paper. A series of experiments on hot-rolled high-strength steel SHS columns was first conducted — six tests on S690 SHS 100×100×4 columns and six tests on S770 SHS 120×120×6.3 columns were performed. Finite-element (FE) models were developed to replicate the experimental results and to carry out parametric studies to expand the column buckling data pool. The accuracy of the European and North American buckling design rules for normal- and high-strength steel SHS and RHS columns was evaluated through comparisons with the freshly generated test and FE results, as well as with existing test data collected from the literature. Finally, a modified
approach was proposed and statistically verified in accordance with existing standards; the new approach features an imperfection factor that is a continuous function of yield strength, reflecting the reducing relative influence of residual stresses and global imperfections with increasing steel grades. Improved consistency in resistance predictions over the existing design provisions is demonstrated across a wide range of steel grades and relative slenderness values.


ABSTRACT: This paper presents a novel experimental investigation into the pre- and postcritical behavior of steel-plate girders in shear. We have quantitatively scrutinized the deformation behavior of the web shear buckling using an optical measurement system. We reveal that the postcritical phase consists of two distinct stages, which refutes the belief of seemingly conflicting modeling approaches between the North American and the European design codes. We show that the first stage ends with the onset of a temporary instability of the main shear buckling that caps the girder’s shear resistance and corresponds to the shear capacity of the Basler model from the North American design code. We also show that the second stage, however, confirms the modeling approach of the Eurocode, because this stage exhibits (after stabilizing secondary buckling develops) a recovery of the shear resistance and terminates with the onset of a failure mechanism with plastic hinges in the flanges. While restoring the validity of the Basler model, we uncover the need for further experimental and numerical investigations to quantitatively assess the range of applicability of the Eurocode model.


ABSTRACT: This study proposes a general framework for topology-finding or topology optimization of tensegrity structures. The existing topology-finding formulation of tensegrity structures based on mixed-integer linear programming (MILP) was improved and transformed into a formulation based on mixed-integer semidefinite programming (MISDP) which considers the global stability condition of tensegrity. We illustrated and analyzed two undesirable phenomena, loss of prestress stability and loss of integrity, caused by the missing global stability condition in previous MILP-based approaches. A branch-and-bound algorithm combined with a primal-dual interior-point algorithm is employed to solve the proposed MISDP model. Some numerical examples illustrated the improvements and effectiveness of the proposed approach. The proposed approach successfully can avoid the two undesirable phenomena and ensure the global stability of the found tensegrity structures. By using different stability conditions in the topology-finding process, the proposed approach can find general stable tensegrity structures and superstable tensegrity structures.


ABSTRACT: With the devolvement of large-span structures and super high-rise buildings, lightweight aggregate concrete (LWAC) materials have been widely utilized. The main content of this work is to explore the failure and size effect of lightweight aggregate concrete-filled steel tube (LWACFST) columns under uniaxial compression. A three-dimensional mesoscale simulation approach considering concrete heterogeneity was developed, in which the ideal bond was assumed between the steel tube and inner concretes. The failure of geometrically similar square and circular LWACFST/CFST columns under axial compression having different structural sizes and transverse constraints was modeled and explored. The size effect on the nominal compressive strength of the columns was examined. The influences of aggregate type, column cross-sectional type, and constraint effect generated by the steel tube on the size effect in axial compressive failure are also investigated. The results indicate that an obvious size effect in axial-compressive failure can be found for both LWACFST and CFST columns. With the increase of the confinement degree of steel tube, the size effect on nominal compressive strength would be weakened. The LWACFST columns exhibits a more obvious size effect than the CFST columns. Moreover, the size effect on the compressive strength of the circular columns is
obviously weaker than the effect on square columns. Finally, considering the quantitative influence of confinement coefficient, a novel size effect law (SEL) for quantitatively describing the size effect in axially-loaded CFST columns was proposed. The accuracy and reasonability of the proposed SEL was verified by the available test data.

ABSTRACT: Collapse evaluation of composite plate shear walls (C-PSWs) under seismic loading requires a reliable analytical model that can accurately capture deterioration in the strength and stiffness of the system. In this study, research was carried out to develop a macromodeling approach for C-PSWs. Nonlinear time history analyses of six multistory (7-, 10-, and 13-story) C-PSWs (traditional and innovative) located in Western Canada were performed. It was observed that a significant portion of the story shear was resisted by the boundary members, while the RC panel resisted less than 10% of the total story shear. To estimate the seismic response parameters (i.e., ductility-related and overstrength-related force modification factors) for designing C-PSWs, incremental dynamic analysis (IDA) was performed for all archetypes following a standard procedure. It was observed that all archetypes provided significant safety margin against collapse (large collapse margin ratio). In addition, a sensitivity study was conducted and the effects of postyielding parameters (ductility capacity and postcapping stiffness) adopted for the deterioration model for infill plate and postcracking parameters (shear strain corresponding to maximum shear stress, yielding shear strain, and residual stress) adopted for the deterioration model for RC panel on seismic collapse capacities of traditional C-PSWs were investigated. It was observed that postyielding parameters for the steel infill plate can affect the seismic response of C-PSWs. On the other hand, variation of postcracking parameters for the concrete panel had a minor effect on seismic collapse capacity of the C-PSW system.

ABSTRACT: This paper aims at investigating the fire-induced collapse behavior of aluminum alloy shells with gusset joints through an experimental analysis. The scale test model (geometric scaling coefficient=1/5) was composed of a K6 aluminum alloy spherical shell with a diameter of 8m and a support structure with a height of 3.2m. Diesel oil was used as the fuel, and the design power of the fire was 2MW (corresponding to 111.8MW of the prototype, calculated by the fire-power scaling law). Test results, including the test phenomenon, the failure mode, the thermal and structural response, and the deformation process, are presented and discussed. In the first fire test, the specimen did not collapse, and no permanent deformation, which would influence the mechanical behavior of the specimen, was observed. In the second fire test, the specimen began to collapse at 528s, and the structural components failed by melting, rupture, and flexural-torsional buckling. While the members at the outside rings presented buckling, it is suggested that the thermal expansion be considered to prevent the buckling of the member in the structural fire design. Besides, the nonuniform temperature distribution was observed throughout the two structural fire tests, which confirmed that the homogeneous temperature assumption is not appropriate in analyzing large-space fires. Finally, the field simulation method to simulate the air temperature field of the tests is presented and verified, and the internal forces of members under nonuniform and uniform temperature distributions are compared. It is found that the field simulation can accurately evaluate the nonuniform air temperature distribution, and the nonuniform structural temperature distribution will significantly influence the internal forces of spherical shells. The experimental data and findings of this paper will be used for a further analysis of the structural fire behavior of aluminum alloy spatial structures.

ABSTRACT: The beam-truss model (BTM), developed for the nonlinear cyclic analysis of reinforced concrete components including softening, is extended to compute the out-of-plane buckling observed in plastic hinges of
various slender structural walls. This is achieved by using fiber-section displacement-based elements with PDelta geometric transformation and diagonal truss-elements with Corotational transformation. The BTM is enhanced by considering strain penetration at the base of the walls. This paper discusses the BTM for three test specimens that exhibited out-of-plane buckling and whose response softened as a result of this phenomenon. The test specimens’ unsupported height-to-wall thickness ratio ranged between 10 and 25. Using the same calibration of the modeling parameters for the development of the three models, the BTM is validated by comparing measured and computed lateral force-displacement responses, out-of-plane displacements, and local strain responses. The BTM accurately computes the force-displacement responses as well as out-of-plane displacements of the test specimens and the buckling behavior.


ABSTRACT: This paper describes an experimental and numerical investigation on the stub column behavior of cold-formed high-strength steel (HSS) circular hollow sections (CHSs). A total of 16 stub column specimens fabricated from Q460, Q690, and Q960 steel plates were tested. Axial load-end shortening responses and failure modes of the stub column tests are presented and discussed. Nonlinear finite-element (FE) models were developed to replicate the stub column tests and subsequently employed to carry out comprehensive parametric studies to further examine the local buckling behavior considering various slenderness values and steel grades. The FE results were used together with experimental results to evaluate the applicability of current codified design methods in Eurocode, North American codes, and Australian standards to cold-formed HSS CHS stub columns. On the basis of the evaluation results, a new form of cross-sectional slenderness limit and a new set of design equations for more efficient designs were proposed and subsequently verified by means of statistical and reliability analyses.


ABSTRACT: In this paper, a geometrically and materially nonlinear numerical model using ANSYS is validated against 13 lateral torsional buckling (LTB) experiments as well as experiments from the literature. A parametric study comprising 30 geometries with each 12 lengths in the slenderness range of 0.35–1.95 is then performed. This numerical study is repeated for the stainless steel ferritic EN 1.4016, austenitic EN 1.4404, and duplex EN 1.4462 grades to ensure a safe design for all stainless-steel families used in civil engineering structures. When compared to the numerical results, the current EN 1993-1-4 (CEN 2006) design rules are slightly unsafe for the intermediate slenderness range and increasingly conservative for stocky sections in the higher slenderness range. Based on this, the reliability assessment according to Annex D of EN 1990 (CEN 1990) leads to safety factors greater than the codified value of 1.1. However, by introducing the recent proposal of Taras and Greiner, improved predictions of the LTB strengths are achieved, especially when the adjusted imperfection factors for each stainless-steel family is used. Safe predictions are obtained in the intermediate slenderness range as well as high improvements of the prediction for stocky sections in the high slenderness range.


ABSTRACT: An experimental and numerical study on the octagonal high-strength steel tubular stub columns under combined compression and bending is presented in this paper. Octagonal high-strength steel tubular stub column specimens with different sizes were prepared. Experiments were performed on these specimens under concentric compression or eccentric compression, which induced various combinations of compression and bending on the structures. In addition, a numerical study through finite-element modeling was also conducted. A finite-element model was developed and validated to be capable of accurately replicating the experimental results. Subsequent parametric studies using the validated model were performed on the structures with a wide range of dimensions and under various combinations of compression and bending. Based on both experimental and parametric studies results, the applicability of existing design approaches in European and American
Standards to the structures subject to combined compression and bending was evaluated. The evaluation results show that the design approaches from the standards, especially the compression and bending interaction relationship, provide conservative strength predictions and can be safely applied to the structures.


ABSTRACT: Horizontally curved concrete bridges are widely used in urban viaducts and overpasses all over the world. A box cross-section is often used in curved concrete girders because of its high resistance to both bending and torsion. This study focuses on the development of a new finite element analysis (FEA) methodology incorporating a novel formulation for curved box sections using orthotropic constitutive models for reinforced concrete, along with a layered shell theory approach. In the new approach, the box section is treated as a frame consisting of curved shell elements modeling webs and flanges and curved beam elements in the web-flange junctions. The use of shell and beam elements in the formulation significantly reduces the number of elements needed to model the box-section girder while maintaining the accuracy of the model. A degenerate superparametric shell element with reduced integration is used to avoid shear-locking, membrane-locking, and zero-energy problems. Prestrain effects are considered in the formulation to account for prestressing forces. The simulation results are compared to the available experimental results on four straight and curved, reinforced and prestressed, concrete box-section girders, with good agreement in terms of the deflections, twist angles, and strains in the prestressed reinforcement. Some critical issues in the analysis of concrete box girders, such as postpeak-strength behaviors, distortion of box section, are also discussed.


ABSTRACT: Composite columns consisting of steel hollow sections filled with concrete offer numerous advantages including high fire resistance. However, there are limited provisions for fire design of these columns, and current European code provisions yield unconservative fire resistance in cases of composite columns having relative slenderness greater than 0.5. To overcome the current knowledge gaps, a set of fire-resistance experiments was carried out on a large number of concrete-filled steel tubular columns (CFST). The test variables in the experiments included cross-section type and size, column slenderness, and the support conditions of the CFST columns. From these tests, detailed response parameters, including the evolution of cross-sectional temperatures, axial displacements, lateral deflections, fire-induced axial forces, and failure times, were evaluated. Results from the analysis clearly indicate that cross-sectional shape, support conditions, and column slenderness have significant influence on the fire behavior of CFST columns. Specifically, the axial stiffness reduces the fire resistance of CFST columns, whereas the rotational stiffness increases their fire resistance. Furthermore, CFST columns with an elliptical cross section provide higher fire resistance than equivalent square-shaped or rectangular-shaped columns under certain boundary conditions.


ABSTRACT: This paper investigates the elastic lateral-torsional buckling of shear deformable circular arches of monosymmetric steel I-section with in-plane elastic rotational end constraints under a central concentrated radial load. In previous studies of monosymmetric arches reported in the literature, their ends were considered to be fix-ended or pin-ended in the plane of their curvature. In practice, the ends of an arch are not always fix-ended or pin-ended. The ends of an arch may have elastic restraints provided by elastic foundations or other adjacent structural elements. In addition, Timoshenko shear deformations, which are inevitable for arches with small and moderate slenderness ratios, are not considered in previous studies of the topic. The major contributions of this article are the following: (1) accurate strains and deformed curvatures for monosymmetric arches, including shear deformations, are derived using position vector analysis; and (2) in-plane analyses, including the influences of the elastic rotational end restraints, are successfully carried out in two steps to obtain
the accurate axial compressive force, bending moment, and shear force distributions for lateral-torsional buckling analysis. The theoretical solutions for the lateral-torsional buckling load are obtained by applying the principle of stationary potential energy together with a Rayleigh-Ritz formulation and validated by ANSYS version 15.0 modeling of the problem.


ABSTRACT: With increasing demand for midrise buildings, automated prefabrication, design for manufacturing and assembly (DfMA), and sustainability, a novel material-efficient post-tensioned (PT) composite steel-timber (CST) stiffened wall system has been developed. As opposed to cross-laminated timber (CLT), this fully prefabricated panelized composite system consists of an engineered wood panel that is integrally stiffened by timber studs and steel square hollow sections (SHS). Each SHS additionally accommodates a PT rod and panel-to-panel connections, allowing for quick onsite assembly, permanent tie-down, and self-centering inverted pendulum rocking. This study presents and evaluates the structural buckling behavior and performance of these systems under vertical axial loading in terms of failure modes, serviceability, ultimate limit states, midheight out-of-plane deflection along the width of the wall, and PT force loss. This has been achieved through an extensive experimental investigation and analysis consisting a total of 10 PT-CST stiffened walls with multiple variables including level of post-tensioning, wall height, end conditions, and the connection between the panel and SHS and the panel and stud stiffeners. Complex behavior through several modes of failure was observed with the increased application of initial PT force, which in turn reduced the ultimate capacity. Additionally, it was found that PT force reduction due to vertical axial loading even within the serviceability limit state (SLS) is significant. Thus, it is recommended that this reduced PT force be considered in design.


ABSTRACT: In this paper, an experimental program is presented consisting of 13 experiments on welded stainless steel I-profile beams subjected to lateral torsional buckling, in which 11 specimens are made of the lean duplex stainless grades EN 1.4062 and EN 1.4162, while the last two specimens are made of the austenitic grade EN 1.4404. The beam heights are 160, 210, and 260 mm, and the beams have a constant flange width of 160 mm. This results in three different strong axis elastic section moduli but similar weak axis bending resistances. The range of beam buckling length covers slenderness values from 0.30 to 0.76. The geometrical imperfections of the specimens were measured using digital image correlation (DIC). The web was first measured along its whole length. Then, the beam was placed on its fork supports, and the imperfection was then remeasured once more to check the influence of both gravity and test setup. Traditional four-point bending tests were carried out, and during which, the displacements were measured using linear variable differential transformer (LVDTs), inclinometers, and DIC. In this paper, the measured ultimate moments, together with results of experiments collected in the literature, are compared to the design rules provided in EN 1993-1-4, for which a safe but rather conservative design is obtained, and to the recent proposal of Taras and Greiner dedicated to carbon steel beams. The latter provides better results for high slenderness values but can be further improved.

ASCE Journal of Structural Engineering, Vol. 147, No. 3, March 2021,


ABSTRACT: The sandwich structures with aluminum foam core and metal surfaces have widespread use in the absorption of energy, because they are light weighted with high performance in dissipating energy. The cell structure of the foam core is subjected to plastic deformation in the constant compression level that absorbs a lot of kinetic energy before destruction of the structure. In this research, experimental tests of low-velocity impact on the sandwich structure by a drop machine are simulated by LS-DYNA software. Numerical results are obtained for different velocities and weights of projectile on samples of aluminum foam core sandwich panels with relative density (the ratio of the density of aluminum foam to the density of solid aluminum) of 18, 23, and 27. The results are compared with experimental results which reveal a good conformity. As well, from the numerical simulations, the effect of weight, velocity and energy of the projectile and the density of the foam core on the global deformation and energy loss rate of projectile have been studied.


ABSTRACT: A new nonlinear finite element model is proposed for the dynamic analysis of cylindrical sandwich panels with shape memory alloy hybrid composite face sheets and flexible core. In order to present a realistic transient vibration analysis, all the material complexities arising from the instantaneous and spatial martensite phase transformation of the shape memory alloy wires are taken into consideration. The one-dimensional constitutive equation proposed by Boyd and Lagoudas is used for modeling the pseudoelastic behavior of the shape memory alloy wires. Since the martensite volume fraction at each point depends on the stress at that point, the phase transformation kinetic equations and the governing equations are coupled together. Therefore, at each time step, an iterative method should be used to solve the highly nonlinear equations. Moreover, considering that the stress resultants generated by the martensite phase transformation in the wires are path-dependent values, an incremental method is used to estimate the increment of the stress resultants at each time step. The governing equations are derived based on the energy method and Newmark time integration method is used to solve the discretized finite element equations. Finally, several numerical examples are presented to examine the effect of various parameters such as intensity of applied pressure load, operating temperature, location of shape memory alloy wires, volume fraction of the shape memory alloy wires, and also boundary conditions upon the loss factor for panels with different aspect ratios.


ABSTRACT: The present paper analyzes the convergence of the exponential matrix method in the solution of three-dimensional equilibrium equations for the free vibration analysis of functionally graded material structures. The three-dimensional equilibrium equations are written in general orthogonal curvilinear coordinates for one-layered and sandwich plates and shells embedding functionally graded material layers. The resulting system of second-order differential equations is reduced to a system of first-order differential equations redoubling the variables. This system is exactly solved using the exponential matrix method and harmonic displacement components. In the case of functionally graded material plates, the differential equations have variable coefficients because of the material properties which depend on the thickness coordinate z. For functionally graded material shells, the differential equations have variable coefficients because of both changing material properties and curvature terms. Several mathematical layers M can be introduced to approximate the curvature terms and the variable functionally graded material properties to obtain differential equations with constant coefficients. The exponential matrix is applied to solve the resulting system of partial differential equations with constant coefficients, where the used expansion has a very fast convergence ratio. The present work investigates the convergence of the proposed method related to the order N used for the
expansion of the exponential matrix and to the number of mathematical layers $M$ used for the approximation of curvature shell terms and variable functionally graded material properties. Both $N$ and $M$ values are analyzed for different geometries, thickness ratios, materials, functionally graded material laws, lamination sequences, imposed half-wave numbers, frequency orders, and vibration modes.


ABSTRACT: Metallic thermal protection systems are used to protect the airframe and payload from aerodynamic and aerothermal heating in hypersonic cruise vehicles that are powered with advanced scramjet engines. Metallic thermal protection systems are a composite structure that contains honeycomb sandwich panels at the top and bottom and a variety of thermal insulating materials placed in between them. Several design factors influence the structural and thermal performance of the honeycomb sandwich panels. Panel bending stiffness is one important structural property that is generally estimated using a destructive 3-point or 4-point bending test. In this study, a numerical model based on the impulse excitation nondestructive evaluation technique has been developed to estimate the effect of various design parameters that affect the bending stiffness of the honeycomb sandwich panels. The results obtained are analyzed using standard statistical procedures. A major advantage of this method lies in evaluating the panel stiffness at the design stage without resorting to actual fabrication of the panels for destructive testing.

Laurent Mezeix, Simon Dois, Christophe Bouvet, Bruno Castanie, Jena-Paul Giavarini and Nathawat Hongkarnjanakui (First author is from: Faculty of Engineering, Burapha University, Chonburi, Thailand; second, third and fourth authors are from: Université de Toulouse; ICA (Institut Clément Ader); INSA, ISAE, UPS, Mines Albi, UMR CNRS 5312, Toulouse, France), “Experimental analysis of impact and post-impact behaviour of inserts in carbon sandwich structures”, Journal of Sandwich Structures & Materials, Vol. 21, No. 1, pp 135-153, January 1, 2019, https://doi.org/10.1177/1099636216687582

ABSTRACT: In aeronautics, honeycomb sandwich structures are widely used for secondary structures such as landing gear doors, flaps or floors, and for primary structures in helicopters or business jets. These structures are generally joined by using local reinforcements of the insert type. In the present study, 50 J low velocity impact tests were performed on inserts using a drop-weight device and the impact response and failure patterns were analysed. Impacted specimens were then pull-through tested to failure. Some of the tests were stopped before final failure in order to obtain precise details on the failure scenario. It was shown that, in the cases studied, the residual strength after impact was very high (about 90%) in comparison to the large reductions habitually observed in compression after impact tests.


ABSTRACT: In this paper, an analytical process is proposed to investigate the size-dependent free vibration of orthotropic multi-viscoelastic microplate systems (OMVMPS) embedded in Kelvin–Voigt visco-Pasternak medium according to the modified strain gradient theory. Governing equations of motion in the partial form and the related boundary conditions are derived by utilizing the Kirchhoff plate theory and Hamilton’s variational principle. The two different sorts of “chain” boundary conditions like “clamped Chain” and “free chain” systems are considered for the ends of microplate system. Navier’s method, which convinces that the simply supported boundary conditions and trigonometric methods are applied to analytically investigate the size effect of the natural frequencies of OMVMPS. The numerical outcomes are offered to report the variation of OMVMPS natural frequencies with the numerous amounts of the microplate numbers, the length scale parameter, aspect ratio, visco-Pasternak foundation parameters, the thickness of microplate, and higher modes number. Several numerical outcomes of this research depict that when the number of microplates is low, there is
a significant distinction between natural frequencies achieved for “clamped chain” and “free chain” systems. Also, it is demonstrated that by increasing the number of microplates, the effect of the visco-Pasternak substrate on the natural frequency of system vibration decreases.


ABSTRACT: This study investigates damage mechanisms and deformation of honeycomb sandwich structures reinforced by functionally graded face plates under ballistic impact. The honeycomb sandwich structure consists of two identical functionally graded face sheets, having different material compositions through the thickness, and an aluminum honeycomb core. The functionally graded face sheets consist of ceramic (SiC) and aluminum (Al 6061) phases. The through-thickness mechanical properties of face sheets are assumed to vary according to a power-law. The locally effective material properties are evaluated using the Mori–Tanaka scheme. The effect of material composition of functionally graded face sheets on the ballistic performance of honeycomb sandwich structures was investigated using the finite element method and the penetration and perforation threshold energy values on ballistic performance and ballistic limit of the sandwich structures are determined. The contribution of the honeycomb core on the ballistic performance of the sandwich structure was evaluated by comparing with spaced plates (without honeycomb core) in terms of the residual velocity, kinetic energy, and damage area.


ABSTRACT: This study addresses the bending impact behaviour of sandwich beams made of a low density core bonded to two metal face sheets under low-velocity impact. The geometrical and material non-linearities were considered in the explicit dynamic analysis. The face sheets and core were made of aluminum and expanded polystyrene foam. The effects of design parameters, such as foam density, foam thickness, plate thickness, on the impact energy absorption of the joint were investigated. The foam material was modelled as a crushable foam material, and the cohesive response of the adhesive interface was analysed using the cohesive zone model. Experimental low-speed impact tests were carried out to validate the finite element analysis, and the temporal variations of the contact force and the permanent central deflections at the top and bottom faces of the sandwich beams were in good agreement.


ABSTRACT: This study was initiated based on the observation that standardized test methods for flatwise compression of foam materials, give significantly different test results for the measured moduli, and that these standards to date lack adequate instructions on how the strain should be measured and what specimen size should be used. A brief review of previous work shows that existing test methodologies provide significantly different results for the compressive moduli of foams depending on how the strains are measured. A thorough experimental study of the out-of-plane compressive properties is conducted on three different closed-cell foam materials, where strains measured with two different extensometer placements, and with digital image correlation, come out significantly differently. A parametric study is also performed showing that the results vary considerably with in-plane specimen dimensions, indicating effects of finite size and localized strain at edges. Both stochastic amorphous and homogenized finite element models of foam back the experimental observations by illustrating the effects of finite size and various boundary conditions on the measured properties.

Ahmed F. Radwan (Department of Mathematics and Statistics, High Institute of Management and Information Technology, Nile for Science and Technology, Kafrelsheikh, Egypt), “Effects of non-linear hygrothermal

ABSTRACT: The non-linear hygrothermal and mechanical buckling responses of FG sandwich plates resting on two-parameter elastic foundations are presented in this study. Non-linear Fourier temperature distribution is considered as a special case. A hyperbolic displacement model is proposed in the present investigation. The present model involves four unknown variables, and the shear stresses on the bottom and top of the plate surfaces are equal to zero. The effective material properties of the FG sandwich face sheets are presumed to be varied in the direction of the thickness using a simple power law distribution, while the core is supposed to be purely ceramic. The stability equations are deduced by the principle of virtual work, containing the effect of foundations interaction and hygrothermal effects based on the present model. The hygrothermal effects are considered as non-linear, linear and uniform distribution through the plate thickness. Comparison examples are presented to verify the accuracy of the present model. The effects played by the temperature rise, moisture concentration, parameters of elastic foundation, side-to-thickness ratio, aspect ratio of the plate, the inhomogeneity parameter on the critical buckling of FG sandwich plates are investigated.


ABSTRACT: This paper presents the free vibration analysis of composite sandwich plates and doubly curved shells with variable stiffness. The reinforcing fibers are located in the external skins of the sandwich structures according to curved paths. These curvilinear paths are described by a general expression that combines power-law, sinusoidal, exponential, Gaussian and ellipse-shaped functions. As a consequence, the reinforcing fibers are placed in these orthotropic layers in an arbitrary manner, in order to achieve the desired mechanical properties. The effect of this variable fiber orientation on the natural frequencies is investigated by means of several parametric studies. As far as the structural theory is concerned, an equivalent single layer approach based on the well-known Carrera Unified Formulation is employed. The Murakami’s function is added to the kinematic model to capture the zig-zag effect, when the soft-core effect is significant. Thus, several higher order shear deformation theories are taken into account in a unified manner. The differential geometry is employed to describe the reference surface of doubly curved shells and panels, which are characterized by variable radii of curvature. The numerical solution is obtained using the generalized differential quadrature method, due to its accuracy and stability features. The present solution is compared with the results available in the literature or obtained by finite element commercial codes.


ABSTRACT: This paper presents a generic multivariate adaptive regression splines-based approach for dynamics and stability analysis of sandwich plates with random system parameters. The propagation of uncertainty in such structures has significant computational challenges due to inherent structural complexity and high dimensional space of input parameters. The theoretical formulation is developed based on a refined \( C^r \) stochastic finite element model and higher-order zigzag theory in conjunction with multivariate adaptive regression splines. A cubical function is considered for the in-plane parameters as a combination of a linear zigzag function with different slopes at each layer over the entire thickness while a quadratic function is assumed for the out-of-plane parameters of the core and constant in the face sheets. Both individual and combined stochastic effect of skew angle, layer-wise thickness, and material properties (both core and laminate) of sandwich plates are considered in this study. The present approach introduces the multivariate adaptive regression splines-based surrogates for sandwich plates to achieve computational efficiency compared to direct Monte Carlo simulation. Statistical analyses are carried out to illustrate the results of the first three stochastic natural frequencies and buckling load.
ABSTRACT: Multi-layered laminated glass panels are those with at least three monolithic glass layers and two viscoelastic interlayers. Multi-layered laminated glass panels are commonly used in floors, roofs and other horizontal glazing accessible to the public where a high level of security is required. Although the glass can be consider as a linear-elastic material, the viscoelastic interlayers determine a non-linear behavior of the laminated structure that must be taken into consideration. In this paper, a dynamic effective thickness is proposed to predict the natural frequencies and damping ratios of multi-layered laminated glass beam-like structures with different boundary conditions and at different temperatures. Furthermore, the presented dynamic effective thickness can be also used to any frequency domain calculations such as displacements and stresses. To validate the proposed model, operational modal analysis was carried out on a multi-layered laminated glass beam to obtain the experimental natural frequencies and damping ratios at 20, 25, 30 and 35°C. Moreover, a finite element model of the beam was also assembly for the sake of comparison. The proposed model predicts the natural frequencies with errors less than 5%, whereas the discrepancies in damping ratios are less than 50%.

Lin Jing and Longmao Zhao (First author is from: State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu, China), “Blast resistance and energy absorption of sandwich panels with layered gradient metallic foam cores”, Journal of Sandwich Structures & Materials, Vol. 21, No. 2, pp 464-482, February 1, 2019, https://doi.org/10.1177/1099636217695651

ABSTRACT: The dynamic response, blast resistance and energy absorption capability of clamped square sandwich panels comparing two aluminum alloy face-sheets and a layered gradient metallic foam core, subjected to air-blast loading, were studied numerically in this paper. Graded sandwich specimens with six different core-layer arrangements and three different face-sheet thickness arrangements were examined, respectively, compared to those ungraded sandwich panels with an equivalent nominally mass. Simulation results show that the blast resistance and energy absorption capability of sandwich panels with layered gradient metallic foam cores could be improved by optimizing the arrangements of different density metallic foam core-layers, and the graded sandwich panel with low-middle-high density core configuration has the best blast resistance capability. The blast resistance of graded sandwich panels with different thickness arrangements for top and bottom face-sheets has no obvious change tendency, since the normal stress distributions of their sandwich cross sections are controlled simultaneously by face-sheets and gradient foam core.


ABSTRACT: As a useful tool for designing wings and tail fins of aircrafts, this paper presents an optimization for flutter characteristics of cantilevered functionally graded sandwich plates. The plate is composed of an isotropic homogeneous core and two functionally graded face sheets. The plate is modeled based on the first-order shear deformation theory. The aerodynamic pressure is estimated using supersonic piston theory and using Hamilton's principle, the set of governing equations and boundary conditions are then derived. Applying a transformation of coordinates, governing equations and boundary conditions are converted and solved numerically by differential quadrature method. Natural frequencies, damping ratio, corresponding mode shapes, critical aerodynamic pressure, and flutter frequency are calculated. In order to achieve an optimum design, particle swarm optimization is employed to find the best values of aspect ratio, thickness of the plate, thickness of the core, power law index, and angles of the plate which increase critical aerodynamic pressure. Some constrains on the angles of the plate and its mass and area (lift force) are also considered.

ABSTRACT: The stuffed corrugated sandwich structure was proposed for the application in the protection of the spacecraft against orbital debris. In order to investigate the protection properties of the stuffed corrugated sandwich structure under hypervelocity impact, numerical simulations were carried out to analyze the impact characteristics. The hypervelocity impact process was presented and the properties such as shock waves propagation, energy absorption, and expansion of the debris cloud were discussed; corresponding properties of mass equal Whipple structure under impact were analyzed for comparison. The results illustrate the protection mechanism of the stuffed corrugated sandwich subject to hypervelocity impact and show that it has superior protection performance to monolithic plate, which prove that the stuffed corrugated sandwich structure has potentially broad application prospect in the field of spacecraft protection against the orbital debris. The research can provide reference for the design of protection shield of the spacecraft.

ABSTRACT: For hierarchical corrugated sandwich structures with second-order core, the prediction error of failure behavior by existing methods becomes unacceptable with the increase of structure thickness. In this study, a novel analytical model called moderately thick plate model is developed based on Mindlin plate theory, which can be used to analyze the failure behavior of hierarchical corrugated structures with second-order core under compression or shear loads. Then, the analytical expressions of nominal stress for six competing failure modes are derived based on the moderately thick plate model. The results of six different unit structures based on the moderately thick plate model agree quite well the ones by finite element methods. Furthermore, the influence of different structure thicknesses is investigated to validate the applicability of the moderately thick plate model. According to the comparative results with the thin plate model, the proposed moderately thick plate model has a better precision with the increase of the ratio of thickness to width for failure components.

ABSTRACT: In the present study, free vibration of magnetostrictive sandwich composite micro plate with magnetostrictive core and composite face sheets are investigated. The modified couple stress theory is taken into account so as to consider the small scale effects. The surrounding elastic medium is simulated as visco-Pasternak foundation to study the effects of both damping and shear effects. Using energy method, Hamilton’s principle and first-order shear deformation theory, the governing equations of motion and related boundary conditions are obtained. Finally, the differential quadrature method is employed to analysis the vibration of magnetostrictive sandwich composite micro plate. In this regard, the dimensionless frequency are plotted to study the effects of small scale parameter, surrounding elastic medium, magnetic field, composite fiber angle, aspect ratio, thickness ratio, and boundary conditions. The results indicate that the magnetic field and composite fiber angle play a key role in the dimensionless frequency of magnetostrictive sandwich composite micro plate. The obtained results in this article can be used to design sensors and actuators, aerospace industry, and control of vibration response of systems.

ABSTRACT: In this paper an elastomeric foam is applied as core for the composite sandwich beams and load carrying capacity, load–deflection response, and progressive failure are examined through experimental and finite element studies. The objective of this study is to assess the efficiency of elastomeric foam-cored sandwich (EFCS) beams relative to crushable foam-cored sandwich (CFCS) beams. The experimental program consists of two phases. In the first phase, some characterization tests are conducted on the constituent materials of the sandwich beams such as tension, compression, and shear tests on the foam and bending test on the composite beams utilized as skins. Then in the second phase, the performance of the sandwich beams is examined under
bending conditions. The load carrying behavior of the sandwich beams is considered dependent on two main features of the constituent materials: (1) the hyperelastic behavior of the foam core and (2) the progressive damage of the composite skins. These characteristics are simulated by the finite element models. Due to elastomeric rather than crushable deformation of the applied foam as the core, the conventional damage modes of the CFCS beams associated to the brittleness of the core material are omitted through load carrying capacity of the EFCS beams. So in the recent sandwich beams by omission of the core failure modes and utilization of compressive residual strength of the top composite skin, considerable energy is absorbed prior to failure of the bottom composite skin. By simulation of the test specimens using FE models, the response of the foam applied as core for the sandwich beams through progressive failure of the beams is investigated. The results show that the elastomeric foam core can provide superior features for the sandwich components especially for the cases in which high energy absorption capacity is required.


ABSTRACT: The nonlocal thermo-magneto-electro-mechanical bending behaviors of a three-layered nanoplate are presented in this study. The three-layered nanoplate includes a nano-sheet and two piezo-magnetic face-sheets at the top and the bottom. Temperature distribution is assumed linear along the thickness of the plate. The piezo-magnetic face-sheets are subjected to three-dimensional electric and magnetic potentials. The applied electric and magnetic potentials are applied at top of the face-sheets. The constitutive thermo-electro-magneto relations are derived based on the sinusoidal shear-deformation plate theory and nonlocal electro-magneto-elasticity. Using the principle of virtual work seven equations of the equilibrium are derived. The numerical results of this research indicate that some parameters have considerable effect on the bending behavior of three-layered nanoplate. Nonlocal parameter, applied electric and magnetic potentials, and temperature distribution are important parameters in this analysis.


ABSTRACT: This paper presents the experimental behavior of low-energy impact and quasi-static compression test of shifted-tri-axial structural wood-fiber-based composite panels made from laminated paper. The experimental results were analyzed based on design parameters and configurations of panels for the further design and optimization. The results showed that the face stiffness and strength was a significant factor to improve both impact performance and compressive performance. The panels made with additional carbon fiber fabric composite faces had higher energy absorption compared with the same panels made without it. The core configuration also affected the impact behavior of the panels, the foam filled core integrated with the shifted-tri-axial rib structure improved the impact load and absorbed more energy than the same panels without the foam. Further, the structure and size of the element in the core influenced the impact performance and energy absorption. The location for both compression and impact at the triangular lattice element center of the ribs had higher absorbed energy than the location at the hexagonal lattice element center of the ribs. A 3D contour surface map of maximum energy absorption was made based on the experimental data, the contour shows localized energy absorption based on the impact location on the core, the small triangular lattice element of the core had highest maximum energy absorption of panels. For both the quasi-static compression tests and the low-velocity impact tests, the panels with the same core configuration had similar compressive load–displacement trends during the early contact phase. However, the peak load was higher in compression than the peak load for the low-velocity impact for panels with the same configuration.

Amaud Wilhelm, Samuel Rivallant and Jean-Francois Ferrero (Primarily from: Institut Clément Ader (ICA), CNRS, Université de Toulouse – ISAE-SUPAERO, Toulouse, France), “Study of the deformation of a sandwich shield subjected to bird impact: A behaviour analysis tool using vector decomposition”, Journal of
ABSTRACT: In this work, a numerical finite element model of a 1.82 kg bird impacting a sandwich shield at 175 m/s is developed. Different shield designs are simulated and it appears that very different sandwich behaviours can occur, depending on the design. A new tool to analyse the deformation of the sandwich during impact is presented and is used to study the behaviour of a shield. As this tool makes it possible to easily compare the behaviour of different shields, it is used in a screening study to identify the more influential sandwich design parameters. If all design parameters are considered to be independent, the core out-of-plane plastic plateaux appear to be the most important. The core in-plane properties, elastic modulus and density and the back skin thickness have much less influence on the sandwich deformation under impact.

Wei Li, Yansong He, Zhongming Xu and Zhifei Zhang (School of Automobile Engineering, Chongqing University, Chongqing, China), “Sound transmission loss characteristics of four-side simply supported sandwich panels”, Journal of Sandwich Structures & Materials, Vol. 21, No. 2, pp 707-726, February 1, 2019, https://doi.org/10.1177/1099636217698394

ABSTRACT: In this study, a theoretical investigation on the sound transmission loss characteristics of four-side simply supported sandwich panels considering the flexural rigidity of the face sheet has been presented. With the flexural rigidity of the face sheet taken into account, the sound transmission problem of the sandwich panels is derived from the governing equation of bending vibration. The sound transmission loss expression is also derived. The validation of the theoretical prediction model is validated by comparing with the high-accuracy finite element and boundary element simulation. Numerical analysis shows that the flexural rigidity of face sheet influences the natural frequencies obviously, and the theoretical prediction model proposed has high accuracy on predicting the natural frequencies and sound transmission loss of four-side simply supported sandwich panels. The effects of the face sheet flexural rigidity, the thickness of face sheets and core layer, as well as the damping coefficient of the core on the sound transmission loss are systematically investigated.


ABSTRACT: In this study, a new shear deformation plate theory is introduced to illustrate the bending, buckling and free vibration responses of functionally graded material sandwich plates. A new displacement field containing integrals is proposed which involves only four variables. Based on the suggested theory, the equations of motion are derived from Hamilton’s principle. This theory involves only four unknown functions and accounts for quasi-parabolic distribution of transverse shear stress. In addition, the transverse shear stresses are vanished at the top and bottom surfaces of the sandwich plate. The Navier solution technique is adopted to derive analytical solutions for simply supported rectangular sandwich plates. The accuracy and effectiveness of proposed model are verified by comparison with previous research. A detailed numerical study is carried out to examine the influence of the critical buckling loads, deflections, stresses, natural frequencies and sandwich plate type on the bending, buckling and free vibration responses of functionally graded sandwich plates.


ABSTRACT: This paper proposed a new reduced passive constrained layer damping finite element model. The passive constrained layer damping structure is a sort of sandwich plate made up of a viscoelastic core sandwiched between two elastic faces. The model is built by combining the first shear deformation theory with the Golla-Hughes-McTavish model that takes the frequency dependence of the viscoelastic material property into consideration. Due to the Golla-Hughes-McTavish model, the stiffness, damping and mass matrices are at least doubled, which requires a large amount of calculation. Then, a modified improved reduced system method is proposed to reduce the order of the model. Finally, the proposed reduced model is compared to the Guyan...
reduction, the mode truncation and the improved reduced system models by two numerical examples. It demonstrates that the proposed modified improved reduced system method is obviously superior to the other three classical methods and the presented passive constrained layer damping model with the Golla-Hughes-McTavish model is an effective and accurate sandwich model, which can be applied to the finite element software.


ABSTRACT: A series of experimental tests have been carried out on three types of novel sandwich panels mainly designed for application in lightweight mobile housing. Two types of the panels are manufactured entirely from wood-based materials while the third one presents a combination of plywood for surfaces and corrugated thermoplastic composite as a core part. All sandwich panels are designed to allow rapid one-shot manufacturing. Mechanical performance has been evaluated in four-point bending comparing the data to the reference plywood board. Additionally, finite element simulations were performed to evaluate global behavior, stress distribution and provide the basis for a reliable design tool. Obtained results show sufficient mechanical characteristics suitable for floor and wall units. Compared to a solid plywood board, sandwich alternative can reach up to 42% higher specific stiffness, at the same time maintaining sufficient strength characteristics.


ABSTRACT: In a hybrid panel with glass fiber-reinforced polymer (GFRP) bottom skin and ribs, and deflection hardening cementitious composites (DHCC) top layer, it is very important to provide good shear connection between these various components in order to increase the load carrying capacity of the resulting hybrid slabs and a larger increment of deflection before the occurrence of the structural softening of this panel. The effectiveness of the proposed hybrid sandwich panels strongly depends on the performance of the shear connectors. The efficiency of indented shear connectors in improving the flexural performance of hybrid sandwich panels is here demonstrated. Since the efficiency of indented shear connectors in the hybrid sandwich panels is unknown, efforts are made in this paper in investigating the shear performance of hybrid slabs. A special focus is given on the indented shear connector’s behavior, considering different shear span ratios in ranges of 2.00, 1.39, and 0.77. In this regard, six hybrid sandwich panels were manufactured and experimentally tested under different shear loads. Then, the results are interpreted comprehensively. The results obtained show that the GFRP rib thickness and height, and shear span ratios influence the damage events and the structural performance of the hybrid sandwich panels. Moreover, it was observed that using indented shear connectors in the hybrid slabs, regardless of the shear span ratios, provides high load capacity, high stiffness, and large residual deflection.


ABSTRACT: The ANSYS/Autodyn software was employed to investigate the dynamic responses of foam-filled corrugated core sandwich panels under air blast loading. The panels were assembled from metallic face sheets and corrugated webs, and PVC foam inserts with different filling strategies. To calibrate the proposed numerical model, the simulation results were compared with experimental data reported previously. The response of the panels was also compared with that of the empty (unfilled) sandwich panels. Numerical results show that the fluid–structure interaction effect was dominated by front face regardless of the foam fillers. Foam filling would reduce the level of deformation/failure of front face, but did not always decrease the one of back face. It is found that the blast performance in terms of the plastic deflections of the face sheets can be sorted as
the following sequence: fully filled hybrid panel, front side filled hybrid panel, back side filled hybrid panel, and the empty sandwich panel. Investigation into energy absorption characteristic revealed that the front face and core web provided the most contribution on total energy absorption. A reverse order of panels was obtained when the maximization of total energy dissipation was used as the criteria of blast performance.


ABSTRACT: In this paper, the load-carrying capacity and failure mechanisms of sandwich beams and panels with elastomeric foam core and composite laminate face sheets are investigated. For this purpose, the flexural behavior of laminated composite beams and panels (applied as face sheets) is firstly investigated under three-point bending and central concentrated loads, respectively. Then, the same examination is conducted for the sandwich beams and panels, in which the proposed elastomeric foam is utilized as the core material. It is shown that the failure mechanisms which are associated to the core in the sandwich structures with crushable foams are not considered in the examined sandwich structures. The collapse of the sandwich specimens, examined here, is observed due to the failure of the skins in some steps. By multi-step collapse of these specimens via separately failure of the top and bottom skins, a considerable amount of energy is absorbed between these steps. Due to non-brittle behavior of the core material under loading, a large compression resistance is observed after failure of the top skin which led to the recovery of the load-carrying capacity in the sandwich beams. A similar behavior for the sandwich panels led to the increase of the ultimate strength after appearance of the failure lines on the top skin. The general outcomes of this investigation promise a good influence for the application of elastomeric foam as core material for sandwich structures.

Sid Ahmed Belalia (Department of Mechanical Engineering, Faculty of Technology, University of Tlemcen, Algeria), “Investigation of the mechanical properties on the large amplitude free vibrations of the functionally graded material sandwich plates”, Journal of Sandwich Structures and Materials, Vol. 21, No. 3, March 2019, pp 895-916,

ABSTRACT: In this paper, the geometrically nonlinear formulation based on von Karman’s assumptions is employed to study the large amplitude free vibrations of functionally graded materials sandwich plates. The functionally graded material sandwich plate is made up of two layers of power-law functionally graded material face sheet and one layer of ceramic homogeneous core. A hierarchical finite element is employed to define the model, taking into account the effects of the transverse shear deformation and the rotatory inertia. The equations of motion for the nonlinear vibration of the functionally graded material sandwich plates are obtained using Lagrange’s equations. Employing the harmonic balance method, the equations of motion are converted from time domain to frequency domain and then solved iteratively using the linearized updated mode method. Results for linear and nonlinear frequency parameters of the simply supported functionally graded material sandwich plates are computed and compared with the published values, and an excellent agreement was found. The influence of the mechanical properties of the functionally graded material, thickness ratio of FGM layers, and volume fraction exponent on the backbone curves and on the nonlinear frequency parameters are investigated. The effects of the material properties of two different types of ceramics on the large amplitude vibration behaviors of the functionally graded material sandwich plates is also presented and discussed for the first time.


ABSTRACT: Buckling of functionally graded sandwich cylindrical microshell under axial load is investigated. For this purpose, Donnell shell theory as well as material length scale parameter as considered by the couple stress theory is used, and equations of motion of the functionally graded sandwich cylindrical microshell along with boundary conditions are developed using Hamilton’s principle. Finally, dimensionless critical buckling load is determined for three functionally graded sandwich cylindrical microshells using the Navier procedure. Results of the new model are compared with the classical theory. The results indicate that the rigidity of the
functionally graded sandwich cylindrical microshell in the couple stress theory is higher than that in the classical theory, which leads to increased dimensionless critical buckling load. Besides, the effect of material length scale parameter on dimensionless critical buckling load of the functionally graded sandwich cylindrical microshell in different wavenumbers is considerable.


ABSTRACT: This paper investigates analytically nonlinear buckling and postbuckling of functionally graded sandwich circular thick cylindrical shells filled inside by Pasternak two-parameter elastic foundations under thermal loads and axial compression loads. Shells are reinforced by closely spaced functionally graded material (FGM) rings and strings. The temperature field is taken into account. Two general Sigmoid law and general power law, with four models of stiffened FGM sandwich cylindrical shell, are proposed. Using the Reddy’s third-order shear deformation shell theory (TSDT), stress function, and Lekhnitsky’s smeared stiffeners technique, the governing equations are derived. The closed form to determine critical axial load and postbuckling load-deflection curves are obtained by the Galerkin method. The effects of the face sheet thickness to total thickness ratio, stiffener, foundation, material, and dimensional parameters on critical thermal loads, critical mechanical loads and postbuckling behavior of shells are analyzed. In addition, this paper shows that for thin shells we can use the classical shell theory to investigate stability behavior of shell, but for thicker shells the use of TSDT for analyzing nonlinear stability of shell is necessary and suitable.


ABSTRACT: In this article, free vibration of rotating fiber–metal laminate thin circular cylindrical shells has been analyzed. Strain–displacement relations have been obtained based on Love’s first approximation shell theory. The variations of frequencies of the fiber–metal laminate cylindrical shell with rotational speeds for different axial and circumferential wave numbers, L/R ratios, metal thicknesses and volume fractions of metal have been presented. Also, free vibrations of the rotating fiber–metal laminate shell have been studied for carbon/epoxy, glass/epoxy and aramid/epoxy composite materials combining thin aluminum layers. The results showed that with increasing rotating speed, the gap between backward and forward waves frequencies increased.


ABSTRACT: Constrained layer damping treatments have been widely used as an effective way for vibration control and noise reduction of thin-walled plates and shells. Despite extensive application in vibration and damping analysis of sandwich plates with viscoelastic core, the rectangular element is challenged by irregular structural forms in practical engineering. In this paper, a three-layer four-node quadrilateral element with seven degrees of freedom at each node is presented. Compared with classical rectangular element, the four-node quadrilateral element has stronger adaptability in complex structural forms and boundary conditions. Based on the layer-wise theory where the constrained layer and the base layer meet Kirchhoff theory and the viscoelastic layer satisfies first-order shear deformation theory, the finite element formulation of the sandwich plate with viscoelastic core is derived by the Hamilton principle in variational form and based on the generalization of the discrete Kirchhoff Quadrilateral plate element. The complex modulus model is employed to describe the viscoelastic core of sandwich plates, allowing for the material’s frequency dependent characteristics. The natural frequencies and associated modal loss factors are computed based on the complex eigenvalue problems. The frequency dependent characteristic of the viscoelastic core is considered and an iterative procedure is introduced to solve the nonlinear eigenvalue problem. At last, six verification numerical examples that include...
three sandwich beam-plates and three sandwich plates are provided to compare present method with experiment, analytical method, Galerkin method, finite element methods and commercial software (NASTRAN). The results show that the proposed finite element can accurately and efficiently simulate the sandwich plates treated with constrained layer damping with a variety of structural forms and boundary conditions.


ABSTRACT: The vibration isolation performance of a PC sandwich plate with periodic hollow tube core is investigated experimentally and numerically. The experiment results reveal that there exist vibration attenuation zones in acceleration frequency responses which can be improved by increasing the number of periods or tuning some structure parameters. The presence of soft fillers shifts the attenuation zone to lower frequencies and enhances the capability of vibration isolation to some extent. Dispersion relations and acceleration frequency responses are calculated by finite element method using COMSOL MULTIPHYSICS. The attenuation zones obtained by experiments fit well with that by simulations, and both are consistent with the band gap in dispersion relations. The numerical and experimental studies in the present paper show that this PC sandwich plate exhibits a good performance on vibration isolation in low frequency ranges, which will provide some useful references for relevant research and potential applications in vibration propagation manipulations.


ABSTRACT: A method was developed to measure the first- and second-order vibration modes in a sandwich microcantilever beam oscillating in the megahertz frequency regime in the present study. Taking advantage of the ultrasonic frequency, a test platform was developed to induce free vibration of the microcantilever using a high-power radio frequency pulser that transmits tone burst signals to a contact transducer, and the resonant frequencies of the microcantilever were measured using a laser-optic interferometer. Results show that the microcantilever’s vibration above 8 MHz can be successfully detected, and its vibration modes were identified through a theoretical study based on the Euler–Bernoulli beam theory and a numerical analysis using the finite element method. The present study proposes a facile and effective way to actuate a high-speed sandwich microcantilever and detect its high-frequency response so that the technique can be employed to study the characteristics of micro- and nanomechanical sandwich structures and their properties.


ABSTRACT: Full thermoplastic composite sandwich structures with a foam core offer the possibility to be manufactured by fusion bonding in significant shorter cycle times than thermoset-based sandwiches. However, the application of foam cores results in lower mechanical properties such as compression and shear strength compared to honeycomb cores, therefore foam-based sandwiches cannot compete with sandwich structures based on Aramid/phenolic honeycomb cores, the current state of the art. In order to improve the mechanical performance of foam core-based sandwiches while maintaining their advantages, concepts to reinforce the foams were developed in this study. By introducing rods either orthogonally or diagonally to the skin plane, which are fusion bonded to the skins during processing, the compression and shear properties can be improved by up to 1000% and 72%, respectively. Even when correcting for the weight increase, an improved specific compression strength could be achieved. And therefore, the pinning looks especially promising when only applied locally in highly loaded areas for example.
ABSTRACT: Aluminum alloy honeycomb structures were designed based on origami technology, and the specimens were fabricated by a new fabrication technology (i.e. a press and folding process). In folding process, a new folding device was successfully developed to achieve automatic fabrication of honeycomb structure. To prove the practicability of developed device, the honeycomb cores with claws were fabricated by this device, which were used to compare the mechanical properties with that bonded by common adhesive. The deformation behaviors and mechanical properties of honeycomb structures were investigated by the flatwise compressive test and three-point bending test. The load–displacement curve obtained at the room temperature showed that the load increased to a peak value and then tended rapidly to a constant. Besides, the deformation process approximately categorized into three zones, namely linear-elastic zone, plastic-plateau zone, and densification zone. The experimental results suggested that regardless of specimen type, the bending stiffness and compressive strengths were approximately 0.32 KN·m and 0.39 MPa, respectively; revealing the bonded method by aluminum claws did not dramatically affect the mechanical properties of honeycomb structure. Moreover, the elastic deformation of honeycomb structure was numerically studied by the finite element analysis.


ABSTRACT: In this study, the strain gradient theory is employed to derive governing equations of motion of a functionally graded Timoshenko’s sandwich microbeam resting on Pasternak’s foundation. The microbeam is including a micro-core and two piezoelectric face-sheets on top and bottom. The plate is actuated with applied electric potential at top of piezoelectric face-sheets. The governing equations of motion are derived using Hamilton’s principle and strain gradient theory. After derivation of governing equations of motion, the problem is solved for three classes of analysis including wave propagation, free vibration and bending analysis. The numerical results are presented to reflect the effect of important parameters such as wave number, applied voltage, inhomogeneous index, parameters of foundation and material length-scale parameters on the different responses. The obtained results indicated that changing material length-scale parameters leads to a stiffer structure that increase natural frequencies and decreases transverse deflection and maximum electric potential.


ABSTRACT: This study presents a nonlinear vibration analysis of function graded sandwich doubly curved shallow shells, which reinforced by functionally graded material stiffeners and rested on the Pasternak foundation. The shells are subjected to the combination of mechanical, thermal, and damping loading. Four models of the sandwich shells with general sigmoid and power laws distribution are considered. The governing equations are established based on the third-order shear deformation theory. Von Kármán-type nonlinearity and smeared stiffener technique are taken into account. The explicit expressions for determining natural frequencies, nonlinear frequency–amplitude relation, and time–deflection curves are obtained by employing the Galerkin method. Finally, the fourth-order Runge–Kutta method is applied to investigate the influences of functionally graded material stiffeners, the boundary conditions, the models of the shells, thermal environment, foundation and geometrical parameters on the natural frequencies and dynamic nonlinear responses of the sandwich shells.

S.M. Hosseini, A. Habibolahzadeh and J. Nemecek (Primarily from: Department of Materials and Metallurgical Engineering, Engineering Faculty, Semnan University, Semnan, Iran), “Static and dynamic responses of a novel
The aim of this study is to analyze mechanical properties of a new Al sandwich structure with a foam core reinforced by 0.75 wt% silicon carbide nanoparticles. The reinforced core as the main component of the sandwich structure is examined by nanoindentation, quasi-static compression, impact and three-point bending tests. The behavior of the nanocomposite foam core sandwiched with AA3103 facing sheets is also analyzed under three-point bending test. The results showed that the silicon carbide nanoparticles play an important role in enhancing the Young’s modulus and hardness of the metallic matrix, static compressive strength, energy absorption of the foam core as well as load carrying capacity and maximum deflection of the sandwich structure. However, they have no significant influence on the morphological features, impact and bending properties of the foam core. The effectiveness of the silicon carbide nanoparticles was dependent on the dominant deformation mode and failure mechanism of specimens under the applied loadings.


ABSTRACT: This article presents the dynamic response of composite structures via refined beam models. The mode superposition method was used, and the Carrera Unified Formulation was exploited to create the advanced structural models. The finite element method was employed to compute the natural frequencies and modes. The main novelty of this article concerns the use of Chebyshev polynomials to define the displacement field above the cross-section of the beam. In particular, polynomials of the second kind were adopted, and the results were compared with those from analytical solutions and already established Carrera Unified Formulation-based beam models, which utilize Taylor and Lagrange polynomials to develop refined kinematics theories. Sandwich beams and laminated, thin-walled box beams were considered. Non-classical effects such as the cross-section distortion and bending/torsion coupling were evaluated. The results confirm the validity of the Carrera Unified Formulation for the implementation of refined structural models with any expansion functions and orders. In particular, the Chebyshev polynomials provide accuracies very similar to those from Taylor models. The use of high-order expansions, e.g. seventh-order, leads to results as accurate as those of Lagrange models which, from previous publications, are known as the most accurate Carrera Unified Formulation 1D models for this type of structural problems.


ABSTRACT: Vibration and buckling analysis of laminated sandwich truncated conical shells with compressible or incompressible core are presented in this work considering curvature effects. The formulation uses the quadratic and cubic functions for transverse and in-plane displacements of the core and the first-order shear deformation theory for the face sheets. The motion equations of each individual layer are derived according to the principle of minimum total potential energy considering the continuity of the displacements and the internal stress fields at the interfaces. Differential quadrature method is applied in order to obtain the frequency and buckling load of the sandwich structure. The effects of different parameters such as core to face sheet stiffness ratio, number of layers of the face sheets, boundary condition, geometrical parameters of the core and the face sheets, semi vertex angle of the cone, trapezoidal shape, and in-plane stresses of the core are examined on the vibration and buckling response of sandwich truncated conical shells. Comparison of the present results with those reported in the literature confirms the accuracy of the proposed theory. Numerical results indicate that the effects of in-plane stresses of the core significantly affect the frequency with increasing the core to face sheet stiffness ratio.

ABSTRACT: In the present article, dynamic response of a thick sandwich truncated conical shells with a transversely flexible/inflexible core and nanocomposite face sheets subjected to low-velocity impact was studied. The face sheets are reinforced with single-walled carbon nanotubes where the agglomeration effects are considered based on Mori–Tanaka model. A new equivalent three-degree-of-freedom spring-mass-damper model is utilized to describe the contact force between impactor and sandwich truncated conical shells. Based on an improved higher order sandwich panel theory, the equations of motion are derived by Hamilton’s principal incorporating the curvature, in-plane stress of the core and the structural damping effects. Differential quadrature method is applied for obtaining the contact force and displacement histories. After validity of the present study, the effects of the single-walled carbon nanotubes volume fraction, single-walled carbon nanotubes agglomeration, number of the layers of the face sheets, boundary conditions, semi-vertex angle of the cone, impact velocity, and mass of impactor on the low-velocity impact response of the nanocomposite structure are studied in details. Numerical results show that increasing the volume fraction of single-walled carbon nanotubes can reduce the amplitude of the dynamic response of the nanocomposite structure.


ABSTRACT: This article deals with the buckling and free vibration analysis of a sandwich plate with viscoelastic core and functionally graded material constraining lamina under high temperature environment. The first-order shear deformation theory is used for the finite element formulation of the plate. Along with the shear deformation, the longitudinal and transverse deformation of the core is also taken into account. The rise in the external temperature is found to reduce the critical buckling loads and fundamental frequencies, and to increase the corresponding modal loss factors. Various parametric studies such as effect of aspect ratio, core thickness ratio and volume fraction index on static and dynamic behaviour of the sandwich plate are also examined.


ABSTRACT: Extensive studies have been previously carried out on the effects of various types of local damage on the performance of sandwich panels used in the hull structures of naval ships. More recently, the approach was adapted for application on board a specific ship series. Strength reduction data were obtained for a set of sandwich materials that were representative for the vessels in question. The face sheet materials were glass fibre-reinforced plastics with non-crimp fabrics and two different types of vinylester resin. The core materials were PVC foams. Tests were performed on laminate specimens with and without circular holes under tensile loading and on sandwich face sheets with holes, cracks and impact damage under compressive loading. The strength reductions caused by impacts with sharp and blunt objects were compared with those caused by machined cracks and circular holes, respectively, and with Whitney and Nuismer’s point stress and average stress models for infinitely large laminates with cracks and holes. It was found that strength reductions due to impact damage can be estimated using tests on specimens with machined cracks and holes, and also with the average stress models if appropriate values of characteristic length are assumed. Special attention is paid to the need to take account of the geometry and the finite size of tested specimens.

ABSTRACT: Composite sandwich structures find wide application in the aerospace sector thanks to their lightweight characteristics. However, composite structures are highly susceptible to low-velocity impact damage and therefore thorough characterization of the impact response and damage process for the used material configurations is necessary. The present study investigates the effect of face-sheet thickness on the impact response and damage mechanisms, experimentally and numerically. A uni-directional, non-crimp fabric is used as reinforcement in the face-sheets, and a closed cell Rohacell 200 Hero polymer foam is used as core material. Low-velocity impact tests are performed in a novel instrumented drop-weight rig that is able to capture the true impact response. A range of impact energies are initially utilized in order to identify when low level damage (LLD), barely visible impact damage (BVID) and visible impact damage (VID) occur. A thorough fractography investigation is performed to characterize the impact damage using both destructive and non-destructive testing. The damage from the impacts in terms of dent depth, peak contact force, deflection and absorbed energy is measured. The results show bilinear responses in dent depth vs. impact energy and absorbed energy vs. impact energy. It is found that the BVID energy works well as an indication for the onset of excessive damage. Fractography reveals that there is a failure mode shift between the LLD and the VID energy levels, and that delaminations predominantly grow along the fiber direction and rotate in a spiral pattern through the thickness, following the laminate ply orientations. Finally, a progressive damage finite element model is developed to simulate both the impact response and the delamination extent, incorporating both intra-laminar and inter-laminar damage modes. The simulation shows good agreement with the experiments.


ABSTRACT: This paper deals with the problem of face/core interfacial disbonds in sandwich panels that are pressurised, i.e. the disbond has an initial fluid pressure that causes the disbond to deform. The problem is often referred to as a blister. The panel with a blister is then subjected to an in-plane compressive load. Four different panels are analysed and tested, having different size disbonds and different initial internal pressure. The cases are analysed using a finite element approach where the blister is modelled using fluid elements enabling the pressure inside the blister to vary as the in-plane load is applied. The analysis uses non-linear kinematics, and in each load step, the energy release rate is calculated along the disbond crack front. This model is used for failure load predictions. The four cases are then tested experimentally by filling a pre-manufactured disbond cavity with a prescribed volume of air. This air volume is then entrapped, and the panel is subjected to an in-plane compressive load. The load and blister pressures are measured throughout the test and compared with the finite element analysis. Surface strains and blister deformations are also measured using digital correlation measurements. The predicted failure loads compare well with the experimental results, and so does the blister pressures, the latter at least qualitatively.


ABSTRACT: The thermal and the thermo-mechanical responses of a sandwich panel with a compliant core are investigated within the framework of the extended high-order approach where the core properties are temperature dependent or independent. Loads schemes include thermal field within temperature working range simultaneous with in-plane compressive loads applied to the core only and to the face sheets and core in the form of the uniform end—shortening of edge of panel. The mathematical formulations use the extended high-order sandwich panel theory approach that takes into account the in-plane rigidity of the core and uses the deformation patterns of the high-order sandwich panel theory. The linear and nonlinear field equations along with the appropriate boundary conditions are presented. A numerical study is conducted, and it investigates the thermal response with temperature independent and temperature dependent mechanical properties of the core as well as the thermo-mechanical response due to in-plane compressive loads. The results include displacements, stress resultants, and stress at critical locations along the panel as well as equilibria curves. They reveal that, in general, the panel with temperature independent properties response remains almost linear while with
temperature dependent ones it takes a general nonlinear response. The addition of an external mechanical load changes the response from a linear/nonlinear one that may be allowable stress controlled to a case where loss of stability occurs.


ABSTRACT: The response and the debonding mechanisms in axially compressed sandwich panels with an interfacial delamination are investigated using a nonlinear model. The mathematical model combines the extended high-order sandwich panel theory with a cohesive interface modeling. It includes the first-order shear deformation kinematic assumptions for the face sheets and high-order small deformations kinematic assumptions that account for out-of-plane compressibility for the core. The interfaces bond the face sheets and the core by means of traction–displacement gap laws. These interfacial laws can describe a diversity of physical conditions. In particular, interfacial debonding nucleation and propagation are described using cohesive laws that introduce the interfacial nonlinearity into the model. Geometrical nonlinearity of the face sheets is introduced in order to capture the instability associated with the buckling of the delaminated face sheet. The cohesive interfaces and others parameters are calibrated to match experimental results taken from the literature for a sandwich specimen subjected to an end-shortening compression. The instabilities due to the in-plane compression, together with the existence of delaminated regions and their tendency to grow, prompt buckling of the delaminated face sheet as well as nucleation and propagation of the interfacial debonding. The theoretical quantification of this complex mechanism compares well with the experimental results in terms of the physical response, the nucleation and propagation of the interfacial crack, and the evolution of local/global geometrical instabilities. In addition, the analysis explores debonding mechanisms that are beyond the capabilities of the experimental technique. Finally, the sensitivity of the response and the associated geometrical and interfacial instabilities to the boundary conditions are investigated.


ABSTRACT: Sandwich composite materials are widely used within the marine industry, particularly as hull panels. Water impact loads, known as slamming, can be very significant for these structures, particularly for high-speed craft. These loadings generate local regions of high transverse shear forces near panel boundaries, which can result in transverse shear failures of core materials. The transient nature of slamming loads can cause stress rates that are high enough to affect the strength of the core material, particularly for polymeric foams. Despite the significant body of work on the constitutive behaviour and failure mechanics of sandwich core materials, there is a lack of understanding of how core materials fail in transverse shear during slamming events. There is also only very limited knowledge of how the core shear strengths measured using standardised, often quasi-static material coupon testing relate to their behaviour in a panel-slamming situation. This paper contributes in two novel areas; controlled experimental characterisation of the failure mechanics of sandwich panels subjected to water slamming to understand and quantify the strength of different polymeric core materials, comparison of the failure modes and transverse shear strength of slam-loaded sandwich panels to predictions from material coupon properties. Core types include low, medium and high elongation polymeric foams. The results demonstrate that the more ductile foams perform better as panel structures under slamming relative to their quasi-static properties compared with the more brittle cores. Prediction of the strength of a panel is shown to be highly dependent on the load distribution and whether the static or dynamic core strength is considered. The results support empirical experience that ductile foams perform well under slamming loads, and that high-elongation materials can perform better in slamming situations than predicted by their quasi-static strengths.


ABSTRACT: A finite element model is developed to investigate the vibration and damping of elastic–viscoelastic–elastic sandwich beams. Two energy dissipation mechanisms, namely the shear and compression
damping, are combined in the finite element model. Numerical examples are provided to verify the finite element model. The vibration and damping characteristics of the viscoelastic sandwich beams are investigated in detail. The numerical results show that the present finite element model has a good accuracy in predicting the natural frequencies and loss factors of viscoelastic sandwich beam structures. Moreover, it shows good applicability for both the thin and relatively thick sandwich beams. Its comprehensive performance is much better than the traditional shear and compression damping models. The effect of the viscoelastic material and geometrical parameters on the natural frequencies and loss factors of elastic–viscoelastic–elastic sandwich beam is studied as well. The results obtained have some significance in engineering application.


ABSTRACT: This paper will try to overcome two difficulties encountered by the C three-node triangular element based on the displacement-based higher-order models. They are (i) transverse shear stresses computed from constitutive equations vanish at the clamped edges, and (ii) it is difficult to accurately produce the transverse shear stresses even using the integration of the three-dimensional equilibrium equation. Invalidation of the equilibrium equation approach ought to attribute to the higher-order derivations of displacement parameters involved in transverse shear stress components after integrating three-dimensional equilibrium equation. Thus, the higher-order derivatives of displacement parameters will be taken out from transverse shear stress field by using the three-field Hu–Washizu variational principle before the finite element procedure is implemented. Therefore, such method is named as the preprocessing method for transverse shear stresses in present work. Because the higher-order derivatives of displacement parameters have been eliminated, a C three-node triangular element based on the higher-order zig–zag theory can be presented by using the linear interpolation function. Performance of the proposed element is numerically evaluated by analyzing multilayered sandwich plates with different loading conditions, lamination sequences, material constants and boundary conditions, and it can be found that the present model works well in the finite element framework.


ABSTRACT: Modifications and improvements to conventional state space differential quadrature method are proposed for free vibration analysis of thick, soft-core sandwich panels with arbitrary edge boundary conditions, using an exact two-dimensional elasticity model. The modifications are based on a systematic procedure to implement all possible combinations of edge boundary conditions including simply supported, clamped, free and guided edges. Natural frequencies and mode shapes are obtained and compared with exact elasticity solutions from state space method and approximate solution from finite element simulations; demonstrating the high numerical accuracy and rapid convergence of the modified method. Further, the proposed framework is compared to the conventional implementation of the state space differential quadrature method for thick cantilever sandwich panels and is shown to give results with better accuracy and faster convergence.


ABSTRACT: In this article, a novel meta-lattice sandwich structure is proposed and designed for impulsive wave attenuation and dynamic load mitigation. This original meta-lattice truss core sandwich structure has a similar configuration as a normal lattice sandwich structure, except that its truss bars are composed of meta-lattice truss unit cells. The design philosophy of locally resonant elastic metamaterials is integrated into the meta-lattice truss unit cell whereby a relatively heavier metal core (the resonator) is coated with a soft material layer (rubber coat), which is then connected to an outer shell. Based on this unique construction, several frequency band gaps are created by the locally resonant behavior of the specially designed resonators, in which stress waves within the stopping band gaps are not able to propagate through the material. Analytical spring-mass model is employed to predict the frequency band gaps, whereas numerical finite element simulation is utilized to model the continuum structure under impulsive loadings. The impact response, wave attenuation, and stress distribution contours between normal sandwich structure and meta-lattice sandwich structure are
compared and analyzed. The mechanisms of wave mitigation and energy absorption by the internal resonators are thoroughly investigated. Results evidently show that the proposed meta-lattice sandwich structure has a more superior ability for impact mitigation and higher kinetic energy absorption capability due to the locally resonant behavior of the internal resonators.

References listed at the end of the paper:


ABSTRACT: In this paper, a refined quasi-three-dimensional shear deformation theory for thermo-mechanical analysis of functionally graded sandwich plates resting on a two-parameter (Pasternak model) elastic foundation is developed. Unlike the other higher-order theories the number of unknowns and governing equations of the present theory is only four against six or more unknown displacement functions used in the corresponding ones. Furthermore, this theory takes into account the stretching effect due to its quasi-three-dimensional nature. The boundary conditions in the top and bottoms surfaces of the sandwich functionally graded plate are satisfied and no correction factor is required. Various types of functionally graded material sandwich plates are considered. The governing equations and boundary conditions are derived using the principle of virtual displacements. Numerical examples, selected from the literature, are illustrated. A good agreement is obtained between numerical results of the refined theory and the reference solutions. A parametric study is presented to examine the effect of the material gradation and elastic foundation on the deflections and stresses of functionally graded sandwich plate resting on elastic foundation subjected to thermo-mechanical loading.

ABSTRACT: An analytical model is developed to predict the loading and unloading response, as well as the residual dent diameter and dent depth, of carbon/epoxy-aluminum honeycomb core composite sandwich structures undergoing quasi-static indentation loading. The model considers damage created using spherical indenters and is valid up to the barely visible external damage threshold. The initial low load regime (until the onset of core crushing) is modeled using a combination of local Hertzian indentation of an elastic half-space and small deflection plate theory of a circular plate on an elastic foundation. For loads above those required to cause core crushing, the model uses the Rayleigh-Ritz method of energy minimization with the total system energy determined using a combination of face sheet bending energy, face sheet membrane energy and work done to the core during both elastic deformation and crushing. Degraded face sheet properties are used in the model beyond the onset of face sheet delamination, which is predicted using Griffith’s energy criterion. The model is validated using experimental results for sandwich structures consisting of quasi-isotropic 8- (thin) and 16- (thick) ply carbon/epoxy face sheets and aluminum honeycomb cores. The results show that the overall mechanics of the model are fundamentally correct and reflective of physical behavior. Thus, in its present form the model shows promise as a preliminary design tool.

ABSTRACT: Based on the classical shell theory, taking into account the nonlinear geometry of von Karman-Donnell, this article deals with the nonlinear dynamic analysis of Functionally Graded Material (Sandwich-FGM) cylindrical shells containing fluid under mechanical and thermal loads. By using the Galerkin method, the nonlinear dynamic equation is transformed into nonlinear differential equation in terms of time. The investigation of nonlinear dynamic response of sandwich-FGM cylindrical shells containing fluid is established. Numerical results show effect of temperature, fluid, geometric parameters of structure and material parameters (coefficient k) on the dynamic response of structure.

ABSTRACT: The in-plane uniaxial and biaxial crushing characteristics of three honeycombs were studied through explicit dynamic finite element analysis in this paper. Crushing models were created, with all square specimens (hexagonal, reentrant and mixed honeycombs) deliberately built in the same scale. The in-plane uniaxial compressive performances of cellular structures in terms of the deformation mode, plateau stress,
energy absorption as well as the impact response were compared and discussed, respectively. In the same loading condition, these honeycombs exhibited distinct characteristics. After that, in-plane orthogonal biaxial crushing simulations were carried out. Deformation processes of honeycombs were analyzed and compared. Results illustrated that some deformation behaviors in the uniaxial crushing case still exist in the biaxial crushing analysis. Their deformation modes were drawn into deformation maps. Energy absorption research illustrated that the transverse shrinking property in the uniaxial crushing case was detrimental to the energy dissipation capacity of honeycomb in the biaxial crushing case. In addition, comparing with the hexagonal honeycomb, reentrant honeycomb with slightly thicker cell walls expressed weaker ability in specific energy dissipation.


ABSTRACT: Hybridization of face, core and their combination is of great interest to develop high performance composite sandwich panels. In this regards, hybrid core of ‘polyester pin-reinforced foam filled honeycomb sandwich panels’ was fabricated and compared with unreinforced ‘foam filled honeycomb sandwich panels’ in terms of compressive and low velocity impact performances. MATLAB image processing techniques was applied to determine the impact damage area. Incorporating reinforcing pins for connecting faces and core is an effective way to improve interfacial bonding, also imparts through thickness properties for sandwich panels. Compression tests performed on the sandwich panels revealed that the polyester pin reinforcement in foam filled honeycomb sandwich panel enhanced the load bearing capacity considerably. The low velocity impact properties such as load at initial damage, total absorbed energy were greatly improved and impact damage area reduced significantly by the addition of the pins.


ABSTRACT: In this present study, the dynamic characterization and instability analysis of a rotating composite magnetorheological fluid sandwich plate under periodic in-plane loading are investigated. The governing differential equation of motion of a rotating composite magnetorheological fluid sandwich plate is derived based on classical laminated plate theory and presented in the finite element formulation. The effectiveness of the developed finite element formulation is demonstrated by comparing the results in terms of natural frequencies and parametric resonance frequencies available in literature. Various parametric studies are performed to investigate the influences of magnetic field intensity, setting angle and rotating speeds on the variation of natural frequencies and instability regions of rotating laminated composite magnetorheological fluid sandwich plate under periodic in-plane loading. It can be observed that the natural frequencies increase with increase in rotating speed and magnetic field irrespective of the modes considered. It can also be observed that the effect of variation in setting angle of non-rotating magnetorheological elastomer sandwich plate on the buckling load is minimal at various magnetic fields. However, it is observed that the buckling load increases with increase in magnetic field. Further, it can be observed that normalized width of principal and secondary instability regions decreases with increase in rotating speed and magnetic field considered.


ABSTRACT: The main objective of the present study is to examine the level of enhancement in performance of three-dimensional fiber metal laminates (3DFML) under low velocity impact, when reinforced by different types of reinforcing face-sheets (i.e. fiberglass or carbon). Three layup configurations of the fabrics are considered in this investigation. The impact response of each of these configurations is assessed numerically using ABAQUS/Explicit, a commercially available finite element software. Specifically, each configuration’s impact capacity, deformation, contact time, and energy absorption capacity are evaluated. The numerical results are validated by comparison against experimental results. Moreover, a semi-empirical equation is developed for
evaluating the impact capacity of such panels, as a function of impact energy, capable of accounting the influence of any type of reinforcement. Finally, the most efficient reinforced three-dimensional fiber metal laminates are identified based on their impact strength with respect to their overall weight and cost.


ABSTRACT: The performance of sandwich beams with expanded metal sheets as core was studied under transverse impact loading. Relationships between the force and displacement at the mid-span of the sandwich beams were obtained from the experiments. Numerical simulations were carried out using ABAQUS/EXPLICIT and the results were thoroughly compared with the experimental results. Then, the influence of the core layer number, cell orientation, size of the cell, and thickness of the substrates was investigated. The results showed that the increase in the core layers up to three times increased the energy absorption (\(E\)) by 33.88%. Moreover, increasing the thickness by up to three times increased the E by 61.33%. It was found that effects of the cell size and cell orientation on the E were dependent on each other, governing the low-velocity impact response of the sandwich beams with lattice cores.


ABSTRACT: The main aim of the paper is to find optimal solutions of sandwich panels with flat steel facings and a hybrid core made of aerogel and polyisocyanurate (PIR) foam. The optimal solutions have to satisfy conflicting criteria, i.e. a maximum range of applications and minimum weight, while at the same time respecting both the principles of sustainable development in the construction industry and the limit states (ultimate and serviceability) conditions. The design vector consists of the geometrical parameters of the sandwich panel including its span length and the parameter which describes the proportion of aerogel thickness to the total thickness of the core. The mechanical properties of the hybrid core are described by mathematical functions which were obtained in laboratory tests. In optimization, an evolutionary algorithm was used. The Pareto results were obtained while respecting the inequality constraints introduced in the optimization procedure directly (box conditions) and by means of the external penalty function. The presented optimization of a sandwich panel extends the class of problems discussed in the literature by considering both the hybrid core and the thermal conductivity aspect.


ABSTRACT: In the present research, modeling and vibration analysis of the double of sandwich beams which are coupled by visco-Pasternak medium are investigated. Also, this system is rested on Winkler foundation. Sandwich beams consist of magnetorheological core and carbon nanotubes/fiber/polymer composite facesheets. The material properties of magnetorheological core are obtained using the experimental data available in literature. Halpin–Tsai model is utilized to determine the material properties of carbon nanotubes/fiber/polymer composite facesheets. Hamilton principle is used to obtain the equations of motion of this system. Based on Navier’s method, a closed-form solution is presented for free vibration analysis of coupled magnetorheological sandwich beams under simply supported boundary conditions. The effects of various parameters such as core-to-facesheets thickness ratio, length-to-thickness ratio, magnetic field intensity, volume fractions of carbon nanotubes, and fibers and visco-Pasternak coefficients on the natural frequencies and loss factors of coupled system are discussed. The results show that the modal loss factor, unlike natural frequency, decreases by increasing magnetic field intensity. These findings can be used in design and manufacturing of sandwich structures.

R Talebitooti, AM Choudari Khameneh, MR Zarastvand, M Kornokar (Noise and Vibration Control Research Laboratory, School of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran),

ABSTRACT: The present work applies three-dimensional elasticity theory as well as extended full method based on Biot’s theory to inspect the effect of compressing porous material on sound transmission loss of the multilayered cylindrical shell subjected to porous core and air-gap insulation in the presence of external flow considering various boundary configurations. According to this fact, first, three-dimensional elasticity theory is employed for the double-walled laminated composite parts of the structure which leads to governing equations with no extra assumptions as well as considering extended full method for poroelastic section which models the structure in three directions with no need to identify the frequency domain (unlike the simplified method). Consequently, the obtained equations are solved applying state space method based on approximate laminate model beside transfer matrix approach. Likewise, the procedure is followed to obtain sound transmission loss in appropriate boundary condition. Second, the influence of compressing porous core on acoustic transmission of the current structure is cleared. Furthermore, this paper includes some configurations which compare the obtained results with those available in literature to indicate the accuracy, reliability and simplicity of the present method particularly in comparison with the simplified method. Finally, some configurations are appeared in numerical result section to show the effects of the various parameters on sound transmission loss.

Gabriele De Pietro¹, Gaetano Giunta, Salim Belouettar, Erasmo Carrera²
¹Materials Research and Technology Department, Luxembourg Institute of Science and Technology, Luxembourg, UK
²Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Turin, Italy


ABSTRACT: A static analysis of three-dimensional sandwich beam structures using one-dimensional modelling approach is presented within this paper. A family of several one-dimensional beam elements is obtained by hierarchically expanding the displacements over the cross-section and letting the expansion order a free parameter. The finite element approximation order over the beam axis is also a formulation free parameter (linear, quadratic and cubic elements are considered). The principle of virtual displacements is used to obtain the problem weak form and derive the beam stiffness matrix and equivalent load vectors in a nuclear, generic form. Displacements and stresses are presented for different load and constraint configurations. Results are validated towards three-dimensional finite element solutions and experimental results. Sandwich beams present a three-dimensional stress state and higher-order models are necessary for an accurate description. Numerical investigations show that fairly good results with reduced computational costs can be obtained by the proposed finite element formulation.


ABSTRACT: This paper presents a finite element based parametric study of the dynamic response and strength of sandwich steel beams with either sinusoidal or trapezoidal corrugated core subjected to impulsive blast loads. The sandwich steel beams consists of flat top and bottom substrates made of Steel 1018 and four core layers of Steel 1008. The core layers are arranged with uniform and non-uniform thicknesses. The finite element model is validated with a set of shock tube experiments and thus makes it feasible for a present parametric design study of core configurations. Sinusoidal and trapezoidal core shapes as well as various core thickness arrangements are taken into consideration for comparing core crushing and buckling behavior and their performances in
mitigating blast load effects onto the main structure. A unit-cell beam and a fully clamped sandwich beam are studied to elucidate the effect of core shapes and arrangement onto its dynamic response.

Nguyen Van Thanh, Vu Dinh Quang, Nguyen Dinh Khoa, Kim Seung-Eock, Nguyen Dinh Duc
Advanced Materials and Structures Laboratory, VNU-Hanoi – University of Engineering and Technology (UET), Hanoi, Vietnam
National Research Laboratory, Department of Civil and Environmental Engineering, Sejong University, Seoul, Korea
Infrastructure Engineering Program, VNU-Hanoi, Vietnam-Japan University (VJU), Hanoi, Vietnam
“Nonlinear dynamic response and vibration of FG CNTRC shear deformable circular cylindrical shell with temperature-dependent material properties and surrounded on elastic foundations”, Journal of Sandwich Structures and Materials, Vol. 21, No. 7, pp 2456-2483, October 2019,
https://doi.org/10.1177/1099636217752243

ABSTRACT: Based on Reddy’s first-order shear deformation theory, the nonlinear dynamic response and vibration of imperfect functionally graded carbon nanotube-reinforced composite (FG CNTRC) circular cylindrical shells subjected to an external dynamic load uniformly distributed on the surface of the shell and axial compression in thermal environment are presented. The circular cylindrical shells are surrounded on elastic foundations and reinforced by single-walled carbon nanotubes which vary according to the linear functions of the shell thickness. The shell’s effective material properties are assumed to depend on temperature and estimated through the rule of mixture. By applying the stress function, Galerkin method and fourth-order Runge–Kutta method, nonlinear dynamic response and natural frequencies for imperfect FG CNTRC circular cylindrical shells are determined. In numerical results, the influences of geometrical parameters, elastic foundations, initial imperfection, temperature increment, dynamic loads and nanotube volume fraction on the nonlinear vibration of FG CNTRC circular cylindrical shells are investigated. The obtained results are validated by comparing with those of other authors.

Jinqiang Li, Fengming Li, Yoshihiro Narita
College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin, China
Faculty of Engineering, Hokkaido University, Sapporo, Japan

ABSTRACT: The present paper is concerned with the active control of thermal buckling and vibration of a sandwich composite laminated plate with piezoelectric fiber-reinforced composite actuator facesheets in a thermal environment. An active temperature feedback control strategy is proposed for the thermal buckling of the composite sandwich plate. The results of numerical simulations show that the piezoelectric actuator can significantly improve the thermal buckling characteristics of the composite plates. The influence of the active thermal buckling control gain on the damping ratio and natural frequency of the structure is also investigated. From the numerical results it is observed that the active thermal buckling control with temperature feedback gain can not only enlarge the critical buckling temperature but can also reduce the resonant amplitude of the structure. Furthermore, the optimization problem is studied and it is found that the critical buckling temperature can be optimized by varying the fiber orientation in the piezoelectric fiber-reinforced composite layer. The active thermal buckling control method presented in this paper working in combination with the vibration control strategy can significantly improve the stability of the laminated composite plates. The present study will be useful for designing laminated composite structures used in the thermal environment.

Peter Rupp, Peter Elsner, Kay A Weidenmann
Institute for Applied Materials, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
Fraunhofer Institute for Chemical Technology (ICT), Pfinztal, Germany
“Failure mode maps for four-point-bending of hybrid sandwich structures with carbon fiber reinforced plastic face sheets and aluminum foam cores manufactured by a polyurethane spraying process”, Journal of Sandwich Structures and Materials, Vol. 21, No. 8, pp 2654-2679, November 2019,
https://doi.org/10.1177/1099636217722052
ABSTRACT: This work focuses on failure mode maps of sandwich panels exposed to bending load, which were produced using a polyurethane spraying process. This process allows for an automated production of sandwich panels omitting a separate bonding step of the face sheets to the core. The investigated sandwich panels consisted of carbon fiber reinforced face sheets in various configurations, and four different core structures of aluminum foam or Nomex honeycomb. After production, measurements of the pores inside the core foam structures, the fiber package thickness inside the face sheets, and the density homogeneity of the core structure were made using X-ray computed tomography. The failure mode maps were based on the individual mechanical properties of the face sheets and the core, determined by mechanical testing. The critical forces determining the failure modes were partially modified to fit the application on foam core structures and face sheets with a porous matrix. The verification of the failure modes was performed with four-point bending tests. Since all tested configurations of sandwich specimens were produced using the same process route, the applied models for the creation of the failure mode maps could be verified for numerous parameter combinations. Except for two parameters with inconstant properties, the failure modes determined by the failure mode maps matched the observed failure modes determined by the bending tests.

Wanyong Tuo, Peixing Wei, Jinxiang Chen, Yoji Okabe, Xiaoming Zhang, Mengye Xu
Key Laboratory of Concrete and Prestressed Concrete Structure of the Ministry of Education, Southeast University, Nanjing, China
Department of Architecture and Landscape, Jiangsu Vocational College of Agriculture and Forestry, Jurong, China
Department of Mechanical and Biofunctional Systems, Institute of Industrial Science, The University of Tokyo, Tokyo, Japan

ABSTRACT: In the present study, the edgewise compressive mechanical properties of the biomimetic fully integrated honeycomb plates manufactured from short basalt fiber reinforced polymer are studied. The findings are as follows: (1) Fully integrated honeycomb plates are primarily characterized by compression failure of the non-perforated surface when bearing an edgewise compressive load. The fully integrated honeycomb plates clearly exhibit the features of plasticity. (2) A buckling failure mode of the upper or lower laminates is not observed in the fully integrated honeycomb plates, and the fully integrated honeycomb plates possess the ideal integrity. Additionally, the fully integrated honeycomb plates produced with 9-mm-long fibers have the greater shearing modulus of elasticity and good plastic deformation ability. These results are of significance for disaster prevention and safety in quakeproof applications. (3) The failure features, mechanical property parameters, and simple calculation formula for edgewise compression of fully integrated honeycomb plates obtained in this work provide a foundation for the prediction of edgewise compression and the design of fully integrated honeycomb plates in future engineering applications.

Mohammad Arefi, Ashraf M Zenkour
Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
Department of Mathematics, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia
Department of Mathematics, Faculty of Science, Kafrelsheikh University, Kafrelsheikh, Egypt
ABSTRACT: In this work, an analytical solution for bending analysis of the three-layer curved nanobeams is presented. The nanobeams are including a nanocore and two piezomagnetic face-sheets. The structure is subjected to applied electric and magnetic potentials while is resting on Pasternak's foundation. To reach more accurate results, sinusoidal shear deformation theory is employed to derive displacement field of the curved nanobeams. In addition, nonlocal electro-magneto-elasticity relations are employed to derive governing equations of bending based on the principle of virtual work. The analytical results are presented for simply supported curved nanobeam to discuss the influence of important parameters on the vibration and bending results. The important parameters are included spring and shear parameters of the foundation, applied electric and magnetic potentials, nonlocal parameter, and radius of curvature of curved nanobeam.
A Alantali, RA Alia, R Umer, WJ Cantwell
Aerospace Research and Innovation Center, Khalifa University of Science and Technology (KUST), Abu Dhabi, United Arab Emirates
Centre for Future Materials, University of Southern Queensland, Toowoomba, QLD, Australia

ABSTRACT: The energy-absorbing behaviour of an aluminium honeycomb core reinforced with unidirectional and woven carbon fibre reinforced plastic composite tubes has been investigated experimentally at quasi-static rates of strain. Small diameter carbon fibre reinforced plastic tubes, with chamfered ends, were inserted into the cells of an aluminium honeycomb in order to yield a lightweight energy-absorbing material. The resulting data are compared with crushing tests on arrays of free-standing composite tubes, supported on a specially designed compression test fixture. The study continues with an investigation into size effects in the energy-absorbing response of these cellular materials, where compression tests are undertaken on four scaled sizes of reinforced honeycomb core.

Crushing tests on the multi-tube arrays have shown that woven carbon fibre reinforced plastic tubes absorb significantly greater levels of energy than their unidirectional counterparts. Here, the specific energy absorption did not vary with the number of tubes in the array, with values for the woven tubes averaging 110 kJ/kg and those for the unidirectional tubes averaging 75 kJ/kg. Inserting composite tubes into aluminium honeycomb served to increase the measured specific energy absorption of the core, resulting in values of specific energy absorption of up to 100 kJ/kg being recorded in the woven-based system. Tests on four scaled sizes of core have shown that the measured SEA does not vary with specimen size, indicating that data generated on small samples can be used to represent the energy-absorbing response of larger, more representative components.

Nguyen D Duc, Ngo Duc Tuan, Phuong Tran, Tran Q Quan, Nguyen Van Thanh
Advanced Materials and Structures Laboratory, VNU-Hanoi, University of Engineering and Technology (UET), Hanoi, Vietnam
Department of Infrastructure Engineering, The University of Melbourne, VIC, Australia

ABSTRACT: This study follows an analytical approach to investigate the nonlinear dynamic response and vibration of eccentrically stiffened sandwich functionally graded material (FGM) cylindrical panels with metal–ceramic layers on elastic foundations in thermal environments. It is assumed that the FGM cylindrical panel is reinforced by the eccentrically longitudinal and transversal stiffeners and subjected to mechanical and thermal loads. The material properties are assumed to be temperature dependent and graded in the thickness direction according to a simple power law distribution. Based on the Reddy’s third-order shear deformation shell theory, the motion and compatibility equations are derived taking into account geometrical nonlinearity and Pasternak-type elastic foundations. The outstanding feature of this study is that both FGM cylindrical panel and stiffeners are assumed to be deformed in the presence of temperature. Explicit relation of deflection–time curves and frequencies of FGM cylindrical panel are determined by applying stress function, Galerkin method and fourth-order Runge-Kutta method. The influences of material and geometrical parameters, elastic foundations and stiffeners on the nonlinear dynamic and vibration of the sandwich FGM panels are discussed in detail. The obtained results are validated by comparing with other results in the literature.

Pankaj V Katariya, Subrata K Panda, Trupti R Mahapatra
Department of Mechanical Engineering, National Institute Technology, Rourkela, India
School of Mechanical Engineering, KIIT University, Bhubaneswar, India
ABSTRACT: The frequency responses of free vibrated composite sandwich panel structure are investigated numerically by considering the geometrical nonlinearity via generalised Green–Lagrange strain kinematics in the framework of the equivalent single layer theory. The consistency and the accuracy of the current finite element solutions have been checked by solving a wide variety of examples taken as same as the reference. After the model standardisation, it is further extended to show the influence of various geometrical design parameters (side-to-thickness ratio, core-to-face thickness ratio, curvature ratio, lamination scheme and support condition) on the nonlinear frequencies of the sandwich composite flat/curved panel structure evaluated when computed using higher-order kinematic model. Also, the sandwich structural responses obtained using the equivalent higher-order kinematic model not only easy to implement but also the computational cost is low without hampering the accuracy of structural response.

Melis Yurddaskalı, Buket Okutan Baba
Department of Mechanical Engineering, Celal Bayar University, Manisa, Turkey
Department of Mechanical Engineering, Izmir Katip Celebi University, Izmir, Turkey

ABSTRACT: In this study, free vibration responses of sandwich composite panels with different radius of curvature were presented numerically. The studies were carried out on square flat and curved sandwich panels made of E-glass/epoxy face sheets and polyvinyl chloride foam with three different radii of curvature. Experimental studies were used to verify the numerical results. Vibration tests were performed on flat and curved sandwich panels under free–free boundary conditions. The experimental data were then compared with finite element simulation, which was conducted by ANSYS finite element software and it was shown that the numerical analysis results agree well with the experimental ones. Effect of the curvature on natural frequencies under different boundary conditions (all edge free, simply supported, and fully clamped) was investigated numerically. Results indicated that the natural frequencies and corresponding mode shapes were affected by boundary conditions and curvature of the panel. For all boundary conditions, the variation of curvature had smaller effect on the natural frequency of the first mode than those of the other modes.

Keivan Torabi, Hasan Afshari, Farhad Haji Aboutalebi
Department of Mechanical Engineering, Faculty of Engineering, University of Isfahan, Isfahan, Iran
Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
Department of Mechanical Engineering, Khomeinishahr Branch, Islamic Azad University, Khomeinishahr/Isfahan, Islamic Republic of Iran

ABSTRACT: In this article, free flexural vibration and supersonic flutter analyses are studied for cantilevered trapezoidal plates composed of two homogeneous isotropic face sheets and an orthotropic honeycomb core. The plate is modeled based on the first-order shear deformation theory, and aerodynamic pressure of external flow with desired flow angle is estimated via the piston theory. For this goal, first applying the Hamilton's principle, the set of governing equations and boundary conditions are derived. Then, using a transformation of coordinates, the governing equations and boundary conditions are converted from the original coordinates into new computational ones. Finally, the differential quadrature method is employed and natural frequencies, corresponding mode shapes, and critical speed are numerically achieved. Accuracy of the proposed solution is confirmed by the finite element simulations and published experimental results. After the validation, effect of various parameters on the vibration and flutter characteristics of the plate are investigated. It is concluded that geometry of hexagonal cells in the honeycomb core has a weak effect on the natural frequencies and critical speed of the sandwich plate, whereas thickness of the honeycomb core has main influence on the natural frequencies and the critical speed. Besides, it is shown that the honeycomb core thickness has optimum values that lead to the most growth in the natural frequencies or critical speed. These optimum magnitudes can be taken into account by designers to increase the natural frequencies or expand flutter boundaries and make
Aircrafts safer in supersonic flights. It is also concluded that geometrical parameters of the hexagonal cells and thickness of the honeycomb core have no significant effect on the value of the critical flow angle.


ABSTRACT: Aluminum honeycomb cores are widely used in sandwich structures due to their high stiffness-to-weight ratios and very low densities. However, owing to their porous architecture, honeycomb cores are inherently weak and are susceptible to damage due to inadvertent or improper loadings on their encompassing sandwich structure. This damage can potentially lead to the failure of the sandwich structure, and therefore it should be detected and evaluated, preferably using nondestructive methods. Common nondestructive techniques have limited effectiveness in inspecting aluminum honeycombs due to their porous structure and dispersive properties. Since honeycombs are less dispersive at sub-ultrasound frequencies, inspecting them using low and sub-ultrasound frequencies has been introduced lately as a promising alternative to ultrasound inspection. However, this approach requires an a priori knowledge of the wave propagation characteristics in the inspected material, which is not readily available for most commercially available aluminum honeycombs, especially the ones manufactured by joining thin corrugated sheets. Thus, this work utilizes finite element computations to assess the low frequency wave propagation characteristics (i.e. phase velocity and dispersive properties) in commercially available aluminum honeycombs made by bonding thin corrugated sheets. Results illustrate that the dispersive behavior and acoustic anisotropy of the studied honeycombs are more significant at higher porosities and high frequencies as well as identify the frequencies below which honeycombs exhibit their least dispersive acoustic behavior.

Reza Kolahchi, Behrooz Keshtegar, Mohammad Hosein Fakhar
Department of Mechanical Engineering, Kashan Branch, Islamic Azad University, Kashan, Iran
Department of Civil Engineering, Faculty of Engineering, University of Zabol, Zabol, Iran

ABSTRACT: Optimization of embedded piezoelectric sandwich nanocomposite plates for dynamic buckling analysis is presented in this work based on Grey Wolf algorithm. The Grey Wolf algorithm mimics the leadership hierarchy and hunting mechanism of grey wolves in nature. In addition, the main steps of hunting, searching for prey, encircling prey, and attacking prey are employed. The structure is composed of a laminated functionally graded-carbon nanotubes reinforced layers as core integrated with sensor and actuator layers considering structural damping effects. Two-dimensional magnetic and 3D electric fields are applied to core and piezoelectric layers, respectively. Sinusoidal shear deformation theory is utilized for obtaining the motion equations and differential quadrature method is applied for solution. Also, a proportional–derivative controller is employed to control the dynamic behavior of the structure. Finally, the optimum designs for the structure are evaluated using proposed Grey Wolf algorithm based on the geometrical parameters of plate, applied voltage, controller parameters, volume fraction of carbon nanotubes, spring, and shear constants of foundation. Numerical results indicate that by applying the positive voltage and transverse magnetic field the optimum dimensionless frequency of the system decreases.

Mohammad Arefi, Masoud Kiani, Ashraf M Zenkour
Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
Department of Mathematics, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia
Department of Mathematics, Faculty of Science, Kafrelsheikh University, Kafrelsheikh, Egypt

ABSTRACT: The present work is devoted to the free vibration analysis of elastic three-layered nano-/micro-plate with exponentially graded core and piezomagnetic face-sheets using the modified couple stress theory. To
capture size-dependency for a nano-/micro-sized rectangular plate, the couple stress theory is used as a non-classical continuum theory. The rectangular elastic three-layered nano-/micro-plate is resting on Pasternak’s foundation. The present model contains one material length scale parameter and can capture the size effect. Material properties of the core are supposed to vary along the thickness direction based on the exponential function. The governing equations of motion are derived from Hamilton’s principle based on the modified couple stress theory and first-order shear deformation theory. The analytical solution is presented to solve seven governing equations of motion using Navier’s solution. Eventually the natural frequency is scrutinized for different side length ratio, thickness ratio, inhomogeneity parameter, material length scale, and parameters of foundation numerically.

LeventUGH, Hayrettin Duzcukoglu, Omer Sinan Sahin, Harun Akkuş
Department of Mechanical Engineering, Faculty of Technology, Amasya University, Turkey
Technology Faculty, Mechanical Engineering Department, Selcuk University, Turkey
Engineering Faculty, Mechanical Engineering Department, Selcuk University, Turkey
Technical Sciences Vocational School, Amasya University, Turkey
https://doi.org/10.1177/1099636217733235
ABSTRACT: In this study, the behavior of aluminium honeycomb structures under low-speed impact has been investigated by experimental and finite element analysis method. The production of aluminium honeycomb composite structures was carried out using different adhesives of different widths and heights. The low-velocity impact experiments of the honeycomb structures produced were performed according to ASTM D7766 standard. As a result of the experiment, the force values which caused damage to the structure were measured according to the time, and the maximum force values were taken. Findings have shown that the decrease in cell width, the increase in cell height, and depletion of multiwall carbon nanotubes increase the maximum impact force values in honeycomb composite structures. It is seen that the results obtained by the finite element method and the experimental results are approximately 85% in agreement. There was no statistically significant difference between the results as a result of conducted t-test.

https://doi.org/10.1177/1099636217732530
ABSTRACT: Stress analysis of adhesively bonded joints of sandwich structures is more complex. Only a few research works have studied this subject. The major obstacle is finding the stress distribution at the adhesive layer of sandwich structures under different loading conditions. This paper presents a study on stress distribution at the adhesive joints of the corrugated sandwich structure subjected to three-point bending using the cohesive zone model. Firstly, three cases of sandwich models with different types of glue on both longitudinal and transverse loading directions were calculated using cohesive zone model, and then the corresponding experiments were carried out and compared to prove the FEM results to validate the results through both load–displacement curves and failure deformation modes. Secondly, the cohesive zone model simulation was used to obtain the detailed stress distribution at the bonding joint with the effect of four major geometrical parameters: adhesive layer thickness, corrugated panel thickness, face panel thickness and adhesive joint width. Lastly, the results of stress analysis showed that the stress distribution is not uniform and is highly affected by the bonding joint's geometrical parameters, adhesive layer thickness and adhesive joint width.

https://doi.org/10.1177/1099636217736003
ABSTRACT: This paper aims to present accurate solutions for flexural vibration of functionally graded sandwich plates resting on two-parameter elastic foundation with any combined boundary conditions. The
governing equations of free vibration problem are derived from the first-order shear deformation theory that covers the important effects of shear deformation and rotary inertia. To solve the coupled differential equations governing vibration behavior of the plates with various boundary conditions, an effective tool, namely Chebyshev collocation method, is implemented to obtain the accurate solutions with several parametric studies. The influences of material volume fraction index, layer thickness ratio, side-to-height ratio, boundary conditions, etc., on natural frequencies of the plates are taken into investigation and discussed in details. Our numerical experiments reveal that the proposed method can offer the accurate frequency results of the plates as compared to those available in the literature. Additionally, the spring constants of elastic foundation have a significant impact on frequency changes of the plates. Increasing the values of spring constants leads to considerable increases of the frequencies.

References listed at the end of the paper:

<table>
<thead>
<tr>
<th>Page</th>
<th>Reference</th>
</tr>
</thead>
</table>


Hanfeng Yin (1, 2), Guilin Wen (1, 2), Zhonghao Bai (1), Zhewu Chen (2) and Qixiang Qing (2)
(1) Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, P R China
(2) Advanced Design and Simulation Techniques for Special Equipment, Hunan University, Changsha, PR China
ABSTRACT: Multi-cell polygonal tubes are highly efficient energy absorbers and widely used in vehicle engineering. There is no doubt that the structure designers have strong interest to know which kind of multi-cell polygonal tube has the best crashworthiness. However, the comparative study on the crashworthiness of multi-cell polygonal tubes with different edges was quite few. In this paper, the multi-cell polygonal single and bitubular tubes were investigated using the numerical simulation and theoretical prediction methods. Theoretical expressions of the mean crushing forces of the multi-cell polygonal single and bitubular tubes with arbitrary edge were derived by employing the simplified super folding element theory. The theoretical prediction also had good agreement with the numerical simulation result for the cell polygonal bitubular tube with 18 edges had the best energy absorption capacity. In order to further improve the crashworthiness of multi-cell polygonal tube, a metamodel-based multi-objective optimization method which jointly employed the finite element simulation, metamodelling method and non-dominated sorting genetic algorithm ver. II multi-objective optimization algorithm was developed. Based on this metamodel-based optimization method, the multi-cell polygonal bitubular tube with 18 edges was optimized. The theoretical prediction also had good agreement with the numerical simulation result for the optimal design. The optimal multi-cell polygonal tube not only had excellent energy absorption capacity but also had stable collapse mode.

References listed at the end of the paper:


36. Liao, XT, Li, Q, Yang, XJ, et al. A two-stage multi-objective optimisation of vehicle crashworthiness under frontal impact. Int J

ABSTRACT: This paper investigates flexural vibration of functionally graded sandwich microbeams supported by different axially immovable boundary conditions. The governing equations of free vibration problem are based on Timoshenko beam theory and the modified couple stress theory which are taking into account the important effects of shear deformation, rotary inertia and material length scale parameter. To solve the governing equations presented in the forms of coupled differential equations for vibration analysis of the beams with various boundary conditions, an effective tool, namely Chebyshev collocation method, is employed to find out accurate solutions with many important parametric studies. The effects of material volume fraction index, layer thickness ratio, slenderness ratio, boundary condition, temperature rise, etc. on natural frequencies of the beams are taken into account and discussed in details. The numerical results of the beams in ambient temperature and high thermal environment are presented in several tables and figures that can serve as benchmarks for further investigations in the field of FG sandwich microbeam analysis.

References listed at the end of the paper:


Karamanli, A. Bending behaviour of two directional functionally graded sandwich beams by using a quasi-3D shear deformation theory. Compos Struct 2017; 174: 70–86.


ABSTRACT: In this paper, the nonlinear dynamic stability analysis of sandwich beam including AL-foam flexible core and carbon nanotubes-reinforced composite face sheets subjected to axial periodic load are investigated by using generalized differential quadrature method. The flexible core of sandwich beam is made of Aluminum alloy foam with variable mechanical properties in the thickness direction. With considering the high-order geometrical nonlinearity in the core and face sheets, the high-order sandwich panel theory and modified couple stress theory are employed for AL-foam flexible core and face sheets, respectively. The
governing nonlinear partial differential equations of dynamic stability are derived from the Hamilton’s principle and then discretized by using generalized differential quadrature method to convert them into a linear system of Mathieu–Hill equations. These formulations lead to nine partial differential equations which are coupled in axial and transverse deformations. The boundaries of the instability region are achieved by Bolotin’s method and are illustrated in the dimensionless nonlinear excitation frequency \( (\Omega_{NL}) \) to load amplitude plane. A parametric study is carried out to investigate the influence of some important parameters such as slenderness ratio, face sheet thickness, temperature rise, carbon nanotube volume fraction, static load factor, coefficients of Pasternak foundation, and end supports on the nonlinear dynamic instability characteristics of AL-foam core sandwich beam. The numerical results show that with temperature increasing, the nonlinear excitation frequency \( (\Omega_{NL}) \) and width of corresponding unstable zone decrease, but dynamic frequency ratio \( (\Omega_{NL}/\Omega_{L}) \) and associated unstable region increase. With an increase in the application of sandwich structures for compressible core in advanced industries such as spacecraft, high-speed aircraft, naval vessels, transportation, and automobiles, a further interest in the problem-involving dynamic instability of structures has resulted. Because of their applications, sandwich structures are frequently exposed to periodic axial compressive forces and so the dynamic instability has been a very important topic in structural dynamics and is of practical importance in different engineering industries.

References listed at the end of the paper:


Mohammadimehr, M, Shahedi, S. High-order buckling and free vibration analysis of two types sandwich beam including AL or PVC-foam flexible core and CNTs reinforced nanocomposite face sheets using GDQM. Compos Part B Eng 2017; 108: 91–107.


Mohammadimehr, M, Mostafavifar, M. Free vibration analysis of sandwich plate with a transversely flexible core and FG-CNTs reinforced nanocomposite face sheets subjected to magnetic field and temperature-dependent material properties using SGT. Compos Part B Eng 2016; 94: 253–270.


Pradyumna, S, Gupta, A. Nonlinear dynamic stability of laminated composite shells integrated with piezoelectric layers in


Zahra Naghizadeh (1), Mehdi Faezipouir (1), Mohammad Hossein Pol (2), Gholamhossein Liaghat (3) and Ali Abodolkhani (1)
ABSTRACT: Effect of adding carboxyl-modified multi-walled carbon nanotubes (COOH-MWCNTs) on the high velocity impact of sandwich panels with plywood core and two different facesheets, E-glass/epoxy and E-glass/nylon 6, was investigated in this study. Facesheets were prepared with and without COOH-MWCNTs. Three different weight percentages of 0.3, 0.5, and 1 wt% of COOH-MWCNTs were used to reinforce epoxy and nylon 6 polymers. The sandwich panels’ estimated ballistic limit ($V_b$) and impact energy absorbed ($E_a$) were determined by subjecting them to impact velocities in their ballistic limit range and above by conical nose projectile. It was found that the sandwich panels containing E-glass/epoxy facesheets exhibited more energy absorption than those containing E-glass/nylon 6 facesheets. Moreover, the high velocity impact response of sandwich panels improved with the increase of COOH-MWCNT content. Besides, the damage area for different types of materials studied is presented, and it is observed that at a given impact velocity, the damage size on the rear facesheet of target around the point of impact decreases on addition of COOH-MWCNTs.

References listed at the end of the paper:

Effects of some manufacturing conditions on wettability and bonding of veneers obtained from various wood species.


Aydın I. Effects of some manufacturing conditions on wettability and bonding of veneers obtained from various wood species.


ABSTRACT: Carbon and glass dry fibre bundles were inserted into a ROHACELL® 71HERO polymethacrylimide foam core under a specific inclination angle and pin pattern in order to enhance the compressive strength and stiffness of the core material. Flatwise compression tests were conducted on pin-reinforced sandwich specimens and unreinforced sandwich to investigate the effect of pin volume fraction and pin material on the compressive mechanical properties and energy absorption characteristics. X-ray computed tomography was performed on tested specimens to investigate the failure modes under compressive loads. It was concluded that the compressive strength is mainly controlled by pin failure due to bending and compression loads at pin base. Moreover, increasing the pin volume fraction improved the compressive properties of the sandwich but using glass fibre pins instead of carbon fibre pins led to a higher increase of the absorbed crushing energy. Finally, an existing analytical model to predict the compressive strength and stiffness has been tested and evaluated.

References listed at the end of the paper:


15: 111–117.


Torayaca T800H data sheet, Doc-no. CFA-007. Santa Ana, CA, USA: Toray Carbon Fibers America Inc.


C.K. Susheel (1), Anshui Sharma (1), Rajeev Kumar (2) and Vishal S. Chauhan (2)
(1) Department of Mechanical Engineering, National Institute of Technology Uttarakhand, Uttarakhand, India
(2) School of Engineering, Indian Institute of Technology Mandi, Mandi, India
https://doi.org/10.1177/1099636217752114
ABSTRACT: In the present article, a parametric study on the geometric nonlinear static and dynamic analysis of thin functionally graded structure sandwiched between functionally graded piezoelectric materials is presented. The properties of functionally graded material are graded in the thickness direction according to a power law distribution and variation of electric field is assumed to be quadratic across the thickness of functionally graded piezoelectric materials layers. The structure is modeled using finite element modeling. The finite element formulation is derived using Hamilton’s principle using full geometric nonlinearities. This is done by using Green-Lagrangian strains instead of von-Karman strains which are usually used by most researchers while conducting similar studies. The ensued non-linear algebraic equations are then solved using the modified Newton–Raphson method. A fuzzy logic controller is used to attenuate the vibration occurring in the host structure.

References listed at the end of the paper:


ABSTRACT: This work investigates the residual mechanical behaviour of composite sandwich panels in bending after impact loading conditions. The sandwich panels were made of an epoxy/glass face sheet with three different core materials: styrene acrylonitrile foam, polyethylene terephthalate foam and Balsa wood. A three-point bending test was performed in order to determine the reference stiffness. A low-velocity impact test and thereafter the three-point bending test were performed with the same specimens. The failure modes during bending tests were captured using a high-speed camera. It was found that multiple shear cracks with progressive failure were present in the core of styrene acrylonitrile and polyethylene terephthalate panels in bending after impact tests, whereas single shear crack with sudden failure was the case for Balsa panels. The initial bending stiffness decreased approximately 30.5, 35.2 and 55.6% for Balsa, styrene acrylonitrile and polyethylene terephthalate panels, respectively, in bending after impact tests due to the influence of the pre-damage from the low-velocity impact tests. The reduction in collapse force was also quantified for Balsa, styrene acrylonitrile and polyethylene terephthalate panels as 22.8, 4.9 and 22.1%, respectively.

References listed at the end of the paper:

2. Hassan, MZ, Cantwell, WJ. The influence of core properties on the perforation resistance of sandwich structures – an


Aminreza Karamoozian (1), Chin An Tan (2) and Liangmo Wang (1)
ABSTRACT: Periodic cellular structures, especially lattice designs, have potential to improve the cooling performance of brake disk system. In this paper, the method of two scales asymptotic homogenization was used to indicate the effective elastic stiffnesses of lattice plates structures. The arbitrary topology of lattice core cells connected to the back and front plates which are made of generally orthotropic materials, due to use in brake disc design. This starts with the derivation of general shell model with consideration of the set of unit cell problems and then making use of the model to determine the analytical equations and calculate the effective elastic properties of lattice plate concerning the connected back and front plates. The analytical and numerical method allows determining the stiffness properties and the internal forces in the trusses and plates of the lattice. Three types of core-based lattice plates, which are pyramidal, X-type and I-type lattices, have been studied. The I-type lattice is characterized here for the first time with particular attention on the role that the cell trusses and plates plays on the stiffness and strength properties. The lattice designs are finite element characterized and compared with the numerical and experimentally validated pyramidal and X-type lattices under identical conditions. Results show that the stiffness and yield strength of the lattices depend upon the stress–strain response of the parent alloy of trusses and plates, the truss mass fraction coefficient, the face carriers thickness and the core elements parameters. The study described here is limited to a linear analysis of lattice properties. Geometric nonlinearities, however, have a considerable impact on the effective behavior of a lattice and will be the subject of future studies.

References listed at the end of the paper:


11. Phan, D, Kondyles, D. Rotor design and analysis; a technique using computational fluid dynamics (CFD) and heat transfer analysis. SAE International. 2003.


<table>
<thead>
<tr>
<th>No.</th>
<th>Author(s)</th>
<th>Title</th>
<th>Journal/Book Details</th>
</tr>
</thead>
</table>

ABSTRACT: In this research, we have investigated the ballistic resistance of sandwich structures with aluminum face-sheet and graded polyurethane foam core with different densities. The effects of graded changes of core foam density and the effect of the sequence of foam layers with different densities on energy absorption and ballistic limit of sandwich structures under the impact of hemispherical nose projectiles at high speeds (160 to 300 m/s) are studied. The results of this study showed that increasing the density and thickness of the foam core leads to increase in the ballistic limit and energy absorption; also, the ballistic limit of sandwich structures with the same mass with graded foam core for three- and five-layer panels is, respectively, 10.37 and 5.57% more than single-layer foam core with the average density in case the foam layer with less density is placed in the impact side. By using the graded foam core (laminate), the core resistance is increased and the damaged zone shape is changed, and the energy absorption of back face-sheet is increased.

References listed at the end of the paper:
ABSTRACT: In some applications such as roofs and walls, it is important to supply low thermal conductivity and high bending stiffness to structures. Generally, foam materials are preferred, which have low thermal conductivity. However, bending stiffness and compression properties of foam materials are low. In this study, composite tubes were inserted to the foam core material to improve the compression and bending properties of the sandwich structure. Vacuum infusion method was used to manufacture the sandwich structure. The bending and compression performance of the structures with and without composite tubes were compared. To measure the bending stiffness and compression properties of the structure, three-point bending and compression tests were conducted according to American Society for Testing and Materials (ASTM) standards. The manufacturing procedure can be easily automated and applied to large and complex shape panels. In addition, a parametric analysis was done to investigate the effect of the number of tubes and the diameter of the tubes on bending and compression stiffness of the structure. According to the test results, the samples including the
composite tubes gave six times higher bending stiffness as compared to the samples without the composite tubes. As the diameter of the tubes increased the bending stiffness and the ultimate core shear strength increased. In addition, the structures including 14 mm diameter tubes had higher specific absorbed energy values under compression loading.

References listed at the end of the paper:


ABSTRACT: This paper presents the theoretical model of sandwich plate with pyramidal truss cores to investigate the acoustic property of transmission loss. The two-dimensional periodic model is established based on the assumption that the trusses are regarded as Euler-Bernoulli beams. The fluid-structure interaction is considered by imposing velocity continuity condition at fluid-structure interfaces. The periodic governing equations are derived by using space harmonic expansions and the principle of virtual work. Meanwhile, the practical specimens are fabricated by slitting and snap-fit assembly to conduct sound insulation experiment via standing wave tube method. The theoretical result shows satisfactory agreement with experimental data. The numerical discussions are conducted to demonstrate the effects of incident angles and topological parameters which should be helpful for practical design.

References listed at the end of the paper:


ABSTRACT: This paper presents the theoretical model of sandwich plate with pyramidal truss cores to investigate the acoustic property of transmission loss. The two-dimensional periodic model is established based on the assumption that the trusses are regarded as Euler-Bernoulli beams. The fluid-structure interaction is considered by imposing velocity continuity condition at fluid-structure interfaces. The periodic governing equations are derived by using space harmonic expansions and the principle of virtual work. Meanwhile, the practical specimens are fabricated by slitting and snap-fit assembly to conduct sound insulation experiment via standing wave tube method. The theoretical result shows satisfactory agreement with experimental data. The numerical discussions are conducted to demonstrate the effects of incident angles and topological parameters which should be helpful for practical design.

References listed at the end of the paper:


Wang, DW, Ma, L. Sound transmission through composite sandwich plate with pyramidal truss cores. Compos Struct 2017; 164: 104–117.


Kurtze, BWG. New wall design for high transmission loss or high damping. J Acoust Soc Am 1959; 31: 739–748.

ABSTRACT: The performance of sandwich structure with expanded metal sheets as the core was studied under axial crushing and transverse impact bending. Relationships between the force and displacement at the mid-span of the sandwich beams were obtained from the experiments. Numerical simulations were carried out using ABAQUS/EXPLICIT and the results were thoroughly compared with the experimental results. Then, the influence of the cell orientation and size of the cell were investigated. It was shown that the cell orientation was a critical parameter affecting the failure mode and energy absorption capability, leading to the increase in the peak load and specific energy absorption during the axial crushing tests. Specific energy absorption of the sandwich beams with lattice core under axial crushing ranges from 117 to 2934 J/kg, which is higher than that of beams under transverse bending. The results showed that the increase in cell angle up to $\Theta = 90^\circ$ increased the energy absorption by 624.4%. It was found that effects of the cell size and cell orientation on the energy absorption were dependent on each other governing the low-velocity impact response of the sandwich beams with lattice cores.

References listed at the end of the paper:


ABSTRACT: The present research deals with magnetic and electric buckling loads of three-layered elastic nanoplate with exponentially graded core and piezomagnetic face-sheets. Material properties of the nanoplate core obey the exponential function along the thickness direction. The governing equations based on first-order shear deformation theory are deduced using variational method. The influence of nanoscale is considered by employing nonlocal piezo-magneto-elasticity theory. The governing equations of nanostructure are solved analytically. Eventually the effect of significant parameters such as length-scale parameter, inhomogenous index, geometrical characteristics and parameters of foundation on the magneto-electro responses of problem is numerically investigated.

References listed at the end of the paper:


ABSTRACT: This paper uses the analytical, experimental and numerical methods to investigate the low-velocity impact response of fully clamped multilayer sandwich beams with metal foam cores struck by a heavy mass. Using the quasi-static method, analytical solutions for dynamic response of the fully clamped multilayer sandwich beams are derived including the interaction between bending and stretching induced by large deflections. Effects of local denting and core strength on the overall bending are considered. The low-velocity impact experiments and numerical calculations are carried out to validate the analytical model. The present
analytical model captures experimental and numerical results reasonably. It is shown that the energy absorption of multilayer sandwich beams increases with decrease of multilayer factor and increase of the core strength. References listed at the end of the paper:


Tagarielli, VL, Fleck, NA. A comparison of the structural response of clamped and simply supported sandwich beams with


Nguyen Dinh Duc (1,2,3), Ngo Duc Tuan (4), Pham Hong Cong (1,5), Ngo Dinh Dat (1) and Nguyen Dinh Khoa (1,2)

(1) Advanced Materials and Structures Laboratory, VNU Hanoi, University of Engineering and Technology (UET), Hanoi, Vietnam
(2) Infrastructure Engineering Program, VNU Hanoi, Vietnam Japan University (VJU), Hanoi, Vietnam
(3) National Research Laboratory, Department of Civil and Environmental Engineering, Sejong University, Seoul, Korea
(4) Department of Infrastructure Engineering, The University of Melbourne, Parkville, Australia
(5) Centre for Informatics and Computing (CIC), Vietnam Academy of Science and Technology, Hanoi, Vietnam


ABSTRACT: Based on the first order shear deformation shell theory, this paper presents an analysis of the nonlinear dynamic response and vibration of imperfect eccentrically stiffened functionally graded material ES-FGM cylindrical panels subjected to mechanical, thermal, and blast loads resting on elastic foundations. The material properties are assumed to be temperature-dependent and graded in the thickness direction according to simple power-law distribution in terms of the volume fractions of the constituents. Both functionally graded material cylindrical panels and stiffeners having temperature-dependent properties are deformed under temperature, simultaneously. Numerical results for the dynamic response of the imperfect ES-FGM cylindrical panels with two cases of boundary conditions are obtained by the Galerkin method and fourth-order Runge–Kutta method. The results show the effects of geometrical parameters, material properties, imperfections, mechanical and blast loads, temperature, elastic foundations and boundary conditions on the nonlinear dynamic response of the imperfect ES-FGM cylindrical panels. The obtained numerical results are validated by comparing with other results reported in the open literature.

References listed at the end of the paper:


23. Matsunaga, H. Free vibration and stability of functionally graded shallow shells according to a 2D higher-order deformation theory. Compos Struct 2008; 84: 132–146.

Mei-Chen Lin (1), Jia-Hong Lin (2), Jan-Yi Lin (1) and Ching-Wen Lou (2)
(1) Department of Fiber and Composite Materials, Feng Chia University, Laboratory of Fiber Application and Manufacturing, Feng Chia University, Taichung City, Taiwan
(2) Department of Chemical Engineering and Materials, Ocean College, Minjiang University, Fuzhou, China

https://doi.org/10.1177/1099636218766230

ABSTRACT: Fiber-reinforced polymer composites are commonly used in different fields because the evenly distributed fibers in polymer can efficiently transmit the load of a force and mechanically reinforce the polymer matrices. This study proposes producing composite sandwiches using thermoplastic polyurethane sheets as the top and bottom layers and a polypropylene/Kevlar nonwoven fabric the interlayer. Thermoplastic polyurethane sheets and a polypropylene/Kevlar nonwoven fabric are combined using the sheet extrusion method, during which the polypropylene staple fibers are melted and firmly bond the thermoplastic polyurethane sheets. The mechanical properties, thermal behavior, and surface morphology of composite sandwiches are evaluated, examining the influence of parameters. The test results show that the composite sandwiches are mechanically reinforced as a result of using the nonwoven covers. Moreover, the improved interfacial bonding between the cover layers and the interlayer inhibits delamination, and the stabilized structure subsequently decreases the level of combustion which is in conformity of the differential scanning calorimetry results. The manufacturing is creative and efficient due to one-step shaping, creating a refined composite sandwich with good mechanical properties and combustion resistance.

References listed at the end of the paper:


Weidong Liu (1), Honglin Li (1), Jiong Zhang (2) and Hongda Li (3)  
(1) College of Energy and Electrical Engineering, Hohai University, Nanjing, PR China  
(2) School of Civil Engineering and Architecture, Wuyi University, Jiangmen, PR China  
(3) Fundamental Science for National Defense-Advanced Design Technology of Flight Vehicle, Nanjing University of Aeronautics and Astronautics, Nanjing, PR China  

https://doi.org/10.1177/1099636218768174

ABSTRACT: Flexible skin is an essential component for morphing wind turbine blade to maintain a smooth profile and bear aerodynamic loads during morphing. Cellular honeycomb cores with low in-plane and high out-of-plane stiffness are potential candidates for support structures of flexible skin. Honeycomb structure also requires zero Poisson’s ratio to avoid unnecessary stress and strain during one-dimensional morphing. A novel accordion cellular honeycomb core of close-to-zero Poisson’s ratio with in-plane corrugated U-type beams was proposed as a solution for these problems. The elastic properties of the structure are illustrated through a combination of theoretical analysis and finite element analysis. Results show that better in-plane morphing and out-of-plane load-bearing capabilities can be obtained with parameters of larger height-to-length ratio, spacing-to-length ratio and vertical beam to U-type beam thickness ratio as well as smaller thickness-to-length ratio.  

Results of comparisons on properties of the proposed honeycomb with two existing accordion honeycombs reveal that the in-plane elastic modulus of the proposed structure is as low as about 56% of that of the accordion honeycomb with V-type beams and 79% of that of the accordion honeycomb with cosine beams, showing better in-plane property but weaker out-of-plane load-bearing capability. Nevertheless, the out-of-plane load-bearing capability can be reinforced by increasing the vertical beam to U-type beam thickness ratio. Smaller driving force and less energy consumption are required by the proposed honeycomb core than conventional structures during morphing. The methods and results could be used for predictions of elasticity in design of sandwich morphing skin with similar cellular honeycomb cores.

References listed at the end of the paper:


ABSTRACT: This paper focuses on the vibration analysis of three-layered curved sandwich beams with elastic face layers and viscoelastic core. First, the equations of motion that govern the free vibrations of the curved beams together with the boundary conditions are derived by using the principle of virtual work, in the most general form. Then, these equations are solved by using the generalized differential quadrature method in the frequency domain, for the first time to the best of the authors’ knowledge. Verification of the proposed beam model and the generalized differential quadrature solution is carried out via comparison with the results that already exist in literature and the ANSYS finite element solution combined with the modal strain energy method. The effect of system parameters, i.e. layer thicknesses, the lamination angle of layers and the curvature on the vibration and damping characteristics of a curved sandwich beam with laminated composite face layers and a frequency dependent viscoelastic core is investigated in detail.

References listed at the end of the paper:


ABSTRACT: The governing equations for the buckling of honeycomb cores with various cell geometries under combined compression and shear are established and three types of core including rectangular, hexagonal and triangular cores are under consideration. After invoking the Bloch wave representation form, the equations are simplified by the periodicity and the hypothesis that the out-of-plane displacement remains zero at the intersections. Different cell geometries and load cases are taken into account and numerical results offer validation for the analytical solutions. Moreover, the results of Finite Element (FE) models show that the fine results can only be acquired by models with appropriate cell numbers. Experimental study is conducted on the regular hexagonal honeycomb structures. Both the results of the numerical benchmarks and the experiments prove the effectiveness of the proposed analytical method and the hypothesis for predicting the buckling load of honeycomb structures.

References listed at the end of the paper:


Seyyed M. Hasheminejad, Masoud Cheraghi and Ali Jamalpoor (Department of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran), “Active damping of sound transmission through an

ABSTRACT: An exact model is proposed for sound transmission through a sandwich cylindrical shell of infinite extent that includes a tunable electrorheological fluid core, and is obliquely insonified by a plane progressive acoustic wave. The basic formulation utilizes Hamilton’s variational principle, the classical and first order shear deformation shell theories, the Kelvin–Voigt viscoelastic damping model (for the electrorheological fluid-core layer), and the wave equations for internal/external acoustic domains coupled by the proper fluid/structure compatibility relations. The Fourier–Bessel series expansions are used to arrange the governing (coupled) system equations in state-space form. The classical Sliding Mode Control law is then applied to semi-actively reduce sound transmission through the composite cylinder by smart variation of stiffness and damping characteristics of the electrorheological fluid-core actuator layer according to the control command. Numerical results present both the uncontrolled and controlled sound transmission loss spectra of the sandwich cylindrical shell at three angles of incidence for three distinct sets of material input parameters that represent the electric-field dependency of the complex shear modulus of the electrorheological fluid-core layer. The superior soundproof performance of electrorheological fluid-based sliding mode control system in avoiding the highly detrimental sound transmission loss dips occurring throughout the critical resonance and coincidence regions is demonstrated. Likewise, remarkable enhancements in the sound insulation characteristics of the electrorheological fluid-actuated structure utilizing the first or second electrorheological fluid material model are achieved within the stiffness-controlled region, especially at lower frequencies in near-grazing incidence situation. A number of limiting cases are introduced and validity of the formulation is confirmed by comparison with the available data.

References listed at the end of the paper:


32. Estéve, SJ, Johnson, ME. Reduction of sound transmission into a circular cylindrical shell using distributed vibration absorbers

33. Henry, JK, Clark, R. Active control of sound transmission through a curved panel into a cylindrical enclosure. J Sound Vib 2002; 249: 325–349.


References listed at the end of the paper: GPLRC, are also less sensitive to the nonlinear deformation.

Weight fraction of graphene platelets in face sheets that are symmetrically distributed in such a way, called O-sheet tends to be much more safety of the soft core from any failure. Besides, sandwich beams. Numerical results demonstrate that distributing more graphene platelets near the upper and lower surface layers of the face sheets, named X-sheet, is capable to improve the bending strength and decrease the local deflection of the top face sheet, and this recovery effect becomes more significant as graphene platelet weight fraction increases. The results also reveal that the graphene platelet distribution pattern of the face sheets plays an important role to decrease the transverse shear stress of the core by dispersing more graphene platelets near surfaces of the face sheets (X-GPLRC). So, reducing the local deflection of the top face sheet tends to be much more safety of the soft core from any failure. Besides, sandwich beams with a lower weight fraction of graphene platelets in face sheets that are symmetrically distributed in such a way, called O-GPLRC, are also less sensitive to the nonlinear deformation.


ABSTRACT: This study investigates the nonlinear bending response of a novel class of sandwich beams with flexible core and face sheets reinforced with graphene platelets that are functionally graded distributed through the thickness. Nonlinear governing equations are established based on extended high-order sandwich panel theory and Von Kármán type of geometrical nonlinearity. In this theory, the face sheets follow the first-order shear deformation theory, and the two-dimensional elasticity is adopted for the core. These nonlinear differential equations are discretized into algebraic systems by means of the Ritz-based method from which the static bending solution can be achieved. The effective Young’s modulus of functionally graded graphene platelet-reinforced composite (GPLRC) face sheets is determined through the modified Halpin–Tsai micromechanics model, and associated Poisson’s ratio is evaluated by employing the rule of mixture. Comparison studies are provided for a sandwich beam with graphene-reinforced face sheets and conventional nanocomposite beam reinforced by graphene platelets due to lack of results for introduced sandwich beams. Besides, three-point bending test was carried out in order to assure the validity of nonlinear bending analysis of a sandwich beam based on extended high-order sandwich panel theory. Afterwards, parametric studies are given to examine the influences of graphene platelet distribution pattern, weight fraction, and core-to-face sheet thickness ratio together with the total number of layers on the linear and nonlinear bending performances of the sandwich beams. Numerical results demonstrate that distributing more graphene platelets near the upper and lower surface layers of the face sheets, named X-GPLRC, is capable to improve the bending strength and decrease the local deflection of the top face sheet, and this recovery effect becomes more significant as graphene platelet weight fraction increases. The results also reveal that the graphene platelet distribution pattern of the face sheets plays an important role to decrease the transverse shear stress of the core by dispersing more graphene platelets near surfaces of the face sheets (X-GPLRC). So, reducing the local deflection of the top face sheet tends to be much more safety of the soft core from any failure. Besides, sandwich beams with a lower weight fraction of graphene platelets in face sheets that are symmetrically distributed in such a way, called O-GPLRC, are also less sensitive to the nonlinear deformation.

References listed at the end of the paper:


Nguyen, KT, Thai, TH, Vo, TP. A refined higher-order shear deformation theory for bending, vibration and buckling analysis of functionally graded sandwich plates. Steel Compos Struct 2015; 18: 91–120.


References listed at the end of the paper. The accurate results presented here will serve as a benchmark for future investigations.

orientational number and stacking sequence of plies. Three transverse shearing stresses are constant in the core; the sign of modal transverse shearing stresses can change through the thickness of the skin; and the shape of modal cross-sectional warping is influenced by the mode number and stacking sequence of plies. Three-dimensional frequencies are presented for different fiber orientation angles, boundary conditions, aspect ratios, thickness ratios, core/skin thickness ratios, and stacking sequences of plies. The accurate results presented here will serve as a benchmark for future investigations.


ABSTRACT: This paper is concerned with the free vibration of variable stiffness laminated sandwich plates with curvilinear fibers. The three-dimensional elasticity theory and the \( p \)-version of the finite element method are adopted for the analysis. The skin is composed of one or more plies with curvilinear fibers. The fiber path orientation angle in a ply is assumed to vary linearly with the \( x \) coordinate. The plies may be stacked symmetrically or anti-symmetrically with respect to the middle surface of the plate. Each layer is modeled as one brick \( p \)-element. The principle of virtual displacements is used to derive the element stiffness and mass matrices. The generalized displacements at vertices, edges, and faces shared by elements are matched to ensure inter-element compatibility. Since no solutions are available for the free vibration of such variable stiffness laminated sandwich plates, the validity, convergence, and accuracy of the present three-dimensional method are established by comparing with existing three-dimensional frequencies for constant stiffness laminated sandwich plates with rectilinear fibers. The study reveals that inter-layer modal bending stresses are discontinuous; modal transverse shearing stresses are constant in the core; the sign of modal transverse shearing stresses can change through the thickness of the skin; and the shape of modal cross-sectional warping is influenced by the mode number and stacking sequence of plies. Three-dimensional frequencies are presented for different fiber orientation angles, boundary conditions, aspect ratios, thickness ratios, core/skin thickness ratios, and stacking sequences of plies. The accurate results presented here will serve as a benchmark for future investigations.

References listed at the end of the paper:


ABSTRACT: In this study, a closed-cell aluminum foam was filled into the interspaces of a sandwich panel with corrugated cores to form a composite structure. The novel structure is expected to have enhanced foam-filled cores with high specific strength and energy absorption capacity. An out-of-plane compressive load under low-velocity impact was experimented and numerically carried out on both the empty and foam-filled sandwich panels as well as on the aluminum foam. It is found that the empty corrugated sandwich panel has poor energy absorption capacity due to the core member buckling compared to that of the aluminum foam. However, by the filling of the aluminum foam, the impact load resistance of the corrugated panel was increased dramatically. The loading-time response of the foam-filled panel performs a plateau region like the aluminum foam, which has been proved to be an excellent energy absorption material. Numerical results demonstrated that the aluminum foam filling can decrease the corrugated core member defects sensitivity and increase its stability dramatically. The plastic energy dissipation of the core member for the foam-filled panel is much higher than that of the empty one due to the reduced buckling wavelength caused by the aluminum foam filling.

References listed at the end of the paper:


different parametric studies are conducted. It has been demonstrated that the variation of the initial kinetic

Afterwards, the solution in the time domain is obtained based on Newmark's numerical time integration scheme.

impactors, the modified Hertz contact law is utilized. Rayleigh-Ritz method is applied to the Hamilton principle in order to find the set of equations of motion for the impactor as well as the CNTRC sandwich plate.


ABSTRACT: In this study, non-linear low-velocity impact response of a simply supported sandwich plate with CNTRC face sheets subjected to the impactors with different geometrical shapes is investigated. It has been assumed that the sandwich plate is made up of two face sheets reinforced with CNTs graded along their thickness as X profile and a homogeneous core. In CNT-reinforced layers, a micromechanical model has been used to obtain the effective material properties and the analysis is performed in the framework of the Reddy’s higher order shear deformation theory with regard to thermal effects. An analytical model is proposed to capture the response performance of the three-layer sandwich plates under different thermal environments. Through the proposed analytical study, in order to characterize the contact force between the sandwich plate and the impactors, the modified Hertz contact law is utilized. Rayleigh-Ritz method is applied to the Hamilton principle in order to find the set of equations of motion for the impactor as well as the CNTRC sandwich plate.

Afterwards, the solution in the time domain is obtained based on Newmark's numerical time integration scheme. After validating the proposed approach, in order to examine the influences of various involved parameters, different parametric studies are conducted. It has been demonstrated that the variation of the initial kinetic
energy as one of the parameters under study has a significant effect on the central displacement, contact force, and indentation in both conical and cylindrical impactors and the change in the radius of the cylinder has an insignificant effect on the central displacement. As well, in the case of equal masses, the cylindrical impactor causes more amount of indentation with respect to conical.

References listed at the end of the paper:


Song, YS, Youn, JR. Modeling of effective elastic properties for polymer based carbon nanotube composites. Polymer 2006; 47: 1741–1748.

Raja Ouled Ahmed Ben Ali and Sami Chatti (LMS (LR 11 ES 36), National Engineering School of Sousse, Sousse Erriadh, Tunisia), “Simplified springback prediction of thick sandwich panel”, Journal of Sandwich Structures and Materials, Vol. 22, No. 4, pp 1019-1038, May 2020, https://doi.org/10.1177/1099636218779320 ABSTRACT: Springback is one of the most important design behavior in air-bending processes. The sandwich panel exhibits more complicated bending and springback behavior due to substantial differences in mechanical properties between the foam core and the metallic skin sheet. In this paper, we will not only propose a semi-analytical model in order to easily predict springback in air-bending process of steel/polyurethane/steel sandwich panel, but also we will carry out experiments to measure springback amount. The semi-analytical model results and the experiment findings proved to be in a good agreement. In addition, numerical simulations and experiments were conducted to investigate the effects of punch radius, die opening, and the foam thickness on springback.

References listed at the end of the paper:


Kim, YW, Kima, JI. Control of spring back for helically coiled steam generator tube. Nucl Eng Design 2004; 234: 61–70.


M. Shaban (1) and A. Alibeigloo (2)
(1) Mechanical Engineering Department, Bu-Ali Sina University, Hamadan, Iran
(2) Mechanical Engineering Department, Faculty of Engineering, Tarbiat Modares University, Tehran, Iran

“Global bending analysis of corrugated sandwich panels with integrated piezoelectric layers”, Journal of Sandwich Structures and Materials, Vol. 22, No. 4, pp 1055-1073, May 2020,
https://doi.org/10.1177/1099636218780172

ABSTRACT: Smart corrugated sandwich panels are special types of sandwich panels which are well suited in advanced devices to provide not only high resistance capability against mechanical loads but also energy harvesting capacity for low power applications. In this paper, analytical solution for corrugated sandwich panels with embedded piezoelectric layers is presented by using three-dimensional theory of elasticity. Energy method in conjunction with homogenization approach is used to determine effective properties of corrugated cores in thickness direction. Due to extreme orthotropic nature of corrugated cores, this method can give an accurate solution by using state-space method. Accuracy of core properties is verified by comparing numerical results with previous investigations. Furthermore, reliability of presented method is guaranteed by comparing the results with finite element analysis. A comprehensive parametric study including influences of geometrical factors such as pitch, height, sheet thickness and corrugation shape is accomplished.

References listed at the end of the paper:


S.M.N. Serdoun (1) and S.M. Hamza Cherif (2)
(1) Department of Technology, Higher School of Applied Sciences, Tlemcen, Algeria
(2) Faculty of Engineering, Department of Mechanical Engineering, University of Tlemcen, Tlemcen, Algeria


ABSTRACT: This paper presents a numerical method for determining natural frequencies and vibration modes of sandwich thick plates reinforced with parabolic fibers. The approach is based on the p-version finite element method with hierarchical trigonometric functions and Reddy’s high order shear deformation theory. The equations of motion of free vibration of thick composite laminated and sandwich plates are obtained based on Hamilton’s principle. A very fast convergence is obtained by increasing the number of hierarchical shape functions. The accuracy of the present method is established by a comparisons made between the present results and published results. The effects of boundary conditions, thickness ratio, material properties, and orientation angle on natural frequencies and normalized cross-sections of mode shape for sandwich plates reinforced with parabolic fibers are studied and investigated.

References listed at the end of the paper:


ABSTRACT: A semi-analytical approach to investigate the nonlinear vibration axisymmetric analysis of functionally graded sandwich shallow spherical caps under external pressure resting on elastic foundation in thermal environment is presented. The governing equations are derived by using the first-order shear deformation theory taking into account von Karman geometrical nonlinearity and Pasternak’s two-parameter elastic foundation. The motion equations are determined by Galerkin method and the obtained equation is numerically solved by using Runge–Kutta method. Results of nonlinear dynamic responses show the effects of foundation, material, geometric parameters, and temperature change on the nonlinear vibration of shells.

References listed at the end of the paper:


ABSTRACT: In this article, dynamic stability of annular sandwich plate with carbon nanotubes reinforced composite facesheets and an isotropic homogeneous core are presented based on first-order shear deformation theory and modified strain gradient theory. The generalized rule of mixture is employed to predict mechanical properties of microcomposite sandwich plate. The equations of motion are derived from Hamilton’s principle and solved by differential quadrature method. The fast rate of convergence of the method is shown and the results are compared against existing results in the literature. The results indicate that volume fraction of carbon nanotubes in facesheets and dimensionless length scale parameter has significant effects on the dynamic stability region and the parametric resonance. Dynamic stability region increases with considering of dimensionless length scale parameter, increasing of volume fraction of carbon nanotubes, and static load factor. Also, the influence of inner-to-outer radius ratios, radius-to-thickness ratios, and core-to-facesheets ratios are considered. The results can be employed for design of materials science, in junction high pressure micropipe connections, solid-state physics, micro-electro-mechanical systems, and nano electromechanical systems such as microactuators and microsensor.

References listed at the end of the paper:


|---|---|
Mohammadimehr, M, Shahedi, S. High-order buckling and free vibration analysis of two types sandwich beam including AL or PVC-foam flexible core and CNTs reinforced nanocomposite face sheets using GDQM. Compos Part B 2017; 108: 91–107.


ABSTRACT: In this study, a new type of flexible sandwich composite with nonwoven facesheets and core reinforced by polyurethane (PU) grid sealing shear thickening fluid (STF) has been presented. With the specific design, the STF was sealed into PU grids as the core to provide shear thickening effect against impact. Rheological property of STF with different mass ratio and PU morphology after first and second foaming were evaluated and optimized for sandwich composite preparation. Both static compression and dynamic impact tests were carried out to obtain the impact dynamic response and investigate the effects of typical parameters including STF volume, core thickness and striker height on low-velocity impact behavior. The test results showed that the optimal concentration of STF was 20 wt.%, whose critical shear rate was 100s⁻¹. The presence of STF had a positive influence on the static compression strength and dynamic impact strength. In particular, the 70% STF volume fraction contributed to the highest compression modulus. The compression modulus was 445 MPa and 466 MPa when the sample thickness was 2 cm and 3 cm, respectively. As for dynamic impact strength with corresponding STF volume fractions, it was 4535.31 mJ for 30%, 4599.72 mJ for 50%, and 4827.46 mJ for 70%, all of which were much higher than that (2348 mJ) of control group (without STF). Regardless of whether the STF volume being 30%, 50% and 70%, the impact displacement of composite was within 10 mm, showing better impact resistance than control group (13.16 mm). Besides, this composite with special PU grid sealing, STF structure demonstrated a certain strain rate effect. The higher the impact energy, the greater the energy absorption was. Specifically, impact energy absorption rate of composite with a thickness of 3 cm was as high as 52.3% under 350 mm impact height.

References listed at the end of the paper:


ABSTRACT: Sandwich pipe, consisting of two steel tubes and a polymeric or cement-based material core layer, has been considered as an attractive solution for oil and gas transporting in deep water. In this paper, the characteristic responses and pressure capacity of sandwich pipes having fiber-reinforced cementitious composites core configuration under external hydrostatic pressure were investigated. The interface adhesion behavior between the fiber-reinforced cementitious composite core and the surrounding steel pipes was modeled based on the inter-layer shear strength test experiments conducted on the sandwich pipe specimens. The parametric studies were carried out to evaluate the influence of geometry parameters and steel grade on the buckling response and ultimate pressure capacity. Furthermore, 768 FE models of sandwich pipes covering a wide range of practical design configurations were rapidly constructed and analyzed using FE software package ABAQUS with the help of programming language Python. Finally, a simplified equation for predicting the pressure capacity of sandwich pipes within the scope of this study was proposed using dimensional analysis combined with singular value decomposition methodology.

References listed at the end of the paper:


ABSTRACT: Although single-layer sandwich materials have been extensively studied in the engineering field, multilayered sandwich structures have rarely been concerned, especially on their dynamic analysis or vibration control. In this study, the dynamics of a double-layer hourglass sandwich beam is investigated by an improved method developed to simplify the calculations. The active vibration control is also analyzed. By using Hamilton’s principle, the governing equations are derived and the natural frequencies are calculated by our
improved method. The results have been validated by comparing with the data obtained by traditional method, and finite element method. The contributions of both structural and material parameters on the dynamics of the double-layer sandwich beam are also investigated. The velocity feedback control method is employed to act as controllers on vibration suppressing of the sandwich structure actively. Further, nonlinear energy sink is used to control the vibration of the sandwich structure passively.

References listed at the end of the paper:

20. Reddy, JN, Phan, ND. Stability and vibration of isotropic, orthotropic and laminated plates according to a higher-order shear


Li, M, Li, FM, Jing, XJ. Active vibration control of composite pyramidal lattice truss core sandwich plates. J Aerosp Eng 2017; 31: 04017097.

Kattimani, SC. Active damping of multiferroic composite plates using 1-3 piezoelectric composites. Smart Mater Struct 2017; 26: 125021.


ABSTRACT: The acoustic radiation responses of laminated sandwich baffled flat panels subjected to harmonic loading in an elevated thermal environment are investigated via a novel coupled finite and boundary elements formulation based on the higher-order shear deformation shell theory. The structural stiffness and mass tensors are obtained using competent finite element steps engaging the Hamilton’s principle followed by computation of acoustic responses by resolving the Helmholtz partial differential equation. An in-house MATLAB code is developed based on the present formulation for the computation of all the desired responses. The accuracy and robustness of the present scheme are recognized by the close conformance of the critical buckling temperature, natural frequencies and the sound power level values with the available benchmark solutions alongside the values obtained via a simulation model implemented using commercially available finite element (ANSYS) and boundary element (LMS Virtual.Lab) packages. Subsequently, the present model is employed to solve wide variety of numerical illustrations and the useful inferences related to the influence of elevated temperature, core-to-face thickness ratio, core-to-face modular ratio and lay-up scheme on the sound emission characteristics of sandwich composite flat panels are deliberated in detail.

References listed at the end of the paper:


Sahu, KC, Tuhkuri, J. Active control of sound transmission through soft-cored sandwich panels using volume velocity cancellation. Proc Meet Acoust 2014; 20: 40004.


S.S. Satheesh Kumar (1), M. Sudhakara Rao (1), I. Balasundar (1), Amit Kumar Singh (2), T. Raghu (1) and G. Madhusudhan Reddy (2)

(1) Near Net Shape Group, Defence Metallurgical Research Laboratory, Hyderabad, India
(2) Metal Joining Group, Defence Metallurgical Research Laboratory, Hyderabad, India


ABSTRACT: Metallic thermal protection systems comprising of sandwich panels consisting of hexagonal honeycomb sandwich structures are envisaged to be used in advanced transportation systems like hypersonic vehicles and reusable launch vehicles. The assessment of compressive mechanical behaviour is necessary to understand the response of sandwich structures to aerothermal loads. The fabrication methodology for realizing Ni based superalloy Superni 263 hexagonal honeycomb sandwich panels is established. This work is aimed at understanding the effect of sandwich panel geometry parameters like hexagonal cell size and core thickness on the out-of-plane flatwise compressive behaviour at room temperature. The ultimate compressive strength decreases with increasing core height irrespective of the cell sizes investigated. The dependence of specific
compressive strength on the cell size is established by a power law relationship. The compressed sandwich panels subjected to understand the deformation behaviour indicated the dominance of cell wall bending and occasional fracture, however in the case of sandwich panels with higher core thickness cell wall buckling coupled with shearing at the face sheet vicinity is noticed.

References listed at the end of the paper:

1. Guthrie, JD, Battat, B, Severin, BK. Thermal protection systems for space vehicles. Advanced Materials and Processes Technology (AMPTIAC), DOD Information Analysis Center (IAC) administered Defence Technical Information Center (DTIC), USA, www.amptiac.iitri.org


ABSTRACT: In the present work, by considering the agglomeration effect of single-walled carbon nanotubes, free vibration characteristics of functionally graded nanocomposite sandwich sectorial plates are presented. The volume fractions of randomly oriented agglomerated single-walled carbon nanotubes are assumed to be graded in the thickness direction. To determine the effect of carbon nanotube agglomeration on the elastic properties of carbon nanotube-reinforced composites, a two-parameter micromechanical model of agglomeration is employed. In this research work, an equivalent continuum model based on the Eshelby–Mori–Tanaka approach is considered to estimate the effective constitutive law of the elastic isotropic medium (matrix) with oriented straight carbon nanotubes. The two-dimensional generalized differential quadrature method as an efficient and accurate numerical tool is used to discretize the equations of motion and to implement the various boundary conditions. The proposed sectorial plates are simply supported at radial edges, while all possible combinations of free, simply supported, and clamped boundary conditions are applied to the other two circular edges. The benefit of using the considered power-law distribution is to illustrate and present useful results arising from symmetric and asymmetric profiles. The effects of agglomeration, geometrical, and material parameters together with the boundary conditions on the frequency parameters of the sandwich functionally graded nanocomposite plates are investigated. It is shown that the natural frequencies of structure are seriously affected by the influence of carbon nanotubes agglomeration. This study serves as a benchmark for assessing the validity of numerical methods or two-dimensional theories used to analyze the sandwich sectorial plates.

References listed at the end of the paper:

<table>
<thead>
<tr>
<th>No.</th>
<th>Author(s)</th>
<th>Title and Details</th>
</tr>
</thead>
</table>
| 30. | Yokozeki, T, Iwahori, Y, Ishiwata, S. | Matrix cracking behaviors in carbon fiber/epoxy laminates filled with cup-stacked carbon


Davide De Cicco and Farid Taheri (Department of Mechanical Engineering, Advanced Composite and Mechanics Laboratory, Dalhousie University, Halifax, Nova Scotia, Canada), “Robust numerical approaches for simulating the buckling response of 3D fiber-metal laminates under axial impact – Validation with experimental
ABSTRACT: The reliability and efficiency of three different numerical modeling approaches for simulating the response of a newly developed 3D fiber-metal laminate (3D-FML), subject to axial impact loading, are considered in this paper. The main objective of the study is to establish the most robust numerical framework for analyzing the performance of such complexly configured hybrid materials subject to axial impact loading in a fairly accurate, yet efficient manner. LS-DYNA finite element software is used for the purpose. The models include: (i) a full 3D solid model, where all 3D-FML constituents are modeled with 3D elements; (ii) a model with intermediate complexity, in which two different element types are used to model the metallic skins and 3D-fiberglass/foam core, respectively; and (iii) a simplified scheme, consisting of a single layer of thin-shell elements, representing all constituents of the FML. An experimental investigation is also conducted in parallel to verify the accuracy of the modeling schemes. Force and axial-shortening histories, energy absorption capacity, and overall qualitative behavior obtained numerically are compared to experimental results. Both accuracy and computation cost are considered as the performance criteria, all with the aim of providing the reader with some perspective for robust modeling of such geometrically sophisticated composites, subject to a complex loading mechanism.

References listed at the end of the paper:


J. Jelovica (1) and J. Romanoff (2)
(1) Department of Mechanical Engineering, The University of British Columbia, Vancouver, BC, Canada
(2) Department of Mechanical Engineering, Aalto University, Espoo, Finland


ABSTRACT: Modeling a periodic structure as a homogeneous continuum allows for an effective structural analysis. This approach represents a sandwich panel as a two-dimensional plate of equivalent stiffness. Known as the equivalent single-layer, the method is used here to analyze bifurcation buckling of three types of sandwich panels with unidirectional stiffeners in the core: truss-core, web-core and corrugated-core panels made of an isotropic material. The transverse shear stiffnesses of these panels can differ by several orders of magnitude, which cause incorrect buckling analysis when using the equivalent single-layer model with the first-order shear deformation theory. Analytical solution of the problem predicts critical buckling loads that feature infinite number of half-waves in the direction perpendicular to the stiffeners. Finite element model also predicts buckling modes that have non-physical, saw-tooth shape with infinite curvature at nodes. However, such unrealistic behavior is not observed when using detailed three-dimensional finite element models. The error in the prediction of the critical buckling load is up to 85% for the cases considered here. The correction of the equivalent single-layer model is proposed by modeling the thick-faces effect to ensure finite curvature. This is performed in the finite element setting by introducing an additional plate with tied deflections to the equivalent single-layer plate. The extra plate is represented with bending and transverse shear stiffness of the face plates. As a result, global buckling is predicted accurately. Guidelines are proposed to identify the sandwich panels where ordinary model is incorrect. Truss-core and web-core sandwich panels need the correction. Corrugated-core panels without a gap between plates in the core have smaller shear orthotropy and do not need the correction. Modeling the thick-faces effect ensures correct results for all cases considered in this study, and thus one should resort to this approach in case of uncertainty whether the ordinary equivalent single-layer model is valid.

References listed at the end of the paper:


<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
</table>
ABSTRACT: In this study, the failure behaviour of lattice sandwich panels under three-point loading has been studied using a nonlinear finite element analysis. The failure mechanisms of lattice-cored sandwich panels can be classified in three modes; facesheet yielding, facesheet wrinkling and core shear. When the panel fails due to facesheet yielding or core shear, the evaluation of the strength of the lattice-cored panel can be undertaken in the same manner as that of a foam-cored panel. In contrast, when wrinkle-like deformation occurs in the facesheets, the failure load can be estimated from the buckling stress of the facesheet. The failure mode map for the lattice-cored panel with the coordinate system $t/l$ and $\rho_c/\rho_s$ can be described by the analytical equations that predict the three failure modes. The failure mode map highlights the dominant failure modes for the lattice-cored sandwich panel based on the key design parameters $t/l$ and $\rho_c/\rho_s$. References listed at the end of the paper:

<table>
<thead>
<tr>
<th>Reference</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hua, Q, Wang, TJ.</td>
<td>An analytical solution for the large deflections of a slender sandwich beam with a metallic foam core under transverse loading by a flat punch. Compos Struct 2009; 88: 509–518.</td>
</tr>
</tbody>
</table>

Tao Fu (1), Zhaobo Chen (1), Hongying Yu (1), Zhonglong Wang (1) and Xiaoxiang Liu (2)
(1) School of Mechatronics Engineering, Harbin Institute of Technology, Harbin, PR China
(2) Beijing Institute of Control Engineering, Beijing, PR China

ABSTRACT: The present study is concerned with free vibration of functionally graded sandwich plates on elastic foundation based on \( n \)-th order shear deformation theory. The material properties of functionally graded plate are assumed to vary according to power law distribution of the volume fraction of the constituents, and two common types of FG sandwich plates are considered. Governing differential equations are derived by means of Hamilton’s principle. The differential quadrature method is developed to formulate the problem, and rapid convergence is observed in this study. A numerical comparison is carried out to show the validity of the proposed theory with available results in the literature. Furthermore, effects of gradient indexes, thickness side
ratio, aspect ratio, foundation parameters, boundary condition and different sandwich types on the natural frequency of plates are also studied. References listed at the end of the paper:


Tao Fu (1), Zhaobo Chen (1), Hongying Yu (1), Qingjun Hao (1) and Yanzheng Zhao (2) (1) School of Mechatronics Engineering, Harbin Institute of Technology, Harbin, PR China (2) Robotics Institute of Shanghai Jiao Tong University, Shanghai, PR China “Vibratory response and acoustic radiation behavior of laminated functionally graded composite plates in thermal environments”, Journal of Sandwich Structures and Materials, Vol. 22, No. 5, pp 1681-1706, June 2020, https://doi.org/10.1177/1099636219856556
ABSTRACT: The present study is concerned with vibro-acoustic behavior analyses of laminated functionally graded carbon nanotube reinforced composite plates based on Reddy’s higher order shear deformation theory. Four types of carbon nanotubes distributions along the plate thickness are considered, which include uniformly distributed and three other functionally graded distributions. Governing differential equations are derived by means of Hamilton’s principle. The sound pressure and radiation efficiency are calculated with Rayleigh integral. A numerical comparison with available results in the literature is carried out to show the validity of the present model. Furthermore, effects of the carbon nanotubes volume fraction, different thermal environments, lamination angle and carbon nanotubes distribution types on the structural and acoustic response of laminated functionally graded carbon nanotube reinforced composite plates are also investigated. References listed at the end of the paper:

and the higher order shear deformation theory. Compos Struct 2017; 180: 116–129.


Wang, Q, Shao, D, Qin, B. A simple first-order shear deformation shell theory for vibration analysis of composite laminated open cylindrical shells with general boundary conditions. Compos Struct 2018; 184: 211–232.


ABSTRACT: In this paper, bending of cylindrical sandwich pipes based on the high-order theory of sandwich structures with flexible core is investigated. The cylindrical sandwich pipe is composed of a flexible core and two composite face sheets. Behavior of the cylindrical sandwich pipe is described by a high-order sandwich shell theory, which explains nonlinear distortions of cross-sectional plane of the flexible core as well as changes in its height. The theory based on variational principles and using an extremely thorough systematic closed-form approach is formulated. In this model, no assumption has been considered for displacement distribution of core components. In this study, stress and displacement of the flexible core are obtained through a three-dimensional elasticity solution and the face sheets are modeled using classical shell theory. Also, a comparison is made in order to verify high-order solution results between a closed-form solution, which is expanded for simply supported boundary conditions and results that are obtained from the commercial finite element method. Finally, influences of physical and geometrical parameters on behavior of the cylindrical sandwich pipe are investigated.

References listed at the end of the article:

13. Xia, M, Kemmochi, K, Takayanagi, H. Analysis of filament-wound fiber-reinforced sandwich pipe under combined internal


Han, J-H, Kardomateas, GA, Simites, GJ. Elasticity, shell theory and finite element results for the buckling of long sandwich cylindrical shells under external pressure. Compos Part B Eng 2004; 35: 591–598.


Thomsen, OT. Analysis of local bending effects in sandwich plates with orthotropic face layers subjected to localised loads. Compos Struct 1993; 25: 511–520.


ABSTRACT: The main objective of this article is to analyze the buckling of sandwich annular plates with carbon nanotube-reinforced face sheets subjected to in-plane mechanical loading resting on the elastic foundation. It is assumed that the sandwich plate is composed of the homogeneous core layer and two functionally graded carbon nanotube-reinforced composite face sheets. The effective material properties of the functionally graded carbon nanotube-reinforced composite face sheets are estimated using the modified rule of mixture method. The higher-order shear deformation theory along with the variational differential quadrature method is employed to derive the governing equations. To this end, the quadratic form of energy functional of the structure is derived based on higher-order shear deformation theory which is directly discretized using numerical differential and integral operators. The validity of the proposed numerical approach is first shown and the effects of various parameters are then investigated on the buckling of sandwich annular plates. It was found that the elastic foundation coefficients, type of distribution of carbon nanotubes, inner-to-outer radius ratio and core-to-face sheet thickness ratio play important roles in the stability of the structure. Furthermore, the numerical results of the higher- and first-order shear deformation theories are compared.

References listed at the end of the paper:


7. Xia, XK, Shen, HS. Vibration of post-buckled sandwich plates with FGM face sheets in a thermal environment. J Sound Vib


ABSTRACT: A sandwich structure consists of a two thin and strong facesheets, bonded to a thick lightweight core material. The mechanical response of a sandwich structure depends on the properties of its constituents. A numerical model and experimental validation of the three-point bending test of sandwich composites are presented in this study. The core material is aluminum honeycomb. The facesheets are made of IM7/Cycom5320-1, which is a carbon fiber/epoxy prepreg system. A comprehensive model of the failure under flexural loading was developed. Facesheet failure was modeled using Hashin’s failure criteria. A detailed meso-scale model of the honeycomb core was included in the model. The experiments indicated that failure initiation was due to local buckling in the honeycomb core. Failure propagation was in the form of core failure, facesheet compressive failure, and interlaminar failure. The developed meso-scale model was able to accurately simulate failure initiation and propagation in the composite sandwich structure. The effect of elevated temperature on the three-point bending behavior was studied numerically as well as experimentally. An increase in test temperature to 100°C resulted in a drop of 9.2% in flexural strength, which was also predicted by the numerical model.

References listed at the end of the paper:


ABSTRACT: The nonlinear buckling and post-buckling response of imperfect porous plates is investigated analytically in this paper. The porous materials with elastic moduli are assumed to vary through the thickness of the plate according to two different distribution types. Governing equations are derived based on the classical shell theory taking into account Von Karman nonlinearity and initial geometrical imperfection. Explicit relations of load–deflection curves for rectangular porous plates are determined by applying stress function and Galerkin’s method. The accuracy of present theoretical formulation is verified by comparing it with available results in the literature. The effects of varying porosity distribution, porosity coefficient, boundary condition and imperfection on post-buckling behavior of the porous plate are studied in detail. A parametric study is carried out to investigate the effects of varying porosity distribution, porosity coefficient, boundary condition and imperfection on post-buckling behavior of the porous plate. The results show that the critical buckling loads decrease with increasing porosity coefficient and the post-buckling curves for nonlinear symmetric porosity distribution are always higher than those for nonlinear non-symmetric porosity.

References listed at the end of the paper:


ABSTRACT: This work presents an asymptotical thermoelastic model for analyzing symmetric composite sandwich plate structures. Use of three-dimensional finite elements to analyze real-life composite sandwich
structures is computationally prohibitive, while use of two-dimensional finite element cannot accurately predict the transverse stresses and three-dimensional displacements. Endeavoring to fill this gap, the present theory is developed based on the variational asymptotic method. The unique features of this work are the identification and utilization of small parameters characterizing the geometry and material stiffness coefficients of sandwich structural panels in addition to the small parameters pertaining to any plate-like structure. In this formulation, using variational asymptotic method, the three-dimensional thermoelastic problem is mathematically split into a one-dimensional through-the-thickness analysis, and a two-dimensional reference surface analysis. The through-the-thickness analysis provides the constitutive relation between the generalized two-dimensional strains, and the generalized force resultants for the plate analysis, it also provides a set of closed-form solutions to express the three-dimensional responses in terms of two-dimensional variables, which are determined by solving the equilibrium equations of the plate reference surface. Numerical results are illustrated for a typical composite sandwich panel subjected to a linear-bisinusoidal thermal loading. The three-dimensional responses of the composite sandwich structure from the present theory are compared with the three-dimensional finite element solutions of MSC NASTRAN. The results from the present theory agree closely with three-dimensional finite element results and yet enable order of magnitude saving in computational resources and time.

References listed at the end of the paper:


ABSTRACT: Mechanical performance of marine sandwich panels comprising E-glass/vinyl ester face sheets and perforated polyvinyl chloride foam core was evaluated and compared with conventional foam core sandwich panels. Circular holes through the foam core thickness were drilled with 12 different arrangements in square patterns and the holes were filled with the resin during the infusion process which created the through-the-thickness solid resin pins. The effect of each pattern on the flatwise compression and core shear properties of the sandwich panels were experimentally investigated. The three-point bending maximum failure load of perforated foam core sandwich panels was increased over 133.8% by increasing the diameter of the resin pins at the expense of increased panel weight up to 67%. The flatwise compression stress to induce core crushing was significantly increased by reinforcing the resin pins.
References listed at the end of the paper:


ABSTRACT: In the first part of this paper, a viscoelastic model is used to numerically study the cellular foam core fatigue behaviour. Material’s temperature evolution is quantified with a numerical/experimental confrontation. In the second part, the slamming phenomenon is discussed by measuring the panel flexural strain on a racing sailboat during navigation. Making use of these results, a new slamming test rig was developed to evaluate the fatigue of sandwich structure under realistic loading. Four-point bending and slamming tests were performed on sandwich beams in order to compare their fatigue life and to discuss the physical parameters.

References listed at the end of the paper:


ASTM. ASTM C393/C393M – 1e1 standard test method for core shear properties of sandwich constructions by beam flexure, 2008.


ABSTRACT: The eigenvibration characteristics of a smart plate with piezoelectric layers and porous-cellular core are investigated in the present article. The core plate is assumed to be composed of materials that contain pores and the porosities may be distributed according to different mathematical rules. Variational principle is applied in order to derive the continuous system equations on the basis of Mindlin plate theory. A highly efficient analytical modeling for eigenfrequency analysis of the smart plate is presented under the assumption that both Skempton’s pore pressure coefficient and normal elongation through the thickness are negligible. Unlike numerical methods that require huge computational cost, this approach enables us to find the system’s response for rectangular plates with arbitrary dimensions. To examine the validity of the present framework, multiple comparison studies are made between the extracted results and those available in the literature. It is shown that the type of porosity distribution influences strongly on the way that frequency changes. Furthermore, it is found out that it is necessary to consider electrical effects for plates with open circuit condition unlike the other electrical condition.

References listed at the end of the paper:


4. Wei, K, He, R, Chen, X, et al. Fabrication and heat transfer characteristics of C/SiC pyramidal core lattice sandwich panel. Appl


ABSTRACT: Advanced composite materials are usually optimized to achieve balance of properties for given range of applications. In recent times, researchers had worked on the sandwich composites by using different foam and metal honeycomb as a core material. In the current project, honeycomb core is prepared by using 3D printed technology. In this case of sandwich composites, cross-linked polyethylene foam and 3D-printed polylactic acid honeycomb as core and GFRP is used as face sheet. The comparison is made between polyethylene foam and 3D printed honeycomb core sandwich composite in the aspect of toughness, strength, and modulus. The present study is to characterize the damages in the sandwich structure for the amount of energy absorbed by the structures such as delamination, indentation, crushing of foams, and debonding of face sheets and core material subjected to free fall impact. The contact force versus time, contact force versus deflection of plates with respect to impact energy levels of 9.3, 16.5, and 25.7 J and impact energy versus time are determined. The current research helps in determination of core materials effecting/absorbing the damage and behavior of sandwich materials subjected to impact loads.

References listed at the end of the paper:


ABSTRACT: This research focuses on the dynamic response of sandwich panels with multilayered graded hourglass lattice core subjected to blast loading. A three-layer lattice core configuration is proposed to improve the absorption efficient of kinetic energy resulted from blast shock wave. The relative density of each core layer is changed with sectional dimension of core truss members to regulate the energy absorption of each core layer. Three-dimensional numerical simulation analyses of dynamic response are carried out, and the applied
Impulsive pressure distribution on the surface of the panels is calculated using the CONWEP code. The panels are made of stainless steel AL6XN, which is assumed to follow bilinear strain hardening and strain rate-dependence. Peak back sheet deflection and energy absorption of core layers for four types of hourglass lattice panels are comparatively analyzed and the effects of load intensity on the peak deflection are discussed. Furthermore, the near-optimal configuration under blast loadings is proposed.

References listed at the end of the paper:


ABSTRACT: The free vibration analysis of a nonlocal strain gradient elastic sandwich nanoplate with porous graded core and piezomagnetic face sheets is presented in this paper. The rectangular elastic sandwich nanoplate is resting on Pasternak's foundation. Porosities are distributed evenly and unevenly through the thickness of the core. The gradation of material properties having porosities is described using a modified power-law function. A nonlocal parameter and a strain gradient parameter are employed to describe both stiffness reduction and stiffness enhancement of nanoplates. The governing equations of the motion are derived from Hamilton’s principle based on the first order shear deformation theory. In addition, Eringen’s nonlocal strain gradient piezo-magneto-elasticity theory is used to consider nanoscale effects. The analytical solution is presented to solve seven governing equations of motion using Navier’s solution. Eventually, the natural frequency is surveyed for different side length ratios, nonlocal coefficient, porosity volume fraction, and parameters of foundation numerically with even and uneven porosity distributions.

References listed at the end of the paper:


Wang, YZ. Nonlinear internal resonance of double-walled nanobeams under parametric excitation by nonlocal continuum theory. Appl Math Model 2017; 48; 621–634.


ABSTRACT: In piezoelectric materials and at the nano-scale, there is a coupling between electrical polarization and strain gradients fields, which is called flexoelectricity. The effects of this phenomenon seem to be negligible in micro/macro scales. The current study has attempted to have a cohesive concentration on the buckling behaviors of sandwich plates. To achieve the abovementioned aim with a higher accuracy, the flexoelectric effect assumes to be existing on the top and bottom face sheets and the core is a composite plate. Also, based on statistics, the first-order shear deformation theory seems to lead to more accurate results. Therefore, in the present research we follow this method to obtain results. The analytical method is applied to solve higher order governing equations. In addition, the critical buckling voltage is calculated considering the flexoelectricity, and it is found that the effects of flexoelectricity play significant roles in determining the critical buckling voltage. Moreover, it is revealed that the thickness of the flexoelectric face sheets and the aspect ratio of the sandwich plate play the same role in critical buckling load variations. It means that the critical buckling load decreases when the thickness of the flexoelectric face sheets or the aspect ratio of the sandwich plate increases and vice versa. The results of the present work can be used for the optimum design and control of similar systems such as micro-electro-mechanical and nano-electromechanical devices.

References listed at the end of the paper:


Ma, W, Cross, LE. Observation of the flexoelectric effect in relaxor Pb(Mg\(_{1/3}\)Nb\(_{2/3}\))O\(_3\) ceramics. Appl Phys Lett 2001; 78: 2920–2921.


ABSTRACT: In this paper, modified couple stress formulation of a small scale doubly curved piezoelectric shell resting on Pasternak's foundation is presented based on first-order shear deformation theory. Size-dependent electro-elastic results of doubly curved shell are presented based on an analytical approach. The
doubly curved piezoelectric shell is subjected to uniform transverse loads and applied voltage. To account the size dependency, modified couple stress theory is employed in conjunction with principle of virtual work. The numerical results are presented in both tabular and graphical forms to show the influence of small scale parameter, applied voltage, geometries and two parameters of Pasternak’s foundation on the electro-elastic results of size-dependent doubly curved piezoelectric shell.

References listed at the end of the paper:


ABSTRACT: The Refined Zigzag Theory (RZT) is assessed for the buckling and nonlinear static response analysis of multilayered composite and sandwich beams. A nonlinear formulation of the RZT is developed taking into account geometric imperfections and nonlinearities using the Von Kármán nonlinear strain-displacement relations. FE analyses are conducted employing C-beam elements based on the RZT and the Timoshenko Beam Theory (TBT) to model three sandwich beams with different core materials and slenderness ratios, in both simply supported and cantilever configurations. The reference solutions are obtained by high-fidelity FE commercial codes, Abaqus® and Nastran®. The first two buckling loads are evaluated for the beams with initial imperfections. Several shapes are then assumed as geometric imperfections to calculate the beams’ nonlinear response to axial-compressive loads. The comparisons show the very high accuracy of the RZT (comparable to high fidelity FE commercial codes) for both the buckling and nonlinear static analyses and its superior capability with respect to the TBT to deal with sandwich beams with low slenderness ratio and higher face-to-core stiffness ratio.

References listed at the end of the paper:


ABSTRACT: This paper improves four-node quadrilateral plate elements by using cell-based strain smoothing enhancement and higher-order shear deformation theory (HSDT) for geometrically nonlinear analysis of composite structures. Small strain-large displacement theory of von Kármán is used in nonlinear formulations of four-node quadrilateral plate elements that have strain components smoothed or averaged over the subdomains of the elements. From the divergence theory, the displacement gradients in the smoothed strains are transformed from the area integral into the line one. The behavior of composite structures follows the third-order shear deformation theory. The solution of the nonlinear equilibrium equations is obtained by the iterative method of Newton–Raphson with the appropriate convergence criteria. The present numerical results are compared with the other numerical results available in the literature in order to demonstrate the effectiveness of the developed element. These results also contribute a better knowledge and understanding of nonlinear bending behaviors of these composite structures.

References listed at the end of the paper:


Matsunaga, H. Vibration and stability of cross-ply laminated composite plates according to a global higher-order plate theory. Compos Struct 2000; 48: 231–244.


Mantari, JL, Oktem, AS, Soares, CG. Static and dynamic analysis of laminated composite and sandwich plates and shells by using a new higher-order shear deformation theory. Compos Struct 2011; 94: 37–49.


Mantari, JL, Soares, CG. Analysis of isotropic and multilayered plates and shells by using a generalized higher-order shear deformation theory. Compos Struct 2012; 94: 2640–2656.


Shin, CM, Lee, BC. Development of a strain-smoothed three-node triangular flat shell element with drilling degrees of freedom.


ABSTRACT: The main objective of this article is to introduce exact analytical closed-form solutions for the prediction of effective transverse Young’s modulus and Poisson ratio of a matrix-filled nanotube (i.e., a representative element of nanotube-based nanocomposites), as well as its mechanical behavior, when subjected to external loads. In this work, both the nanotube and its filler were considered to be generally cylindrical orthotropic. To ensure no loss of generality, the no plane strain condition was used, and the axial strain was taken into consideration to obtain a more precise set of solutions. Analytical formulae were developed based on the well-established principles of linear elasticity and continuum mechanics, considering effective orthotropic properties for both constituents as continuum tubes. To validate and verify the accuracy of the closed-form solutions obtained from the analytical approach, a three-dimensional finite element analysis was performed, and results were compared to those obtained from the analytical exact solutions. Excellent agreement was achieved, and the analytically obtained solutions were verified.

References listed at the end of the paper:


ABSTRACT: A new theoretical model based on the extended high order sandwich panel theory is established to predict the mechanical response of sandwich panels under static loads with the bilinear constitutive stress–strain relation in the core. The constitutive relations of normal stresses related to the longitudinal and vertical normal strains in the bilinear isotropic hardening core are first formulated. The influence of the in-plane rigidity on the elastoplastic response of sandwich structures is analyzed. An in-plane loaded sandwich structure with the bilinear core is first studied based on extended high order sandwich panel theory, and the effect of the bilinear ratio on the mechanical response is evaluated. The governing equations are derived from the principle of minimum potential energy, and a Ritz-based half-analytical method is applied to get the solutions. The plastic response is acquired by an iterative procedure along with the convergence criteria. The results reveal that the local effect can be captured when the axial rigidity of the core is considered. The bilinear characteristic of the core decreases the maximum normal stress with an increase of the average value. The equivalent plastic region extends with the increase of the bilinear ratio when the sandwich structure is loaded in plane. By comparison with open literatures and finite element results, the present theoretical model is proved to be effective and efficient.

References listed at the end of the paper:


ABSTRACT: A novel sandwich panel with double-directional corrugated core is proposed in this paper. This complex-corrugated core makes the conventional detailed finite element analysis of large structures a tough work. Thus, an equivalent homogeneous method is proposed, the key of which is to obtain the equivalent property of this novel structure. The equivalent elastic modulus considering the effect of geometrical parameters is analytically derived and verified by finite element method. Besides, equivalent shear modulus and Poisson’s ratios are obtained by finite element method. Three-dimensional detailed and equivalent models are established for further validation of this equivalent homogeneous method. Results show that elastic modulus predicted by analytical formulas is in good agreement with that by finite element method no matter how geometrical parameters change. It has been proved that stretching deformation is dominating in thickness direction, and only corrugation along loading direction can bear the load. The proposed novel sandwich structure owns better mechanical property than the conventional one with single-corrugated core. The result by equivalent model agrees well with that by detailed model, which means that this equivalent homogeneous method can well predict the macroscopic property of this novel structure.

References listed at the end of the paper:


ABSTRACT: In this work, we study the material and geometric uncertainty effects on the static, free vibration and dynamic behaviour of sandwich beam structures. A higher-order sandwich panel theory is considered for the analysis. The elastic properties of the sandwich beam are considered as 1-D non-Gaussian random field which causes local variation in mass and stiffness matrices of the beam. The discretization of the non-Gaussian random fields is performed using the expansion optimal linear estimation. To perform the numerical analysis, Monte-Carlo simulation along with the computationally efficient time-domain spectral element method is proposed. Numerical results are obtained for different boundary conditions as well as for different materials in the sandwich face sheet and core. Results obtained in this work quantify the effects of material and geometric uncertainty in the response behaviour of a sandwich beam. The individual effect of core thickness and Poisson’s ratio of the core on the static, free vibration and dynamic response is quantified. It is observed that the uncertainties in material and geometric properties along with loading and boundary conditions influence the static, free vibration and dynamic response.

References listed at the end of the paper:


ABSTRACT: The present work is devoted to investigating the transient responses of a sandwich structure based on the generalized thermoelastic diffusion theory with memory-dependent derivative. Both the left and the right bounding surfaces are subjected to a thermal shock and a chemical potential shock simultaneously. It is assumed that the values of thermal contact resistance and diffusional contact impedance at the interface are zero with ideal adhesion. The coupled governing equations containing time delay factors and kernel functions, which can be chosen freely according to specific problems, are solved by the Laplace transform together with its numerical inversion. The influences of the material characteristic parameters at the interface on the structural responses are emphatically discussed, and the non-dimensional temperature, chemical potential, displacement, stress as well as concentration at different values of time delay factors and kernel functions are obtained and illustrated graphically. The results show that: the changes of the time delay factors, kernel functions, and material characteristic parameters have the varying degrees of influences on the considered variables. Based on the above conclusions, the sandwich structure working under the thermoelastic diffusion coupling condition can be designed reasonably.

References listed at the end of the paper:

<table>
<thead>
<tr>
<th>No.</th>
<th>Author(s)</th>
<th>Title</th>
<th>Journal</th>
<th>Year</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Green, AE, Lindsay, KA.</td>
<td>Thermoelectricity</td>
<td>J Elasticity</td>
<td>1972</td>
<td>2: 1–7</td>
</tr>
<tr>
<td>5</td>
<td>Othman, MIA.</td>
<td>Effect of rotation on plane waves in generalized thermo-elasticity with two relaxation times</td>
<td>Int J Solids Struct</td>
<td>2004</td>
<td>41: 2939–2956</td>
</tr>
<tr>
<td>7</td>
<td>Youssef, HM.</td>
<td>Generalized magneto-thermoelasticity in a conducting medium with variable material properties</td>
<td>Appl Math Comput</td>
<td>2006</td>
<td>173: 822–833</td>
</tr>
<tr>
<td>12</td>
<td>Caputo, M.</td>
<td>Linear models of dissipation whose Q is almost frequency independent-II</td>
<td>Geophys J Int</td>
<td>1967</td>
<td>13: 529–539</td>
</tr>
<tr>
<td>15</td>
<td>Wang, JL, Li, HF.</td>
<td>Surpassing the fractional derivative: concept of the memory-dependent derivative</td>
<td>Comput Math Appl</td>
<td>2011</td>
<td>62: 1562–1567</td>
</tr>
<tr>
<td>18</td>
<td>Ezzat, MA, El-Karamany, AS, El-Bary, AA.</td>
<td>Generalized thermoelasticity with memory-dependent derivatives involving two temperatures</td>
<td>Mech Compos Mater Struct</td>
<td>2016</td>
<td>23: 545–553</td>
</tr>
<tr>
<td>22</td>
<td>Ezzat, MA, El-Bary, AA.</td>
<td>Magneto-thermoelectric viscoelastic materials with memory-dependent derivative involving two-temperature</td>
<td>JAE</td>
<td>2016</td>
<td>50: 549–567</td>
</tr>
</tbody>
</table>


43. Li, XY, Li, CL, Xue, ZN, et al. Analytical study of transient thermo-mechanical responses of dual-layer skin tissue with variable...

ABSTRACT: In this work, a first-order discrete layer model is performed to deal with the free vibration and buckling analysis of composite sandwich plates in thermal environment. Owing to considering the effect of rotary inertias and shear deformation, thin-to-moderately thick shells can be analyzed. The differential equations of motion are derived from Hamilton’s principle, and account for the nonlinear variation of the in-plane and transverse displacements through the thickness due to temperature variation. These equations are solved by means of the closed-form Navier method, and validated by comparing the numerical results obtained by the present method with the findings published in literatures. Finally, the variation tendency of critical buckling temperature with material parameters is evaluated and shown graphically.

References listed at the end of the paper:


ABSTRACT: Sandwich panels can be subjected to significant changes in ambient temperature, which develop and sustain over certain time periods and lead to creep of the core material, and consequently to changes in the internal stresses and deformations with time. This paper deals with this issue with focus on the geometrically nonlinear aspects of structural behaviour. A theoretical model is developed, which combines the concepts of the principle of superposition of viscoelasticity, with the high-order sandwich theory (HSAPT), and the temperature dependency of the viscoelastic material properties. The nonlinear HSAPT formulation accounts for the deformability of the core in shear and through its thickness and it is based on large displacement kinematics of the face sheets. The convolution integral of viscoelasticity is converted into a rheological generalized Maxwell model after the expansion of the relaxation moduli into Prony series with temperature-dependence terms, which enables the solution of the governing equations through an incremental step-by-step time analysis without the need to store the response history. The capabilities of the model are demonstrated through numerical examples. It is shown that the creep of the core material can lead to bifurcation buckling of the sandwich panel under sustained temperatures that are smaller than the critical temperature obtained under an instantaneous increase of temperature.

References listed at the end of the paper:


ABSTRACT: This paper presents the free vibration analysis of a composite laminated and sandwich square plate with circular cutout. The problem formulation is based on the higher order shear deformation plate theory HDST C\(^0\) coupled with a curved quadrilateral p-element. The elements of the stiffness and mass matrices are calculated analytically. The curved edges are accurately represented using the blending function method. A calculation program is developed to determine the fundamental frequencies for different physical and mechanical parameters such as the cutout size and location, plate thickness, fiber orientation angle and boundary conditions. The results obtained show a good agreement with the available solutions in the literature. New results for the fundamentals frequencies of composite laminated and sandwich plates with circular cutout are presented.

References listed at the end of the paper:
14. Khaldoon, FB. Free vibration analysis of a symmetric and anti-symmetric laminated composite plate with a cutout at the center.
In this paper, the transverse loading of sandwich plate is formulated to study the three-dimensional stress field in the sandwich plates for various edge conditions. The formulation is based on the weak formulation approach. A complete three-dimensional displacement field is considered and the weak formulation approach is employed to obtain the governing equations of the plate using the three-dimensional equilibrium equations of elasticity. An analytical solution is presented for governing equations when two opposite edges of plate are simply supported. A one-step stress recovery scheme is used to compute the out-of-plane stresses in the sandwich plates. A comparison is made with the predictions of exact elasticity solutions in the open literature and very good agreements are achieved. The distribution of stresses is investigated for various boundary conditions and the log-linear procedure is employed to study the order of stress singularity at free and clamped edge of the plate. It is seen that the present approach accurately predicts the distribution of out-of-plane stresses and local concentration of stresses in the vicinity of free and clamped edges of sandwich structures.

References listed at the end of the paper:


ABSTRACT: In this study, aluminum thin-walled cylindrical absorbers for crashworthiness are investigated to introduce a novel system with better energy absorption and crushing characteristics under quasi-static axial compressive loading. The inside of the thin-walled cylinders is meshed with a square welded from vertices to the thin-walled cylinder. Here, the response surface method, which is one of the design of experiments techniques has been used to examine the effect of the parameters on energy absorption, initial peak crushing force, specific energy absorption per unit mass and energy absorption per length. The variables of thickness (t), height (h) and length of square (l) of the thin-walled cylinder were considered in three levels and initial peak crushing force, specific energy absorption per unit mass and energy absorption per length were selected as response. The specimens were analyzed under a quasi-static compressive test at a constant speed of 10 mm/min. Subsequently, for further investigation, the experimental results were compared with those obtained from the finite element simulation using Abaqus software, which indicated desirable accuracy. To decrease the solution time in this numerical analysis, the speed was set at 0.5 m/s. Finally, the experimental results were compared with the simulation ones, which showed acceptable compatibility. Further, there are the equations obtained from the multi-objective optimization testing design. The results indicated a linear relationship of thickness with responses, nonlinear relationship of height with responses, linear relationship of length of square with initial peak crushing force, and nonlinear relationship with specific energy absorption per unit mass and energy absorption per length.

References listed at the end of the paper:


**ABSTRACT:** In this paper, a numerical model is developed to simulate the ballistic impact of a projectile on a sandwich panel with honeycomb core and composite skin. To this end, a suitable material model for the aluminum honeycomb core is used taking the strain-rate dependent properties into account. To validate the ballistic impact of the projectile on the honeycomb core, numerical results are compared with the experimental results available in literature and ballistic limit velocities are predicted with good accuracy. Moreover, to achieve composite skin material model, a VUMAT subroutine including damage initiation based on Hashin’s seven failure criteria and damage evolution based on MLT approach modulus degradation is used. To validate the composite material model VUMAT subroutine, the ballistic limit velocities of the projectile impact on the composite laminates are predicted similar to the numerical results presented by other researchers. Next, the numerical model of the sandwich panel ballistic impact at different velocities is compared with the available experimental results in literature, and energy absorption capacity of the sandwich panel is predicted accurately. In addition, the numerical model simulated the sandwich panel damage mechanisms in different stages similar to empirical observations. Also, the composite skin damages are investigated based on different criteria damage contours.

References listed at the end of the paper:


ABSTRACT: The dynamic stability of composite sandwich plates with a smart elastomer layer subjected to an axial periodic load is investigated. A finite element model of the composite sandwich plate with Magnetorheological elastomer (MRE) core is developed. A MRE layer, which its mechanical properties change with the applied magnetic field, is used as a damping layer to improve the stability of the structure. Due to the intrinsic characteristics of the MREs, these materials commonly operate in their pre-yield region. In this region, complex shear modulus is used for these materials.

The effect of different parameters such as stacking sequences, boundary conditions, geometry of the sandwich plate, thickness and partial activation of the MRE layer on the damping treatment and stability boundaries is investigated. The presented results show that the application of an MRE layer as a core in the composite sandwich plate changes the stability region of the structure. Therefore, the instability boundaries can be manipulated to achieve the desired dynamic response of the structure.

References listed at the end of the paper:


ABSTRACT: In the present study, the free and forced vibration responses of the composite sandwich plate with carbon nanotube reinforced honeycomb as the core material and laminated composite plates as the top and bottom face sheets are investigated. The governing equations of motion of hybrid composite honeycomb sandwich plates are derived using higher order shear deformation theory and solved numerically using a four-noded rectangular finite element with nine degrees of freedom at each node. Further, various elastic properties of honeycomb core materials with and without reinforcement of carbon nanotube and face materials are evaluated experimentally using the alternative dynamic approach. The effectiveness of the finite element formulation is demonstrated by performing the results evaluated experimentally on a prototype composite sandwich plate with and without carbon nanotube reinforcement in core material. Various parametric studies are performed numerically to study the effects of carbon nanotube wt% in core material, core thickness, ply orientations, and various boundary conditions on the dynamic properties of composite honeycomb sandwich plate. Further, the transverse vibration responses of hybrid composite sandwich plates under harmonic force excitation are analyzed at various wt% of carbon nanotubes and the results are compared with those obtained without addition of carbon nanotubes to demonstrate the effectiveness of carbon nanotube reinforcement in enhancing the stiffness and damping characteristics of the structures. The study provides the guidelines for the designer on enhancing both the stiffness and damping properties of sandwich structures through carbon nanotube reinforcement in core materials.

References listed at the end of the paper:


Mohammadimehr, M, Mostafavifar, M. Free vibration analysis of sandwich plate with a transversely flexible core and FG-CNTs reinforced nanocomposite face sheets subjected to magnetic field and temperature-dependent material properties using SGT. Compos Part B 2016; 94: 253–270.


ABSTRACT: The design and fabrication of shop-welded and prefabricated relatively small tanks, when compared to field-welded tanks, used in the upstream segment of the oil and gas industry is governed by the American Petroleum Institute specification 12F (API 12F). This study explores the changing designs of API 12F tanks to include a new rectangular cleanout design with reinforcement as shell extension internally of cleanout frame and a stepped shell design. This study also investigated the introduction of two additional tank sizes in addition to existing eleven tank sizes in the current 12th edition of API 12F. The adequacy of the new design changes and proposed tank designs were verified by elastic stress analysis with nonlinear geometry, elastic-plastic stress analysis with nonlinear geometry, and elastic buckling analysis to verify their ability to operate at a design internal pressure of 16 oz/in² (6.9 kPa) and maximum pressure during emergency venting of 24 oz/in² (10.3 kPa). A vacuum pressure of 1.5 oz/in² (0.43 kPa) was also investigated using the elastic buckling analysis. The stress levels and uplift of the tanks are reported in this report to provide insights into the behavior of proposed API 12F tanks exposed to higher internal pressure and vacuum pressure.

References listed at the end of the paper:
In this paper, modified transfer entropy theory is combined with a surrogate data algorithm to produce a new method in order to identify nonlinearity in the vibration data of a damaged cylindrical shell. The proposed identification method can eliminate the necessity of acquiring baseline statistics by comparing the transfer entropy of original vibration data and that of surrogate data. Moreover, a new index $\xi$ is established to reflect the degree of nonlinearity by quantifying the discreteness of the entropy of each group of surrogate data. Vibration tests are conducted and experimental data are analyzed to confirm the effectiveness of this method. The corresponding results show that the proposed method can not only identify the structural damage but also be further applied to the evaluation of such damage for cylindrical shells. In addition, the influence of different load pressures and degrees of damage on the effectiveness of the identification method is analyzed and discussed. As verified, the proposed methodology can be potentially used for structural damage identification and evaluation in areas such as civil engineering, mechanical engineering, and ocean engineering.

ABSTRACT: A simplified approach is presented for the seismic performance assessment of liquid storage tanks. The proposed methodology relies on a nonlinear static analysis, in conjunction with suitable “strength ratio-ductility-period” relationships, to derive the associated structural demand for the desired range of seismic intensities. In the absence of available relationships that are deemed fit to represent the nonlinear-elastic response of liquid storage tanks, several incremental dynamic analyses are performed for variable post-yield hardening ratios and periods in order to form a set of data that enables the fitting of the response. Following the identification of common modes of failure such as elephant's foot buckling (EFB), base plate plastic rotation, and sloshing wave damage, the aforementioned relationships are employed to derive the 16%, 50%, and 84% percentiles for each of the respective response parameters. Fragility curves are extracted for the considered failure modes, taking special care to appropriately quantify both the median and the dispersion of capacity and demand. A comparison with the corresponding results of incremental dynamic analysis (IDA) reveals that the pushover approach offers a reasonable agreement for the majority of failure modes and limit states considered.

References listed at the end of the paper:


ABSTRACT: Catastrophic failure of the above ground steel storage tanks was observed during past earthquakes, which caused serious economic and environmental consequences. Many of the existing tanks were designed in the past with outdated analysis methods and with underestimated seismic loads. Therefore, the evaluation of the seismic vulnerability of these tanks, especially ones located in seismic prone areas, is extremely important. Seismic fragility functions are useful tools to quantify the seismic vulnerability of structures in the framework of probabilistic seismic risk assessment. These functions give the probability that a seismic demand on a given structural component meets or exceeds its capacity. The objective of this study is to examine the seismic vulnerability of an unanchored steel storage tank, considering the uncertainty of modeling parameters that are related to material and geometric properties of the tank. The significance of uncertain modeling parameters is first investigated with a screening study, which is based on nonlinear static pushover analyses of the tank using the ABAQUS software. In this respect, a fractional factorial design and an analysis of variance (ANOVA) have been adopted. The results indicate that the considered modeling parameters have significant effects on the uplift behavior of the tank. The fragility curves of two critical failure modes, i.e., the buckling of the shell plate and the plastic rotation of the shell-to-bottom plate joint, are then developed based on a simplified model of the tank, where the uplift behavior is correctly modeled from the static pushover analysis. The uncertainty associated with the significant parameters previously identified are considered in the fragility analysis using a sampling procedure to generate statistically significant samples of the model. The relative importance of different treatment levels of the uncertainty on the fragility curves of the tank is assessed and discussed in detail.

References listed at the end of the paper:

ABSTRACT: The evaluation of seismic vulnerability of atmospheric above ground steel storage tanks is a fundamental topic in the context of industrial safety. Depending on the shell portion affected, on the extent of damage, and on toxicity, flammability, and reactivity of stored substances, liquid leakages can trigger hazardous chains of events whose consequences affect not only the plant but also the surrounding environment. In light of that, the study proposed herein provides an analysis of the seismic fragility of cylindrical above ground storage tanks based on observational damage data. The first phase of this work has consisted in collecting a large empirical dataset of information on failures of atmospheric tanks during past earthquakes. Two sets of damage states have then been used in order to characterize the severity of damage and the intensity of liquid releases. Empirical fragility curves have been fitted by using Bayesian regression. The advantage of this approach is that it is well suited to treat direct and indirect information obtained from field observations and to incorporate subjective engineering judgement. Different models have been employed in order to investigate the effects of tank aspect ratio, filling level, and base anchorage. Moreover, the effects of interaction between these critical aspects are included in fragility analysis. The hazard parameter used is the peak ground acceleration (PGA). Seismic fragility curves obtained from the described procedure are compared to those available in the technical literature.

References listed at the end of the paper:
7 ASCE, 1987, The Effects of Earthquakes on Power and Industrial Facilities and Implications for Nuclear Power Plant Design, American Society of Civil Engineers, Reston, VA.


ABSTRACT: Seismic hazard represents one of the possible triggering causes for NaTech accidents in refineries and production plants. The vulnerability of steel storage tanks was evaluated within the framework of a rapid risk assessment. Tanks dataset is composed of 70 refinery items in located in various parts of Italy and the seismic calculations are performed in accordance to API 650 Annex E Standard. The paper summarizes the results of the investigation through two normalized parameters related to the masses and to the seismic load. Some trends in the solution are highlighted. The empirical fragility curve obtained from the analysis is compared with similar curves found in the literature and the resulting similarities (and dissimilarities) are critically discussed.

References listed at the end of the paper:
An analytical method and a semi-analytical method are proposed to analyze the dynamic thermo-elastic behavior of structures resting on a Pasternak foundation. The analytical method employs a finite Fourier integral transform and its inversion, as well as a Laplace transform and its numerical inversion. The semi-analytical method employs the state space method, the differential quadrature method (DQM), and the numerical inversion of the Laplace transform. To demonstrate the two methods, a simply supported Euler–Bernoulli beam of variable length is considered. The governing equations of the beam are derived using Hamilton's principle. A comparison between the results of analytical method and the results of semi-analytical method is carried out, and it is shown that the results of the two methods generally agree with each other, sometimes almost perfectly. A comparison of natural frequencies between the semi-analytical method and the experimental data from relevant literature shows good agreements between the two kinds of results, and the semi-analytical method is validated. Different numbers of sampling points along the axial direction are used to carry out convergence study. It is found that the semi-analytical method converges rapidly. The effects of different beam lengths and heights, thermal stress, and the spring and shear coefficients of the Pasternak medium are also investigated. The results obtained in this paper can serve as benchmark in further research.

References listed at the end of the paper:

deformations assumption allows for the investigating of buckling loads as well as pressure profiles. The pressure profiles studied here can be described by rings under nonuniform pressure.


ABSTRACT: Thin elastic circular rings under uniform pressure have been extensively studied by many researchers. Both the deflection and buckling behavior of rings were considered in these studies, but most have focused on the small deformations analysis approach. Even though the use of the small deformations assumption helps find the deflections of the ring prior to reaching the buckling load, it does not accurately capture the behavior of the ring after buckling. The in-plane large deformations analysis of thin elastic circular rings under nonuniform pressure explored in this paper expands on previous work and investigates varying pressure profiles. The pressure profiles studied here can be described by $p = p_0 (1 + q \cos(n \theta))$. The large deformations assumption allows for the investigating of buckling loads as well as post-buckling behavior.
Nonuniform normal pressure acting on a thin elastic circular ring results in a behavior that is described by a second-order ordinary differential equation (ODE) of the Duffing type, which is solved here through a numerical approach.

References listed at the end of the paper:

15 Bresse, J. A. C., 1866, Cours de Mécanique Appliquée, Professé à L’École Impériale Des Ponts et Chausées, Gauthier-Villars, Paris, France.


ABSTRACT: Based on the detailed three-dimensional (3D) finite element (FE) limit analyses, the present study investigates the plastic limit loads of complex-cracked pipes with two-layered materials for determining maximum load-carrying capacity or critical crack length of pipes with two-layered materials. The complex cracks in pipes with two-layered materials consist of a partial through-wall crack and 360-deg circumferential surface crack in the inner side of pipe in the same plane in pipe, which could be developed in the preemptive weld overlay region on the dissimilar metal weld (DMW) of nuclear pipe. In terms of FE limit analyses for complex-cracked pipes with two-layered materials, total thickness of pipe, depth of 360-deg internal surface crack, length of partial through-wall crack and the effect of strength mismatch between two materials are systematically considered in the present study. As for loading conditions, axial tension, global bending moment, and internal pressure are employed in the present FE analyses, and then, the confidence of the present FE procedure is confirmed by comparing the FE results with the existing solutions for complex cracks in single material. The results of the present FE plastic limit loads are compared with the existing solutions for complex-cracked pipes with two-layered materials. Also, a simple approach using equivalent single material based on the weighted average concept instead of using the properties of two materials is suggested for predicting plastic limit loads of two-layered materials. The present results can be applied to leak-before-break (LBB) analyses of nuclear piping with weld overlay.


ABSTRACT: As the debris flow caused by sustained rainfall would cause destructive damage to buried pipeline, the safety of buried pipeline under impact of debris flow draws increasing attention. This paper focuses on the mechanical and deformed behavior of buried pipeline subjected to the debris flow. The effects of relevant parameters are investigated, including the velocity and impact angle of debris flow, massive stone, diameter to thickness ratio of pipeline (D/T), and parameters of corrosion pit (i.e., the depth, length, and width of corrosion pit). A finite model of soil and buried pipeline under the impact of debris flow is established.
Multiple regression analysis is implemented to evaluate these influence parameters. The results show that: (1) the velocity and the impact angle of debris flow have a great influence on the pipeline; (2) the massive stone in the debris flow has little effect on the buried pipeline; (3) the internal pressure of the pipeline has an inhibitory effect on the deformation of the pipeline, which can enhance the ultimate bearing velocity of pipeline; (4) D/T determines the ultimate bearing velocity of pipeline. Moreover, the effects of the parameters of corrosion pit on the maximum von Mises stress are analyzed by multiple regression and ranked as follows: corrosion depth (A) > corrosion length (L) > corrosion width (B). The result may provide effective guidance for the prevention of pipeline against debris flow in mountain area.

References listed at the end of the paper:
Zhang, B. J., 2013, “Research on Strength Behavior of Long-Distance Buried Pipe for Oil and Gas Transportation in the Landslide Area,” Ph.D. dissertation, Zhe Jiang University, Hangzhou, China.

ABSTRACT: The buckling design criteria of elliptical heads in ASME VIII-1, ASME NH, and RCC-MRx are reviewed and compared. Accordingly, an external pressure chart (EPC) based buckling design approach is developed for elliptical heads in the creep range. Results indicate that for instantaneous buckling design, RCC-MRx predicts higher allowable pressure compared with ASME NH, which is ascribed to the smaller design factor. The proposed method produces a similar result with that given by ASME VIII-1. By contrast, the proposed method leads to a reasonably conservative result with the factor n of 0.03 for the creep buckling design. While the simplified method in RCC-MRx provides an over-conservative solution.

References listed at the end of the paper:
ABSTRACT: The results of wind tunnel tests indicate that there is an internal inward pressure induced by wind excitation when open-top tanks are examined, but not when close-top tanks are examined. This internal pressure is considered in many design documents outside of the U.S., however, ASCE-7 and API 650 do not explicitly address this factor. This study examined the effect of this internal pressure by conducting finite element analyses. Open-top tanks with height to diameter ratios of 0.11, 0.2, 0.5, 1.0, 2.0, and 4.0 were modeled using a finite element program. A linear bifurcation analysis and a post-buckling analysis were then conducted to verify the tank's stability when subjected to wind loading in accordance with the wind profiles specified in the selected design documents. To ensure the quality of the analyses, a study on mesh convergence and the load increment of Riks analysis was conducted. It was determined that the presence of the additional internal pressure term has a drastic impact on the buckling capacity of all the tanks examined. As a consequence, it can be concluded that the additional internal pressure generated by the wind on an open-top tank should not be neglected.

References listed at the end of the paper:


ABSTRACT: The behavior of aboveground storage tanks subjected to seismic excitation was investigated using numerical methods by taking flexibility of foundation into account. The hydrostatic load due to stored liquid has an axisymmetric distribution on the tank shell and base. However, during seismic events, the hydrodynamic load originating from the seismic acceleration of liquid in the tank starts to act in the direction of the earthquake motion. This leads to a nonaxisymmetric loading distribution, which may result in buckling and uplifting of the tank structure. Finite element models were created having nonlinear material properties and large deformation capabilities. Three different tank geometries with liquid height to tank radius aspect ratios of 0.67, 1.0, and 3.0 were selected representing broad, nominal, and slender tanks. These tanks were subjected to two different hydrodynamic loading based on Housner's and Jacobson–Veletsos' pressure distributions, which forms the basis of design provisions used in American Petroleum Institute API 650 and Eurocode 8, respectively. These pressure distributions were formulated under the assumption of rigid tank wall and base. Furthermore, each tank for a given geometry was subjected to two different foundations: (1) representing a rigid foundation and (2) representing a flexible foundation. The flexible foundation was created using a series of compression-only elastic springs attached to tank base having equivalent soil stiffness. Static analysis corresponding to maximum dynamic force was performed. The finite element results for circumferential and longitudinal stress in the shell were compared with the provisions of API 650. It was found that the effect of foundation flexibility from the practical design point of view may be neglected for broad tanks, but should be considered for nominal and slender tanks.

References listed at the end of the paper:
ABSTRACT: The dynamic response of composite shells subjected to internal blast loading has been widely reported by experimental observations. In this study, we propose an analytical method to predict the dynamic response of open-ended cylindrical composite shells subjected to internal blast loading. The cylindrical composite shell has an outer fiber composite shell with an inner steel liner, in which the outer fiber composite shell is simplified as a single elastic layer by an effective modulus in the hoop direction. Considering the impact between the two layers during the dynamic response, the analytical solution for response histories of two layers could be obtained. Finite element analysis on the double-layer model is also conducted by Is-dyna. The analytical solution and the simulation result agree well, which demonstrates that the current analytical method can be employed in the design of this composite structure under blast loading.

Ziqian Zhang (School of Mechanical Engineering & Automation,

ABSTRACT: Cross-sectional ovalization (ovalization) usually occurs when thin-walled pipe is subjected to large plastic bending. This paper is concerned with residual deformation of thin-walled pipe's cross section in a radial direction when external bending moment is removed. In order to clarify the fundamental ovalization characteristics, find out what factors influence the residual flattening (value of ovalization), the ovalization behavior is investigated experimentally. The experiments are carried out on 21 stainless steel specimens with different geometric parameters under different bending radii by means of a four-point pure bending device. The residual cross-sectional flattenings are monitored continuously by scanning the cross section periodically along the circumferential direction. From the experimental results, it is observed that the cross-sectional shape of the thin-walled pipe is not perfect standard ellipse, and the appearance of the maximum residual flattening is usually found in the direction normal to the neutral surface. It is also revealed the relationships between the residual flattening and the bending radius, the wall thickness, and the pipe outer diameter, i.e., the residual flattening increases as the bending radius and the wall thickness reduce, but it increases as the outer diameter increases. These results are expected to find their potential application in thin-walled pipe bending operation.


ABSTRACT: The purpose of this paper is to show the electro-elastic static behavior of cylindrical sandwich pressure vessels integrated with piezoelectric layers. The core is made of functionally graded carbon nanotube-reinforced composite (FG-CNTRC). The cylinder is embedded between two piezoelectric layers made of PZT-4. The effective material properties of reinforced core with carbon nanotubes (CNTs) are calculated based on rule of mixture. The constitutive relations are developed in cylindrical coordinate system based on a higher-order shear deformation theory for both core and piezoelectric layers. The employed higher-order theory is based on third-order variation of deformations along the thickness direction to improve the accuracy of numerical results. The method of eigenvalue-eigenvector is used for solution of system of governing equations along the longitudinal direction. The numerical results are provided along the longitudinal and radial directions in terms of significant parameters such as various patterns of CNTs, various volume fractions of CNTs, various elastic foundation coefficients, and various applied electrical potentials.

Le Zhao, Hong Zhang, Qingquan Duan, Guoping Tang “Failure Analysis of Large-Diameter Coiled Tubing Based on Diameter Growth”, J. Pressure Vessel Technol. June 2020, 142(3): 031301. doi: https://doi.org/10.1115/1.4045511

ABSTRACT: Fatigue tests were conducted to analyze the fatigue behavior and diameter growth of large-diameter coiled tubing (CT) under the combined loads of bending and internal pressure. The experimental results reveal that mechanical limitations on the allowable diameter growth mean that the effective working life of CT at high pressures is only a fraction of the available fatigue life. The finite element software abaqus is used to further research the changes in diameter growth and to analyze the sensitivity of CT diameter growth to the main influencing factors, including internal pressure, tubing outside diameter (OD), wall thickness, yield strength, and bending radius. For CT with a diameter larger than 2 in., the diameter growth is sensitive to the above factors. As the bending and straightening cycles increase, the OD of the CT increases in association with obvious ovalization deformation, and the increase in the OD is closely related to the internal pressure load. The redistribution of material causes the wall thickness of the CT to become universally thinner. The ovality of the CT and the uneven decrease in wall thickness reduce the resistance to external extrusion. Therefore, it is becoming increasingly necessary to account for diameter growth as one of the key elements when predicting CT life or determining when to retire a string from service.

Albert E. Segall (1), Craig C. Schoof (2) and Daniel E. Yastishock (3)
(1) Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16803
(2) Cascadia Engineering LLC, Redmond, WA 98053
(3) Propulsion and Subsystems Flight Test, NAVAIR, Lexington Park, MD 20653

ABSTRACT: Thick plates that are thermally loaded on one surface with convection on the other are often encountered in engineering practice. Given this wide utility and the limitations of most existing solutions to an adiabatic boundary condition, generalized direct thermal solutions were first derived for an arbitrary surface loading as modeled by a polynomial and its coefficients on the loaded surface with convection on the other. Once formulated, the temperature solutions were then used with elasticity relationships to determine the resulting thermal stresses. Additionally, the inverse thermal problem was solved using a least-squares type determination of the aforementioned polynomial coefficients based on the direct-solution and temperatures measured at the surface with convection. Previously published relationships for a thick-walled cylinder with internal heating/cooling and external convection are also included for comparison. Given the versatility of the polynomial solutions advocated, the method appears well suited for complicated thermal scenarios provided the analysis is restricted to the time interval used to determine the polynomial and the thermophysical properties do not vary with temperature.

References listed at the end of the paper:
(Cannot cut and paste them)


ABSTRACT: In this paper, two practical large cylindrical floating-roof tanks with diameters of 60 m and 100 m are selected as research objects. Wind pressures on the internal wall of tank shells under various liquid levels are carefully investigated by both experimental and numerical methods, especially those around the sealing device. It is found that computational fluid dynamics (CFD) simulation gives similar but generally greater results than wind tunnel tests (WTTs), and that wind pressures around the sealing device increase with the rise of liquid level. Geometrically nonlinear analyses (GNA) are then performed to figure out the variation of buckling behavior of tank shells with the liquid level. Two buckling modes are specified, featured by large buckles in the unstiffened region and local short-wave buckles in the stiffened region, respectively. Buckling loads are found to increase stepwise with the liquid level, with critical heights roughly calculated by positions of stiffening rings. Finally, recommendations on liquid levels maintained in strong wind conditions are given, considering the safety of both sealing devices and tank shells.


ABSTRACT: The buckling characteristics of toroidal shells with closed circular cross sections loaded with a static external pressure were investigated. Eight toroidal shell test models were developed: two ribless, two semicircular discrete ribs, two rectangular discrete ribs, and two rectangular continuous ribs. The geometry, toroidal shell thickness, buckling load, and failure of each model were measured and compared. The effects of different ribbing methods (discrete, continuous unidirectional single-wire, continuous unidirectional multiwire wound, and continuous bidirectional wound ribs) on the buckling behavior of a ribbed toroidal shell were investigated, and the results provide guidance for practical engineering.


ABSTRACT: This paper aims to provide experimental results into the buckling behavior of cones having single dimple imperfection subjected to axial compression. Results of eight laboratory scaled conical test models and their accompanying numerical data are presented. Cones were manufactured in pairs with single dimple imperfection amplitude, A, of 0.0, 0.56, 1.12, and 1.68. Experimental results reveal good repeatability of collapse load. The errors between each pair were found to be 3%, 7%, 11%, and 1%. Furthermore, the
comparison between test data and the numerically predicted collapse load was seen to be good. The ratio of collapse test load to finite element predicted values are [(0.96, 0.99), (1.04, 1.10), (1.06, 0.94), (1.0, 1.01)]. The buckling of axially compressed conical shells using the single dimple imperfection type appears to be strongly influenced by: (i) the dimple/imperfection amplitude, (ii) the cone geometric parameter, i.e., radius-to-thickness ratio and cone angle, and (iii) the location of the dimple. References listed at the end of the paper: (Cannot cut and paste them because ASME puts one word on each line for some reason)


ABSTRACT: In engineering, many pressure pipes are made of steels with good plasticity, which are subject to internal pressure, axial force, shear force, bending moment, torsion moment or their combined loads. The plastic limit load is an important indicator of the load capacity of pressure pipe. According to Hill yield function, the theoretical solutions of limit load of orthotropic cylindrical pipe under various combined loads under internal pressure, axial force, shear force, torsion moment, and bending moment have been derived on the basis of elastic perfectly plastic constitutive model. The effects of radial stress on different combined limit loads of cylindrical pipe are explored and these results show that the radial stress should be considered about the limit load calculation especially for thick-walled cylindrical pipe. The interactions of various load combination are analyzed in detail and drawn with the interaction curves. For isotropic cylindrical pipe, the limit load increases with the yield strength. For the orthotropic cylindrical pipe, the limit loads of cylindrical pipe under axial force, bending moment, shear force, and torsion moment without internal pressure are only related to the axial yield strength. The limit bending moment is mainly dependent on the axial yield strength when internal pressure is lower, while the impact of the circumferential yield strength of orthotropic cylindrical pipe is obvious when internal pressure is some higher. When the axial yield strength of orthotropic cylindrical pipe is the same, the circumferential yield strength can enhance the limit axial load, limit torsion moment, and limit shear load. Under the different load conditions including internal pressure, bending moment, axial force, shear force, and torsion moment or their combined loads, the relation of limit bending moment with yield strength ratio is diverse, which is decide by the load combination, the circumferential yield strength, and the axial yield strength.


ABSTRACT: Ellipsoidal and torispherical heads, whose geometric shapes are close, are usually used as end closures of internally pressurized vessels. In pressure vessel codes, for example, ASME BPVC Section VIII and EN13445-3, ellipsoidal heads are designed as torispherical heads using geometric equivalency approaches. However, the difference between ellipsoidal and equivalent torispherical heads has not been studied in detail. In this paper, we first investigate shape deviation between the two types of heads. Then we compare elastic–plastic behaviors between ellipsoidal and equivalent torispherical heads as well as their failure modes, i.e., buckling and plastic collapse (bursting). It is found that ellipsoidal heads have more buckling resistance than equivalent torispherical heads, indicating that the current design rules for buckling of ellipsoidal heads based on the geometric equivalency approaches result in uneconomical design. In addition, experimental and numerical results show that such heads experience geometric strengthening. The finite element (FE) method considering the effect of geometric strengthening provides a good prediction of plastic collapse pressure. However, the current design equation for bursting does not consider the effect of geometric strengthening, also leading to uneconomical design. Therefore, in order to avoid uneconomical design, we recommend that (1) with respect to buckling of ellipsoidal heads, a new design equation be proposed rather than implementing the geometric equivalency approaches, and (2) the current design equation for bursting be deleted, and a new design equation, considering the effect of geometric strengthening, be proposed for bursting of ellipsoidal and torispherical heads.
ABSTRACT: This work investigates the response of industrial steel pipe elbows subjected to severe cyclic loading (e.g., seismic or shutdown/startup conditions), associated with the development of significant inelastic strain amplitudes of alternate sign, which may lead to low-cycle fatigue. To model this response, three cyclic-plasticity hardening models are employed for the numerical analysis of large-scale experiments on elbows reported elsewhere. The constitutive relations of the material model follow the context of von Mises cyclic elasto-plasticity, and the hardening models are implemented in a user subroutine, developed by the authors, which employs a robust numerical integration scheme, and is inserted in a general-purpose finite element software. The three hardening models are evaluated in terms of their ability to predict the strain range at critical locations, and in particular, strain accumulation over the load cycles, a phenomenon called “ratcheting.” The overall good comparison between numerical and experimental results demonstrates that the proposed numerical methodology can be used for simulating accurately the mechanical response of pipe elbows under severe inelastic repeated loading. Finally, this paper highlights some limitations of conventional hardening rules in simulating multi-axial material ratcheting.

ABSTRACT: This research deals with the stability analysis of shallow segments of the toroidal shell made of saturated porous functionally graded (FG) material. The nonhomogeneous material properties of porous shell are assumed to be functionally graded as a function of the thickness and porosity parameters. The porous toroidal shell segments with positive and negative Gaussian curvatures and nonuniform distributed porosity are considered. The nonlinear equilibrium equations of the porous shell are derived via the total potential energy of the system. The governing equations are obtained on the basis of classical thin shell theory and the assumptions of Biot's poroelasticity theory. The equations are a set of the coupled partial differential equations. The analytical method including the Airy stress function is used to solve the stability equations of porous shell under mechanical loads in three cases. Porous toroidal shell segments subjected to lateral pressure, axial compression, and hydrostatic pressure loads are analytically analyzed. Closed-form solutions are expressed for the elastic buckling behavior of the convex and concave porous toroidal shell segments. The effects of porosity distribution and geometrical parameters of the shell on the critical buckling loads of porous toroidal shell segments are studied.

More papers published in the journal, Advances in Structural Engineering (2019 and on)
Google the string: “Advances in Structural Engineering”, then click on the entry: “Advances in Structural Engineering – All Issues – SAGE Journals”

ABSTRACT: The collapse problem of transmission tower upon strong winds was well noted in past few years. This article analyses the wind-induced collapse problem of a long-span transmission tower–line system. The member buckling effect was particularly considered. In doing so, a three-dimensional finite element model of the long-span transmission tower–line system was established in ABAQUS based on a practical project. The transmission tower and line were simulated by the frame and truss elements, respectively. The nonlinear
behavior of a compressive member was simulated using the Marshall model, and the nonconvergence of numerical calculation was set to be the collapse criterion. The critical wind speed, damage position, and collapse probability were obtained from a collapse analysis of the long-span transmission tower–line system under different wind attack angles. The collapse mechanism of the long-span transmission tower–line system under a wind attack angle of 45° was investigated, and an incremental dynamic analysis was performed to evaluate the collapse-resistant capacity of the transmission tower. The study reveals that the interaction between bending moment and shear deformation is critical to the collapse of transmission tower.


ABSTRACT: Steel–concrete–steel composite structure comprises a concrete core sandwiched between the outer steel plates. It combines the advantages of both steel and reinforced concrete structures. In thick steel–concrete–steel structural members, the shear performance becomes rather critical. Experimental works have been carried out to study the failure mode and shear strength of steel–concrete–steel deep beams, and an analytical model has been proposed. In this article, parametric studies are carried out on the original analytical model to discuss the influence of each geometric and material variable on the shear strength, and a simplified strength predicting method is developed. Different shear failure modes, identified as “top+bottom triangular area damage” or “bottom triangular area damage+horizontal cracking,” can be predicted with the method. The simplified approach shows good correlation with the experimental results, regarding to shear resisting pattern and failure modes. Through the simplified formulas, the upper and lower bounds of the shear resistance are obtained. The requirement on stud spacing to maintain full composite behavior in the top and bottom triangular areas and the requirement on concrete strength are proposed.


ABSTRACT: To address the various instability problems in cold-formed steel members, many researchers have mainly focused on developing innovative sectional profiles wherein geometry of the section plays a vital role in enhancing the inherent resistance of such sections against premature buckling. However, the process of forming such innovative shapes is not only complex and time-consuming but sometimes such sections fail to mobilize their complete reserve strength. Hence, a stiffening arrangement of weaker zones for mobilizing the untapped reserve strength is suggested. The contribution of this simple, effective and partly stiffening arrangements, aimed at eliminating/delaying the premature local buckling, is studied both experimentally and numerically and also compared with existing codes. Experimental study was carried out on different simply supported cold-formed steel beams with judiciously proposed stiffening arrangements under four-point loading. An equivalent hot-rolled steel beam was also tested to compare the efficiency of the cold-formed steel beams. The cold-formed steel beams investigated had different width-to-thickness ratio, different geometries and different stiffening arrangements. The test strengths, failure modes, deformed shapes, load versus mid-span displacements and geometric imperfections were measured and reported. The test strengths of the beam models are also compared with the design strength predicted by North American Standards and Eurocode for cold-formed steel structures. To validate the test results further, a numerical study was carried out on such stiffened cold-formed steel beams using finite element software ABAQUS. All these results show that the proposed strengthening system is efficient and economical and allow cold-formed steel beams to reach greater load carrying capacity.


ABSTRACT: Coupled shear walls are widely used as the primary lateral load resisting element in high-rise buildings. But the coupling beams, which are often designed as deep members, usually suffer from brittle shear
failure. The steel-concrete-steel sandwich deep beams showed high bearing capacity and great ductile performance during shear failure. Therefore, it is proposed that the steel-concrete-steel members can be used into deep coupling beams instead of conventional reinforced concrete members, to improve the shear strength and deformability. The shear failure of steel-concrete-steel deep beams is characterized by plastic yielding of the outer steel plates in the triangular areas, rather than concrete diagonal crushing. Reliable shear transfer paths are maintained by the interaction between the outer steel plates and the diagonal concrete struts, so excellent strength and ductile performance can be expected after critical diagonal cracking. The triangular failure areas are able to dissipate seismic energy, thus effectively avoiding overall collapse. The shear strength of steel-concrete-steel deep coupling beams is developed with simple expressions.


ABSTRACT: A six-bar tetrahedral unit of a rhombic projection plane is a basic geometric invariable body with a simple configuration. A six-bar tetrahedral cylindrical lattice shell can be assembled by rhombic projection plane six-bar tetrahedral units with identical geometry sizes, which is conducive to standardized design, industrial production, and prefabricated construction. The popularization and application requirements of green architecture industry can also be met using such a shell. A model test of a six-bar tetrahedral cylindrical lattice shell was developed to simulate the practical application of the prefabricated structural system. A new type of joint for the prefabricated structure was proposed that is easy to assemble and is lightweight. A tridimensional fine-tuning bed jig was developed to ensure the manufacturing precision of the pre-made six-bar tetrahedral units. Stacking and transport of the units were practiced. The assembly process from units to the integral shell was conducted in an experimental hall; the result testified the advantages of easy stack, convenient transport, and highly efficient fabrication. The structural assembly errors of the shell were measured, and the measurement results verified the installation accuracy of the test model. This practical study lays the foundation for further engineering applications of six-bar tetrahedral cylindrical lattice shells.


ABSTRACT: Torsion can be regarded as a principal factor in some cases, such as in curved girders and eccentrically loaded girders, when conducting the structural analysis of prestressed concrete composite box girders with corrugated steel webs. Recently, a rational model, called the softened membrane model for torsion, was proposed for the torsional analysis of reinforced concrete members; thereafter, this model was extended to prestressed concrete members under pure torsion and called softened membrane model for torsion prestressed concrete. This article presents a modified model, the softened membrane model for torsion prestressed concrete for prestressed concrete composite box girders with corrugated steel webs, to analyze full torsional behavior. To build the model, the softened membrane model for torsion in reinforced concrete members is first extended to perform the torsional analysis of prestressed concrete composite box girders with corrugated steel webs by incorporating the torsional contribution of corrugated steel webs. Afterward, the initial stresses and strains due to prestressing are considered to extend the softened membrane model for torsion to softened membrane model for torsion prestressed concrete for prestressed concrete composite box girders with corrugated steel webs by modifying the equilibrium equations, convergence criteria, and constitutive laws of materials. The modified model is validated by experimental data and is proven to be capable of predicting the overall torque–twist curve, especially the precracked branch and postcracked ascending branch. In addition, a comparison between the softened membrane model for torsion and softened membrane model for torsion prestressed concrete indicates that the torque values before and after concrete cracking will be overestimated and underestimated, respectively, without considering the effect of the initial stresses and strains. Finally, another comparison shows that the softened membrane model for torsion prestressed concrete is superior to the rotating-angle truss model for torsion in its ability to predict the precracked branch of the torque–twist curve.
ABSTRACT: A total of 11 L-shaped multi-cell concrete-filled steel tubular stub columns were fabricated and researched in axial compression test. The key factors of width-to-thickness ratio $D/t$ of steel plates in column limb and prism compressive strength of concrete $f_c$ were investigated to obtain influence on failure mode, bearing capacity, and ductility of the specimens. The test results show that the constraint effect for concrete provided by multi-cell steel tube cannot be ignored. The ductility decreases with the increase of width-to-thickness ratio $D/t$ of steel plates in column limb. The bearing capacity increases and the ductility decreases with the increase in prism compressive strength of concrete $f_c$. A finite element program to calculate concentric load–displacement curves of L-shaped multi-cell concrete-filled steel tubular stub columns was proposed and verified by the test results. A parametric analysis with the finite element program was carried out to study the influence of the steel ratio $a$, steel yield strength $f_y$, prism compressive strength of concrete $f_c$, and width-to-thickness ratio $D/t$ of steel plates in column limb on the stiffness, bearing capacity and ductility. Furthermore, the design method of bearing capacity was determined based on mainstream concrete-filled steel tubular codes.


ABSTRACT: Thin-walled aluminium mullions are the vertical framing members of the façade systems used in buildings. This article investigates the buckling behaviour of these complex-shaped aluminium mullions. For this purpose, the aluminium mullion sections were simplified into elements of varying thickness and modelled using CUFSM finite strip analysis programme. Elastic buckling analyses were performed with and without considering the availability of glass panel restraints for both negative and positive wind actions, and the results are presented in this article. The effect of providing return flanges to enable a good connectivity between the male and female mullions was also evaluated. The lateral restraints provided by glass panels were simulated using the spring stiffness option available in CUFSM, and the analyses were performed for spring stiffness values in the range of $0–1$ N/mm/mm. The applicability of the buckling analysis results to the design of aluminium mullions was then evaluated using the direct strength method. For this purpose, the section moment capacities of mullions were determined from finite element analyses and compared with the direct strength method predictions using the CUFSM buckling analysis results. This comparison showed that direct strength method–based design can be adopted for the complex-shaped aluminium mullions provided their elastic buckling capacities are available. Overall, this study has provided good understanding of the buckling behaviour of mullion sections under both positive and negative wind actions and has proposed the use of direct strength method for the design of aluminium mullion sections.

M. Anbarasu and M. Venkatesan (Department of Civil Engineering, Government College of Engineering, Salem, India), “Behaviour of cold-formed steel built-up I-section columns composed of four U-profiles”,


ABSTRACT: Under seismic action, the severe damage in critical regions of structures could be ascribed to the cumulative damage caused by cyclic loading. This article describes an investigation of the hysteresis behaviour of Q690 circular high-strength concrete-filled thin-walled steel tubular columns with out-of-code diameter-to-thickness ratios. A total of eight specimens were tested under constant axial compression and cyclic lateral loading. The study results of phase I testing consisting of a benchmark test were summarized to examine the seismic behaviour under standard loading, and those of the phase II testing that considered different fatigue loading modes and different concrete strengths were summarized to investigate the low-cycle fatigue behaviour. The load–displacement hysteretic curves, energy dissipation, strength and stiffness degradation were discussed in detail. A simplified method was proposed to predict the low-cycle fatigue life, which can be applied in the damage-based seismic design of circular concrete-filled steel tubular structures.

Jiantao Wang and Qing Sun (Department of Civil Engineering, Xi’an Jiaotong University, Xi’an, P.R. China), “Cyclic testing of Q690 circular high-strength concrete-filled thin-walled steel tubular columns”, Advances in Structural Engineering, Vol. 22, No. 2, pp 444-458, January 1 2019, https://doi.org/10.1177/1369433218790769
ABSTRACT: This work reports numerical results concerning the cold-formed steel built-up I-section columns composed of four U-profiles under axial compression. A finite element model is developed by using the software program ABAQUS. The developed model includes geometric, material nonlinearities and geometric imperfections. The finite element model was verified against the experimental results reported in the cold-formed steel built-up open section columns. In the parametric study, the sections are analysed with several cross-sectional dimension ratios and lengths, in order to assess their influence on the buckling behaviour and ultimate strength of cold-formed steel built-up I-section columns. After presenting and discussing the numerical parametric results, the article shows that the current direct strength method in the North American Specification for cold-formed steel compression members design curve fails to predict adequately the ultimate strength of some of the columns analysed and addresses the modification proposed on current direct strength method curves, providing improved predictions of all the numerical ultimate strength available. The proposed method is also assessed by reliability analysis.


ABSTRACT: In this article, a parametric study on the lateral-torsional buckling performance of thin-walled cold-formed steel Hybrid Double-I-Box Beams through numerical analyses has been presented. These built-up beams have distinctive cross-section geometry; the presence of more section modulus at the flanges provides high resistance to flexural bending and the closed-box portion offers high stiffness to resist torsion and lateral buckling. Therefore, these beams can be used for longer spans. The nonlinear finite element analysis was performed using ABAQUS software. All the beams were modelled as ideal finite element models adopting simply supported boundary conditions and loads were applied as end moments. To acquire a large number of data, three varying parameters were considered namely, hybrid parameter ratio, that is, yield strength of flange steel to web steel (1.0, 1.3, 1.5 and 1.7); ratio of breadth to depth of the beam (4/6, 5/6, 6/6 and 7/6); and length of the beam (1.0, 2.5, 5.0, 10, 15, 20, 30, 40, 50 and 60 in m). The thickness of both the flanges and the webs were 2.5 mm. All these parameters alter the overall slenderness of the members. It is shown that at larger spans, Hybrid Double-I-Box Beams experience lateral buckling. The results obtained from the numerical studies were plotted on nondimensional moment versus nondimensional slenderness graph. These results were compared with the predictions using effective width method design rules specified in Euro codes EN 3-1-3 and buckling curve-d of EN 3-1-1, which was originally adopted lateral-torsional buckling capacities of hot-rolled steel ‘I’ sections, and the adequacy is checked. It was found that Hybrid Double-I-Box Beams has higher lateral-torsional buckling capacity than common ‘I’ or box sections. Hence, a new simplified design equation was proposed for determining lateral-torsional buckling capacity of Hybrid Double-I-Box Beams.


ABSTRACT: This study proposes a new type of shear wall, namely, the concrete-filled steel tube composite shear wall, for high performance seismic force resisting structures. In order to study the seismic behavior of concrete-filled steel tube composite shear wall, cyclic loading tests were conducted on three full-scale specimens. One conventional reinforced concrete shear wall was included in the testing program for comparison purpose. Regarding the seismic performance of the shear walls, the failure mode, deformation capacity, bearing capacity, ductility, hysteresic characteristics, and energy dissipation are key parameters in the analysis procedure. The testing results indicated that the bearing capacity, the ductility, and the energy dissipation of the concrete-filled steel tube composite shear walls are greater than that of conventional reinforced concrete shear walls. In addition, the influence of axial compression ratio on the seismic behavior of concrete-filled steel tube composite shear wall is also investigated. It was found that higher axial compression ratio leads to an increase
in the bearing capacity of concrete-filled steel tube composite shear walls while a reduction in the ductility capacity.


ABSTRACT: The study on damage evaluation induced by atmospheric corrosion of engineering structures has attracted more and more international concern over the past three decades. However, the effects of atmospheric corrosion on reticulated shells have not been systematically investigated. In this regard, the performance assessment of a reticulated shell subjected to atmospheric corrosion damage is actively conducted in this study. The atmospheric corrosion model of shell elements is first presented, and a refined exponential model for estimating the corrosion depth of steel elements is developed by using the pattern recognition technique. The sensitivity of stiffness matrix to element thickness is established by using Euler–Bernoulli beam element. The sensitivity of mass matrix to element thickness is developed based on lumped mass assumption. Then, the expression of natural frequency sensitivity to element thickness and mass is derived by considering the section loss induced by both the inner and outer surface corrosion. In addition, the explicit expression of frequency sensitivity to mass of spherical joints is also established in detail. The nonlinear static structural analysis is conducted to evaluate effects of atmospheric corrosion on the stress of structural elements. A real reticulated shell constructed in northern China is taken as the example structure to examine the feasibility of the proposed approach and to assess the potential damage caused by atmospheric corrosion to the structure.


ABSTRACT: Numerous research studies experimentally investigated the axial compressive behavior of fiber-reinforced polymer tube confined concrete cylinders in the past two decades. However, only a limited number of research studies developed stress–strain models to predict the strength and strain enhancement ratio of fiber-reinforced polymer tube confined concrete cylinders under axial compression. The available strength and strain enhancement ratio models of fiber-reinforced polymer tube confined concrete cylinders are a function of actual confinement ratio only. This study develops strength and strain enhancement ratio models for circular fiber-reinforced polymer tube confined concrete under axial compression based on artificial neural network analyses using Purelin and Tansig transfer functions. The developed strength and strain enhancement ratio models are functions of actual confinement ratio, orientation of fibers, height to diameter ratio, and axial strain in unconfined concrete at peak axial stress. The formulation and performance evaluation of the developed strength and strain enhancement ratio models are carried out using experimental investigation results of 238 circular fiber-reinforced polymer tube confined concrete under concentric axial compression compiled from a database of 599 fiber-reinforced polymer tube confined concrete specimens. The predictions of the developed strength and strain enhancement ratio models match well with the experimental investigation results of the compiled database. The developed strength and strain enhancement ratio models exhibit smaller statistical errors than the available models in the research studies for predicting the strength and strain enhancement ratios of circular fiber-reinforced polymer tube confined concrete under axial compression.


ABSTRACT: In literature, there is no theoretical research focusing on moment–shear interaction behavior of the hybrid girders. This article investigates the moment–shear interaction behavior of non-composite hybrid steel plate I-girders at ambient and elevated temperatures. In this regard, based on a more realistic distribution of bending and shear stresses, theoretical equations have been proposed to achieve the moment–shear interaction curve without considering shear buckling. The results obtained from the proposed equations were
out using the developed finite element model to study the effect of member slenderness, height were validated with the available experimental results present in the literature. The results of the nonlinear finite element analysis nonlinearities were included in the finite element model. The effects of initial local and overall geometric imperfections have been considered in the finite element modelling. The results of the nonlinear finite element analysis were compared with the design strengths obtained using the American, Australian/New Zealand and European specifications for aluminium structures. An empirical unified web crippling equation with new coefficients for aluminium alloy channels under end-two-flange and interior-two-flange loading conditions is proposed. Since two failure modes of web buckling and web yielding were observed in the tests, the web crippling strength is also predicted using the proposed theoretical design rules for channels. The web crippling strength is the lesser of the web buckling strength and web yield strength.

ABSTRACT: At present, extensive studies have been conducted relative to the topic of fiber-reinforced polymer(FRP)-reinforced concrete (RC) flexural members, and many design methods have also been introduced. There have, however, been few studies conducted on the topic of FRP-RC compression members. In light of this, eight glass-fiber-reinforced polymer (GFRP)-RC square columns (200×200×600 mm) were tested in order to investigate their axial compression performance. These columns were reinforced with GFRP longitudinal reinforcement and confined GFRP stirrup. These experiments investigated the effects of the longitudinal reinforcement ratio, stirrup configuration (spirals versus hoops) and spacing on the load-carrying capacity and failure modes of GFRP-RC rectangular columns. The test results indicate that the load-carrying capacity of longitudinal GFRP bars accounted for 3%-7% of the ultimate load-carrying capacity of the columns. The ultimate load-carrying capacity of RC columns confined with GFRP spirals increased by 0.8%-1.6% with higher ductility, compared to GFRP hoops. Reducing the stirrup spacing may prevent the buckling failure of the longitudinal bars and increase the ductility and load-carrying capacity of the GFRP-RC columns. It has been found that setting the GFRP compressive strength to 35% of the GFRP maximum tensile strength yields a reasonable estimate of ultimate load-carrying capacity of GFRP-RC columns.

Feng Zhou and Ben Young (First author is from: Department of Structural Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China), “Aluminium alloy channels subjected to web crippling”, Advances in Structural Engineering, Vol. 22, No. 7, pp 1617-1630, May 2019, https://doi.org/10.1177/1369433218819564
ABSTRACT: This article reports experimental and numerical investigations of aluminium alloy plain and lipped channels subjected to web crippling. A total of 240 data are presented that include 24 test results and 216 numerical results. A series of tests was conducted first on channels fabricated by extrusion using 6063-T5 and 6061-T6 heat-treated aluminium alloys under end-two-flange and interior-two-flange loading conditions. The concentrate transverse loads were applied by means of bearing plates. The flanges of the specimens were not fastened (unrestrained) to the bearing plates. A non-linear finite element model is then developed and verified against experimental results. Geometric and material non-linearities were included in the finite element model. It was shown that the finite element model closely predicted the web crippling strengths and failure modes of the tested specimens. Hence, the model was used for an extensive parametric study of cross-section geometries, and the web slenderness value ranged from 24.0 to 207.3. The test results and the web crippling strengths predicted from the finite element analysis were compared with the design strengths obtained using the American, Australian/New Zealand and European specifications for aluminium structures. An empirical unified web crippling equation with new coefficients for aluminium alloy channels under end-two-flange and interior-two-flange loading conditions is proposed. Since two failure modes of web buckling and web yielding were observed in the tests, the web crippling strength is also predicted using the proposed theoretical design rules for channels. The web crippling strength is the lesser of the web buckling strength and web yield strength.

ABSTRACT: This article aims at investigating the structural response and predicting the ultimate resistance of cold-formed steel built-up columns composed of lipped sigma sections with pinned ends. For this purpose, a numerical model is established by using the finite element code ABAQUS. The finite element models include geometric, material nonlinearity. The effects of initial local and overall geometric imperfections have been taken into consideration in the finite element modelling. The results of the nonlinear finite element analysis were validated with the available experimental results present in the literature. A parametric study was carried out using the developed finite element model to study the effect of member slenderness, height-to-width ratio.
and depth of trapezoidal stiffener on the ultimate resistance of cold-formed steel closed built-up columns. On the basis of the parametric results, presented herein, appropriateness of the current direct strength method in the North American Specification for cold-formed steel columns is assessed. Based on such comparison, design expression is proposed to provide reliable design strength prediction of cold-formed steel built-up column composed of lipped sigma sections and verified through reliability analysis.


ABSTRACT: As China’s infrastructure grows rapidly, the use of concrete-filled steel tubular structures for engineering applications is attracting increasing interest owing to their high section modulus, high strength and good seismic performance. However, for concrete-filled steel tubular members with large width-to-thickness ratio, steel tubes are prone to outward buckling when they are subjected to axial compression. Welding of longitudinal stiffeners on the steel tubes is one of the most efficient approaches for delaying local buckling and thus improving the mechanical performance of such type of concrete-filled steel tubular members. This study attempts to investigate the axial compression behaviour of concrete-filled stiffened steel tubular members with square sections through experimental study and finite element analysis. First, 14 concrete-filled steel tubular stub columns, with different width-to-thickness ratios of steel tube and depth-to-thickness ratios of stiffener, were subjected to axial compression loads and tested. It was found that the use of stiffeners increases the ultimate strength and improves the stability of the stub columns. Later, an investigation on the behaviour of the stiffened concrete-filled steel tubular stub columns was carried out through a three-dimensional finite element analysis. The accuracy of the finite element analysis model was verified by the test results. A parametric study was conducted to further evaluate the stiffening schemes that influence the axial compression strength. Finally, the research findings were synthesized into a new simplified model to predict the load-carrying capacity of stiffened concrete-filled steel tubular stub columns that allows for large width-to-thickness ratios.


ABSTRACT: Composite sandwich structure possesses unique characteristics in which the facings’ material provides a high in-plane stiffness/strength, while the core material keeps the facings a part to enhance the flexural stiffness/strength. However, sandwich structure is susceptible to shear failure due to the weak bond between the facings and the core materials. This article addresses this issue and provides an efficient semi-circular shear keys concept to be inserted in the interfacial surface between the sandwich structural elements to improve the facings–core interaction with marginal sacrifice in the strength-to-weight ratio. Composite sandwich panels composed of glass fibre–reinforced polymer skins and polyurethane foam core material have been investigated in this study. Mechanical tension, compression and shear tests were performed on the facings, while compression tests were conducted on the core materials to define the elasto-plastic response of the constituent’s materials. Four-point bending tests were performed on the conventional composite sandwich panel and panels incorporated with shear keys concept. Considerable improvement in the flexural stiffness and strength along with detouring the crack path was noticed for the samples incorporated with shear keys. A non-linear finite element analysis was established to verify the experimental results. Comparisons between the experimental and finite element results were presented and showed good agreement between both results which justified the parameters used in the finite element models and their capabilities to capture the mechanical behaviour and the damage mode of the investigated models.


ABSTRACT: An artificial neural network model was developed as a reliable modeling method for simulating and predicting the ultimate force capacities of cellular steel beams. The required data in training, validating, and testing states were obtained from a reliable database. A new formula based on the artificial neural network was proposed to predict the failure loads of cellular steel beams subjected to lateral torsional buckling. The attempt was done to evaluate a practical formula considering all parameters which may affect the lateral torsional
buckling strength. Then, a comparison was made between the proposed formula and the predictions obtained from Australian Standard (AS4100). The results provided some evidence that proposed formula obtained more accurate predictions than AS4100 design guides. Finally, a sensitivity analysis was developed using Garson’s algorithm to determine the importance of each input parameters.


ABSTRACT: A built-up I-section with web stiffeners and complex edge stiffeners is expected to have better performance to resist against local and distortional buckling compared to conventional built-up I-section. In order to study the influence of perforations on compression behavior of above section forms, a series of pin-ended compression tests and numerical analysis on perforated double-limb cold-formed steel built-up I-section columns with complex edge stiffeners and web stiffeners were conducted. The test specimens contained 12 concentrically loaded specimens and 8 eccentrically loaded specimens with two cross-section shapes, respectively. The test results were found that the web stiffeners could obviously increase the ultimate bearing capacity of the built-up members, especially for stub and medium-long columns. The ultimate bearing capacity of two cross-section shaped medium-long columns decreased gradually with the increase of eccentricity. Two adjacent single-limb webs of conventional built-up I-section could provide support to each other. The web stiffeners restricted the deformation of the plate around the holes effectively, but it also weakened the composite action between the single-limb webs. A finite element model was developed and verified against experiments of perforated built-up columns. Furthermore, a total of 96 parametric analyses were completed to investigate the optimal ratio of the hole depth to web sub-element in the Σ-shaped built-up I-section perforated columns. Finally, two types of direct strength method formulas were used to calculate the ultimate bearing capacity of perforated built-up specimens. The appropriateness of those direct strength method was compared. It was shown that the existing direct strength method formulas were both valid for perforated built-up I-section columns with complex edge stiffeners.


ABSTRACT: As steel plate shear walls are typically used in the building central cores around the elevators and stairs, introduction of an opening as door seems to be inevitable in steel plate shear wall spans. Due to the weakening of the steel plate shear walls’ performance caused by this particular type of opening, the use of stiffeners around the opening is necessary. Nevertheless, introduction of stiffeners around all sides of the opening, which does continue to boundary elements, is very expensive and inefficient. Therefore, the study on the effect of different arrangements of stiffeners on the behavior of steel plate shear walls is significant. In this research, a number of steel plate shear walls with different characteristics in terms of the plate aspect ratio, location of openings, arrangement of stiffeners around the openings, and number of stories are designed, and also a series of nonlinear static analyses are performed. Then, the optimum locations of openings along with the arrangement of stiffeners for each case are identified based on the structural and economic criteria. Finally, a modified model, which is more efficient in terms of cost and performance in comparison with the similar unmodified model, is proposed.


ABSTRACT: Cold-formed stainless steel is becoming popular as a structural member with its increased corrosion resistance and durability when compared with carbon steel. Examples of cold-formed steel structures include trusses, wall frames and portal frames. In cases where increased axial capacity is required, it is becoming increasingly popular to use back-to-back gapped built-up channels, instead of just back-to-back sections. In such an arrangement, however, the beneficial effect of the gap between the back-to-back cold-formed steel channels is ignored by the current design guidelines (American Iron and Steel Institute and the Australian and New Zealand Standard and Eurocode (EN 1993-1-3)) for both cold-formed carbon as well as
correlations between the wind loads and the structural responses. The explanation for this observation is that the correlation calculation, it is found that the correlations are much stronger for the load comparison than those for the exact wind tunnel measurement. The correlation method has been recognized by the wind engineering community as a useful equivalent static wind load calculation method for structural design of quasi-static structures against strong winds. However, it has been found that the load–response correlation method is less effective to non-linear systems and in situations where load processes are non-Gaussian, such as large cooling towers subjected to strong winds. To validate the applicability of the load–response correlation method to large cooling towers, an aero-elastic model has been designed for a 215-m-high cooling tower in this article, which can simultaneously produce wind loads and wind-induced displacements of the structure according to wind tunnel model tests. Using the aero-elastic model, the exact results of correlation coefficients between wind loads and structural responses are obtained and validated by a non-linear finite element analysis. By comparing the correlation coefficients measured on the scaled model to the results based on the load–response correlation calculation, it is found that the correlations are much stronger for the load–response correlation calculation than those for the exact wind tunnel measurement. The explanation for this observation is that the non-linearity of the real structure and the non-Gaussian feature of the actual wind loads can weaken the correlations between the wind loads and the structural responses.


ABSTRACT: Experimental and numerical investigations of concrete-filled double-skin aluminium stub column with a circular hollow section as the outer skin and a square hollow section as the inner skin are presented in this article. A test program was carried out to study the influences of aluminium tube geometric dimensions and concrete strength on structural performance and strength of composite columns. A series of composite columns was tested on outer circular hollow section tubes and inner square hollow section tubes; the spaces between them had been filled with concrete of different nominal cylinder strengths of 40, 70 and 100 MPa. A non-linear finite element model was developed and verified against experimental results. The test and numerical results were compared with the design strengths to evaluate the applicability of the design rules in the American specifications for aluminium and concrete structures. In addition, the proposed design equations, developed by the authors for concrete-filled double-skin aluminium tubular stub columns with circular hollow section as both outer and inner skins, were used to calculate the design strengths and compared with the experimental and numerical results obtained in this study. The proposed design equations also predicted the ultimate strengths of the concrete-filled double-skin aluminium tubular stub columns accurately with circular hollow section as the outer skin and square hollow section as the inner skin.


ABSTRACT: The load–response correlation method has been recognized by the wind engineering community as a useful equivalent static wind load calculation method for structural design of quasi-static structures against strong winds. However, it has been found that the load–response correlation method is less effective to non-linear systems and in situations where load processes are non-Gaussian, such as large cooling towers subjected to strong winds. To validate the applicability of the load–response correlation method to large cooling towers, an aero-elastic model has been designed for a 215-m-high cooling tower in this article, which can simultaneously produce wind loads and wind-induced displacements of the structure according to wind tunnel model tests. Using data measured on the aero-elastic model, the exact results of correlation coefficients between wind loads and structural responses are obtained and validated by a non-linear finite element analysis. By comparing the correlation coefficients measured on the scaled model to the results based on the load–response correlation calculation, it is found that the correlations are much stronger for the load–response correlation calculation than those for the exact wind tunnel measurement. The explanation for this observation is that the non-linearity of the real structure and the non-Gaussian feature of the actual wind loads can weaken the correlations between the wind loads and the structural responses.

ABSTRACT: Existing research on the widely used concrete-filled steel tubes is mainly focused on static or cyclic loading, and the studies on effects of high strain rate are relatively rare. In this article, seven stub concrete-filled steel tubular columns with square section were tested under both static and impact loads, using a large-capacity drop-weight testing machine. The research parameters were variable height of the drop-weight and different load types. The experimental results show that the failure modes of the concrete-filled steel tube columns from the impact tests are similar with those under static load, characterized by the local buckling of the steel tube. The time history curves of impact force and steel strain were investigated. The results indicate that with increasing impact energy, the concrete-filled steel tube stub columns had a stronger impact-resistant behavior. The dynamic analysis software LS-DYNA was employed to simulate the impact behaviors of the concrete-filled steel tube specimens, and the finite element results were reasonable compared with the test results. The parameter analysis on the impact behavior of concrete-filled steel tube columns was performed using the finite element model as well. A simple method was proposed to calculate the impact strength of square concrete-filled steel tube columns and compared favorably with experimental results.


ABSTRACT: When casting wet concrete into hollow steel tubular arch during the construction process of a concrete-filled steel tubular arch bridge, an initial stress (due to dead load, etc.) would be produced in the steel tube. In order to understand the influence of this initial stress on the strength of the concrete-filled steel tubular arch bridge, a total of four single tubular arch rib (bare steel first) specimens (concrete-filled steel tubular last) with various initial stress levels were constructed and tested to failure. The test results indicate that the initial stress has a large influence on the ultimate load-carrying capacity and ductility of the arch structure. The high preloading ratio will reduce significantly the strength and ductility that the maximum reductions are over 25%. Then, a finite element method was presented and validated using the test results. Based on this finite element model, a parametric study was performed that considered the influence of various parameters on the ultimate load-carrying capacity of concrete-filled steel tubular arches. These parameters included arch slenderness, riseto-span ratio, loading method, and initial stress level. The analysis results indicate that the initial stress can reduce the ultimate loading capacity significantly, and this reduction has a strong relationship with arch slenderness and rise-to-span ratio. Finally, a method for calculating the preloading reduction factor of ultimate load-carrying capacity of single concrete-filled steel tubular arch rib structures was proposed based on the equivalent beam–column method.


ABSTRACT: The use of high-strength steel wires is proposed to provide external confinement for concrete-filled steel tubular columns. This article presents an experimental study on high-strength steel-wire-confined concrete-filled steel tubular columns with various high-strength steel wire spacings and steel tube thicknesses and diameters. As observed from the experimental results, high-strength steel wires can effectively constrain and delay the local buckling of the steel tube in concrete-filled steel tubular columns. As a result, the load-carrying capacity and the post-peak stiffness of concrete-filled steel tubular columns are significantly increased by the high-strength steel wire confinement. When the spacing of the high-strength steel wires decreases, the load–axial strain response can evolve from a softening behavior to a hardening behavior for the concrete-filled steel tubular columns. Moreover, theoretical models were developed to predict the load-carrying capacity of the externally confined concrete-filled steel tubular columns, taking into account the mechanical mechanism and the triaxial stress state of the inner concrete. The analytical results are generally in reasonable agreement with the experimental results.
ABSTRACT: The shape of the imperfection induced by welding has an influence on the buckling resistance of thin shell structures, and many previous studies have come up with various models to estimate the critical imperfection shape. The aim of the current study is to assess the adequacy of three different approaches available in the literature, which consider that the imperfection wavelength matching the first buckling mode of a perfect tank to be the critical one. The first approach is based on buckling formulae calculated using a linear eigenvalue analysis performed on extensive experimental results of buckling of conical shells. The second approach assumes the critical wavelength, in view of the buckling mode profile detected from finite element analysis, as the distance between the inflection points of the elastic curve of the first buckling mode of a perfect tank. The third approach estimates the critical wavelength as double the distance between maximum and minimum points of the elastic curve. To determine the optimum wavelength that would lead to the minimum buckling capacity of the tank, the current study is conducted numerically by coupling a nonlinear finite element model, developed in house, and a direct search optimization technique. The results obtained from this numerical tool show good agreement with the first and the second approaches, which proves the adequacy of these two approaches in estimating the critical wavelength of the governing buckling mode, while the third approach yields a wavelength that overestimates the buckling capacity of the tank.

ABSTRACT: Double-layer barrel vault roofs with double-layer vertical walls are frequently used as a structural system for highly important public buildings; therefore, their seismic design needs special considerations. In this article, the seismic collapse behavior of these structures, used as a lateral load-resisting system, is evaluated by carrying out incremental dynamic analysis. For this purpose, different rise-to-span and height-to-span ratios are considered for the roofs and the walls, respectively. The structures are first designed in accordance with Iranian design codes and then they are modeled in OpenSees. The material and geometric nonlinearities are considered in the analyses, including the buckling response of the compression members. At the next stage, the models are subjected to incremental dynamic analysis and their median collapse capacities are extracted. Collapse margin ratios of various structures are finally derived, following FEMA-P695 methodology, and compared against the established acceptable limits. The obtained results show that collapse of the structures occurs mainly due to the buckling-mode failure of the roof. The collapse performance of the structures with large rise-to-span ratio of roofs and large height-to-span ratio of walls is unacceptable.

Fei Lin, Chuanzhi Chen, Jinbao Chen, Meng Chen
College of Aerospace Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China
College of Aeronautics, Nanjing University of Aeronautics and Astronautics, Nanjing, China
Aerospace Systems Engineering Shanghai, Shanghai, China
ABSTRACT: Existing cylindricaldeployable structures have poor controllability of deployment or weak bearing capacity. In order to satisfy the application needs of cylindrical deployable structures in the space industry, a cylindrical net-shell deployable mechanism is established in this article. The proposed cylindrical net-shell deployable mechanism has a regular cuboid shape in the folded state and a truss structure in the deployed state, and it can fit cylindrical surface, parabolic cylindrical surface, sine cylindrical surface and so on. Furthermore, based on reciprocal screw theory and screw synthesis theory, the mobility of cylindrical net-shell deployable mechanism in the whole motion cycle is analysed by the proposed equivalent model method. Results show that the cylindrical net-shell deployable mechanism is a single-degree-of-freedom mechanism. Moreover, a prototype is manufactured, and its motion performance is tested. The experiment shows that the cylindrical net-shell deployable mechanism has a smooth motion performance, and the mobility analysis method for complex coupled mechanism in this study is valid. This study has a certain significance in expanding the application field of cylindrical shell structure.
Xi Wang, Ruo-qiag Feng, Gui-rong Yan, Bao-chen Zhu, Feng-cheng Liu
The Key Laboratory of Concrete and Prestressed Concrete Structures of the Ministry of Education, Southeast University, Nanjing, China
School of Civil Engineering, Southeast University, Nanjing, China
Department of Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology, Rolla, MO, USA
ABSTRACT: The cable-stiffened lattice shell is a new structural system for its translucence and lighting. This article discusses the effect of the connections’ behavior and geometric imperfection on the structural stability and reveals the buckling mechanism of the cable-stiffened lattice shell. The spring stiffness for bolted connections of cable-stiffened lattice shells is deduced from the spring in series model. The buckling mechanism of cable-stiffened lattice shells with three types of joints have been studied based on the prototypical static experiments of bolted connections. The decrease of bolted connections’ stiffness would lead to the change in the displacement distribution for the lattice shell under its ultimate load. The buckling loads and initial structural stiffness of cable-stiffened lattice shells with shim-strengthened bolted joints are approximately 80% of those for cable-stiffened lattice shells with rigid joints. The result indicates that the buckling loads of cable-stiffened lattice shells with bolted connections decrease much more slowly than the decrease of bolted connections’ stiffness. The cable-stiffened lattice shell with SBP connections is more sensitive to the initial geometric imperfection. Finally, a formula has been proposed for estimating buckling loads of elliptic paraboloid cable-stiffened lattice shells with bolted connections.

Hui Zhao, Rui Wang, Chuanchuan Hou, Dongjie Zhang
College of Architecture and Civil Engineering, Taiyuan University of Technology, Taiyuan, China
School of Transportation Science and Engineering, Beihang University, Beijing, China
ABSTRACT: This work investigated the impact performance of hollow reinforced concrete members with inner octagonal steel tube. Experiments on 13 specimens subjected to low-velocity drop weight impact are presented in this article, covering key parameters such as the impact height, boundary condition, axial load ratio and thickness of the inner tube. The dynamic processes, failure patterns, impact force and mid-span deflection histories, and residual mid-span deflections were obtained from the experiments. Flexure-shear was observed as the main failure pattern for all the specimens under impact. It was found that all the key parameters considered had influences on the impact performance of hollow reinforced concrete specimens with inner octagonal steel tube. Effects of these parameters on the impact performance of hollow reinforced concrete members were discussed.

M. Anbarasu (Department of Civil Engineering, Government College of Engineering, Salem, India),
ABSTRACT: This article mainly investigates the behaviour and strength of built-up batteded box column composed of lipped angles under axial compression. Ten specimens were fabricated and tested under pinned with warping-restrained end condition including two different cross-section dimensions of columns with five different geometric lengths. Three material tensile coupon tests were conducted to obtain the material properties of the steel used for fabricating the test specimens. The overall initial geometric imperfections were measured. The plate slenderness, member slenderness, chord slenderness and slenderness of batten plates may affect the compression behaviour of cold-formed steel built-up batteded box columns and were accordingly investigated. It was found that the chord slenderness significantly affects the compressive strength of the built-up columns. Test results, including the compression resistances, the load versus displacement responses and the deformed shapes were presented. The test strengths were compared with the design strengths predicted using the North American Specifications (AISI-S100:2016), EuroCode (EN1993-1-3:2006) and design equations proposed by EI Aghoury et al. The design strengths predictions by these two design standards were unconservative, with EI
Aghoury et al.’s standard performing better. Finite-element models were developed and verified against the test results.

Vui Van Cao, Quoc Dinh Le, Phuoc Trong Nguyen
Faculty of Civil Engineering, Ho Chi Minh City University of Technology – Vietnam National University, Ho Chi Minh City, Vietnam
Faculty of Civil Engineering, Ho Chi Minh City Open University, Ho Chi Minh City, Vietnam

ABSTRACT: This study experimentally investigated the behaviour of concrete-filled steel tubes under cyclic axial compression. A total of 42 concrete-filled steel tube specimens of two groups were tested to failure. In each group, 18 specimens were subjected to three cyclic axial loading histories while three specimens were subjected to monotonic loading for comparison. The results indicated that concrete-filled steel tube specimens under cyclic axial compression failed in the form of buckling and still kept their form which was similar to the failure of specimens under monotonic loading. Effect of cyclic axial loading slightly reduced (approximately 2%–3%) the maximum stress but it increased 25% of the strain corresponding to the maximum stress. Loading and unloading moduli in post-peak stress phase were, respectively, about 70% and 85% higher than initial moduli because better interaction and confinement were resulted from the initial loading cycle. In addition, the absorbed energy exhibited a heavy dependence on strain and confinement while it was insignificantly affected by cyclic loading histories. Details and application of obtained experimental results are reported in this article.


ABSTRACT: It is common that initial gaps exist between the steel tube and the core concrete in concrete-filled steel tubular structural members, which might affect the performance of the structure. This article aims to study the effects of the gaps on the cyclic behaviour of circular concrete-filled steel tubular members. A total of 24 concrete-filled steel tubular specimens were tested under constant axial load and cyclically lateral loads, where the main testing parameters included the types of gap, the gap ratio, the axial load level and the steel ratio. The failure mode, lateral load versus lateral displacement hysteretic curve and load versus displacement envelope curve of concrete-filled steel tubular specimens with pre-designed gaps were experimentally investigated and compared with those of the reference ones without any gap. The effects of gaps on the ultimate strength, ductility and dissipated energy of the concrete-filled steel tubular members were quantitatively evaluated according to the test results. The influence of gaps on circular concrete-filled steel tubes under different loading conditions, such as axial compressive loading, pure bending, eccentrically compressive loading and cyclic lateral loading, was also compared and discussed.


ABSTRACT: In order to verify the accuracy of the panel zone shear capacity calculation method of diaphragm-through connections which were proposed in previous research, the low cycle repeated load tests of six cross-shaped specimens were carried out. The seismic performance of the panel zone’s stress distribution, failure mode, hysteresis curve, and skeleton curve are comprehensively studied and analyzed. The results showed that the steel tube web and core concrete were mainly participating to bear the horizontal shear force, and the “steel frame” composed of the steel tube flange and through-diaphragm was negligible for the shear resistance; the core concrete strut calculated width and height were all one-fourth of the height and width of the panel zone. The test results are in good agreement with the results of the calculation method, which indicated that the calculation method proposed in the previous research results had good accuracy and applicability, and would use for the panel zone shear capacity calculated in the connections design.

Junjie Guo, Haojun Tang, Yongle Li, Lianhuo Wu, Zewen Wang (Department of Bridge Engineering, Southwest Jiao tong University, Chengdu, China), “Optimization for vertical stabilizers on flutter stability of

ABSTRACT: Wind environment in mountainous areas is very different from that in coastal and plain areas. Strong winds always show large angles of attack, affecting the flutter stability of long-span bridges which is one of the most important design factors. The central vertical stabilizer has been demonstrated to be an effective aerodynamic measure to improve the flutter stability, and this article optimizes the stabilizer to improve its applicability in mountainous areas. Computational fluid dynamics simulations are first performed to analyze the effects of stabilizers with different positions and forms on the flutter stability of an ideal box girder, and the aerodynamic mechanism is discussed based on the static and the dynamic flow fields, respectively. Wind tunnel tests are then carried out to test the critical flutter wind speed of a real box girder equipped with different stabilizers, and the change in its flutter stability is further analyzed. The results show that the vertical stabilizer with appropriate positions and heights can improve the participation level of structural heaving vibration, and thereby increases the flutter stability. At large angles of attack, the big vortex on the leading edge which may drive the bridge to flutter instability is gradually weakened with the increase in stabilizer’s height. Compared with a single stabilizer, double vertical stabilizers, in the midst of which exists a negative pressure region, could achieve better effects.

Tao Huo, Lewei Tong
State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University, Shanghai, China
College of Civil Engineering, Tongji University, Shanghai, China
East China Architectural Design & Research Institute Co., Ltd, Shanghai, China

ABSTRACT: This study discusses the wind-induced response of existing pitch-controlled 1.25 MW wind turbine structures, with a particular focus on the influence of the blade-rotation effect, cross-wind loads of the tubular tower and the wind direction, and compares numerical responses with the measured dynamic responses. An integrated finite-element model consisting of blades, a nacelle, a tower and a foundation is established. The aerodynamic loads exerted on the rotating blades and the aerodynamic loads acting on the tubular tower are then obtained. A wind-induced response calculation method of the wind turbine structures corresponding to different wind speeds and wind directions is established for performing a wind-induced response analysis. Finally, comparisons between the measured responses and the corresponding numerical response results are performed to verify the accuracy of the proposed wind-induced response calculation method. The results indicate that neglecting the cross-wind aerodynamic loads of large-scale wind turbine structures can lead to unsafe design. The wind direction has different influences on the along-wind and cross-wind dynamic responses. The statistical values of the measured dynamic responses are slightly greater than those of the numerical analysis results, but the magnitudes of the responses are the same. Therefore, the proposed wind-induced response calculation method for wind turbine structures is feasible and reasonable. It can be used to conduct the fatigue life prediction of wind turbine tubular towers in future research which is an important issue in the structural design of wind turbine tubular tower structures.

Yuanlong Yang, Xianggang Liu, Jun Zhang, Jiepeng Liu, Wei Cheng
Key Laboratory of New Technology for Construction of Cities in Mountain Area, Ministry of Education, Chongqing University, Chongqing, China
Department of Civil Engineering, Chongqing University, Chongqing, China
China HuanQiu Contracting & Engineering Corporation (Guangzhou), Guangzhou, China

ABSTRACT: Three large-scale connections between circular concrete-filled steel tubular columns and H-section steel beams were tested. The specimens include one connection with T-shaped stiffeners under static load and two connections, respectively, with T-shaped stiffeners and diaphragms (including interior and exterior diaphragms) under cyclic loads. During the test, the experimental phenomena were observed. The static
properties of strength and ductility are calculated for static connection based on load-displacement curves, while the seismic properties of strength, ductility, and energy dissipation are analyzed for seismic connections based on hysteretic load-displacement curves. Combining experimental phenomena, mechanical properties, and stress development, the beam-hinge failure mode can be identified for all specimens. The measured beam strengths of specimens are compared with those predicted by the current AISC-360, EC4, and GB 50017-2017 codes. The study results show that all connections are reliable. A finite element model, established and verified with the experimental results, is used to perform parametric analysis. Furthermore, design suggestions of T-shaped stiffeners and diaphragms are proposed based on a parametric analysis.

Qiang Qing, Xiao Guo, Jinghai Gong, Zhongli Li
Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai, China
Beijing Z&T Fabric Architecture Technology Co., Ltd., Beijing, China


ABSTRACT: The structural behavior of an air-supported structure with long span and large volume probably experiencing severe deflation in a massive snow weather deserves in-depth assessment study for occupant’s safe evacuation. This article presents experimental and numerical studies on the loading deflation process of a 1:10 scale joined hemispherical-cylindrical air-supported structure, whereby three different sandbag loadings were respectively applied on the hemisphere in each test to study the effect of vertical loads to collapse process. Numerical models based on the vector form intrinsic finite element method were employed to predict the deflation responses of the structure under the three loading cases. The structural behavior was evaluated by the pressure response, the wrinkling distribution and development, and the structural collapse mode. A comparison of their pressure responses and structural deflated forms is made to evaluate the contribution of external loading to the deflation progress and the collapse mode. It is found that the pressure will decrease quickly first and then remain relatively stable at a higher level in response to a larger vertical load in addition to the membrane weight. Due to pressure reduction during deflation, the structure loses tension stress in vertical direction so that vertical wrinkles develop in addition to local wrinkles due to external loading. The vertical loading determines distribution of wrinkles in the structure hence produce different collapse progresses for the three loading deflation cases, and accordingly changes the residual pressure it needs to hold its deflated form. Accordingly, the study proposes a feasible method for residual pressure estimation by identifying the distribution of critical residual pressures at different heights from the equilibrium equation of vertical forces. The full-scale structure presents similar structural behaviors when subjected to snow loading deflation, and the feasible method is valid to predict its residual pressure.

Zhao Li, , Jingwei Gao, Jindong Xu, Guofeng Du
School of Urban Construction, Yangtze University, Jingzhou, China
Hubei Key Laboratory of Roadway Bridge & Structure Engineering, Wuhan University of Technology, Wuhan, China


ABSTRACT: Compared with the traditional reinforced concrete columns, the concrete-filled steel tubular columns with a better restraint effect of steel tube on core concrete showed higher bearing capacity and ductility under static loads. However, except static loads, concrete-filled steel tubular columns are commonly exposed to the extreme dynamic loads including earthquake, explosion, and impact. The study on dynamic behavior of concrete-filled steel tubular columns is extremely significant to ensure their safety against such dynamic loads. In this article, a polyvinylidene fluoride piezoelectric smart sensor was proposed to monitor the axial impact bearing capacity of specimen based on stress monitoring under impact loads. The concrete-filled steel tubular columns with smart sensor embedded were tested, which considered the effects of both hammer impact heights and steel tube thickness on the axial impact bearing capacity. The impact bearing capacity calculated based on the monitoring results of polyvinylidene fluoride sensor is in good agreement with the measured values, which verifies the feasibility of this method. Moreover, it is found that the failure mode of concrete-filled steel tubular short columns is the local tearing failure or local buckling. In addition, non-linear finite element models were
also established to study the effect of different parameters on the axial bearing capacity. The simplified formula for calculating the axial impact bearing capacity of concrete-filled steel tubular short columns was proposed based on the large amount verified model. Through the comparison between the calculation value and the test value, the formula is found to well reflect the axial impact bearing capacity of concrete-filled steel tubular short columns, which provides a reference for similar research.

Shaochua Zhang (1), Xizhi Zhang (2,3), Shengbo Xu (1) and Xingqian Li (1)
(1) School of Civil Engineering, Tianjin University, Tianjin, China
(2) Architectural Design & Research Institute, Tianjin University, Tianjin, China
(3) Key Laboratory of Coast Civil Structure Safety, Ministry of Education, Tianjin University, Tianjin, China

ABSTRACT: This study reports the cyclic loading test results of normal-strength concrete-filled precast high-strength concrete centrifugal tube columns. Seven half-scale column specimens were tested under cyclic loads and axial compression loads to investigate their seismic behavior. The major parameters considered in the test included axial compression ratio, filled concrete strength, and volumetric stirrup ratio. The structural behavior of each specimen was investigated in terms of failure modes, hysteresis behavior, bearing capacity, dissipated energy, ductility, stiffness degradation, drift capacity, and strain profiles. Test results revealed that the concrete-filled precast high-strength concrete centrifugal tube column exhibited good integral behavior, and the failure modes of all columns were ductile flexural failures. Lower axial compression ratio and higher volumetric stirrup ratio resulted in more satisfactory ductile performance. In contrast, the filled concrete strength has a limited influence on the structural behavior of concrete-filled precast high-strength concrete centrifugal tube columns. Based on the limit analysis method, the calculation formula for the bending capacity of the concrete-filled precast high-strength concrete centrifugal tube column was developed, and the results predicted from the formulas were in good agreement with the experiment results.

Shu Fang (1), Li-Juan Li (1), Tao Jiang (2) and Bing Fu (1)
(1) School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, China
(2) Space Structures Research Center, Department of Civil Engineering, Zhejiang University, Hangzhou, China

ABSTRACT: Concrete infilled in a small-diameter fiber-reinforced polymer tube is strongly confined, thus having a high compressive strength and excellent deformability. Such a feature is exploited in the development of two types of high-performance hybrid members at Guangdong University of Technology, China, by incorporating small-diameter (30 to 60 mm) concrete-filled fiber-reinforced polymer tubes as internal reinforcements. Understanding the compressive behavior of small-diameter concrete-filled fiber-reinforced polymer tubes is essential to understanding the behavior of the proposed hybrid members and the development of their design approaches. This article therefore presents a systematic study on the axial compressive behavior of small-diameter concrete-filled fiber-reinforced polymer tubes with the test parameters being the thickness, diameter, and fiber type of fiber-reinforced polymer tubes and concrete strength. The test results show that the tested small-diameter concrete-filled fiber-reinforced polymer tubes have a compressive strength and an ultimate axial strain of up to 267 MPa and 10.3%, which are, respectively, about 6 and 34 times that of the corresponding unconfined specimens, demonstrating the great potential of small-diameter concrete-filled fiber-reinforced polymer tubes as internal reinforcements for use in high-performance hybrid members. The applicability of three widely accepted stress–strain models developed based on test results of fiber-reinforced polymer-confined concrete cylinders with a diameter of 150 mm or above is also examined. It is shown that the three models tend to predict a steeper second portion of stress–strain responses than the test results, revealing the need of a tailored stress–strain model for small-diameter concrete-filled fiber-reinforced polymer tubes.

References listed at the end of the paper:
<table>
<thead>
<tr>
<th>Reference</th>
<th>Details</th>
</tr>
</thead>
</table>


Yong Yang (1), Xing Du (1), Yunlong Yu (1,2) and Yongpu Pan (1)
(1) School of Civil Engineering, Xi'an University of Architecture and Technology, Xi'an, China
(2) Key Laboratory of Structure and Earthquake Resistance, Xi’an, China


ABSTRACT: The ultra-high-strength concrete-encased concrete-filled steel tube column consists of a concrete-filled steel tube core and a rectangle-shaped reinforced concrete encasement. This article presents the seismic performance analysis of ultra-high-strength concrete-encased concrete-filled steel tube columns subjected to cyclic loading. Based on the measured load-lateral displacement hysteresis curves of six ultra-high-strength concrete-encased concrete-filled steel tube columns and two conventional RC columns, the seismic behaviours, such as the ductility, energy dissipation, stiffness and load-bearing capacity, were analysed. The effects of the arrangement of the stirrups and the layout of the prestressed steel strips on the seismic performance of the composite columns were critically examined. The test results indicated that the ductility and energy dissipation performance of the ultra-high-strength concrete-encased concrete-filled steel tube columns were increased by 74.8% and 162.7%, respectively, compared with the conventional columns. The configuration of the prestressed steel strip increased the ductility of the composite column by 28.9%–63% and increased the energy consumption performance by 160.2%–263.3%. By reducing the stirrup spacing and using prestressed steel strips, the concrete-filled steel tube core columns could be effectively confined, leading to a great enhancement in ductility, energy dissipation, stiffness and load-bearing capacity.

References listed at the end of the paper:


Y. Ouyang (1), J.J. Zeng (1), L.G. Li (1) and A.K.H. Kwan (2)
(1) School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, China
(2) Department of Civil Engineering, The University of Hong Kong, Hong Kong, China
ABSTRACT: Self-compacting concrete is quite commonly used in concrete-filled steel tube structures, but the compaction level of the self-compacting concrete, that is, the percentage of volume occupied by materials other than air void, within the steel tube is seldom investigated. The authors are of the view that the concrete mix proportions of the self-compacting concrete may have significant effects on the compaction level of the self-compacting concrete, which will be quantified by the ‘compaction index’ proposed in this study and thus the performance of the concrete-filled steel tube. Moreover, the mix proportions would also influence the performance of the concrete-filled steel tube by affecting the aggregate–aggregate and aggregate–paste interactions of the concrete, albeit this important issue is rarely addressed in previous studies either. Herein, a pilot study is conducted to investigate the influences of the self-compacting concrete mix proportions on the axial performance of concrete-filled steel tube. Four groups of concrete-filled steel tube specimens made with different self-compacting concrete were tested, and the investigated concrete mix parameters included the paste volume, fine to coarse aggregate ratio, and 9.5–19.0 mm aggregate ratio. It was found that the compaction index of the self-compacting concrete is a key factor enabling the successful use of self-compacting concrete in concrete-filled steel tube. Moreover, the paste volume and aggregate proportions of the concrete mix have certain effects on the post-peak behaviour and ductility of concrete-filled steel tube.

References listed at the end of the paper:


References listed at the end of the paper: concrete reinforced polymer tubes with ±80° and ±60° fiber angles, but it underestimates the ultimate axial strain of tubes with only hoop fibers, are capable of providing reasonably accurate predictions for concrete strain models, which were developed mainly on test results of concrete confined by fiber the confined concrete increased with the decrease of the absolute value of fiber angles. Two existing stress–strain models, which were developed mainly on test results of concrete confined by fiber-reinforced polymer tubes with only hoop fibers, are capable of providing reasonably accurate predictions for concrete-filled fiber-reinforced polymer tubes with ±80° and ±60° fiber angles, but it underestimates the ultimate axial strain of concrete-filled fiber-reinforced polymer tubes with ±45° fiber angles.

References listed at the end of the paper:

**ABSTRACT:** Concrete-filled fiber-reinforced polymer tubes are a novel form of composite columns, which are particularly attractive for structural members in harsh environments and seismic regions due to their corrosion resistance and ductile behavior. Over the past two decades, many studies have been conducted on concrete-filled fiber-reinforced polymer tubes under axial compression, and many stress–strain models have been proposed. However, existing studies mainly focused on concrete-filled fiber-reinforced polymer tubes with only hoop fibers. In order to investigate the effect of fiber angles (i.e. the fiber angle between the fiber orientation and the longitudinal axis of fiber-reinforced polymer tube), this study conducted axial compression tests of 42 concrete-filled fiber-reinforced polymer tubes with ±80°, ±60°, or ±45° fiber angles. These concrete-filled fiber-reinforced polymer tubes were constructed using normal-strength concrete or high-strength concrete. Fiber-reinforced polymer tube thickness was also investigated as an important parameter. In order to clarify the effect of fiber angles on the properties of fiber-reinforced polymer tubes, axial compression tests on 15 short fiber-reinforced polymer tubes and tensile split-disk tests on 75 fiber-reinforced polymer rings were conducted. Experimental results indicate that fiber angles had significant influences on the hoop properties of fiber-reinforced polymer tube; the confinement effect of fiber-reinforced polymer tube and the peak stress of the confined concrete decreased with the decrease of the absolute value of fiber angles, while the ultimate strain of the confined concrete increased with the decrease of the absolute value of fiber angles. Two existing stress–strain models, which were developed mainly on test results of concrete confined by fiber-reinforced polymer tubes with only hoop fibers, are capable of providing reasonably accurate predictions for concrete-filled fiber-reinforced polymer tubes with ±80° and ±60° fiber angles, but it underestimates the ultimate axial strain of concrete-filled fiber-reinforced polymer tubes with ±45° fiber angles.

**References**


Bing Zhang, Xia-Min Hu, Qing Zhao, Tao Huang, Ning-Yuan Zhang and Qian-Biao Zhang (College of Civil Engineering, Nanjing Tech University, Nanjing, China), “Effect of fiber angles on normal- and high-strength concrete-filled fiber-reinforced polymer tubes under monotonic axial compression”, Advances in Structural Engineering, Vol. 23, No. 5, pp 924–940, April 2020. [https://doi.org/10.1177/1369433219886082](https://doi.org/10.1177/1369433219886082)
<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Title</th>
<th>Journal/Conference</th>
</tr>
</thead>
</table>


<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Journal/Book</th>
<th>Volume/Issue</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saafi, M, Toutanji, HA, Li, Z</td>
<td>Behavior of concrete columns confined with fiber reinforced polymer tubes</td>
<td>ACI Materials Journal</td>
<td>96(4)</td>
<td>500–509</td>
</tr>
<tr>
<td>Samaan, M, Mirmiran, A, Shahawy, M</td>
<td>Modeling of concrete confined by fiber composites</td>
<td>Journal of Structural Engineering</td>
<td>124(9)</td>
<td>1025–1031</td>
</tr>
<tr>
<td>Spoelstra, MR, Monti, G</td>
<td>FRP-confined concrete model</td>
<td>Journal of Composites for Construction</td>
<td>3(3)</td>
<td>143–150</td>
</tr>
<tr>
<td>Teng, JG, Lam, L</td>
<td>Compressive behavior of carbon fiber reinforced polymer confined concrete in elliptical columns</td>
<td>Journal of Structural Engineering</td>
<td>128(12)</td>
<td>1535–1543</td>
</tr>
<tr>
<td>Toutanji, HA</td>
<td>Stress-strain characteristics of concrete columns externally confined with advanced fiber composite sheets</td>
<td>ACI Materials Journal</td>
<td>96(3)</td>
<td>397–404</td>
</tr>
<tr>
<td>Vincent, T, Ozbakkaloglu, T</td>
<td>Influence of fiber angle and specimen end condition on axial compressive behavior of FRP-confined concrete</td>
<td>Construction and Building Materials</td>
<td>47</td>
<td>814–826</td>
</tr>
<tr>
<td>Wu, YF, Jiang, C</td>
<td>Effect of load eccentricity on the stress–strain relationship of FRP-confined concrete columns</td>
<td>Composite Structures</td>
<td>98</td>
<td>228–241</td>
</tr>
<tr>
<td>Wu, YF, Wei, Y</td>
<td>General stress-strain model for steel- and FRP-confined concrete</td>
<td>Journal of Composites for Construction</td>
<td>19(4)</td>
<td>040140691–0401406914</td>
</tr>
<tr>
<td>Xiao, QG, Teng, JG, Yu, T</td>
<td>Behavior and modeling of confined high-strength concrete</td>
<td>Journal of Composites for Construction</td>
<td>14(3)</td>
<td>249–259</td>
</tr>
<tr>
<td>Xiao, Y, Wu, H</td>
<td>Compressive behavior of concrete confined by carbon fiber composite jackets</td>
<td>Journal of Materials in Civil Engineering</td>
<td>12(2)</td>
<td>139–146</td>
</tr>
<tr>
<td>Xiao, Y, Wu, H</td>
<td>Compressive behavior of concrete confined by various types of FRP composites jackets</td>
<td>Journal of Reinforced Plastics and Composites</td>
<td>22(13)</td>
<td>1187–1202</td>
</tr>
<tr>
<td>Zhang, B</td>
<td>Hybrid FRP-concrete–steel double-skin tubular columns under static and cyclic loading</td>
<td>PhD Thesis, The Hong Kong Polytechnic University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zhang, B, Yu, T, Teng, JG</td>
<td>Behaviour of concrete-filled FRP tubes under cyclic axial compression</td>
<td>Journal of Composites for Construction-ASCE</td>
<td>19(3)</td>
<td>04014060</td>
</tr>
<tr>
<td>Zhang, B, Wei, W, Feng, GS, et al.</td>
<td>Influences of fiber angles on the axial compressive behavior of GFRP-confined concrete</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ABSTRACT: This article experimentally investigates the cyclic behavior of ultra high performance concrete–filled steel tube column. A total of eight specimens were tested. The considered parameters were the axial load ratio and steel ratio. The results showed that all ultra high performance concrete–filled steel tube beam-columns had a very good cyclic behavior without significant pinching. Increasing the axial load ratio results in the decrease of strength and ductility, but it has no obvious influence on the initial flexural stiffness. Reducing the steel ratio results in the decrease of the strength, stiffness and ductility, and energy dissipation capacity.

References listed at the end of the paper:


Han, LH, Yang, YF, Tao, Z (2003) Concrete-filled thin-walled steel SHS and RHS beam-columns subjected to cyclic loading. Thin-Walled Structures 41(9): 801–833.


ABSTRACT: This article investigates the behaviour of slender concrete columns strengthened by square concrete filled steel tube jacketing. The columns were realised by placing a square outer steel tube around the original slender concrete filled steel tube column and pouring strengthening concrete into the gap between the inner and outer steel tubes. Three concrete-filled steel tube square columns and seven retrofitted columns ranging from 1200 to 2000 mm were tested to failure under axial compression. The experimental parameters included three length-to-width (L/B) ratios, three width-to-thickness (B/t) ratios and three strengths of concrete jacket (C50-grade, C60-grade and C70-grade). Experimentally, the retrofitted columns failed in a similar manner to traditional slender concrete-filled steel tube columns. After strengthening, the retrofitted columns benefitted greatly from the component materials, with their load-bearing capacity and ductility notably enhanced. These enhancements were mainly brought about by sectional enlargement and good confinement of concrete. A finite element model was developed using ABAQUS to better understand the axial behaviour of the retrofitted specimens. A parametric study was conducted, with parameters including the length of the column, thickness of the outer steel tube, strength of the concrete jacket, yield strength of the outer steel tube, thickness of the inner steel tube and strength of the inner concrete. Furthermore, the finite element model was adopted to study the behaviour of rust-damaged and post-fire slender concrete-filled steel tube square columns strengthened by square concrete-filled steel tube jacketing. A modified formula was proposed to predict the load-bearing capacity of retrofitted specimens, and the numerical results agreed well with the experiments and the finite element results of undamaged, rust-damaged and post-fire specimens. It could be used as a reference for practical application.

References listed at the end of the paper:


Hou, C, Han, LH, Zhao, XL (2013) Full-range analysis on square CFST stub columns and beams under loading and chloride corrosion. Thin-Walled Structures 68: 50–64.


A novel method for rapidly calculating explosion dynamic displacement response of reticulated shell structure based on influence surfaces

ABSTRACT: In order to analyse the mechanical behaviour of a reticulated shell structure under explosive load, a novel method was proposed to calculate the dynamic displacement response of the cylindrical reticulated shell structure by using the influence surface in this article. First, the theory of the dynamic influence line was developed and the consistency between the dynamic influence lines and the static ones was verified. Then, based on the theory of the dynamic influence line and for the simplified calculation of dynamic responses, the dynamic influence lines of a simply supported beam were simplified as the static ones multiplied by the dynamic amplification factor $\beta$. And then the explosion dynamic responses of the beam could be fast calculated using the influence lines. The extended application of the above method to single-layer cylindrical reticulated shell was the influence surface method. The results of numerical examples showed that the nodal displacements of the structure obtained by using the influence surface method agreed well with those obtained by using ANSYS/LS-DYNA. The research results also indicated that the influence surface method was applicable to the node displacement calculation of the structure under three different conditions, including the centre node of the symmetrical structure, the arbitrary nodes (excluding those near the supports) of symmetrical structure under symmetrical loads and the arbitrary nodes of arbitrary structures in which the load holding time is much longer than the natural vibration period of structure. The proposed approach could reduce the computation cost for analysing the explosion dynamic response of the reticulated shell structure, thereby providing a more effective method for the anti-explosion design of reticulated shell structures.

References listed at the end of the paper:


<table>
<thead>
<tr>
<th>Last Name</th>
<th>First Name</th>
<th>Year</th>
<th>Title of the Paper/Book</th>
<th>Journal/Publication</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li, C</td>
<td>(2016)</td>
<td>Failure mechanism and explosion protection method of cylindrical reticulated shell structures under internal explosion.</td>
<td>Master’s Thesis, Huqiao University, Xiamen, China.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Na Yang and Fan Bai (School of Civil Engineering, Beijing Jiaotong University, Beijing, China), “Buckling behavior of cold-formed C/Z-section purlins incorporating the effects of diaphragm and the screw location”, Advances in Structural Engineering, Vol. 23, No. 6, pp 1114-1128, April 2020, https://doi.org/10.1177/1369432219888739

ABSTRACT: This article presents a study on the impact of the screw location and the diaphragm effects on the buckling behavior of the simply supported C/Z-section purlins under wind uplift loadings. The diaphragm effects provided by the sheeting and the warping-torsional effect induced by load eccentricity are taken into account in the differential equations of the nonlinear twisting flexural-torsional model. The biaxial bending moments, bi-moments, as well as the flexural-torsional buckling load of the purlin can be numerically obtained with the proposed model. The global, local, and distortional buckling interaction behavior and the limit states capacities are formulated based on the modified Direct Strength Method. The effects of both the restraints provided by the sheeting and impact of the screw location on the mechanical performance of the purlins are evaluated with the proposed method. The relationship between the buckling load and rotational restraint stiffness is also provided. The proposed methodology will contribute to the assessment of buckling capacity of purlin-sheeting systems.

References listed at the end of the paper:
AISI-S100-16 (2017) North American specification for the design of cold-formed steel structural members.


Center for Advanced Structural Engineering (2006) THINWALL—a computer program for cross-section analysis and finite strip buckling analysis and direct strength design of thin-walled structures. Ver.2.1.


LaBoube, RA (1983) Laterally unsupported purlins subjected to uplift. Report, Prepared for the Metal Building Manufacturers Association, Cleveland, OH.


ABSTRACT: In a previous study, 17 rectangular concrete-filled steel tubular columns were tested using a push-out test method to examine the interfacial bond behaviour. In this study, these specimens were subjected to axial compressive tests to study the effects of interfacial damage on the ultimate axial compressive capacity. The variations in both the load–axial displacement curves and load–strain curves were recorded and then compared to study the influences of both the steel tube fabrication method and the D/B ratio on the axial load–carrying capacity. The axial compressive behaviour of rectangular concrete-filled steel tubular columns with no interfacial damage was then studied using a numerical analysis method. The contact stress distribution along the length and width of the face and at the height of the interface was obtained and discussed. In addition, the ultimate axial compressive capacity of rectangular concrete-filled steel tubular columns with no interfacial
damage was calculated using the formulas from three international codes. The influence of interfacial damage on the axial compressive bearing capacity of a rectangular concrete-filled steel tubular column was discussed through a comparison of the results of the numerical simulation, formula calculation and experiments. The influence of the interfacial gaps caused by the push-out tests on the axial bearing capacity of the concrete-filled steel tubular columns can be ignored, because the core concrete was not destroyed and the outside steel tube can provide a sufficient constraint force on the concrete when the two materials yielded. Finally, the influences of the gap type and size on the bearing capacity were discussed.

Youwu Xu (1), Jian Yao (1,2) and Xin Sun (2)
(1) Institute of Structural Engineering, Zhejiang University, Hangzhou, China
(2) College of Urban Construction, Zhejiang Shuren University, Hangzhou, China

ABSTRACT: Concrete-filled steel tubular columns are widely used in structural systems, and elliptical concrete-filled steel tubular columns are receiving more and more attention. An experimental study on cold-formed elliptical concrete-filled steel tubular columns was carried out under monotonic and cyclic axial compression. The failure modes, axial load–displacement curves, ultimate loads, hoop strain–axial strain behavior, strength deterioration, and residual deformation were obtained and discussed. Complementary finite element models considering the complex non-uniform confinement between steel tube and concrete were developed and validated by experimental results. Then, the validated FE model was used to study the influence of aspect ratio, yield strength of steel, and compressive strength of concrete on the axial capacity of elliptical concrete-filled steel tubular stub columns. Finally, a relatively simple superposition method was put forward to predict the axial bearing capacity of elliptical concrete-filled steel tubular stub columns. Compared with the test data, both the numerical method and superposition method can generate accurate predictions.

Bing Zhang (1), Jun-Liang Zhao (2), Tao Huang (1), Ning-Yuan Zhang (1), Yi-Jie Zhang (1) and Xia-Min Hu (1)
(1) College of Civil Engineering, Nanjing Tech University, Nanjing, China
(2) College of Civil Engineering and Architecture, Wenzhou University, Wenzhou, China

ABSTRACT: Hybrid fiber-reinforced polymer–concrete–steel double-skin tubular columns are a novel form of hollow columns that combine two traditional construction materials (i.e. concrete and steel) with fiber-reinforced polymer composites. Hybrid fiber-reinforced polymer–concrete–steel double-skin tubular columns consist of an inner tube made of steel, an outer tube made of fiber-reinforced polymer, and a concrete layer between the two tubes. Existing studies, however, are focused on hybrid fiber-reinforced polymer–concrete–steel double-skin tubular columns with fibers of the fiber-reinforced polymer tube oriented in the hoop direction or close to the hoop direction. In order to investigate the effect of fiber angles (i.e. the fiber angle between the fiber orientation and the longitudinal axis of the fiber-reinforced polymer tube), monotonic axial compression tests were conducted on hybrid fiber-reinforced polymer–concrete–steel double-skin tubular columns with an fiber-reinforced polymer tube of ±45°, ±60°, or ±80° fiber angles. There were two types of steel tubes adopted for these hybrid fiber-reinforced polymer–concrete–steel double-skin tubular columns. The fiber-reinforced polymer tube thickness was also investigated as an important parameter. Experimental results showed that the confinement effect of the fiber-reinforced polymer tube increased with the increase of the absolute value of fiber angles, whereas the ultimate axial strain of hybrid fiber-reinforced polymer–concrete–steel double-skin tubular columns decreased with the increase of the absolute value of fiber angles. An existing stress–strain model, which was developed on the basis of hybrid fiber-reinforced polymer–concrete–steel double-skin tubular columns with an fiber-reinforced polymer tube of ±90° fiber angles, is verified using the test results of this study. For the compressive strength of the confined concrete in hybrid fiber-reinforced polymer–concrete–steel double-skin tubular columns, the existing model provides conservative predictions for specimens with a ±80° fiber-reinforced polymer tube, overestimated predictions for specimens with a ±60° fiber-reinforced polymer tube, and close predictions for specimens with a ±45° fiber-reinforced polymer tube.
Zhi Zhou (1,2), Jiang Qian (2) and Wei Huang (3)
(1) School of Transportation, Wuhan University of Technology, Wuhan, China
(2) Disaster Reduction in Civil Engineering, Tongji University, Shanghai, China
(3) Advanced Materials Mechanics, School of Science, Wuhan University of Technology, Wuhan, China


ABSTRACT: This article investigates the shear strength of steel plate reinforced concrete shear wall under cyclic loads. A nonlinear three-dimensional finite element model in ABAQUS was developed and validated against published experimental results. Then, a parametric study was conducted to evaluate the effects of the parameters on the lateral capacity of composite shear wall, including shear span ratio, concrete strength, axial load ratio, steel plate ratio and transverse reinforcement ratio of the web. Furthermore, a modified formula of shear strength of composite shear wall was proposed. Regression analyses were used to obtain the contribution coefficients of different parts from 720 finite element models. Finally, the shear strengths of specimens from published tests were compared with design strengths calculated using the proposed formula, American Institute of Steel Construction Provisions and Chinese Code. It was found that the Chinese Code well predicts the shear strength of composite shear wall of a steel plate ratio of less than 5%, while unsafely predicting that of a higher steel plate ratio. The American Institute of Steel Construction Provisions predictions are quite conservative because the contribution of the reinforced concrete is neglected. The modified formula safely predicts the shear strength of composite shear wall.

Wenwen Chen (1) and Jihong Ye (1,2)
(1) School of Civil Engineering, Southeast University, Nanjing, China
(2) Environmental Impact and Structural Safety in Engineering, China University of Mining and Technology, Xuzhou, China


ABSTRACT: The conventional simplified model only restricts the bending buckling around the minor axis and overall torsional buckling, which is not suitable for external sandwiched cold-formed steel composite walls. Moreover, a solution to stud-track connections must be achieved in establishing the overall structure model. In this article, a simplified calculation model is proposed to accurately and efficiently reveal the fire performance of cold-formed steel composite walls. A tension spring is adopted to simulate the boundary condition that limits the axial thermal expansion of the studs at elevated temperature. Meanwhile, the simplified applications of the panel constraints and stud-track connections are also given in details. Finite element analysis using the developed simplified calculation model is conducted to simulate five full-scale cold-formed steel composite walls with different configurations. Comparisons between the finite element analysis and fire test results show an overall agreement on the failure modes, cold flange temperatures and lateral deflections at mid-height of the studs. These results demonstrate that the developed simplified calculation model is able to simulate the fire performance and predict the lateral deflection of the external sandwiched cold-formed steel composite walls accurately. Finally, the key factors affecting the lateral deflection of the studs are analysed.


ABSTRACT: This article presents test results of a recent study on the axial compressive behaviour of fibre-reinforced polymer–confined compound concrete–filled thin steel tubes. The usage of compound concrete, which is a mixture of fresh concrete and large pieces of recycled concrete lumps, can recycle waste concrete in a simple but effective way. Totally, three series of tests were conducted, with the parameters including the relative strength between fresh concrete and recycled concrete lumps, the volumetric percentage (i.e. mix ratio) of recycled concrete lumps, the diameter-to-thickness ratio of the steel tubes, and the thickness of the fibre-reinforced polymer jackets being investigated. The stress–strain curves of the steel tube and compound concrete
core were derived and the effects of different parameters were then examined and discussed. An existing stress-strain curve model of fibre-reinforced polymer–confined normal concrete-filled steel tubes was also found performing well in predicting the behaviour of fibre-reinforced polymer–confined compound concrete-filled steel tubes.

References listed at the end of the paper:

American Concrete Institute (ACI) (2008) ACI 318-08 Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary. Farmington Hills, MI: ACI.


ABSTRACT: Based on the energy method, this article presents a theoretical study on the elastic local buckling of steel plates in rectangular concrete-filled steel tubular columns with binding bars subjected to eccentric compression. The formulas for elastic local buckling strength of the steel plates are derived, assuming that the loaded edges are clamped and the unloaded edges of the steel plate are elastically restrained against rotation. Then, the experimental results are compared with these formulas, which exhibits good agreement. Subsequently, the formulas are used to study the elastic local buckling behavior of steel plates in rectangular concrete-filled steel tubular columns with binding bars under eccentric compression. It is found that the local buckling stress of steel plates in eccentrically loaded rectangular concrete-filled steel tubular columns with binding bars is significantly influenced by the stress gradient coefficient, width-to-thickness ratio, and the longitudinal spacing of binding bars. With the decrease of width-thickness ratios or the longitudinal spacing of binding bars or with the increase of the stress gradient coefficient, the local buckling stress increases. Furthermore, the influence of the longitudinal spacing of binding bar is more significant than the stress gradient coefficients. Finally, appropriate limitation for depth-to-thickness ratios (D/t), width-to-thickness ratios (B/t), and binding bar longitudinal spacing at various stress gradient coefficients (a) corresponding to different cross-sectional aspect ratios (D/B) are suggested for the design of rectangular concrete-filled steel tubular columns with binding bars under eccentric compression.

References listed at the end of the paper:

Abdalla, S, Abed, F, AlHamaydeh, M (2013) Behavior of CFSTs and CCFSTs under quasi-static axial compression. Journal of...


ABSTRACT: This article focuses on the lateral-torsional buckling resistance of girders with slender, class 4 cross-sections with a research aim to check the accuracy of the design resistance model of EN1993-1-1 and EN1993-1-5 on the coupled instability of lateral-torsional buckling and local plate buckling resistances. The current Eurocode-based design method considers in the effective cross-sectional resistance calculation that yield strength is reached in the extreme fibre of the cross-section, and the reduction factor ($\rho_p$) related to local plate buckling is calculated based on this assumption. However, if lateral-torsional buckling occurs, maximum stress in the web can be significantly smaller at the ultimate limit state which is not considered in the effective cross-sectional resistance calculation. On the other side, EN1993-1-1 proposes to consider the effective bending moment resistance in the relative slenderness calculation of lateral-torsional buckling, which is in contradiction with the general definition of the relative slenderness ratio ($\lambda_{LT}$), which should refer to the plastic resistance divided by the critical load of the structure. This article aims to check if the current Eurocode-based design rules need improvement and to check the effect of the above-mentioned specific issues on the calculated lateral-torsional buckling resistance. An extensive numerical research programme is executed to check and compare the lateral-torsional buckling resistance of class 3 (as reference) and class 4 cross-sections, and results are compared to Eurocode-based design models.

References listed at the end of the paper:

ANSYS (2016)
ANSYS® v17.2, Canonsburg, PA: ANSYS.


ABSTRACT: In this article, three hot-rolled steel combined short columns and a pure steel short column under eccentric load were tested. The failure modes and load–displacement curves of the specimens under eccentric load were reported. A finite element model was developed and validated against the experimental results, and good agreement was achieved in terms of failure modes, bearing capacity and load–displacement curves. Upon validation, a series of finite element models were employed for the parameter analysis over the parameter of concrete strength (30–120 MPa) and steel strength (235–420 MPa). The finite element parameters analysis results showed that the steel strength has limited effect on the reduction coefficient (1 +η) of the ultimate bearing capacity of specimens, whereas the reduction coefficient (1 +η) of the ultimate bearing capacity of specimens decreases gradually as concrete strength increases. Based on the finite element parameter analysis results, the N–M correlation curve and a simplified design method for the reduction coefficient (1 +η) of the ultimate bearing capacity of hot-rolled steel combined short columns under eccentric load are proposed. Good agreement is achieved between the design method and finite element analysis results, and the prediction of the design method is accurate and consistent.

References listed at the end of the paper:


Han, LH, Yang, YF (2007) Modern Concrete-Filled Steel Tube Structure Technology. Beijing, China: China Architecture & Building Press.


ABSTRACT: Due to the improvement of steel properties, many steel structures with attractive appearance emerge unceasingly. In this article, a new structure of steel octagon-web beam which has the similar appearance with honeycomb beam was presented. The mechanical characteristics of steel octagon-web beam under bending loads were analyzed theoretically. Based on the Vierendeel truss theory in deflection calculation of honeycomb beam, the deflection calculation method of steel octagon-web beam which was validated by finite element method was studied. Two parameters affecting deflection of steel octagon-web beam, such as opening type and expansion ratio, were analyzed. A scale model of steel octagon-web beam was manufactured in order to study bending behavior of the structure. The failure patterns of test specimen under four-point bending test are the buckling of deck and web. A nonlinear finite element model of test specimen whose results were compared with test was established by software ABAQUUS 2017. The stresses of slabs under ultimate load have reached yield stress, which shows steel octagon-web beam has good flexural performance.

References listed at the end of the paper:


ABSTRACT: The behaviour of axially loaded prestressed stayed columns is a commonly studied area. Despite the fact that load eccentricity in columns is commonplace in practice, the amount of investigation into these systems under eccentric loading is limited. This study employed finite element analysis to investigate the interactive post-buckling behaviour of prestressed stayed columns. Critical imperfection combination with respect to the load carrying capacity was established and a comparison of a planar and a three-dimensional model was carried out to investigate key differences in the models. In this work, it has been shown that the load carrying capacity of eccentrically loaded columns can be significantly reduced when buckling in interactive mode is observed. Furthermore, it was established that increase in eccentricity results in a decrease in load carrying capacity of columns for both planar and three-dimensional models. However, a major difference
between the models is the twisting effect exhibited in the three-dimensional model under out-of-plane eccentric loading. This work highlights the importance of carefully designing prestressed stayed columns’ connections to minimise loading eccentricity as it has been shown that the benefit of employing these systems over unstayed columns reduces with increasing load eccentricity.

References listed at the end of the paper:


References listed at the end of the paper:


ABSTRACT: Fiber-reinforced polymer composites have been widely used to design fiber-reinforced polymer–based confined concrete columns with potential benefits. However, it is critical to design a column with sufficient post-peak performance that can prevent its collapse at the rupture of the fiber-reinforced polymer tube. This article presents the experimental results on the prior and post peaks behavior of concrete-filled double-skin tubular columns with basalt fiber-reinforced polymer (BFRP)–punched-in outer steel and BFRP-circular inner steel (BFST-DSTC). Twenty-two specimens were tested under axial compression to investigate the effects of design parameters on the behavior of the BFST-DSTC. The outcomes reveal that the BFST-DSTC exhibits the best performance in terms of load capacity, confinement ratio, failure and damage mechanisms, and ductility in prior and post peaks. The inner fiber-reinforced polymer jacket delays the buckling of the inner tube. The punched-in patterns of the outer steel improve the confinement effectiveness of the fiber-reinforced polymer jacket. The BFST-DSTC displays a good post-peak performance with high-energy dissipation capacity that prevents the concerned structure from collapse after the fiber-reinforced polymer jacket rupture. Finally, a new confinement model is proposed to predict the ultimate point of the confined concrete.

References listed at the end of the paper:


ABSTRACT: Steel plate shear wall is one of the most effective dissipation systems which are commonly used in buildings. In order to improve the hysteretic behavior of shear panels, large perforation patterns may be applied, transforming the shear plate into a sort of grid systems, where plastic deformations are concentrated on specific internal link elements. This study investigates the behavior of grid systems loaded in shear where the internal links are created by cutting out internal parts, leaving rectangular tube–shaped link elements. The influence of internal link geometry on the cyclic performance of the systems is investigated experimentally. To this purpose, two specimens that varied in the width of links were fabricated and tested. The results indicate that any increase in the width of links leads to the growth of the ultimate strength, stiffness, and energy absorption capacity. Likewise, the stress distribution and fracture tendency of the tested specimens have been simulated by the finite element software (ABAQUS) and validated according to the experimental results. Based on finite element results, a suitable analytical formulation for the prediction of the shear strength at several shear deformation demands, considering the effect of thickness of the link, has been provided. Moreover, to improve the fracture tendency of the specimens, butterfly-shaped links, which varied in the middle length, were applied. The obtained results, which have been interpreted by considering the equivalent plastic strain value, prove that the shear panel behavior improves significantly when butterfly-shaped links are considered.

References listed at the end of the paper:


European Convention for Constructional Steelwork (ECCS) (1986) Recommended


ABSTRACT: Free vibration analysis of a single edge cracked multi-layered symmetric sandwich stepped Timoshenko beams, made of functionally graded materials, is studied using finite element method and linear elastic fracture mechanic theory. The cantilever functionally graded beam consists of 50 layers, assumed that the second stage of the beam (step part) is created by machining. Thus, providing the material continuity between the two beam stages. It is assumed that material properties vary continuously, along the thickness direction according to the exponential and power laws. A developed MATLAB code is used to find the natural frequencies of three types of the stepped beam, concluding a good agreement with the known data from the literature, supported also by ANSYS software in data verification. In the study, the effects of the crack location, crack depth, power law gradient index, different material distributions, different stepped length, different cross-sectional geometries on natural frequencies and mode shapes are analysed in detail.

References listed at the end of the paper:


Gayen, D, Chakraborty, D (2016) Variation of local flexibility coefficients of functionally graded cracked shaft. Procedia


Nandwana, BP, Maiti, SK (1997) Detection of the location and size of a crack in stepped cantilever beams based on measurements of


Advances in Structural Engineering, Vol. 23, No. 16, pp 3415-3428, December 2020,

More papers published in the journal, Archive of Applied Mechanics (2019 and on)

Google the string: “Archive of Applied Mechanics”, then click on the entry: “Archive of Applied Mechanics – Springer – Springer Link”; then click on “Browse Volumes & Issues”.


ABSTRACT: In this study, the free vibration analysis of two joined laminated conical shells is investigated. Five equilibrium equations for each conical shell have been derived in a particular coordinate system; using Hamilton’s principle and first-order shear deformation theorem. The analytical solutions are obtained in the form of power series based on separation of variables method. The boundary conditions at both ends of the joined shells and the continuity conditions, at the conical shells contact, are extracted from energy formulations. As a result, the non-dimensional natural frequencies are studied for cross-ply laminated shells. The effects of semi-vertex angle, circumferential modes, number of layers, thickness, length of shells and different boundary conditions on non-dimensional frequencies are considered. As a comparing result, the non-dimensional frequencies and mode shapes are extracted using finite element method (FEM). The results are compared and verified with the previous available results in other researches. The results reveal a good agreement among analytical solutions, FEM and other results. The output of this paper can be used for analyzing cylindrical–conical shells in addition to joined conical shells.

References listed at the end of the paper:
Xuejuan Niu, Wenfeng Pan and Yang Li, “MCT failure analysis of variable stiffness plate with a central hole”, Archive of Applied Mechanics, Vol. 88, No. 12, pp 2283-2292, December 2018

ABSTRACT: Steered-fiber placement has been a very interesting approach to enhance the mechanical properties of fiber-reinforced composite structures, especially with holes. Based on flow field theory and the Levenberg–Marquardt algorithm, the fiber orientations on a variable stiffness (VS) ply in a composite plate with a central hole are represented and optimized. The fiber orientations on the VS plies are aligned with those of the maximum principal stress as much as possible. By transforming the complex planning problem of curvilinear trajectory into the function design of a scalar field, this method leads to better efficiency and general optimization. Comparative failure analysis based on the MCT criterion shows that the VS model has a 197% higher capability for initial damage and a 97% higher capability for ultimate load. The contour plots of the failure state and the load–displacement plots also certify the validity and the feasibilities of the proposed VS planning method.

References listed at the end of the paper:


ABSTRACT: A new one-dimensional finite element model is developed to investigate the nonlinear elastic response of cracked beams. Classical and continuum-based approaches are adopted into four different nonlinear theories to derive relationships which characterize the influence of initial cracks on the bending behavior of beams subjected to quasi-static loading. A linear rotational spring is used to simulate the crack whose stiffness factor is considered in terms of the geometric parameters of the crack. A cracked element is subdivided into two sub-elements, and the conditions of continuity are maintained in the crack position. By implementing a novel technique in this element, the tangent and secant stiffness matrices and the internal force vector are originally enriched due to the crack properties. Some case studies are performed to compare the rate of convergence, the accuracy of the theories, the difference in results obtained from linear and nonlinear analyses and the effects of the depth and the position of single and double cracks on the deflection pattern.

References listed at the end of the paper:
Also a com

References listed at the end of the paper:


Venkatachalam Gopalan, Vimalanand Suthenthiraveerappa and Vignesh Pragasam (First author is from: School of Mechanical and Building Sciences, Vellore Institute of Technology, Chennai, India), “Experimental and numerical investigation on the dynamic characteristics of thick laminated plant fiber-reinforced polymer composite plates”, Archive of Applied Mechanics, Vol. 89, No. 2, pp 363-384, February 2019

ABSTRACT: Although considerable attention has been devoted to the experimental research works of plant fiber-reinforced composites, theoretical determination of their structural characteristics is also much needed one in their evolution. But it is still considered as a difficult process due to the several factors such as short and discontinuous fiber form, plant fiber’s intrinsic characteristics, fiber anisotropy and porosity. In this study, vibration characteristics of woven jute/epoxy and woven aloe/epoxy laminated composite plate structures are investigated theoretically and experimentally. The elastic constants of the woven jute/epoxy and woven aloe/epoxy laminated composites are obtained through experimental testing. The governing differential equations of motion for the uniform woven jute/epoxy and woven aloe/epoxy laminated thick composite plates are carried out using the p-version finite element method based on higher-order shear deformation theory. The effectiveness of the developed finite element formulations is demonstrated by comparing the natural frequencies obtained using the present finite element method with those obtained from the experimental measurements. Also a comparative study is carried out between the results of h-version FEM and p-version FEM to check their
accuracies and efficiencies. The effects of aspect ratio and angle of fiber orientation under various end conditions on the free vibration responses of the woven jute/epoxy laminated composite plate are also investigated. The forced vibration response of the woven jute/epoxy laminated composite plate under the harmonic force excitation is carried out under various end conditions.

References listed at the end of the paper:
ABSTRACT: In this paper, nonlinear vibration of an Euler–Bernoulli beam excited by a harmonic random axial force is studied. The equation of motion contains a term with time-varying coefficient which is solved by modified Lindstedt–Poincaré method. Then the effect of the random axial force on the response is investigated using the obtained approximate solution. Two cases are considered in random analysis, namely random amplitude and random phase of the axial force. For both cases, the ensemble average, mean square value and the autocorrelation function are obtained. The results have indicated that for each case the mean and the mean square value are a function of time which means that the lateral displacement of the beam is a nonstationary process. A numerical study is also conducted based on the iteration of numerical solution in order to verify the derived analytical formulae. It is shown that a good agreement is seen between the analytical and numerical solution statistical properties.

References listed at the end of the paper:


ABSTRACT: This paper evaluates the longitudinal wave speed through a plate in which its two opposing sides are elastically restrained in the width direction, taking into consideration the material auxeticity and strain as well as changes to the density and cross-sectional area. Apart from the known role of Young’s modulus and density, the present results reveal that the wave speed can be enhanced by increasing the width elastic restraint. In the case of high elastic restraint, the speed of both tensile and compressive waves can be minimized by selecting plate materials with Poisson’s ratio of low magnitude. In the case of low elastic restraint, the speed of tensile and compressive waves can be greatly reduced by selecting plate materials with large positive and large negative Poisson’s ratio, respectively. For the special case of negligible strain, the longitudinal wave speed reduces to the elementary wave speed in prismatic rods and in plates of infinite width when the width elastic restraint stiffness approaches zero and infinity, respectively. The obtained results not only allow more parameters for adjusting the longitudinal waves in plates, but also identify the differing methods of effectively controlling the wave speed between tensile and compressive waves when the strain magnitude is non-negligible.

References listed at the end of the paper:
References listed at the end of the paper:

ABSTRACT: The present paper deals with a new holistic closed-form analytical model for the local buckling load of thin-walled composite beams with I-, Z-, C-, L- and T-cross sections under axial compressive load. The beam is simply supported at both ends (Euler case II), and the plate behaviour of web and flanges is described by the Classical Laminated Plate Theory. Furthermore, symmetric and orthotropic laminates are considered. In previous investigations on composite beams under compression, the web and flange plates are considered as separate composite plates. The present analysis is performed using the Ritz method in which an approach for the entire cross section is realized. The individual webs and flanges of the beam are assembled by suitable continuity conditions into one system. In order to achieve that, new displacement shape functions for web and flange that fulfil all boundary conditions have been developed. The present closed-form analytical method enables the explicit representation of the buckling load for the entire composite beam under axial compression. The comparison between the present approach and comparative finite element simulations shows a very satisfactory agreement. The present method is ideal for pre-designing such structures, highly efficient in terms of computational effort and very suitable for practical engineering work.

References listed at the end of the paper:


ABSTRACT: The electromechanical behavior of an angle-ply laminated plate in cylindrical bending with surface-bonded piezoelectric layers is investigated. The interlaminar bonding of this smart laminate is described by a Kelvin–Voigt viscoelastic model. Besides, a matrix reduction method is employed to construct the transfer relations between the piezoelectric layer and the elastic strip. Based on the space-state approach, a state differential equation of the interfacial sliding displacements with respect to time variable is derived, from which the exact solutions are obtained in the time domain. Comparison with the existing techniques validates the high
efficiency and excellent accuracy of the present analysis. Furthermore, the numerical results indicate that the intelligent laminate may lose partly or completely the load-bearing capacity and the function of sensor/actuators with time elapsing because of the viscoelastic interfaces.

References listed at the end of the paper:


ABSTRACT: This study introduces an accurate and effective mesh-free approximation based on the radial point interpolation method (RPIM) to predict the post-buckling responses of FGM plates in mechanical edge compression. In the RPIM, a new radial basis function is presented in a compactly supported form to build the shape functions without any fitting parameters. The equilibrium and governing equations for the plate are derived by using the higher-order shear deformation theory in which a new hybrid type transverse shear function is incorporated in order to better represent the displacement fields. A von Kármán type nonlinear equation which accounts for both the geometric nonlinearity and the initial geometric imperfection is constructed. A solution procedure based on the total Lagrangian formulation to trace the post-buckling path, which utilizes the modified Newton–Raphson method, is designed. The numerical results illustrate the accuracy of the proposed meshless method for predicting the post-buckling behavior of FGM plates.

References listed at the end of the paper:

ABSTRACT: A unified solution procedure applicable for analyzing the free transverse vibration of both rectangular and annular sectorial plates is presented in this study. For the annular sectorial plate, the basic theory is simplified by a variable transformation in the radial direction. The analogies of coordinate system, geometry and potential energy between the two different shapes are drawn and then unified in one framework by introducing the shape parameter. A generalized solving procedure for the two shapes becomes feasible under the unified framework. The solution adopts the spectro-geometric form that has the advantage of describing the geometry of structure by mathematical or design parameters. The assumed displacement field and its derivatives are continuous and smooth in the entire domain, thereby accelerating the convergence. In this study, the admissible functions are formulated in simple trigonometric forms of the mass and stiffness matrices for both rectangular and annular sectorial plates.

References listed at the end of the paper:


ABSTRACT: This article is intended to present an overview of various mechanical analyses of rectangular nanobeams and single-, double-, and multi-walled (SW-, DW-, and MW-) carbon nanotubes (CNTs) with combinations of simply supported, free, and clamped edge conditions embedded or non-embedded in an elastic medium, including bending, free vibration, buckling, coupled thermo-elastic and hygro-thermo-elastic, dynamic instability, wave propagation, geometric nonlinear bending, and large amplitude vibration analyses. This review introduces the development of various nonlocal beam and shell theories incorporating Eringen’s nonlocal elasticity theory and the application of strong- and weak-form-based formulations to the current issue. Based on the principle of virtual displacements and Reissner’s mixed variational theorem, the corresponding strongand weak-form formulations of the local Timoshenko beam theory are reformulated for the free vibration analysis of rectangular nanobeams and SW-, DW-, and MW-CNTs, and presented for illustrative purposes. A comparative study of the results obtained using assorted nonlocal beam and shell theories in combination with the analytical and numerical methods is carried out.

References listed at the end of the paper:


·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·

·


ABSTRACT: A first endeavor is made in this paper to explore new analytic buckling solutions of moderately thick rectangular plates by a straightforward double finite integral transform method, with focus on typical non-Lévy-type fully clamped plates that are not easy to solve in a rigorous way by the other analytic methods. Solving the governing higher-order partial differential equations with prescribed boundary conditions is elegantly reduced to processing four sets of simultaneous linear equations, the existence of nonzero solutions of which determines the buckling loads and associated mode shapes. Both numerical and graphical results confirm the validity and accuracy of the developed method and solutions by favorable comparison with the literature and finite element analysis. The succinct but effective technique presented in this study can provide an easy-to-implement theoretical tool to seek more analytic solutions of complex boundary value problems.

References listed at the end of the paper:


ABSTRACT: We discuss the role of the principle of virtual work, of the objectivity and of the energy balance in the formulation of planar static rod theories, in a large deformations framework and consider the effects of transverse shear. According to these principles, we also discuss the differences of Haringx approach to equilibrium and bucking over Engesser approach, as well as the advantages of choosing the curvature strain measure as the derivative of the rotation of the cross section with respect to the reference, rather than current, arc length.

References listed at the end of the paper:


ABSTRACT: The free vibration of a flat plate with a side crack of Mode I fracture, reinforced by one stiffener parallel to the edges of the plate, is studied in this paper. Based on the classical theories of plate and beam, the plate and its stiffener are modeled separately and joined by implementing the condition for compatibility of displacement. To describe the singularity in stress at the tip of the crack and the discontinuity in displacement across the crack, a set of functions are introduced and incorporated into the admissible functions of the displacement. The effects of location, length and orientation of side cracks on the vibration frequencies and mode shapes of the stiffened plate are demonstrated through the Ritz method with the special admissible functions. The natural frequencies of the intact and cracked stiffened plates with different stiffener locations are analyzed with two typical boundary conditions, i.e., SSMS and FSFS. The accuracy of the present solutions is verified through a convergence test. The solutions are compared with the finite element results as well.

References listed at the end of the paper:


This paper investigates the vibration characteristics of a circular ring with an arbitrary number of concentrated elements based on the Hamilton principle. The shear and inertia effects are introduced to the variational functional of system kinetic and potential energy by adopting the generalized shell theory. The concentrated elements are treated as the concentrated masses with elastic boundary condition. The system vibration displacements are analytically expanded in the form of Fourier series and substituted into the variational functional to obtain the equation of motion. Computed results are compared with those solutions obtained from the finite element program ANSYS to validate the accuracy of the present method. Effects of the asymmetrical concentrated elements on the convergence of circumferential wavenumbers are discussed. Moreover, the coupling characteristics of different circumferential wavenumbers caused by the asymmetrical or symmetrical concentrated elements and their influences on the vibration response characteristics of the system under simple harmonic excitations are studied. References listed at the end of the paper:


ABSTRACT: In this paper, the free vibration of laminated composited cylindrical shells with two kinds of non-continuous supported boundary condition are investigated. The artificial springs are used to simulate the arcs
static and kinematic matrix operator equations are formulated in the case of shells of revolution, emphasizing conjectures proposed by, among others, French, German, and Russian authors are discussed. Moreover, results show that the method can accurately deal with the free vibration of laminated shells with arbitrary non-continuous boundary and arbitrary lamination schemes.

References listed at the end of the paper:

how these operators are one the adjoint of the other. In this way, any possible inaccuracy provided by the previous approaches can be overcome.

References listed at the end of the paper:

1. Cauchy, A.: Sur l’équilibre et le movement d’une lame solide, Exercices de Mathématique, p. 3 (1828)
33. Novozhilov, V.V.: Teoriya Tonkich Obolochek (Theory of Thin Shells, in russian). Leningrad (1947)
34. Novozhilov, V.V.: The Theory of Thin Shells. Noordhoff, Groningen (1959)
ABSTRACT: In this paper, free vibration of a metal foam core sandwich (MFCS) beam embedded in Winkler–Pasternak elastic foundation is studied using the Chebyshev collocation method (CCM). This method can achieve high precision within the range allowed by the effective number of bits of computers. Three foam distribution types along the thickness direction are considered for the core. The Timoshenko beam theory is adopted and Hamilton’s principle is utilized to derive the boundary conditions and governing equations of the model. The numerical results show that natural frequencies of the sandwich beam initially increase and then decrease with the rise in thickness of metal foam core. By arranging the foam distribution in the core, natural frequencies of the sandwich beam can be significantly changed. Moreover, natural frequencies of the uniform foam distribution beam are insensitive to the foam coefficient. For the beam with non-uniform foam distribution, however, the natural frequencies increase or decrease with the foam coefficient, depending closely on the foam type. In addition, the present method is validated by comparing with the published ones for special cases.

References listed at the end of the paper:

41. Winkler, E.: Die Lehre von Elastizität und Festigkeit. H. Domen, Prague (1867)
ABSTRACT: Membranes are widely applied in the large-span buildings and spatial deployable structures. They are prone to wrinkle under compression due to their small bending stiffness. The wrinkling deformation may affect the surface precision of a membrane structure and its static and dynamic behaviors. Research on the wrinkling behavior of a membrane and its variation with the wrinkle-influencing factors would shed light on the effective control over the wrinkling deformation. In this paper, a rectangular membrane under shear is numerically studied based on the stability theory of plates and shells to explore the wrinkle-influencing factors, such as boundary conditions, pre-stress, thickness and material constants, and their effects on the characteristic parameters of wrinkles. Besides, some of the results are also compared with those derived from the membrane element previously proposed by the authors for further exploration. Some new and interesting findings are obtained.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: In this paper, three-dimensional elastic deformation of rectangular sandwich panels with functionally graded transversely isotropic core subjected to transverse loading is investigated. An exponential variation of Young’s and shear moduli through the thickness is assumed. The approach uses displacement potential functions for transversely isotropic graded media and a three-dimensional elasticity solution for a transversely isotropic graded plate developed by the authors. The effects of transverse shear modulus, loading localisation, panel thickness and anisotropy on the stresses and displacements in the panel are examined and discussed.

References listed at the end of the paper:

This paper investigates the buckling of isotropic plates with circular cutout subjected to non-uniform in-plane loading. The buckling load is calculated in two steps. In the first step, the prebuckling stress distribution is computed. The existence of cutout causes the solution of stress distribution to be nontrivial. In this paper, a novel analytical method is presented for calculating the stress distribution. This method is based on expansion of the stress function in polar coordinates and using a boundary integral to satisfy the boundary conditions at plate edges. In the second step, the obtained stress distribution is used to calculate the buckling load from the Ritz method. In this method, The displacement field is defined according to the first order shear deformation theory and the characteristic beam functions are used for approximation. The effect of cutout size, plate’s aspect ratio, different uniaxial and biaxial loading profiles, i.e. constant, parabolic and cosine loading and different boundary conditions on the buckling load is studied.

References listed at the end of the paper:

Van-Hieu Dang (1), Dong-Anh Nguyen (2), Minh-Quy Le (3) and Quang-Hai Ninh (4)
(1) Department of Mechanics, Thai Nguyen University of Technology, Thai Nguyen City, Vietnam
(2) Institute of Mechanics, Hanoi, Vietnam
(3) Department of Mechanics of Materials and Structures, School of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam
(4) Ha Noi Architectural University, Hanoi, Vietnam


ABSTRACT: We investigate the nonlinear vibration of microbeams based on the nonlinear elastic foundation through the modified couple stress theory. The equivalent linearization method with a weighted averaging is used to solve approximately the ordinary differential equation that describes the equation of motion of the microbeam. The effects of length scale parameter, the flexural rigidity ratio, the slenderness ratio, the Winkler parameter, the Pasternak parameter and the nonlinear foundation parameter on the nonlinear vibration of the microbeam are studied and discussed.

References listed at the end of the paper:
ABSTRACT: In the present paper, the optimization problem of the dynamic vibration absorbers (DVAs) for suppressing vibrations in thin plates within the wide frequency band is investigated. It is considered that the plate has simply supported edges and is subjected to a concentrated harmonic force. The vibration suppression is accomplished by the implementation of multiple mass–spring absorbers in order to minimize the plate deflection at the natural frequencies of the plate without absorbers. The governing equations of the plate equipped with DVAs for both isotropic and FG plates are derived and solved numerically and analytically. The formulation of the problem is capable of optimizing the $L^2$ norm of the plate deflection at the wide frequency band with respect to mass, stiffness and position of each absorber attachment point. In this study, the possibility of simultaneous absorption of one or multiple natural frequencies of the plate without any absorbers is also studied. Some numerical results are also presented.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: This paper studies the analytical solution for the vibration of simply supported beams with arbitrarily and continuously varying thickness based on the two-dimensional elasticity theory. The general expression of stress function, which exactly satisfies the governing differential equations and the boundary conditions, is derived. Frequency equation governing the free vibration of beams with variable thickness can be obtained by using the Fourier sinusoidal series expansion on the upper and lower surfaces of the beam. The present solution method ensures a rapid convergence and meets the need of high accuracy in modern precise instruments. Several examples are provided to show the application of the proposed solution method which can be used to assess the validity of various approximate solutions and numerical methods for the beams with arbitrarily and continuously varying thickness.
Onur Şahin, Barış Erbaş, Julius Kaplunov and Tomaž Savšek (First author is from: Department of Mathematics, Giresun University, Giresun, Turkey), “The lowest vibration modes of an elastic beam composed of alternating stiff and soft components”, Archive of Applied Mechanics, Vol. 90, No. 2, pp 339-352, February 2020. ABSTRACT: Harmonic vibrations of a strongly inhomogeneous elastic beam with piecewise uniform stiffnesses and densities are considered. The focus is on the lowest eigenmodes, which are often most harmful and unwanted. They are evaluated by perturbing the limiting rigid body translations and rotations of stiff beam components. The developed methodology is adapted for two particular configurations of a three-span beam. The derived approximate formulae are tested by comparison with the exact solution of a symmetric beam with two stiff outer components and free ends.

References listed at the end of the paper:


ABSTRACT: This paper aims to obtain the analytical free vibration solution of an orthotropic rectangular thin plate using the finite integral transformation. Due to the mathematical difficulty of complex boundary value problems, it is very hard to solve the title problem with common analytical methods. By imposing the integral transformation, the high-order partial differential equation with specified boundary conditions is converted into linear algebraic equation and the exact solutions with high precision and fast convergence are obtained elegantly. The main advantage of the proposed method is that it is simple and general, and it does not need to pre-determine the deflection function, which makes the solution procedure more reasonable. The method has a wide range of applications and can deal with other elastic plate problems, such as buckling and bending. The present results are validated by comparison with the existing analytical solutions that showed satisfactory agreement. The new analytical solution obtained can be used as a benchmark for validating other numerical and approximate methods.

References listed at the end of the paper:

functions in the thickness direction. In several numerical examples, the proposed model is verified for the

dimensional steady

extended finite element method. The temperature field in the thickness direction is obtained by using a one

respectively, while the transverse crack is simulated in the in


– 919 (2017)


https://doi.org/10.1115/14003700


ABSTRACT: A steady-state thermomechanical analysis model is established for the composite laminated plate with transverse cracks and delaminations based on the extended layerwise method. The one-dimensional weak and strong discontinuous functions are employed to simulate the interlaminar interfaces and the delaminations, respectively, while the transverse crack is simulated in the in-plane displacement fields by using the standard extended finite element method. The temperature field in the thickness direction is obtained by using a one-dimensional steady-state heat conduction equation and constructed with the linear Lagrange interpolation functions in the thickness direction. In several numerical examples, the proposed model is verified for the
laminated plates with/without transverse crack and/or delaminations against the classic laminated plate theory, first-order shear deformation theory, Reddy’s layerwise theory or three-dimensional elastic model.

References listed at the end of the paper:

Hai Qian, Ding Zhou, Jie Yin and Yuexiang Qiu, “A theoretical investigation on the thermal response of laminated cylindrical panel”, Archive of Applied Mechanics, Vol. 90, No. 3, pp 475-493, March 2020,

ABSTRACT: This paper presents a theoretical investigation on the temperature and thermal stress distributions developed in simply supported laminated open cylindrical panels subjected to thermal load. Cylindrical panels were divided into several thin layers, where the radial variable r in heat conduction equation and elasticity equations was approximately replaced by the center coordinate of each layer. The analytical expressions in terms of temperature, displacements and stresses can be then deduced in a thin layer. Transfer matrix method was used to recursively generate the relations of temperature, displacements and stresses between outermost and innermost surface for the laminated panel. The panel surface condition was thereafter used to determine the coefficients in the solutions. These coefficients were substituted in solutions for each thin layer to obtain the distributions of temperature, displacements and stresses in the panel. The number of the terms of series was used to check the solution convergence. The validity and feasibility of the proposed method were verified by comparing the theoretical results with the numerical results from the finite element method. The effects of surface temperatures, panel thickness, number of laminated layers and material properties were detailed and investigated with respect to the temperature, displacement and stresses distributions in the panel.

References listed at the end of the paper:
ABSTRACT: Introducing the fractional A-derivative, with the corresponding A-fractional spaces, the fractional beam bending problem is presented. In fact, non-local derivatives govern the beam bending problem that accounts for the interaction of microcracks or materials non-homogeneities, such as composite materials or materials with fractal geometries. The proposed theory is implemented to the fractional bending deformation of a simply supported beam and a cantilever beam under continuously distributed loading.

References listed at the end of the paper:

ABSTRACT: An efficient procedure based on the semi-analytical finite strip method with invariant matrices is developed and applied to analyze the initial post-buckling of thin-walled members. Nonlinear strain–displacement equations are introduced in the manner of the von Karman assumption for the classical thin plate theory, and the formulations of the finite strip methods are deduced from the principle of the minimum potential energy. In order to improve the computational efficiency, an analytical integral of the stiffness matrix is transformed into matrix multiple calculation with introducing invariant matrices which can be integrated in advance only once. Three commonly employed benchmark problems are tested with proposed method and other state-of-the-art methods. The corresponding comparison results show that: (1) this finite strip method is proved to be a feasible and accurate tool; (2) compared with the calculation process of the conventional finite strip methods, the proposed procedure is much more efficient since it requires the integration of the stiffness matrix only once no matter how many iterations are needed; and (3) the advantage of time-saving is greatly remarkable as the number of iterations increases.

References listed at the end of the paper:


Pusong Ma, Bin He, Yuan Fang, Yanmei Jiao and Haonian Qi (Department of Engineering Mechanics, Nanjing Tech University, Nanjing, Jiangsu, China), “An efficient finite strip procedure for initial post-buckling analysis of thin-walled members”, Archive of Applied Mechanics, Vol. 90, No. 3, pp 585-601, March 2020,

ABSTRACT: In this paper, a boundary node method is presented to study wave propagation in laminated composite plates. The Zig-Zag theory of Cho and Parmerter is used for deriving the governing equations of laminated plates. To the best of the authors’ knowledge, this study is the first one employing the theory in non-stationary dynamic plate problems addressing wave propagation issues. For this theory, there is no information about the Green’s functions and thus the presented method can be considered as an alternative to the boundary integral method. With the use of exponential basis functions (EBFs), the response of the structure is first found in the frequency domain and finally the time-domain response is obtained using inverse Fourier transformation. The EBFs are found so that they satisfy the governing equations in the frequency domain. For the first time, in this paper, we shall present explicit relations for the EBFs in the frequency domain for Cho and Parmerter’s Zig-Zag theory. The coefficients of the EBFs are found through the collocation of the boundary conditions. The dynamic analysis of some composite laminated plates is presented, and the results are compared to those obtained from the dynamic analysis of two-/three-dimensional finite element method (FEM). We shall discuss the capabilities and limitations of the theory and the solution method. The capability of the method, in the analysis of problems excited by high-frequency loads, is shown in the solution of wave propagation problems for which the FEM needs excessive number of elements and thus it is practically impossible to be applied.

References listed at the end of the paper:

A. Czekanski and V. V. Zozulya (Department of Mechanical Engineering, Lassonde School of Engineering, York University, Toronto, M3J 1P3, Canada), “Dynamics of vibrating beams using first-order theory based on Legendre polynomial expansion”, Archive of Applied Mechanics, Vol. 90, No. 4, pp 789-814, April 2020, ABSTRACT: First-order models are used in the analysis of the tension–compression and transverse bending modes of beam vibration. The equation of motion for each mode and the expressions for boundary conditions are obtained using the generalized variational principle. Systems of partial differential equations for the longitudinal and bending modes of vibrating beams are reduced to a single fourth-order equation, and frequency equations are obtained. The problem of free and forced vibrations of beams that are simply supported at both ends is presented. An analysis and comparison with well-known theories is performed using computer algebra system Mathematica.

References listed at the end of the paper:
In this work, a model is presented for nonlinear static bending of single circular nanoplates with cubic material anisotropy, "Nonlinear static bending of single-crystalline circular nanoplates with cubic material anisotropy", Archive of Applied Mechanics, Vol. 90, No. 4, pp 847-868, April 2020.

ABSTRACT: In this work, a model is presented for nonlinear static bending of single circular nanoplates with cubic material anisotropy. The material anisotropy is modeled based on Zener ratio for which some new functions are presented to get closer formulations. The Ritz and Galerkin weighted residual methods are used to solve the derived nonlinear differential equation using different deflection surfaces defining two integral functions for material anisotropy in polar coordinate. The results show that the deflection surface remains approximately axisymmetric even at extreme material anisotropy levels similar to orthotropic materials. This is verified by FEM too. The comprehensive results are presented and discussed for the mostly used materials at MEMS/NEMS technology including Ag, Au, Al, Si, Ni, Mo, Cu and W single-crystalline nanoplates. It is observed that the size scale effects related to material surface stresses are greater for BCC nanoplates in comparison with FCC ones. Moreover, the Poisson’s ratio in [100] direction plays an essential role in the...
problem which is evaluated carefully. Finally, the effective Young’s modulus of the nanoplasts with 10–80 nm of thickness is compared by the experiments for Ag nanowires using a correction factor due to lack of direct experiments for nanoplasts.

References at the end of the paper:

ABSTRACT: This work presents an analytical approach to investigate the mechanical buckling of functionally graded material (FGM) thin conical panels surrounded by Winkler–Pasternak foundation and exposed to thermal environments. The material properties of FGMs are assumed to be temperature-dependent and graded only in the thickness direction according to the power-law, sigmoid and the exponential distribution of volume fraction. Eight well-known types of micromechanical models, namely Voigt, Reuss, Mori–Tanaka, Hashin–Shtrikman, modified Wakashima–Tsukamoto, Halpin–Tsai, Tamura and LRVE estimations, are studied to determine the effective two-phase FGM material properties as a function of the particles’ volume fraction considering thermal effects. Further, it is been supposed that the FG conical panel is heated uniformly, linearly and nonlinearly through the thickness. The nonlinear temperature distribution is obtained based on Fourier’s law by applying a semi-analytical procedure. The fundamental relations and the basic equations are derived by using Love’s thin shell theory. Finally, the numerical results are provided to reveal the effect of explicit micromechanical model, FGM profile, temperature distribution with various thermal boundary conditions, foundation conditions and the geometric parameters on the stability of these panels. Additionally, the critical buckling load is compared with that of FG truncated conical shells, cylindrical panels and the cylindrical shells.

References listed at the end of the paper:
67. Sofiyev, A.H.: The buckling of FGM truncated conical shells subjected to combined axial tension and hydrostatic pressure. Compos. Struct. 92, 488–498 (2010a)

ABSTRACT: This paper studies the bending behavior of two-dimensional functionally graded (TDFG) beam based on the Timoshenko beam theory, where the material properties of the beam vary both in the length and thickness directions. By introducing a new auxiliary function, we simplify the coupled governing equations for the deflection and rotation to a single governing equation. Moreover, all physical quantities of interest can be expressed in terms of the auxiliary function. Then, the exact analytical solutions for bending of TDFG Timoshenko beams are derived for various boundary conditions. The influence of gradient indexes on the deflection and stress distribution of TDFG Timoshenko beams is discussed subjected to different transverse loadings, including uniformly distributed loading, linearly distributed loading and concentrated external loading. The introduced approach is of benefit to exact bending analysis of TDFG beams by employing other beam theories.
References listed at the end of the paper:


ABSTRACT: Circular and annular elastic plates have wide applications as essential elements in various engineering structures and products demanding accurate analysis of their vibrations. At higher frequencies, the analysis of vibrations needs appropriate equations, as shown by the Mindlin plate equations for rectangular plates with tailored applications for the analysis of quartz crystal resonators. Naturally, there are equally strong demands for the equations and applications in circular and annular plates with the consideration of higher-order vibration modes. By following the procedure established by Mindlin based on displacement expansion in the thickness coordinate, a set of higher-order equations of vibrations of circular and annular plates are derived and truncated for comparisons with classical and first-order plate equations of circular plates. By utilizing these equations, coupled thickness-shear and flexural vibrations of circular and annular plates are analyzed for vibration frequencies and mode shapes.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: Bifurcation analysis of the nonlinear vibration of an inextensible cantilever beam is analyzed by using the nonlinear normal mode concept. Two flexural modes of the cantilever beam, one in each transverse plane is considered. Two degrees-of-freedom nonlinear model for the vibration in the transverse direction is obtained by the discretization of the governing equation using Galerkins method based on the eigenmodes in each direction. The method of multiple scales is used to derive two first-order nonlinear ordinary differential equations governing the modulation of the amplitude and the phase of the dominant mode for the case of 1:1 internal resonance. The bifurcation diagrams are computed considering the frequency of excitation and the magnitude of the excitation as the control parameters. The stability of the fixed point is determined by examining the eigenvalues of the Jacobian matrix. The results show that a saddle-node-type bifurcation of the solution can occur under certain parameter conditions.

References listed at the end of the paper:


ABSTRACT: This paper presents a theoretical investigation on the response of free vibration of functionally graded material (FGM) micro-plates with thermoelastic damping (TED). Continuous through thickness variation of the mechanical and thermal properties of the FGM plate is considered. By employing the simplified one-way coupled heat conduction equation and Kirchhoff’s plate theory, governing equations for the free vibration of the FGM micro-plates with thermoelastic coupling effect are established, in which stretching-bending coupling produced by the material inhomogeneity in the thickness direction is also considered. The heat conduction equation with variable coefficients is solved effectively by a layer-wise homogenization approach. Harmonic responses of the FGM micro-plates with complex frequency are obtained from the mathematical similarity between the eigenvalue problems of the FGM micro-plate with TED and that of the...
homogenous one without TED. The presented analytical solutions are suitable for evaluating TED in FGM micro-plates with arbitrary through-thickness material gradient, geometry and boundary conditions. Numerical results of TED for a ceramic-metal composite FGM micro-plate with power-law material gradient profile are illustrated to quantitatively show the effects of the material gradient index, the plate thickness, and the boundary conditions on the TED. The results indicate that by adjusting the physical and geometrical parameters of the FGM micro-plate, one can get the minimum of the TED which is even smaller than that of the pure ceramic resonator.

References listed at the end of the paper:

J. Joudaki (1) and M. Sedighi (2)

(1) Department of Mechanical Engineering, Arak University of Technology, P.O. Box. 38181-41167, Arak, Iran
(2) School of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran


ABSTRACT: Bending is a conventional manufacturing process of sheet forming. This process induces reasonable residual stress through the thickness. Prediction of this residual stress profile is more difficult in bilayer sheet bending due to different material properties and thickness of layers. In this article, the residual stress distribution will be derived analytically for a bilayer sheet. The induced stress profile due to loading and released stress after unloading has been derived by integration along with the thickness. Also, the neutral axis movement due to non-uniform plastic deformation has been involved in the solution. The stress distribution has been derived analytically for elastic–perfect plastic, elastic–linear plastic and elastic–power law hardening material behavior. The results obtained from the proposed equation are compared by a finite element analysis. The finite element analysis contains bending a bilayer sheet to a specified curvature radius by a three-roll bending process. Comparing the results of the analytical solution and finite element analysis shows good agreement. The location of the neutral axis and the maximum of residual stresses in the thickness have been predicted very well with the proposed equation.

References listed at the end of the paper:

ABSTRACT: A two-dimensional (2-D) elasticity solution is developed to investigate the time-dependent response of laminated functionally graded beam with viscoelastic interlayer. The elastic modulus in each functionally graded layer varies through the thickness following an exponential function, and the mechanical property of each layer is described by the exact 2-D elasticity equations. Viscoelastic property in the interlayer is simulated by the Maxwell–Wiechert model, in which the memory effect of it is neglected. By virtue of the recursive matrix method, the solution of stress and deformation can be obtained efficiently. The comparison studies indicate that the relative error of the Euler–Bernoulli solution is slight for slender beam with small gradient factor, but it significantly increases as the beam thickness or the gradient factor grows. The finite element solution is close to the present one with large number of sub-layers in FE modeling and small gradient factor of FG layer, while the error of FE solution increases as the number of sub-layers decrease or the gradient factor increases. Besides, the influences of material parameters upon the time-dependent behavior and the optimization for the stress and deformation in the beam are discussed in detail.

References listed at the end of the paper:


ABSTRACT: This paper presents a simple and effective analytical approach to investigate buckling behavior of carbon nanotube-reinforced composite (CNTRC) cylindrical shells and toroidal shell segments surrounded by elastic media and subjected to elevated temperature, lateral pressure and thermomechanical load. The properties of constituents are assumed to be temperature-dependent, and effective properties of CNTRC are estimated according to extended rule of mixture. Carbon nanotubes (CNTs) are reinforced into matrix material such in a way that their volume fraction is varied in the thickness direction according to functional rules. Formulations are established within the framework of first-order shear deformation theory taking surrounding elastic media and tangential elasticity of edges into consideration. The solutions of deflection and stress function are assumed to satisfy simply supported boundary conditions, and Galerkin method is used to derive expressions of buckling loads. In thermal buckling analysis, an iteration algorithm is employed to evaluate critical temperature. The effective temperature-dependent, and effective properties of CNTRC are estimated according to extended rule of mixture. Carbon nanotubes (CNTs) are reinforced into matrix material such in a way that their volume fraction is varied in the thickness direction according to functional rules. Formulations are established within the framework of first-order shear deformation theory taking surrounding elastic media and tangential elasticity of edges into consideration. The solutions of deflection and stress function are assumed to satisfy simply supported boundary conditions, and Galerkin method is used to derive expressions of buckling loads. In thermal buckling analysis, an iteration algorithm is employed to evaluate critical temperature. The effective temperature-dependent, and effective properties of CNTRC are estimated according to extended rule of mixture. Carbon nanotubes (CNTs) are reinforced into matrix material such in a way that their volume fraction is varied in the thickness direction according to functional rules. Formulations are established within the framework of first-order shear deformation theory taking surrounding elastic media and tangential elasticity of edges into consideration. The solutions of deflection and stress function are assumed to satisfy simply supported boundary conditions, and Galerkin method is used to derive expressions of buckling loads. In thermal buckling analysis, an iteration algorithm is employed to evaluate critical temperature. The effective temperature-dependent, and effective properties of CNTRC are estimated according to extended rule of mixture. Carbon nanotubes (CNTs) are reinforced into matrix material such in a way that their volume fraction is varied in the thickness direction according to functional rules. Formulations are established within the framework of first-order shear deformation theory taking surrounding elastic media and tangential elasticity of edges into consideration. The solutions of deflection and stress function are assumed to satisfy simply supported boundary conditions, and Galerkin method is used to derive expressions of buckling loads. In thermal buckling analysis, an iteration algorithm is employed to evaluate critical temperatures. The effects of CNT volume fraction and distribution patterns, degree of in-plane edge constraints, geometrical parameters, preexisting loads and surrounding elastic foundations on the critical loads of nanocomposite shells are analyzed through a variety of numerical examples.

References listed at the end of the paper:


Pham Thanh Hieu (1) and Hoang Van Tung (2)

(1) Faculty of Civil Engineering, University of Transport Technology, 54, Trieu Khuc Street, Thanh Xuan, Ha Noi, Viet Nam
(2) Faculty of Civil Engineering, Hanoi Architectural University, Km 10, Nguyen Trai Street, Thanh Xuan, Ha Noi, Viet Nam

60. Tung, H.V.: Nonlinear axisymmetric response of FGM shallow spherical shells with tangential edge constraints and resting on elastic foundations. Compos. Struct. 149, 231–238 (2016)
ABSTRACT: This article presents the free vibration frequencies of composite plates reinforced with single-walled carbon nanotubes by using a refined simplified two-variable nth-order theory. Four kinds of distribution of uniaxially aligned reinforcement material are presented. The most famous one is the uniform; in addition, three types of functionally graded distributions of carbon nanotubes in the through-thickness direction of the plates are investigated. The effective physical properties of composite media are given according to a refined rule of mixtures approach that contains the efficiency parameters. Exact closed-form formulation based on a refined simplified two-variable nth-order plate theory that can be adapted to the vibration of such plates is investigated. Accuracy of presented approach is validated by comparing its results with those given by other investigators.

References listed at the end of the paper:


ABSTRACT: In this paper, the buckling and free vibration of a Mindlin plate with a side crack are presented considering a uniaxial in-plane compressive or tensile load. The side crack is through the thickness of the plate. In the Ritz method, a series of corner functions are incorporated into the admissible functions which consist of the modified characteristic functions. With this treatment, one can describe the singularity in stress near the tip of the crack as well as the discontinuities in both displacement and bending rotations across the crack. The buckling loads and natural frequencies are solved through eigenvalue problems considering the existence of the crack. The effects of location, length and orientation of the crack on the buckling and free vibration of the loaded plate are demonstrated. The coupling effect of the crack and the in-plane load on the vibrational characteristics of the plate is analyzed with varying parameters. It is shown that the influences of the tensile and compressive preloads are enhanced by the crack, and the tensile preload can cause the low-order frequency to increase with the growing crack.

References listed at the end of the paper:


ABSTRACT: Nano-sized batteries composed of nanostructured electrode materials stand as one of the most promising candidates for next-generation rechargeable charging devices which have been widely used in the energy storage systems for advanced power applications. Buckling analysis of nanobeam under non-uniform concentration is significantly important for the design of nano-sized batteries under the rapid charging mode. In this work, such issue is investigated in the framework of the size-dependent mechanical–diffusion model, and size effect of mass transfer on buckling property is considered for the first time. By using the eigenvalue method, the critical buckling loads of Euler–Bernoulli nanobeam under the conditions of clamped–clamped, clamped–free, simply supported–simply supported and clamped–simply supported are analytically obtained. The derived results are compared with those of non-gradient nonlocal elastic stress theory, classical elasticity theory and classical theory of mass transfer. It is also found that the value of critical buckling load will be reduced if diffusive nonlocal parameter becomes larger.
References listed at the end of the paper:


References listed at the end of the paper:

ABSTRACT: A higher-order shear deformation theory is utilized to discuss the vibration of a laminated composite plate containing four magnetostriective layers based on Pasternak’s foundations in the current article. Hamilton’s principle is used to derive the governing dynamic equations related to the vibration of present smart structure under velocity feedback control with constant gain distributed. Navier’s approach is utilized to give a solution of simply supported laminated composite plates. Effects of all material properties, modes, thickness ratio, aspect ratio, lamimation schemes, magnitude of the feedback parameter, the elastic foundations parameters and the thickness, location and number of magnetostriective layers, on the vibration damping characteristics of the system are investigated and extensively discussed. Findings of the damping coefficients, damped natural frequency, dependent resonant frequency and flexural sensitivity of atomic force microscope microcantilevers based on the modified strain gradient theory. Int. J. Optomech. 9(2), 111–130 (2015)

References:


ABSTRACT: The purpose of this paper is to provide a high-order finite element method (FEM) formulation of nonlocal nonlinear nonlocal graded Timoshenko based on the weak form quadrature element method (WQEM). This formulation offers the advantages and flexibility of the FEM without its limiting low-order accuracy. The nanobeam theory accounts for the von Kármán geometric nonlinearity in addition to Eringen’s nonlocal constitutive models. For the sake of generality, a nonlinear foundation is included in the formulation. The proposed formulation generates high-order derivative terms that cannot be accounted for using regular first- or second-order interpolation functions. Hamilton’s principle is used to derive the variational statement which is discretized using WQEM. The results of a WQEM free vibration study are assessed using data obtained from a similar problem solved by the differential quadrature method (DQM). The study shows that WQEM can offer the same accuracy as DQM with a reduced computational cost. Currently the literature describes a small number of high-order numerical forced vibration problems, the majority of which are limited to DQM. To obtain forced vibration solutions using WQEM, the authors propose two different methods to obtain frequency response curves. The obtained results indicate that the frequency response curves generated by either method closely match their DQM counterparts obtained from the literature, and this is despite the low mesh density used for the WQEM systems.

References listed at the end of the paper:
ABSTRACT: Free vibration response of a joined shell system including cylindrical and spherical shells is analyzed in this research. It is assumed that the system of joined shell is made from a functionally graded material (FGM). Properties of the shells are assumed to be graded through the thickness. Both shells are unified in thickness. To capture the effects of through-the-thickness shear deformations and rotary inertias, first-order shear deformation theory of shells is used. The Donnell type of kinematic assumptions is adopted to establish the general equations of motion and the associated boundary and continuity conditions with the aid of Hamilton’s principle. The resulting system of equations is discretized using the semi-analytical generalized differential quadrature method. Considering the clamped and free boundary conditions for the end of the cylindrical shell and intersection continuity conditions, an eigenvalue problem is established to examine the vibration frequencies of the joined shell. After proving the efficiency and validity of the present method for the
case of thin isotropic homogeneous joined shells, some parametric studies are carried out for the system of combined moderately thick cylindrical–spherical shell system. Novel results are provided for the case of FGM joined shells to explore the influence of power-law index and geometric properties.

References listed at the end of the paper:


ABSTRACT: We obtain here a new fundamental solution for the harmonic vibration of asymmetric, laminated, anisotropic plates. The fundamental solution is derived via the Fourier transform and its final form is given in terms of definite integrals, which are evaluated numerically. Moreover, we present some of the higher order derivatives of the solution and their explicit spatial singularities, which are necessary for a boundary element method implementation.

References listed at the end of the paper:


ABSTRACT: In this paper, the localized method of approximate particular solutions using polynomial basis functions is proposed to solve plate bending problems with complex domains. The closed-form particular solutions of fourth-order differential equations can be reduced to the linear combination of the particular solutions of Helmholtz and modified Helmholtz equations. To alleviate the difficulty of solving overdetermined fourth-order plate bending problems using the localized collocation method, additional ghost points outside the computational domain are introduced to improve the stability and accuracy. Three examples are illustrated to validate the feasibility of the proposed localized MAPS.

References listed at the end of the paper:


ABSTRACT: Based on the Hamilton’s principle, a nonlinear mathematical model of the cantilever-type piezoelectric energy harvester with a tip mass is systematically derived under parametric and external excitations. The proposed model accounts for geometric and electro-mechanical coupling nonlinearities, damping nonlinearity and the inextensibility condition of beam. Using the Galerkin approach, the proposed model is converted into the electro-mechanical coupling Mathieu–Duffing equations. Analytical solutions of the frequency–response curves are presented by the multiple scales method. Nonlinear characteristics of the energy harvesters are explored under parametric excitation and hybrid parametric and external excitations. Analytical results provided new insights into the effects of tip mass and nonlinear damping on the performance of the energy harvester. The results show that with the tip mass increasing, the frequency–response curves of the energy harvester change from the nonlinear hardening type to the nonlinear softening type and the operating bandwidth and the output voltages of the energy harvester enlarge. For parametrical excitation, variation of the quadratic damping does not alter the initial threshold of the harvesters and the position of two transcritical bifurcation points of the frequency–response curves. The initiation threshold decreases with the tip mass increasing. Hybrid parametric and external excitations enhance the bandwidth and output voltage of the energy harvester, which will probably be used as an ideal way to improve the performance of the energy harvesting system.

References listed at the end of the paper:

Maoying Zhou and Huijun Zhao, “Revisit to the theoretical analysis of a classical piezoelectric vibration energy harvester", Archive of Applied Mechanics, Vol. 90, No. 11, pp 2379-2395, November 2020,

ABSTRACT: In this paper, we investigate the problem for a classical piezoelectric vibration energy harvester. Exact theoretical solution to the problem is derived and compared to the solutions proposed in the literature. Asymptotic expansions of the solution are explored in the hope of finding a plausible simpler approximation of the solution and corresponding output performance measures. Dependence of the output performance measures upon the electromechanical coupling factor is therefore studied. Some tips are then provided for the design of piezoelectric energy harvester.

References listed at the end of the paper:


ABSTRACT: The objective of this contribution is the numerical investigation of growth-induced instabilities of an elastic film on a microstructured soft substrate. A nonlinear multiscale simulation framework is developed based on the FE method, and numerical results are compared against simplified analytical approaches, which are also derived. Living tissues like skin, brain, and airways are often bilayered structures, consisting of a growing film on a substrate. Their modeling is of particular interest in understanding biological phenomena such as brain development and dysfunction. While in similar studies the substrate is assumed as a homogeneous material, this contribution considers the heterogeneity of the substrate and studies the effect of microstructure on the instabilities of a growing film. The computational approach is based on the mechanical modeling of finite deformation growth using a multiplicative decomposition of the deformation gradient into elastic and growth parts. Within the nonlinear, concurrent multiscale finite element framework, on the macroscale a nonlinear eigenvalue analysis is utilized to capture the occurrence of instabilities and corresponding folding patterns. The microstructure of the substrate is considered within the large deformation regime, and various unit cell topologies and parameters are studied to investigate the influence of the microstructure of the substrate on the macroscopic instabilities. Furthermore, an analytical approach is developed based on Airy’s stress function and Hashin–Shtrikman bounds. The wavelengths and critical growth factors from the analytical solution are compared with numerical results. In addition, the folding patterns are examined for two-phase microstructures and the influence of the parameters of the unit cell on the folding pattern is studied.

References listed at the end of the paper:

ABSTRACT: This study aims to examine the effect of the diameter, number, and location of the circular cutout on the free vibration response and buckling loads of the laminated composites. Eigen-buckling and free vibrations analyses are performed for the laminated composite plates by using the finite element software ANSYS. Numerical results obtained by the finite element method are compared to the experimental ones. In the numerical analyses, the effect of the delamination around the cutout on the buckling load and the natural frequency is also examined. The critical buckling load and first natural frequency values obtained by both numerical and experimental studies are used to create a prediction model using the artificial neural networks. The Levenberg–Marquardt backpropagation algorithm is used as the training method. It is observed that both the number and location of the cutout affect the critical buckling load and first natural frequency values. Numerical and experimental results are presented together with the ANN prediction results.

References listed at the end of the paper:


ABSTRACT: The widespread usage of prestressed concrete (PC) box girder with corrugated steel webs (CSWs) can be attributed to its many remarkable merits over traditional concrete box girders, such as significantly reducing the deadweight of the girder, speeding up the construction process, avoiding the problem of web cracking and increasing the prestress introduction efficiency. Numerous previous studies were conducted to investigated the mechanical properties of CSWs as well as simply supported box girder bridges with CSWs, whereas very few studies focused on the FE modeling methods of continuous PC box girders with CSWs. In addition, experimental work on scale bridge models or full-scale bridges adopting the box girder with CSWs is very limited. In this paper, an equivalent orthotropic web (EOW) model was developed for CSWs and used to analyze the performance of the continuous PC box girder bridges with CSWs. To verify this model, a one-tenth-scale bridge model was developed for an existing continuous PC box girder bridge with CSWs. Both static and dynamic tests were carried out on this scale bridge model. The results obtained from the bridge finite element (FE) model with EOWs were compared to the results obtained from the bridge FE model with CSWs and also the experimental results from the scale bridge model. Good agreement was achieved between these results, indicating that the EOW model can provide a trustworthy and convenient tool in the FE analysis of PC continuous box girder bridges with CSWs.

References listed at the end of the paper:


ABSTRACT: The back plate with brake insulator of a disc brake system used in automobile is a sandwich structure. Mitigating brake squeal associated with the operation of the disc brake has been a focus of many automobile researchers. As on today’s practice, steel–acrylic–steel is used for back plate–brake insulator assembly. The present study focuses on proposing Al–Al2O3 functionally graded metal ceramic composite material (FGM) for the back plate attached with conventional Steel–Acrylic brake insulator. Accordingly, a comparison study is presented in terms of the free and forced vibration characteristics of different material combinations for back plate–brake insulator sandwich beams such as steel–acrylic–steel, FGM–acrylic–aluminium and steel–acrylic–aluminium. The associated governing equations for sandwich beam which are well established in the literature are presented, and they are solved for simply supported conditions using trigonometric displacement functions. The real and imaginary parts of the various parameters come into the picture because of complex shear modulus of viscoelastic core. The comparison study among the combinations reveals that the natural frequency, loss factor and with regard to dynamic loading the imaginary part of transverse displacement, axial displacement, stress and strain of FGM–acrylic–steel are higher. As a result, FGM–acrylic–steel is suitable combination for back plate and brake insulator assembly which enhances the damping capacity of overall disc brake system and also helps in reducing brake squeal problem associated with operation of disc brake system.

References listed at the end of the paper:

ABSTRACT: Based on the modified couple stress and non-classical Timoshenko beam theories, the nonlinear forced vibration of an elastically connected double nanobeam system subjected to a moving particle is assessed here. This system is assumed to be resting on an elastic medium. Hamilton’s principle and the Galerkin method are applied to govern the equations of system motion and corresponding boundary conditions and to solve these equations, respectively. The numerical study reveals that by applying the nonlinear and modified couple stress theories the system is predicted stiffer than what is obtained through linear and classical theories. To determine the effects of different parameters like the material length scale, the elastic stiffness modulus of the interlayer and medium, and the velocity of the moving particle on the system’s vibration, a parametric study is performed. The material length scale has a significant effect on the dynamic response of the system, indicating that the classical theory cannot predict the dynamic behavior of nanosize beam systems. The elastic stiffness modulus of both the interlayer and medium and the velocity of the moving particle have considerable effects on the dynamic deflections of the double nanobeam system.

References listed at the end of the paper:


ABSTRACT: The vibration characteristics of two piezoelectric cantilevered plates in air and water are investigated in this study. The two-piezoelectric-plate system can provide different vibration characteristics compared to the previous studies in which only one cantilever plate is used because the anti-phase motion can be evoked in this newly designed system. First, the vibration characteristics of the plates coupled with a bounded compressible inviscid fluid are derived by theoretical analysis. The governing equation of the piezoelectric plate and the superposition method are used to analyze the vibration displacement of the piezoelectric plate, and the acoustic wave equation is used to derive the fluid equation. The frequency eigenfunction of the coupled system is derived by the boundary conditions of hydrostatic equilibrium. After solving the characteristics equation, the resonant frequencies and corresponding mode shapes for assumptions about both compressible and incompressible fluids and the velocity and pressure fields of the fluid can be obtained. Next, finite element analysis (FEA) is used to verify the theoretical results. It is shown from this study that the theoretical predictions of resonant frequencies and the corresponding mode shapes have a good agreement with those of the FEA for water and compressible fluid assumption of air. The unique high pressure value in the outer or middle layer in an air-coupled condition does not occur in water because water’s compressibility is relatively smaller than that of air. The influence of the depth and properties of the fluid on the behavior of the coupled solid–fluid is also investigated. For anti-phase motion, the frequency variation with change in the depth of the middle layer is similar to that of the outer layer for both air- and water-coupled conditions. For in-phase motion, the variation in frequency with the change in the depth of the middle layer is negligible. The particular modes in fluid compounded by modes in vacuum are analyzed on the distortion of mode shapes at higher resonant modes. These results can provide complete information on the vibration characteristics of a solid–fluid coupled system and will contribute to the evolution of hydroacoustic devices in which two piezoelectric plates are used.

References listed at the end of the paper:


Archive of Applied Mechanics, Vol. 90, No. 12, pp 2775-2798, December 2020,

More papers published in the journal, Meccanica (2019 and on)
Google the string: “Meccanica”, then click on the entry: “Meccanica – Springer – Springer Link”; then click on “Browse Volumes & Issues”.

Kepeng Qiu, Ruoyao Wang, Zhi Wang and Weihong Zhang, “Effective elastic properties of flexible chiral honeycomb cores including geometrically nonlinear effects”, Meccanica, Vol. 53, No. 15, pp 3661-3672, December 2018

ABSTRACT: Flexible chiral honeycomb cores generally exhibit nonlinear elastic properties in response to large geometric deformation, which are suited for the design of morphing aerospace structures. However, owing to their complex structure, it is standard to replace the actual core structure with a homogenized core material presenting reasonably equivalent elastic properties in an effort to increase the speed and efficiency of analyzing the mechanical properties of chiral honeycomb sandwich structures. As such, a convenient and efficient method is required to evaluate the effective elastic properties of flexible chiral honeycomb cores under conditions of large deformation. The present work develops an analytical expression for the effective elastic modulus based on a deformable cantilever beam under large deformation. Firstly, Euler–Bernoulli beam theory and micropolar theory are used to analyze the deformation characteristics of chiral honeycombs, and to calculate the effective elastic modulus under small deformation. On that basis, the expression for the effective elastic modulus is
improved by including the stretching deformation of the chiral honeycomb structure for a unit cell under conditions of large deformation. The effective elastic moduli calculated by the respective analytical expressions are compared with the results of finite element analysis. The results indicate that the analytical expression obtained under consideration of the geometric nonlinearity is more suitable than the linear expressions for flexible chiral honeycomb cores under conditions of high strain and low elastic modulus.

References listed at the end of the paper:

Liwen He, Jia Lou, Youheng Dong, Sritawat Kitipornchai and Jie Yang. “A shearable and thickness stretchable finite strain beam model for soft structures”. Meccanica, Vol. 53, No. 15, pp 3755-3777, December 2018

ABSTRACT: Soft materials and structures have recently attracted lots of research interests as they provide paramount potential applications in diverse fields including soft robotics, wearable devices, stretchable electronics and biomedical engineering. In a previous work, an Euler–Bernoulli finite strain beam model with thickness stretching effect was proposed for soft thin structures subject to stiff constraint in the width direction. By extending that model to account for the transverse shear effect, a Timoshenko-type finite strain beam model within the plane-strain context is developed in the present work. With some kinematic hypotheses, the finite deformation of the beam is analyzed, constitutive equations are deduced from the theory of finite elasticity, and by employing the standard variational method, the equilibrium equations and associated boundary conditions are derived. In the limit of infinitesimal strain, the new model degenerates to the classical extensible and shearable elastica model. The corresponding incremental equilibrium equations and associated boundary conditions are also obtained. Based on the new beam model, analytical solutions are given for simple deformation modes, including uniaxial tension, simple shear, pure bending, and buckling under an axial load. Furthermore, numerical solution procedures and results are presented for cantilevered beams and simply supported beams with immovable ends. The results are also compared with the previously developed finite strain Euler–Bernoulli beam model to demonstrate the significance of transverse shear effect for soft beams with a small length-to-thickness ratio. The developed beam model will contribute to the design and analysis of soft robots and soft devices.

References listed at the end of the paper:
10. Chan BQY, Low ZWK, Heng SJW, Chan SY, Owh C, Loh XJ (2016) Recent advances in shape memory soft materials for biomedical applications. ACS Appl Mater Interfaces 8:10070–10087
ABSTRACT: The paper presents an analytical estimate for an area of contact for a thin-walled noncircular cylindrical shell placed between two parallel rigid plates. Meccanica, Vol. 53, No. 15, pp 3831–3838, December 2018


References listed at the end of the paper:
Computational cost, the coupled problem of free fluid, porous media flow and solid mechanics is split among its components. For this purpose, we develop and use a nonlinear poroelastic computational model and apply it to the study of fluid flow through a deformable porous matrix in the energy dissipation behavior of a poroelastic structure. More precisely, we analyze the role of fluid flow through a deformable porous matrix in the energy dissipation behavior of a poroelastic structure. For this purpose, we develop and use a nonlinear poroelastic computational model and apply it to the fluid–structure interaction simulations. We discretize the problem by means of the finite element method for the spatial approximation and using finite differences in time. The numerical discretization leads to a system of non-linear equations that are solved by Newton’s method. We adopt a moving mesh algorithm, based on the Arbitrary Lagrangian–Eulerian method to handle large deformations of the structure. To reduce the computational cost, the coupled problem of free fluid, porous media flow and solid mechanics is split among its components.

Rana Zakerzadeh and Paolo Zunino (First author is from: Center for Cardiovascular Simulation, Institute for Computational Engineering and Sciences (ICES), The University of Texas at Austin, Austin, USA), “A computational framework for fluid-porous structure interaction with large structural deformation”, Meccanica, Vol. 54, Nos. 1-2, pp 101-121, January 2019

ABSTRACT: We study the effect of poroelasticity on fluid–structure interaction. More precisely, we analyze the role of fluid flow through a deformable porous matrix in the energy dissipation behavior of a poroelastic structure. For this purpose, we develop and use a nonlinear poroelastic computational model and apply it to the fluid–structure interaction simulations. We discretize the problem by means of the finite element method for the spatial approximation and using finite differences in time. The numerical discretization leads to a system of non-linear equations that are solved by Newton’s method. We adopt a moving mesh algorithm, based on the Arbitrary Lagrangian–Eulerian method to handle large deformations of the structure. To reduce the computational cost, the coupled problem of free fluid, porous media flow and solid mechanics is split among its components.
components and solved using a partitioned approach. Numerical results show that the flow through the porous matrix is responsible for generating a hysteresis loop in the stress versus displacement diagrams of the poroelastic structure. The sensitivity of this effect with respect to the parameters of the problem is also analyzed.

References listed at the end of the paper:
Hui-Shen Shen and Y. Xiang (First author is from: School of Aeronautics and Astronautics, Shanghai Jiao Tong University, Shanghai, People’s Republic of China), “Thermal buckling and postbuckling behavior of FG-GRC laminated cylindrical shells with temperature-dependent material properties”, Meccanica, Vol. 54, Nos. 1-2, pp 283–297, January 2019

ABSTRACT: Thermal postbuckling analysis is presented for graphene-reinforced composite (GRC) laminated cylindrical shells under a uniform temperature field. The GRC layers are arranged in a functionally graded (FG) graphene reinforcement pattern by varying the graphene volume fraction in each GRC layer. The GRCs possess temperature dependent and anisotropic material properties and the extended Halpin–Tsai model is employed to evaluate the GRC material properties. The governing equations are based on a higher order shear deformation shell theory and include the von Kármán-type kinematic nonlinearity and the thermal effects. A singular
perturbation method in conjunction with a two-step perturbation approach is applied to determine the thermal postbuckling equilibrium path for a GRC shell with or without geometric imperfection. An iterative scheme is developed to obtain numerical thermal buckling temperatures and thermal postbuckling load–deflection curves for the shells. The results reveal that the FG-X piece-wise FG graphene distribution can enhance the thermal postbuckling capacity of the shells when the shells are subjected to a uniform temperature loading.

References listed at the end of the paper:
14. Duc ND, Cong PH, Tuan ND, Tran P, Thanh NV (2017) Thermal and mechanical stability of functionally graded carbon nanotubes (FG CNT)-reinforced composite truncated conical shells surrounded by the elastic foundations. Thin-Walled Struct 115:300–310
References listed at the end of the paper:

- Bourrières F (1939) Sur un phénomène d’oscillation auto-entretenu en mécanique des fluides réels. E. Blondel La Rougery
- Dodds HL, Runyan HL (1965) Effect of high-velocity fluid flow on the bending vibrations and static divergence of a simply supported pipe. National Aeronautics and Space Administration 2870

M. Javadi, M.A. Noorian and S. Irani (Faculty of Aerospace Engineering, K.N. Toosi University of Technology, Tehran, Iran), “Stability analysis of pipes conveying fluid with fractional viscoelastic model”, Meccanica, Vol. 54, No. 3, pp 399–410, February 2019

ABSTRACT: Divergence and flutter instabilities of pipes conveying fluid with fractional viscoelastic model has been investigated in the present work. Attention is concentrated on the boundaries of the stability. Based on the Euler–Bernoulli beam theory for structural dynamics, viscoelastic fractional model for damping and, plug flow model for fluid flow, equation of motion has been derived. The effects of gravity, and distributed follower forces are also considered. By transferring the equation of motion to the Laplace domain and using the Galerkin method, the characteristic equations are obtained. By solving the eigenvalue problem, frequencies and damped of the system have been obtained versus flow velocity. Some numerical test cases have been studied with viscoelastic fractional model and the effect of the fractional derivative order and the retardation time is investigated for various boundary conditions.

References listed at the end of the paper:
ABSTRACT:

State feedback controller design is performed for a cantilever pipe conveying fluid. A theoretical analysis of the system is given and a signal parameter optimization method is applied. The effectiveness of the designed controller is validated by making a comparison with the corresponding passive solutions on the specially designed and constructed experimental test stand of a pipe conveying air. The effectiveness of the designed optimal controller is validated by making a comparison with the corresponding passive solutions on the specially designed and constructed experimental test stand of a pipe conveying air.

References listed at the end of the paper:


Tomasz Szymidt, Dominik Pisarski, Robert Konowrocki, “Semi-active stabilisation of a pipe conveying fluid using eddy-current dampers: state-feedback control design, experimental validation”, Meccanica, Vol. 54, No. 6, pp 761-777, April 2019

ABSTRACT: An application of electromagnetic devices of the motional type (i.e. eddy-current dampers) to improve the dynamic stability of a cantilever pipe discharging fluid is proposed. When the flow velocity reaches a critical value, this system loses stability through the flutter. A contactless damping device is used. This actuator is made of a conducting plate attached to the pipe that moves together with it within the perpendicular magnetic field that is generated by the controlled electromagnets. During the motion the eddy currents in the plate and a resultant drag force of a viscous character are generated. First, an optimal control problem that aims to stabilise the system with the optimal rate of decrease of the system’s energy is posed and solved. Then a state-feedback parametrisation of the obtained optimal control, which can be used in a closed-loop scheme is proposed. The effectiveness of the designed optimal controller is validated by making a comparison with the corresponding passive solutions on the specially designed and constructed experimental test stand of a pipe conveying air.

References listed at the end of the paper:

S. Stelios (1), S. Qin (2), F. Shan (2), D. Mathioulakis (1,3)

(1) School of Mechanical Engineering, National Technical University of Athens (NTUA), Athens, Greece
(2) School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan, China
(3) China-EU Institute for Clean and Renewable Energy, Huazhong University of Science and Technology, Wuhan, China

“Forced and unforced flow through compliant tubes”, Meccanica, Vol. 54, No. 6, pp 779-798, April 2019

ABSTRACT: The behavior (wall deformation and motion) of two compliant tubes made of an elastomer material were experimentally examined being part of a hydraulic loop. The basic feature of the tubes was the nonlinear dependence of their compliance on transmural pressure. One of the tubes, with a thickness to tube diameter ratio \( h/D = 12.5\% \) and length to tube ratio \( L/D = 8.75 \) was set to a periodic motion, when a peristaltic pump was used for flow generation, buckled non axisymmetrically with a frequency equal to that of the pump. Due to the large amplitude pressure pulsations induced by the pump, the transmural pressure took in each period both positive and negative values which caused a tube shrinkage and expansion with a maximum amplitude of 60% of the tube radius. Moreover, resonance phenomena appeared when the pump frequency coincided with the natural frequency of the hydraulic system. When a progressive cavity pump was used, the weak pressure pulsations induced by this pump caused mild tube pulsations (up to 1.6% of the tube radius) and only when the transmural pressure was varying in the plateau of the pressure versus cross-sectional area curve. In both the above two cases, pressure amplitudes differed between the entrance and the exit of the tube approximately two times. The other tube with \( h/D = 3.3\% \) and same \( L/D \) exposed to a flow established by gravity performed self-sustained oscillations causing large amplitude pressure pulsations downstream of the tube, flow limitation and negative resistance phenomena for which details are presented.

References listed at the end of the paper:


- 47. Modarres S. Stelios (1), S. Qin (2), F. Shan (2), D. Mathioulakis (1,3)
- 49. Modarres S. Stelios (1), S. Qin (2), F. Shan (2), D. Mathioulakis (1,3)
This paper is devoted to investigate the nonlinear dynamic characteristics of lattice sandwich composite panels on Winkler–Pasternak elastic foundations with thermal effects in supersonic airflow.


ABSTRACT: This paper is devoted to investigate the nonlinear dynamic characteristics of lattice sandwich composite panels resting on Winkler–Pasternak elastic foundations under simultaneous aerodynamic and thermal loads in supersonic airflow. The first-order shear deformation and von Kármán large deflection theories are applied in the structural modeling. The supersonic piston theory is used to model the aerodynamic pressure acting on the lattice sandwich composite panel. The equation of motion of the structure is established by Hamilton’s principle with the assumed mode method. The nonlinear vibration responses of the lattice sandwich composite panel under different aerodynamic pressures are computed. In addition, the influences of several significant parameters including the ply angle of laminated face sheets, elastic foundation parameters, aerodynamic pressure and temperature change on the nonlinear aerothermoelastic characteristics and the route to chaos for the lattice sandwich composite panel are investigated. Time histories, phase maps, Poincaré plots and fast Fourier transform frequency spectra are presented to identify the periodic, quasi-periodic and chaotic motions.
References listed at the end of the paper:

This paper focuses on the interaction of low Reynolds number (Re) flows and thin shell type double curves shallow shells using TSDT. Compos Struct 185:455–465.


References listed at the end of the paper:


ABSTRACT: This study contributes to a possibility of evaluating composite structures configuration such as steel and concrete using buckling and volume constraints based on multi-material topology optimization. A Jacobi active-phase algorithm is used to generate multiphase topology optimization. It provides a rational solution appropriated to the topology optimizer. Method of Moving Asymptotes due to the conflict in updating the design variables. A modified material interolation scheme solving spurious buckling modes problem which occurs in the multi-material topology optimization process is given and discussed. An investigation of buckling constraint parameter is described. It allows a single-objective minimum compliance topology optimization to obtain two objectives of maximizing both structure stiffness and first buckling load factor. The optimal changing topologies of single material structure and multi-material structure corresponding to different buckling constraints are presented. Numerical examples of compression-only structures and compression-tension
structures considering structural instability are performed using both single material and multiple materials to verify the efficiency and superiority of the present method.

References listed at the end of the paper:


ABSTRACT: The pin-ended, slender, Euler strut has been used as the archetypal buckling problem for many years (Euler in Additamentum I de curvis elasticis, methodus inveniendi linias curvas maximi minimivi proprietate gaudentes, Bousquet, Lausanne, 1744). Even though it is not conventionally imperfection-sensitive (i.e., in which the magnitude of the buckling load is compromised by the presence of imperfections), initial
geometric imperfections are still important, and 3D-printing now allows a versatility in geometric prescription and accuracy previously unavailable. This paper focuses attention on Euler struts, primarily from an experimental viewpoint, in which a second mode (full sine wave) initial shape, with varying magnitude, is used to produce specimens, test them, and compare with the elementary theory.

References listed at the end of the paper:
1. Euler L (1744) Additamentum I de curvis elasticis, methodus inveniendi lineas curvas maximi minimivi proprietate gaudentes. Bousquet, Lausanne


ABSTRACT: A novel statistical linearization technique is developed for computing stationary response statistics of randomly excited coupled bending-torsional beams resting on non-linear elastic supports. The key point of the proposed technique consists in representing the non-linear coupled response in terms of constrained linear modes. The resulting set of non-linear equations governing the modal amplitudes is then replaced by an equivalent linear one via a classical statistical error minimization procedure, which provides algebraic non-linear equations for the second-order statistics of the beam response, readily solved by a simple iterative scheme. Data from Monte Carlo simulations, generated by a pertinent boundary integral method in conjunction with a Newmark numerical integration scheme, are used as benchmark solutions to check accuracy and reliability of the proposed statistical linearization technique.

References listed at the end of the paper:
Giuseppe Failla, Mario Di Paola, Antonina Pirrotta, Andrea Burlon, Iain Dunn, “Random vibration mitigation of beams via tuned mass dampers with spring inertia effects”, Meccanica, Vol. 54, No. 9, pp 1365-1383, July 2019

ABSTRACT: The dynamics of beams equipped with tuned mass dampers is of considerable interest in engineering applications. Here, the purpose is to introduce a comprehensive framework to address the stochastic response of the system under stationary and non-stationary loads, considering inertia effects along the spring of every tuned mass damper applied to the beam. For this, the key step is to show that a tuned mass damper with spring inertia effects can be reverted to an equivalent external support, whose reaction force on the beam depends only on the deflection of the attachment point. On this basis, a generalized function approach provides closed analytical expressions for frequency and impulse response functions of the system. The expressions can be used for a straightforward calculation of the stochastic response, for any number of tuned mass dampers. Numerical results show that spring inertia effects may play an important role in applications, affecting considerably the system response.

References listed at the end of the paper:

in term confirmed by analyzing a damaged prismatic cantilever steel beam subjected to an impulsive load. The results approximate explicit expression of the frequency response function. The accuracy of the present method is starting point is the application of the so uncertainty. Aim of this paper is to provide an alternative procedure developed in the frequency domain: the

ABSTRACT:

Taking into account the unavoidable uncertainty affecting also the damage characteristics in practical structures under deterministic time variant excitations assuming the crack d

Roberta Santoro, Giuseppe Muscolino, “Dynamics of beams with uncertain crack depth: stochastic versus interval analysis”, Meccanica, Vol. 54, No. 9, pp 1433-1449, July 2019

ABSTRACT: The present paper deals with the evaluation of the structural response of single-cracked beam-like structures under deterministic time variant excitations assuming the crack depth as an uncertain parameter. Taking into account the unavoidable uncertainty affecting also the damage characteristics in practical applications, the crack depth is modelled by both a stochastic and an uncertain-but-bounded variable. It follows that the structural beam response becomes a stochastic process or an interval function, respectively. In scientific literature for this kind of uncertainties the statistics as well as the bounds of the structural response are usually evaluated by applying the perturbation approach, whose accuracy is valid only for very small value of uncertainty. Aim of this paper is to provide an alternative procedure developed in the frequency domain: the starting point is the application of the so-called rational series expansion, recently proposed to derive an approximate explicit expression of the frequency response function. The accuracy of the present method is confirmed by analyzing a damaged prismatic cantilever steel beam subjected to an impulsive load. The results in terms of statistics as well as bounds of the displacement beam tip are reported and compared with the
Monte Carlo simulation and the combinatorial vertex method. The effects of the two models for the uncertain crack depth on the dynamic response are also compared in terms of interval bounds and the so-called confidence intervals provided by the stochastic analysis.

References listed at the end of the paper:


X.-F. Li (1) and K. Y. Lee (2)
(1) School of Civil Engineering, Central South University, Changsha, China
ABSTRACT: The classical analysis of bending of a circular plate subjected to transverse loading often neglects the effect of the radial component of the reaction force. This paper analyzes this effect for a moderately thick circular plate with roller constraint. A nonclassical axisymmetric bending problem of a circular Mindlin plate is studied for a concentrated force and uniformly distributed loading. The governing equation is derived based on the incremental deformation theory of elasticity. With the aid of Bessel functions, explicit expressions for small- and large-scale transverse deflections and section rotation are obtained. Singular behavior at the plate center is discussed in detail. Two possible hypotheses at the plate center are analyzed, and they give rise to different singularities of the deflection, rotation, and stresses at the plate center. When neglecting the radial reaction force component, our model reduces to the classical circular Mindlin plate theory. Obtained results are useful in the safety design of circular plates under complicated loading.

References listed at the end of the paper:


ABSTRACT: Shape memory polymers (SMPs) are a class of smart materials which can recover their shape even after many shape changes in application of an external stimulus. In this paper, flexural behavior of a composite beam, constructed of a corrugated part filled with SMPs, is studied. This composite beam is applicable in sensor and actuator applications. Since the corrugated profiles display higher stiffness-to-mass ratio in the transverse to the corrugation direction, the beams with a corrugated part along the transverse direction are stiffer than ones with a corrugated part along the length. Employing a developed constitutive model for SMPs and the Euler–Bernoulli beam theory, the behavior of the composite beam is studied. Since the utilized constitutive model is in the integral form, the finite-difference-method is used for discretizing the equations. It is shown that load capacity is increased in both composite beams compared to a pure SMP beam. This bigger load capacity is obtained by a low decrease in shape fixity. In addition, for different corrugated shapes (trapezoidal, pseudo-sinusoidal and triangular) with the same SMP content, the beam response is obtained. Finally, the results of the constrained stress-recovery are obtained and the effects of mechanical properties on its behavior, are studied.

References listed at the end of the paper:


Samira Akbari-Azar (1), Mostafa Baghani (1), Mohammad-Reza Zakerzadeh (1), Hamid Shahsavari (1) and Saeed Sohrabpour (2)
(1) School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran
(2) Mechanical Engineering Department, Sharif University of Technology, Tehran, Iran

Shape memory polymers (SMPs) are a class of smart materials which can recover their shape even after many shape changes in application of an external stimulus. In this paper, flexural behavior of a composite beam, constructed of a corrugated part filled with SMPs, is studied. This composite beam is applicable in sensor and actuator applications. Since the corrugated profiles display higher stiffness-to-mass ratio in the transverse to the corrugation direction, the beams with a corrugated part along the transverse direction are stiffer than ones with a corrugated part along the length. Employing a developed constitutive model for SMPs and the Euler–Bernoulli beam theory, the behavior of the composite beam is studied. Since the utilized constitutive model is in the integral form, the finite-difference-method is used for discretizing the equations. It is shown that load capacity is increased in both composite beams compared to a pure SMP beam. This bigger load capacity is obtained by a low decrease in shape fixity. In addition, for different corrugated shapes (trapezoidal, pseudo-sinusoidal and triangular) with the same SMP content, the beam response is obtained. Finally, the results of the constrained stress-recovery are obtained and the effects of mechanical properties on its behavior, are studied.
References listed at the end of the paper:

1. Euler L (1744) De Curvis Elasticis, Additamentum I to his Methodus Inveniendi Lineas Curvas Maximi Minimiv Proprietate Gaudentes. Lausanne and Geneva


ABSTRACT: This paper intends to establish a unified theory of structures based on the micropolar elasticity (ME). ME allows taking into consideration the microstructure of the material, through the adoption of four additional material parameters. In this way, the size-effects of the structure can be caught. The proposed model is developed in the domain of the Carrera unified formulation (CUF), according to which theories of structures can degenerate into unknown kinematics that makes use of an arbitrary expansion of the generalized variables. CUF is a hierarchical formulation that considers the order of the structural model as input of the analysis, so that no specific approximation and manipulation is needed to implement refined theories. Different types of structures have been analyzed in the present work, and the results are compared and validated from the literature. The effects of the new material parameters are addressed too, along with the capability of the proposed model to deal with size-effects and high-order structural behaviors. Finally, stress analysis is detailed to further highlight the differences between micropolar and classical elasticity.
In this paper, numerical investigation of the statical and dynamical stability of aligned and misaligned viscoelastic cantilevered beam is performed with a terminal nozzle in the presence of gravity in two cases: (1) effect of fluid velocity on the flutter boundary of beam conveying fluid and (2) effect of gravity on the buckling boundary of beam conveying fluid. The beam is assumed to have a large width-to-thickness ratio, so the out-of-plane bending rigidity is far higher than the in-plane bending and torsional rigidities. Gravity vector is considered in the vertical direction. Thus, deflection of the beam because of the gravity effect couples the in-plane bending and torsional equations. The beam is modeled by Euler–Bernoulli beam theory, with the flow-induced inertia, Coriolis and centrifugal forces along the beam considered as a distributed load along the beam. Furthermore, the end nozzle is regarded as a lumped mass and modeled as a follower axial force. The extended Hamilton’s principle and the Galerkin method are utilized to derive the bending–torsional equations of motion. The coupled equations of motion are solved as eigenvalue problems. Also, several cases are examined to study the impact of gravity, beam inclination angle, mass ratio, nozzle aspect ratio, bending-to-bending rigidity ratio and bending-to-torsional rigidity ratio on flutter and buckling margin of the system. References listed at the end of the paper:


ABSTRACT: Lattices composed of cubic and triangular prismatic unit cells with polymeric Sarrus linkage rib elements are designed, fabricated via 3D printing and studied experimentally. Size effects in these lattices are observed experimentally; slender specimens appear more rigid in torsion and in bending than expected via classical elasticity. Effects are analyzed via Cosserat elasticity. The magnitude of size effects is sensitive to geometry of the lattices; triangular cells with short ribs revealed the most extreme effects, also the largest characteristic length in relation to cell size. The torsion coupling number is 1, its upper bound, for all lattices. A path to the attainment of arbitrarily large nonclassical effects is delineated.

References listed at the end of the paper:

ABSTRACT: Nonlinear forced vibrations of a fractional viscoelastic pipe conveying fluid exposed to the time-dependent excitations is investigated in the present work. Attention is focused in particular on the primary and secondary resonances with the Kelvin–Voigt fractional order constitutive relationship model. The nonlinear geometric partial differential equations due to stretching effect have been expressed by assumptions with Von Karman’s strain-displacement relation and Euler–Bernoulli beam theory. Viscoelastic fractional model for damping and stiffness, and also plug flow model for fluid flow are considered to derive the equation of motion. Based on the Galerkin truncation, the coupled Fluid–Solid interaction nonlinear equation transferred to ordinary differential equations. The method of multiple scales is adopted to analyze steady-state solutions for the primary, superharmonic, and subharmonic resonances. Finally, the detailed parametric studies on the nonlinear dynamic behavior are discussed. Results delineate that the fractional derivative order and the retardation time have significant effects on the oscillation exhibited for different values of flow velocity.

References listed at the end of the paper:

This paper investigates the linear free vibration of axially moving simply supported thin circular cylindrical shell using multiple scales method. Meccanica, Vol. 54, No. 14, pp 2227-2246, November 2019.

ABSTRACT: This paper investigates the linear free vibration of axially moving simply supported thin circular cylindrical shells with constant and time-dependent velocity considering the effect of viscous structure damping. Classical shell theory is employed to express strain-displacement relation. Linear elasticity theory is used to write stress-strain relation considering Hook’s Law. Governing equations in cylindrical coordinates are derived using the Hamilton principle. Equilibrium equations are rewritten with the help of Donnell–Mushtari shell theory simplification assumptions. Motion equations for displacements in axial and circumferential directions are solved analytically concerning to displacement in the radial direction. As the displacement in the radial direction is the combination of driven and companion modes, the third motion equation is discretized using the Galerkin method. The set of ordinary differential equation obtained from the Galerkin method is solved using the steady-state method, which in practice leads to the prediction of the exact frequencies of vibration. By employing multiple scale method the critical speed values of a circular cylindrical shell and
several types of instabilities are discussed. The numerical results show that by increasing the mean velocity, the system always loses stability by the divergence instability in different modes, and the critical speed values of lower modes are higher than those of higher modes. As well as the unstable regions for the resonances between velocity function fluctuation frequencies and the linear combination of natural frequencies is gained from the solvability condition of second order multiple scale method. The accuracy of the method is checked against the available data.

References listed at the end of the paper:


REFERENCES


Isaac Sfiso Radebe (1), Georgios A. Drosopoulos (2) and Sarp Adali (3)
(1) Department of Mechanical Engineering, Durban University of Technology, Durban, South Africa
(2) Discipline of Civil Engineering, Howard College, University of KwaZulu-Natal, Durban, South Africa
(3) Discipline of Mechanical Engineering, Howard College. University of KwaZulu-Natal, Durban, South Africa


ABSTRACT: Present work investigates the biaxial buckling of three-phase, angle-ply laminates reinforced with graphene platelets and carbon or glass fibres. The analysis is based on Classical Plate Theory with the shear effect neglected. The laminate is defined as a three-ply symmetric laminate with simply supported boundary conditions and with different graphene and fibre contents in the surface and middle layers. As such, the laminate has a non-uniform distribution of the reinforcements in the surface and middle layers. Thicknesses of surface and middle layers are also non-uniform, but symmetrical. The objective is to investigate the effect of having a higher content of graphene and fibre in the surface layers as compared to the middle layer and also the effect of the relative thicknesses of the surface and middle layers on the buckling load. The main idea is to produce a cost effective design by concentrating the reinforcements in the surface layers where they are most effective. Thickness of the surface layers can be specified as the minimum required for a given buckling load to reduce the cost and to keep the volume content of the expensive reinforcements to a minimum. Effective properties of the three-phase composite are determined via micromechanical relations. Cost-effective designs using the minimum amount of reinforcements for a given buckling load can be determined from the graphs in the numerical results section. It is observed that relative graphene and fibre contents and thickness ratios of surface and middle layers affect the buckling load at different degrees. It is also observed that higher fibre contents can lead to lower buckling loads if the graphene content exceeds a critical value.

References listed at the end of the paper:


ABSTRACT: In this paper, a geometrically nonlinear size-dependent Elastic Kirchhoff nanoplate model is developed based on the second-order strain gradient nonlocal theory useful for capturing the size effects. Taking the mid-plane stretching into consideration as the source of the nonlinear behaviour, weak form
of the governing partial differential equations of equilibrium and the relevant classical/non-classical boundary conditions are derived using the variational method. For finite element analysis, the weak form requires continuity of the in-plane displacements and continuity of the transverse displacement. In the present work, a new computationally efficient subparametric nonconforming 4-noded finite element of arbitrary quadrilateral shape is presented for the first time for the modelling of nanoplates using the second-order negative strain gradient theory. The performance of the developed finite element is investigated for static bending of rectangular nanoplates with all edges simply supported and all edges clamped boundary conditions. The proposed element is found to be accurate and depicts good convergence characteristics for rectangular and non-rectangular meshes. The strain gradient model with negative nonlocal coefficient predicts results matching with those from the lattice model available in the literature.

References listed at the end of the paper:

ABSTRACT: This study focuses on vibration characteristics analysis of fiber metal laminated thin plate (FMLTP) with partial constraint layer damping (CLD) patches treatment. Firstly, the overall stress–strain relationships of the viscoelastic layer, the constraint layer and the covered FMLTP are deduced to establish the theoretical model. Then, the classical laminates theory, orthogonal polynomial method, complex modulus method and energy method are employed to solve the natural frequencies, modal shapes, vibration responses and modal damping ratios. As an example to demonstrate the feasibility of the developed model, the experimental test of TA2/TC500 laminated thin plate treated with different sizes and shapes of stainless steel/Zn-33 CLD patches is implemented. The calculated and measured results show a good consistency. Moreover, the influences of different CLD treating positions and shapes on the vibration characteristics of FMLTP are investigated here.

References listed at the end of the paper:

As in the classical AEM formulation, the integral representation of the solution to the analog equation is represented by an integral form involving appropriate Green’s functions of the differential operator and generalised functions.

In this paper, an improved version of the analog equation method (AEM) is proposed, ideally suitable for non-linear dynamic analysis of time-fractional beams with discontinuities. Various sources of non-linearity will be considered as well as different discontinuities, such as those associated with external point supports (shear force discontinuity) and local flexural flexibility (rotation discontinuity). The main idea of the proposed approach is to reformulate the classical AEM by considering an analog equation with an unknown time dependent fictitious load and a spatial generalised operator, which includes the classical 4th-order differential operator and generalised functions modelling the discontinuities along the beam. Consistently, the solution to the analog equation is represented by an integral form involving appropriate Green’s functions of the generalised operator. As in the classical AEM formulation, the integral representation of the solution is then

approximated dividing the beam in finite elements and considering a constant value of the fictitious load within every beam element. Substituting the so-built approximate solution in the original equation of motion yields a system of fractional differential equations governing the discrete values of the fictitious load, solved by employing a Newmark integration scheme in conjunction with a G-1 algorithm to account for the fractional-derivative memory effects. Computational efficiency and accuracy will be demonstrated against the classical AEM formulation.

References listed at the end of the paper:


ABSTRACT: A three-dimensional modelling of free vibrations and static response of functionally graded material (FGM) sandwich plates is presented. Natural frequencies and associated mode shapes as well as displacements and stresses are determined by using the finite element method within the ABAQUS™ code. The three-dimensional (3-D) brick graded finite element is programmed and incorporated into the code via the user-defined material subroutine UMAT. The results of modal and static analyses are demonstrated for square metal-ceramic functionally graded simply supported plates with a power-law through-the-thickness variation of the volume fraction of the ceramic constituent. The through-the-thickness distribution of effective material properties at a point are defined based on the Mori-Tanaka scheme. First, exact values of displacements, stresses and natural frequencies available for FGM sandwich plates in the literature are used to verify the performance and estimate the accuracy of the developed 3-D graded finite element. Then, parametric studies are carried out for the frequency analysis by varying the volume fraction profile and value of the ceramic volume fraction.

References listed at the end of the paper:

47. ABAQUS User’s manual, ver. 2016 (2016) Dassault Systèmes Simulia Corp., Providence, RI, USA

ABSTRACT: We propose a mixed variational principle for deducing the generalized Marguerre–von Kármán equations, governing the relatively large deflections of thin elastic shallow shells. These equations account for both non-flat stress-free configurations of the shell and inelastic strains. We implement this formulation by using C0 interior penalty methods within the UFL language provided by the FEniCS project. We present two numerical examples, with the aim to discuss the role of the shallowness and the inelastic strain, comparing the results with the fully non-linear shell model à la Naghdi and the classical displacement formulation.

References listed at the end of the paper:


Angelo Luongo and Daniele Zulli (International Center for Mathematics and Mechanics of Complex Systems, M&MoCS, University of L’Aquila, Monteluco di Roio (AQ), L’Aquila, Italy), “Free and forced linear dynamics of a homogeneous model for beam-like structures”, Meccanica, Vol. 55, No. 4, pp 907-925, April 2020,

ABSTRACT: A homogeneous shear beam model is used here to address the free and forced dynamic behavior of a multi-story building. After a brief recall of the model, which is taken from the literature, and the hypotheses on which it is grounded, discussion on the free dynamics is carried out, highlighting the intriguing organization
of the natural frequencies and modes in triplets, as functions of the wave-number. Then, the properties of the undamped and proportionally damped forced response to external loads is evaluated, and a discussion on the effects of the tip mass related to the top story is addressed. A case-study is analyzed to show the reliability of the homogeneous model, after comparing the outcomes with those provided by F.E.M. procedures applied to the corresponding multi-d.o.f. structure.

References listed at the end of the paper:


Demin Zhao (1), Peng Hao (2), Jiangwei Wang (1) and Jianlin Liu (1)
(1) Department of Engineering Mechanics, College of Pipeline and Civil Engineering, China University of Petroleum (East China), Qingdao, 266580, People’s Republic of China
(2) College of Mining and Safety Engineering, Shandong University of Science and Technology, Qingdao, 266590, People’s Republic of China


ABSTRACT: The study of surface effects on quasi-periodical vibration is significant because of its promising applications in sensors of nano/micro-electro-mechanical systems (N/MEMS). In this study, the surface effects parameters are adopted from the atomistic calculations. The governing equation of the nanobeam considering the nonlinear curvature and surface effects is established. Considering the first two modes, the Garlerkin method is used to translate the partial differential equation into ordinary differential equations. The multi-level
Residue harmonic balance method (RHBM) with two time variables is developed to solve these ODEs. The influences of surface and aspect ratio on the two frequencies and corresponding amplitudes are analyzed. Both of the frequency and amplitude discrepancies of the nanobeam to the counterparts of the classical beam become greater when the height of the beam shrinks at nanoscale. For the beam with the same height, both of the first- and second-frequencies decrease with the increase of the aspect ratio, and for the beams with the same aspect ratio, they decrease with the increase of the height. The solution of RHBM fits well with the molecular dynamics and Runge–Kutta numerical simulations. The study provides insight into the mechanism of the nonlinear dynamics of nanostructures, and shed light on quantitative design of the elements in N/MEMS, sensors, actuators, and resonators.

References listed at the end of the paper:

Implementing transfer matrix method in conjunction with Bloch–Floquet theorem, a unified methodology has


ABSTRACT: Band gaps appear in the frequency spectra of an elastic beam having periodic spring-mass attachment, acronymed as metabeam. Two widely used beam theories, i.e. Euler–Bernoulli and Timoshenko, are non-dimensionalized in order to obtain the dimensionless periodicity parameters. In this paper, the location and width of band-gaps are investigated due to the variation of these periodicity parameters of a metabeam. Implementing transfer matrix method in conjunction with Bloch–Floquet theorem, a unified methodology has
been adopted to estimate the propagation and attenuation bands in a metabeam. This paper provides a guideline towards the designing of wide-band metabeam by tuning the non-dimensional parameters.

References listed at the end of the paper:

33. Timoshenko SP (1921) On the correction for shear of the differential equation for transverse vibrations of prismatic bars. Philos Mag 41(245):744–746
• 34. Timoshenko SP (1921) On the additional deflection due to shearing. Glas Hrvat Prirodosl Drus Zagreb 33(Part 1, Nr. 1):50–52

Sourav Mandal, B. Santosh Kumar and A. P. Shashikala, “Effect of undulating bottom on wave interaction with a floating flexible plate coupled with a flexible porous barrier”, Meccanica, Vol. 55, No. 9, pp 1801-1820, September 2020,

ABSTRACT: In the present study, under the assumption of small amplitude water wave theory and structural response, effect of bed undulation on the wave interaction with a combination of flexible porous barrier and a flexible floating plate, is studied. The flexible porous barrier is modelled using the porous wave maker-theory while the elastic floating plate is modelled using thin plate theory. The physical problem is handled for solution using eigenfunction expansion method by matching pressure and velocity at interface boundaries while finite difference method is used to deal with modified mild-slope equation. In the present study, two types of plate configurations are namely (a) finite plate and (b) semi-infinite plate. To understand the role of undulating seabed, wave and structural parameters, in attenuating wave force and plate deflection, numerical results are computed and compared with available literature. It is found that full wave reflection occurs for certain critical angle and wave force acting on the barrier vanishes for the same critical angle for the semi-infinite plate case while the wave reflection tends to attain maximum value at critical angle for the finite case and these maximum value increases with the increase of plate length. It is observed that less wave reflection occurs for sloping bed profile compare to rest of the bed profile. The study reveals that positioning a barrier between plate and undulated region, helps in the reduction of plate deflection significantly. As special case, wave interaction problem with a finite floating elastic plate is studied experimentally and the experimental result has shown good agreement with the numerical result. The findings of the present study are likely to be of immense help in the design of various types of marine structures for protecting very large floating structures (VLFS). The present theory can be extended to handle large class of acoustic wave interaction problems with flexible porous structures.

References listed at the end of the paper:


ABSTRACT: This research considers size effects in the linear three-dimensional elasticity analysis of microtori. The fundamental relations (displacement form) are derived for isotropic toroidal shells in the framework of the modified couple stress theory in the curvilinear coordinate system to predict the mechanical responses. A numerical solution for the displacement field is obtained using the GDQ method. The numerical results are in a
close agreement with those found by the finite element and the Galerkin method. Parametric studies are conducted to explore the effect of size-dependency, micro-tori geometry, meridional and circumferential angle, toroidal shell thickness, and different boundary conditions on the distribution of the displacement fields. Numerical results for displacement also show that natural frequencies of micro-toroidal shells, predicted by modified couple stress theory, are less than those predicted by the classical theory, due to the significant effect of length scale parameter (related to material microstructures) on the mechanical responses. The use of general curvilinear coordinates in toroidal structures enables us to also study the mechanical behavior of irregular geometries, cap-shaped panel, saddle-shaped panel, and sectorial-shaped panel.

References listed at the end of the paper:

41. Cosserat E, Cosserat F (1909) Théorie des corps déformables
In general, the dynamics of rotating twisted beams is coupled in the two transverse planes. However, in the first part of the work the problem is assumed to be uncoupled and it is shown that this assumption is valid under certain cases. In the second part, the problem of general coupled dynamics is solved. Interesting insights based on the formula are presented. The accuracy of the derived formula is verified by comparing it with the literature.


ABSTRACT: Structures such as turbomachinery blades, industrial fans, propellers, etc. can be modeled as twisted beams. The study of dynamics of these structures is vital as operational failure of such structures can have catastrophic consequences. As the inclusion of twist and rotation complicates the problem, Finite Element (FE) method is widely used to determine the modal characteristics of rotating twisted beams. In this work, a novel formula is derived to estimate the natural frequencies of rotating twisted beams. The formula is derived using the perturbation method. The twist angle and the rotating speed are treated as the perturbation parameters. In general, the dynamics of rotating twisted beams is coupled in the two transverse planes. However, in the first part of the work the problem is assumed to be uncoupled and it is shown that this assumption is valid under certain cases. In the second part, the problem of general coupled dynamics is solved. Interesting insights based on the formula are presented. The accuracy of the derived formula is verified by comparing it with the literature.
References listed at the end of the paper:


ABSTRACT: The analytical approach of Leonhard Euler to the solution of an elastic column under compression is seen today as a landmark in buckling studies. However, this work was not well received in Great Britain during the late XVIII and XIX centuries. This paper considers the reaction of John Robison, Professor at the University of Edinburgh, published as an article in Encyclopedia Britannica, who attempted to disqualify Euler at scientific, methodological, and personal levels. The article was reproduced from edition three to eight, thus covering a period of some 90 years. The technical arguments made by Robison, together with the context in which he lived, are taken into account in order to explore the reasons behind the aggressive campaign of Robison against one of the most famous mathematicians of the XVIII century.

References listed at the end of the paper:
1. Anon (1801) Philosophical magazine. vol X, pp 348–353
6. Encyclopedia Britannica (1797/1887), editions 3 to 9, Edinburgh
7. Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers (1751/1772), Paris
10. Euler L (1744) Methodus inveniendi lineas curvas maximim minimive proprietate gaudentes, sive solution problematis isoperimetrici. Marcum Michaelem Bousquet, Laussane & Geneve
ABSTRACT: Dynamics of a rotor composed of a flexible beam attached to a slewing rigid hub is presented in the paper. Dynamics of the structure is studied for a slender beam model, based on extended Bernoulli-Euler theory, which takes into account a nonlinear curvature, coupled transversal and longitudinal oscillations and non-constant angular velocity of the hub. Moreover, to demonstrate a general case for dynamical boundary conditions, lumped mass fixed at the beam tip is added. The partial differential equations (PDEs) are derived from Hamilton principle of the least action. The analytical solutions of the PDEs are obtained by the multiple time scale method applied directly to PDEs. Forced vibrations around selected resonance zones are studied and the influence of beam rotation, preset angle, hub radius, tip mass is presented. Hardening and softening phenomena, respectively for the first and the second mode, are obtained for various angular velocity values.

References listed at the end of the paper:


ABSTRACT: In this paper the new semi-analytical solution for the moving mass problem on massless foundation, published by the author of this paper, is extended to account for inertial foundation modelled by a continuous homogeneous finite depth foundation with simplified shear resistance. Derivations are presented for infinite as well as for finite homogeneous beams. Mode expansion method is used to solve the problem on finite beams, thus vibration modes, the corresponding orthogonality condition, reengagement of coupled equations to ensure significant calculation time savings are derived. Methods of integral transforms and contour integration are exploited to obtain the solution on infinite beams. Resulting vibrations are derived as a sum of the steady and unsteady harmonic vibrations and a transient contribution. The unsteady harmonic vibration is proven to be a useful indicator of unstable behaviour through the mass induced frequencies. Besides frequency lines also discontinuity lines are determined and their influence on the proximity of harmonic and full solutions is discussed. Even if the differences between these two versions are larger than for the massless foundation, it is shown that the harmonic solution provides a very good estimate of the full solution (in several cases perfect match is achieved) with the advantage to be obtainable by a simple evaluation of the derived closed-form results. Like for the massless foundation, also here, vibrations on infinite beams can be obtained on long finite beams with eliminated effect of its supports. All mentioned approaches are also validated by the finite element method.

References listed at the end of the paper:


ABSTRACT: The problem of linear dynamic thermoelasticity in Kirchhoff–Love-type circular cylindrical shells having properties periodically varying in circumferential direction (uniperiodic shells) is considered. In order to describe thermoelastic behaviour of such shells, two mathematical averaged models are proposed—\textit{the non-asymptotic tolerance and the consistent asymptotic models}. Considerations are based on the known Kirchhoff–Love theory of elasticity combined with Duhamel-Neumann thermoelastic constitutive relations and on Fourier’s theory of heat conduction. The non-asymptotic tolerance model equations depending on a cell size are derived applying the \textit{tolerance averaging technique} and a \textit{certain extension of the known stationary action principle}. The consistent asymptotic model equations being independent on a microstructure size are obtained by means of the \textit{consistent asymptotic approach}. Governing equations of both the models have constant coefficients, contrary to starting shell equations with periodic, non-continuous and oscillating coefficients. As examples, two special length-scale problems will be analysed in the framework of the proposed models. The first of them deals with investigation of the effect of a cell size on the distribution of total temperature field approximated by sum of an averaged temperature and temperature fluctuations. The second one deals with study of the effect of a microstructure size on the distribution of total temperature field approximated by sum of an averaged temperature and temperature fluctuations.

References listed at the end of the paper:


ABSTRACT: Thermoelastic analysis of a shear deformable reduced model of laminated plates with von Kármán nonlinearities and cubic temperature along the thickness is presented. Parametric investigation of the response is accomplished by means of bifurcation diagrams, phase portraits and planar cross sections of the four-dimensional basins of attraction, in order to describe the local and global dynamical behavior of the model. Different scenarios induced by the boundary conditions are highlighted, along with the effect of a different modeling of temperature distribution (constant/dome-shape) on the system response. The effects of diverse (boundary/body) thermal sources are also comparatively explored. In all examined cases, proper consideration of system global dynamics is shown to be essential for reliably unveiling transient to steady effects due to thermomechanical coupling.

References listed at the end of the paper:
comparison to classical methods, since basins of attraction by means of sampling initial conditions. We demonstrate that the proposed approach has a major advantage in performed using three integrity measures, global and local integrity measures (GIM and LIM, respectively) and significant computational resources, being a rather time-consuming procedure. Thus the second aim of the paper on are not needed. Computationally expensive on of integrity measures of multidimensional system requires finite element approach. Aerosp Sci Technol 45:154–164


**ABSTRACT:** In the present work, a truss model inspired by von Mises and Bergan trusses is considered. The resulting structure is a phenomenological model that represents the behavior of many engineering structures and may exhibit in-plane snap-through or pitchfork unstable bifurcation and/or lateral buckling, leading two a multiwell potential function. The topology of the resulting potential function generates a complex bifurcation scenario under harmonic forcing with multiple attractors. The first aim of this work is to investigate the nonlinear vibrations of the proposed model. The interaction of the bifurcation phenomena leads to motions in two-, four- and six-dimensional phase-space. The use of different integrity measures is essential for assessing the robustness of the driven structure to unpredictable finite disturbances of a both static and dynamic nature in such cases. However of the various numerical tools for global dynamic analysis, few are well suited for higher-dimensional systems. In particular the evaluation of integrity measures of multidimensional system requires significant computational resources, being a rather time-consuming procedure. Thus the second aim of the paper is to propose numerical methodologies for evaluating the dynamic integrity measures of multidimensional systems by a Monte Carlo approach. Dynamic integrity analysis of the resulting multidimensional system is performed using three integrity measures, global and local integrity measures (GIM and LIM, respectively) and the integrity factor. Three algorithms based on the Monte Carlo method are proposed to estimate these measures by means of sampling initial conditions. We demonstrate that the proposed approach has a major advantage in comparison to classical methods, since basins of attraction are not needed. Computationally expensive
procedures, such as simple cell mapping, are not required. Therefore, the proposed approach has the potential to estimative the dynamic integrity of high dimensional systems with less computational effort, as shown by the obtained results.

References listed at the end of the paper:

- Santana MVB (2019) Tailored coronational formulations for the nonlinear static and dynamic analysis of bistable Structures. Pontificial Catholic University of Rio de Janeiro & Université Libre de Bruxelles

MathSciNet Article MATH Google Scholar


Google Scholar

Meccanica, Vol. 55, No. 12, pp 2623-2657, December 2020,

More papers published in the journal, Latin American Journal of Solids and Structures. (2019 and on)  
Google the string: “Latin American Journal of Solids and Structures”, then click on the item “Archives”


ABSTRACT: This work aims to contribute for the development of shm sys-tems based on vibration methods to be applied on sandwich structures. The main objective is focused on experimental damage identification via changes in the frequency response function (frf) with the usage of damage metrics. Specimens of sandwich structures made from skins in epoxy resin reinforced by glass fiber and a core of pvc foam are manufactured.
First, preliminary non-damped finite element (fe) models are performed, and results obtained are used to define the frequency range of interest for the experimental procedure. After that, vibration experimental analyses are carried out on undamaged specimens. The natural frequencies are compared to the preliminary fe results. Second, experimental analyses are performed on damaged specimens with piezoelectric sensors or not. Then, damage metric values are calculated based on frfs for damaged and undamaged structures, which were obtained from experimental and fe analyses (with damping effects). In addition, a new procedure is proposed to improve the quality of results provided by the damage metric. It is shown that the new procedure is very effective to identify the damage using both amplitude and phase from frfs. Lastly, it is discussed the potentialities and limitations of the fe model to predict damage metric values, comparing to experimental data.

References listed at the end of the paper:


ABSTRACT: Accidental collision of striking objects, such as a supply vessel, into the side panel of a FPSO highly influences its ultimate strength assessment. An empirical formula for predicting the ultimate strength of damaged stiffened panels under combined loading of shear and longitudinal compression is empirically derived in this work based on curve fitting of quasi-static non-linear finite element FE analyses. Initial imperfections are introduced by scaling the first buckling mode shape and the damage is caused by residual deformation from a rigid sphere indentation. A pure shear loading is applied at several levels followed by compression loading using the modified Riks method for a number of sphere indentation damages. The suggested formula for a typical FPSO stiffened side shell panel presented an excellent correlation with the nonlinear FE results and can be particularly useful in the preliminary design phase no damage and for a quick estimation of the panel residual strength with indentation damage.

References listed at the end of the paper:


ABAQUS, 2014 . “ABAQUS Documentation”. Dassault Systèmes, Providence, RI, USA.


ABSTRACT: The response of single and double layered steel plates to localised air-blast loading was examined. Two configurations, both comprising fully clamped circular plates with a 200 mm exposed diameter, were considered: 4mm thick single and 2 2 mm double layered plates. The localised air-blast loading was applied by centrally detonating discs of PE4 plastic explosive. Similar failure modes were evident in the single and double plate configurations, namely, Mode I large inelastic deformation and Mode II capping failure along with deformation responses. The double plates exhibited larger midpoint deflections than the single plates, and partial tearing of the front plate in the double plates was observed at a lower impulse than in the single plates. However, complete capping of both plates in the double plate configuration occurred at the same charge mass as for the single plates, implying that both configurations offer equivalent protection from capping failure as a result of this type of localised blast loading. A metallographic study of the deformed and torn plate regions did not reveal any phase transformation in the steel. It was also found that the 2 mm thick plates exhibited larger increases in grain size than the 4 mm thick plates.

References listed at the end of the paper:


ABSTRACT: As a new kind of composite structures and its advantages, the using of steel tube confined reinforced concrete (STCRC) columns have received increasing attention in civil engineering. Acoustic emission (AE) technique is applied to monitor the damage process of STCRC columns during an uniaxial compression test. The aim of this study is to investigate the damage evaluation and failure mechanisms of the STCRC columns from the perspective of microscopic damage. Typical AE parameters are extracted to quantify different damage condition and identify the critical point. Peak-frequency analysis classify the damage signal into groups, representing different AE generation mechanisms. Extended AE features, such as the RA value and the average frequency are calculated to discriminate the cracking modes of core concrete. The probability based Gaussian mixture model (GMM) are proposed for unsupervised damage pattern recognition. All presented AE results are good in accordance with the observed experimental outcomes. The AE technology enabled evaluating the damage condition, identifying critical point, disclosing the failure mechanism and classifying damage modes for steel confined RC columns effectively.

References listed at the end of the paper:

ABSTRACT: the R-functions theory and Ritz approach are applied to analyze free vibrations of laminated shallow shells with different types of curvatures and complex planforms. Shallow shells are considered as sandwich shells of different types: a) face sheets of shallow shells are made of a functionally graded material (fgm) while cores are made of an isotropic material; b) face sheets of shallow shells are isotropic, but the core is made of fgm. It is assumed that fgm layers are made of a mixture of metal and ceramics, and the effective material properties of layers are varied according to Voight’s rule. The formulation of the problem is carried out using the first-order (Timoshenko’s type) refined theory of shallow shells. Different types of boundary conditions, including clamped, simply supported, free edge, and their combinations, are studied. The proposed method and the developed computer code were examined on test problems for shallow shells with rectangular planforms. In order to demonstrate the capability of the developed approach, novel results are presented for laminated FGM shallow shells with a cut of a complex form. Effects of different material distributions, mechanical properties of the constituent materials, vibration scheme, boundary conditions, and geometrical parameters on natural frequencies are shown and analyzed.

References listed at the end of the paper:

convolution and differential quadrature methods. Compos Struct 183:7-20


ABSTRACT: This paper applies acoustic analysis of Sound Transmission Loss (STL) through infinite Functionally Graded (FG) thick plate employing Hyperbolic Shear Deformation Theory (HSDT). The procedure for applying a FG plate is followed by considering the material properties are changed continually based on power-law distribution of the materials in terms of volume fraction. The main benefit of HSDT can be justified knowing the fact that, it uses parabolic transverse shear strain across thickness direction. Therefore, no need to enter the extra effect of shear correction coefficient factor. Besides, the displacement field is extended as a combination of polynomial as well as hyperbolic tangent function by neglecting the effect of thickness stretching. Furthermore, the equations of motion are obtained employing Hamilton’s Principle. To provide an analytical solution based on HSDT, equations of motion are combined with acoustic wave equations. Moreover, some comparisons are made with the known theoretical and experimental results available in literature to verify the accuracy and efficiency of the current formulation. These comparisons reveal an excellent agreement. Consequently, some configurations are presented to demonstrate which parameters appear to be effective to improve the behavior of STL including the effects of modulus of elasticity and density in the thickness direction with respect to various power-law distributions.

References listed at the end of the paper:


ABSTRACT: Free vibration of a bimaterial circular nano-tube is investigated. The tube is formed by bonding together a Si3N4/SUS304 functionally graded upper semi tube and a ZrO2/Ti-6Al-4V functionally graded lower semi tube. The material properties of the tube are assumed to vary along the radius according to power law with the power index of upper semi tube differing from that of lower semi tube. Based on non-local elasticity theory and Hamilton’s principle, a refined beam model considering the effect of transverse shear deformation is used to derive the governing equations, then analytical solution is obtained by using a two-steps perturbation method. Our results were compared with the existing ones. The effects on tube’s linear and non-linear frequency are analyzed by the factors, including small scale parameter, temperature, the double volume fraction indexes, slenderness ratio and different types of beam model. A new approach is suggested in this article to change the natural frequency of the tubes by adjusting constituent materials. In contrast to conventional approach, the new one can result in more accurate frequency control in the same dimensionless size of tubes.

References listed at the end of the paper:
This paper presents some recent advances on the numerical solution of the classical Germain-Lagrange equation for plate bending of thin elastic plates. A meshless strategy using the Generalized Finite Difference Method (GFDM) is proposed upon substitution of the original fourth-order differential equation by a system composed of two second-order partial differential equations. Mixed boundary conditions, variable nodal density and curved contours are some of the explored aspects. Simulations using very dense clouds and parallel processing scheme for efficient neighbor selection are also presented. Numerical experiments are performed for arbitrary plates and compared with analytical and Finite Element Method solutions. Finally, an overview of the procedure is presented, including a discussion of some future development.

References listed at the end of the paper:

ABSTRACT: The wing leading edge is one of the aircraft structures which are vulnerable to birdstrike. Therefore, Federal Aviation Regulation has clear requirements of anti-birdstrike performance for wing leading edge. However, the impact location is not specified in aviation regulation. The forefront of the wing leading edge is selected as a critical location for the birdstrike in most researches. But the rationality of the selection is not given. This paper proposes an analytical method for determining the critical location that causes the most severe damage under impact due to birdstrike. The analysis is based on the concept of effective impact, i.e. the component of the bird velocity perpendicular to the surface of wing leading edge. A birdstrike model is established using Pam-crash and used to validate the analytical prediction. The numerical model proves its effectiveness compared to the birdstrike test. The residual compressive strength of the spar when the birdstrike is at the critical impact location determined by the proposed method is 44.5% of that at the traditional impact location. Moreover, the critical penetrating velocity of the traditional impact location is not the lowest. In other words, the traditional impact location is not the weakest. Airworthiness verification experiment of birdstrike on wing structure should pay attention to this aspect.

References listed at the end of the paper:
Lopez-Lago, M., R. Casado, A. Bermudez and J. Serna (2017). A predictive model for risk assessment on imminent bird strikes on
ABSTRACT: Strain-rate effects can distort model testing with geometrically-similar models. In impact modelling this problem is usually addressed by revising the impact conditions, but such kind of method is inadequate for modelling impact on a reticulated dome. A new technique was proposed and tested. Apart from adjusting the impact conditions, the technique adds additional mass to components of the model to balance the strain-rate effects. That allows studying in model scale more complex structures in which the strain rate varies over the structure’s components. Model scale tests of impact on a reticulated dome showed good agreement with full scale in terms of displacements and axial forces on the structure’s rods. Those results verify the effectiveness of the new technique.

References listed at the end of the paper:


Perrone N., Bhadra P. (1979). A simplified method to account for plastic rate sensitivity with large deformations [J]. Journal of...
References listed at the end of the paper:


Yang, J., & Chen, Y. (2008). Free vibration and buckling analyses of functionally graded beams with edge cracks. Composite...

ABSTRACT: Effect of the presence of perforations on thin structure has been extensively investigated for decades. Various perforation parameters were investigated in past studies. However, study on thin cylinder with multiple perforations has not been carried out. In searching for lighter structural members, the concept of perforated hollow section has been inspired by the shape and arrangement of multiple perforations observed in the Cholla skeleton. Effects of multiple perforation parameters on circular hollow section have been the main interest. This paper presents the verification of FEM simulation with test results. A non-perforated circular hollow section (control model) and a circular hollow section penetrated with 12 nos. of circular shape perforations in array arrangement were selected for the verification process. Both test specimen and FEA models were subjected to compression, flexural and torsional loads. For result comparison within the material linear range, FEA models show good agreement with test results for compression and flexural load cases, and for control models under torsional load case. For perforated models under torsional load, FEA results correspond well with the inclined strain gauge readings. FEM analysis method is considered capable to produce reliable result for loading within the material linear range for circular hollow sections with multiple perforations.

References listed at the end of the paper:


Masoumeh Soltani and Behrouz Asgarian (First author is from: Department of Civil Engineering, Faculty of
ABSTRACT: In this paper, a new hybrid approach is presented based on the combination of the power series expansions and the Rayleigh-Ritz method for stability and free vibration analyses of axially functionally graded non-uniform beams resting on constant Winkler-Pasternak elastic foundation. In the proposed novel technique, the power series approximation is first adopted to solve the motion equation. Regarding this numerical methodology, the transverse displacement and all mechanical properties are expanded in terms of power series of a known degree. By solving the eigenvalue problem, one can acquire the fundamental natural frequencies. According to aforementioned method, the expression of vibrational mode shape is also determined. Based on the similarities existing between the vibrational and buckling deformation shapes, Rayleigh-Ritz method is finally employed to construct eigenvalue problem for obtaining the critical loads. In order to illustrate the correctness and convergence of the method, several numerical examples of axially non-homogeneous and homogeneous beams are conducted. The obtained outcomes are compared to the results of Finite Element Analysis in terms of ANSYS software and those of other available numerical and analytical solutions. The accuracy of the method is then remarked.

References listed at the end of the paper:
Khaniki H.B. and Rajasekaran S. (2018). “Mechanical analysis of non-uniform bi-directional functionally graded intelligent micro-
MATLAB 7.6, The MathWorks, Inc., Natick, Massachusetts, United States.


ABSTRACT: The behavior and response of pipelines subjected to slip fault movement is studied by numerical simulations as well as experimental setup. A finite element modeling is also developed via ABAQUS software. In this study, an artificial accelerogram is applied to the system and matched against the response spectrum according to the standard No. 2800 (Iranian code of practice for seismic resistant design of buildings, 2014).
Three different pipe nominal sizes and thicknesses (1 1/2, 2 and 4 inch) are considered in the experiments on the shaking table. According to the results, plastic hinge as well as the extremum stress and strain is formed in the fixed soil wedge and at locations close to the fault line. Further, as the pipe D/t ratio increases, the plastic hinge forms further away from the fault line. According to the results, the pipe-soil strain ratio (ep/s) has lower values at larger pipe diameters. Also, the axial strains would be greater for the systems with higher (ep/s) ratios.

References listed at the end of the paper:


ABSTRACT: The assessment of the differences in results obtained from various micromechanics homogenization schemes, as well as the implications of assuming different volume fraction profiles was carried out in the present work. The functionally graded composite chosen for the analysis was al/sic and comparisons were made in terms of stress and strain distributions along the wall of an internally pressurized hollow cylinder. Different micromechanics homogenization schemes were implemented into abaqus as user-defined subroutines (umat). The numerical simulations were compared to a set of analytical solutions available in the literature. The obtained results varied substantially according to the homogenization scheme employed. It was also found that the type of function chosen to describe the volume fraction distribution plays a major role in the development of the hoop stresses. Additionally, the finite element analysis showed significant stress variation when the actual volume fraction distribution was used. These gradients did not appear when the same profile was approximated by smooth exponential functions. This paper points out some important issues related to common practices associated with the analysis of fgm composites and serves as an overtone to a more in-depth discussion of such problems.

J.M. Martinez Valle (1), A. Albanesi (2) and C. Fachinotti (2)

(1) Departamento de Mecánica, Escuela Politécnica Superior de Córdoba, Universidad de Córdoba, España.
(2) CIMEC Centro de Investigación de Métodos Computacionales, UNL, Santa Fe, Argentina.


ABSTRACT: To date, a large number of finite element methods have been developed to study the dynamics of shell structures. Most of them are generally based on the degenerated solid approach and other less in shell theories, but introducing, in this last case, some assumptions to analyze this problem: some of them refer to shallow shells (slightly curved shells), or consider thin shells neglecting shear deformation, or dispense some terms in their stress-strain developments like the off-diagonal components of the curvature or metric tensors (orthogonal coordinates). In the present work, we present an improved finite element method for the linear dynamic analysis of shells, from thin to moderately thick and thick shells, developed in general curvilinear coordinates, based on a refined shear deformation shell theory and free of the well-known shear locking effect. Exact constitutive equations, including higher order moments-strains relations, are also deduced for the adequate analysis of thick shells. To circumvent the shear locking problems, the mixed interpolation of the tensorial components (MITC) of the linear strain tensor is used. An exhaustive study of different surfaces is performed, especially in doubly curved shells, and interesting conclusions of the higher order modes of vibration and the strain energy of the element are derived. Other desirable features like a low computational effort, a straightforward extension to nonlinear formulation and applications for composite shells are found in this novel and general formulation. Very good results in the proposed practical cases have been found.

References listed at the end of the paper:

ABSTRACT:

In this study, finite element analysis was performed to investigate the feasibility of multi-layer pyramidal truss structures as a filler material of energy absorbing tubes. Rectangular tubes with the filler and empty tubes were compressed at a constant velocity of 10km/h and their energy absorbing capabilities were compared to demonstrate the structural benefit of filling materials in the tubes. Additionally, the compressive...
References listed at the end of the paper:


ABSTRACT: The use of integrally stiffened panels (ISP's) in wings of small and medium-sized aircraft is frequent in aviation. These thin-walled structures are often subjected to compressive loads during their life-time and, although the finite element method has become an important tool for engineers to obtain the buckling load of structural members, some results based in charts published by NACA are still used in the preliminary stages of the wing design in many aircraft companies. However, these charts used for calculation of the critical compressive stress consider only idealized stiffened panels and neglect geometric details as the fillet radius used in the current design of ISP's. The objectives of this paper are twofold: (i) to show that the charts published by NACA provide good results for the critical buckling stresses for several geometries of ISP's, when compared to finite element results with proper boundary conditions, providing fillet radii are also neglected in the finite element models and (ii) to show that the values of the critical buckling stresses for local instability of ISP’s may be significantly increased when one considers the effect of the fillet radius, meaning that this parameter should also be considered in the optimal design of such structures. Several numerical results obtained with finite element simulations based on different geometrical parameters of ISP's are presented in this study.

References listed at the end of the paper:

ABSTRACT: The dynamic behavior of cylindrical shells is essential in many practical applications. These include in-vacuum and coupled vibrations of structures with contained fluids. Closed-form solutions are extremely complex since they involve many terms and algebraic operations that require numerical solvers. In this work, a simplified closed-form solution for the free vibration analysis of an empty or filled with an inviscid and incompressible fluid cylindrical tank is presented. The proposed analytical method is developed for a simply supported cylindrical shell, based on an energy formulation obtained with variational calculus, and provides explicit expressions for natural frequencies, which can be easily programmed in a spreadsheet. The fluid is represented by an acoustic cavity, modeled by the wave equation, and the fluid-structure interaction is reduced to an added mass of fluid in the uncoupled shell equations of motion. A finite element model was built using ANSYS software to validate the proposed procedure. The natural frequencies and mode shapes were studied, and the results obtained are consistent with analytical, numerical and experimental results.

References listed at the end of the paper:


ABSTRACT: Digital image correlation (DIC) method has been widely used on dynamical experiments. This full-field and real-time method can fill in the gap of traditional point-based measurements of typical structures subjected to soft body impact such as bird strike. In order to get further understandings of soft body impact process, the present study analyzed the time-dependent energy exchange during impact experiments. The dynamic responses of the aluminum target panels were obtained using 3D digital image correlation method so that their displacement and strain field histories can be tracked. By introducing the material properties of the targets, their time-dependent stress state and consequently the strain energy can be calculated. With the help of time-dependent profiles of target panels, their energy absorption properties were theoretically analyzed.
including the exchange of kinetic energy and plastic work. The results showed that when the impact loadings were increased, the plastic work generated by radial membrane force became the major source of energy dissipation. The transverse movements consumed more kinetic energies than rotatory moments. This research may provide a further application of DIC results and help to better understand the soft body impact process on targets with large deformations.

References listed at the end of the paper:


Chen W., Song B. (2011) Split Hopkinson (Kolsky) Bar Springer US.


ABSTRACT: In this paper, we give overview of deformation modes for the uniform foam filled thin-walled structure such as circular tubes, square tubes, rectangular tubes, tapered tubes, hat tubes and cone tubes. Foam material is used as a reinforcing material on a thin wall tube which has potential as being a good energy absorber. This is evident from many of the studies undertaken on the crashworthiness performance and energy absorption of the thin wall tube. Also, this paper presents a review of the current state of the art in computational optimization methods applied to foam filled structures, offering a clear vision of the latest research advances in this field.

References listed at the end of the paper:
Fang, J., Gao, Y., Sun, G., Qiu, N. & Li, Q. 2015. On design of multi-cell tubes under axial and oblique impact loads. Thin-Walled
Structures 95: 115-126.


ABSTRACT: A simple quasi-3D sinusoidal shear and normal deformations theory for the hygro-thermo-mechanical bending of functionally graded piezoelectric (FGP) plate is developed under simply-supported edge conditions. The governing equations are deduced based on the principle of virtual work. The exact solutions for FGP plate are obtained. The current study investigates the effect of some parameters, like piezoelectricity, hygrothermal parameter, gradient index and electric loading on the mechanical and electric displaceiments, electric potential and stresses. They are explored analytically and numerically presented and discussed in detail. The numerical results clearly show the effect of piezoelectric and hygrothermal parameter on the FGP plate.

References listed at the end of the paper:


ABSTRACT: In this study, a new sub-parametric strip element is developed to simulate the axially loaded composite cylindrical panel with arbitrary cutout. For this purpose, a code called ssfsm is developed in fortran to analyze the buckling of panels. The first order shear deformation theory is used to form the strain-displacement relations. spline and lagrangian functions are used to derive element shape functions in the longitudinal and transverse directions, respectively. The computational cost of the ssfsm is decreased dramatically, as mapping functions of the strip element are very simple. The results obtained from the ssfsm are compared with those of the literature and the results obtained by abaqus to show the validity of the proposed
approach. A parametric study is performed to show the capability of the ssfsm in calculating the panel buckling load. Results indicate that increasing the panel thickness and panel central angles cause an increase in panel buckling load. The cutout shape is an important factor influencing the panel buckling load. For instance, when the angle between the direction of big chord of the elliptical cutout and compressive load direction are 0 and 90 degrees, the panel buckling load reaches its minimum and maximum magnitude, respectively.

References listed at the end of the paper:


References listed at the end of the paper:


Babuška, I., Banerjee, U., 2011. Stable Generalized Finite Element Method (SGFEM), ICES Report (11-07), The Institute for Computational Engineering and Sciences, The University of Texas at Austin. Austin, TX, USA.


In this paper, nonlinear analysis of thick cylindrical shells with arbitrary variable thickness made of hyperelastic FGM cylindrical shells with arbitrary variable thickness made of hyperelastic FGM with radially variable material properties in nearly incompressible state under non-uniform pressure loading is presented. Thickness and pressure of the shell vary in axial direction by linear and/or nonlinear functions. The governing equilibrium equations are derived based on shear deformation theory (SDT). The Mooney-Rivlin type material is considered which is a suitable hyperelastic model for rubbers.

Boundary Layer Method of the perturbation theory which is known as Matched Asymptotic Expansion (MAE) is used for solving the governing equations. A new ingenious solution and formulation have been defined during current study to simplify and abbreviate the representation of inner and outer equations components in MAE. In order to validate the results of the current analytical solution, a numerical modeling based on Finite.
Element Method (FEM) have been investigated. Afterwards, for different rubber case studies, the effect of material constants, inhomogeneity index, geometry and pressure profiles on displacements, stresses and hydrostatic pressure distributions resulting from MAE and FEM solution have been illustrated. This approach enables insight into the nature of the deformation and stress distribution across the wall of rubber vessels and offers the potential for investigating the mechanical functionality of blood vessels such as arteries in physiological pressure range. The results prove the effectiveness of SDT and MAE combination to derive and solve the governing equations of nonlinear problems such as nearly incompressible hyperelastic FG shells.

References listed at the end of the paper:


ABSTRACT: This study aims to generalize a previously developed accurate and inexpensive 3-D zig-zag theory up to an arbitrary representation form and to determine which simplifications are yet accurate in determining transverse shear and normal stress/deformation effects on vibrations of soft-core sandwiches with not moving middle/neutral plane (pumping). Natural frequencies are calculated using displacements assumed differently across the thickness, having fixed d.o.f., not yet explored forms of representation and zig-zag functions differently accounting for the transverse normal deformability and that partially or fully fulfill physical constraints. Applications are presented for sandwich plates and beams with length-to-thickness ratios and material properties of faces and core varying within an industrial range, for which layerwise effects are very important and so suited to the evaluation of theories. Analytical solutions are found using the same trial functions and expansion order for all theories, so to evaluate their accuracy under the same conditions. The choice of the representation form and of zig-zag functions is shown immaterial if displacement field coefficients are recomputed across the thickness by enforcing the fulfillment of all physical constraints (using symbolic calculus). Furthermore, it is shown that assigning a specific role to each coefficient is immaterial, as well as exchanging the order of representation of in-plane and transverse displacement components and even that zig-zag functions could be omitted. This no longer occurs for lower-order theories with only a partial fulfillment of constraints. Pumping motions are highlighted as the first modes, which require the theories much accurately accounting for transverse normal deformability.

References listed at the end of the paper:


Augsburg, Germany

Özgür Kalbaran and Hasan Kurtaran (2)

(1) Department of Mechanical Engineering, Gebze Technical University, Gebze/Kocaeli, Turkey.

(2) Department of Mechanical Engineering, Adana Alparslan Türkes Science and Technology University, Adana, Turkey


ABSTRACT: Nonlinear static response of laminated composite Elliptic Panels of Revolution structure(s) (EPRS) having variable thickness resting on Winkler-Pasternak (W-P) Elastic Foundation is investigated in this article. Generalized Differential Quadrature (GDQ) method is utilized to obtain the numerical solution of EPRS. The first-order shear deformation theory (FSDT) is employed to consider the transverse shear effects in static analyses. To determine the variable thickness, three types of thickness profiles namely cosine, sine and linear functions are used. Equilibrium equations are derived via virtual work principle using Green-Lagrange nonlinear strain-displacement relationships. The deepness terms are considered in Green-Lagrange strain-displacement relationships. The differential quadrature rule is employed to calculate the partial derivatives in equilibrium equations. Nonlinear static equilibrium equations are solved using Newton-Raphson method. Computer programs for EPRS are developed to implement the GDQ method in the solution of equilibrium equations. Accuracy of the proposed method is verified by comparing the results with Finite Element Method (FEM) solutions. After validation, several cases are carried out to examine the effect of elastic foundation parameters, thickness variation factor, thickness functions, boundary conditions and geometric characteristic.
parameter of EPRS on the geometrically nonlinear behavior of laminated composite EPRS.

References listed at the end of the paper:
ABSTRACT: The present study investigates the stability conditions of reinforced concrete panels subjected to fire loading within the framework of limit analysis theory. The method relies in a first step upon the preliminary determination of the temperature dependent interaction diagrams of the structural element. Interaction diagrams derived from the static approach are shown to depend on the geometry of panel cross-section as well as on the strength properties of the constituents, which degrade continuously as fire proceeds. The second step of the method consists in determining the deformed configuration of panel from the analysis of thermo-elastic equilibrium of the structure. The stability analysis and design of the panel in its deformed geometry are then carried out by comparing the distribution of internal efforts to its reduced strength capacities expressed by means of the associated interaction diagrams evaluated in the first step. Several numerical examples are presented to assess the effect of relevant parameters on the overall fire safety of the structure, emphasizing the effectiveness of the approach for design purposes.

References listed at the end of the paper:


ABSTRACT: The present study develops and applies a neuro-fuzzy modal vibration control of smart laminated composite structures with piezoelectric layers via Mixed theory. Differently from previous studies, the composite structures in this paper are modeled via the Mixed Theory using the High-order Shear Deformation Theory (HSST) theory. The Mixed Theory adopts a single layer when representing the mechanical displacement field, through HSST theory, and multiple layers (Layerwise theory) for the electrical degrees of freedom. The Mixed Theory is computationally implemented in the Matlab® software using a plate-type element called Serendipity. Moreover, a neuro-fuzzy active vibration controller is implemented to attenuate the vibration of the smart composite structures. The numerical results validate the electric-mechanical coupling adopted, showing the importance of the mixed theory in the static and dynamic modeling of slender beams and plates with piezoelectric layers. Finally, the results of the robustness analysis indicate that the neuro-fuzzy controller has benefits compared with the linear quadratic regulator.

Ruilin Shen, Jianchun Xiao, Kejian Ma, Jiayi Mao, Guiping Li, Weiyi Zeng and Qin Wang (First author is from: Space Structures Research Center, Guizhou University, Guiyang, China / Key Laboratory of Structural

ABSTRACT: Steel open-web sandwich floors (SOSFs) have been applied in several pioneering industrial and public buildings. The traditional square tube shear key (STSK) is changed into a flanged cruciform section shear key (FCSK) to further improve the bearing capacity of SOSFs. A half-scale test model is designed. A graded static loading test is performed to measure deflection and strain. The calculation formula of the intersection beam analogy method (IBAM) considering the influence of shear stiffness is proposed. A finite element (FE) analysis was also performed. The results of the test, IBAM and FE method are compared. The maximum deflection of the deflection obtained by them is less than 5%, and the maximum strain error is less than 7%. These figures prove that all three methods have high precision in the elastic range. Compared SOSFs use a different shear keys with the same grid size and chords, the maximum Mises stress is reduced by 55.9% and the maximum displacement is reduced by 36.1%. The new shear key imparts the structure with improved bearing capacity and safety margin.

References listed at the end of the paper:
ABSTRACT: Maintenance work is very important for the continuation of the long service periods planned in engineering structures. Some damage to the steel elements, such as the growth of the holes in the structure, leads to reduced buckling strength and shortened service life. Moreover, the criterion of the hole is uncertain for steel structures. For this reason, it is very important to predict and evaluate the buckling strength of a damaged structure and to take necessary measures. Therefore, in this article, a series of systematic experimental studies are carried out to calculate the buckling strength of elliptical perforated steel columns. Deformation shapes and load-displacement graphs of the test columns are plotted. In addition, the behavior of the column under axial load is analyzed by constructing a finite element model. Numerical simulations are performed with Dynaform finite element package. The effect of the elliptical hole on the column buckling strength by changing the width, height and center is investigated numerically and experimentally. Prepared samples are subjected to axial loading test and compared with numerical results. In light of the data obtained from the numerical results, the effect of the width, height and center of a single elliptical hole on the buckling strength of the column is clearly demonstrated.

References listed at the end of the paper:


ABSTRACT: Composite alveolar beams consist in the union of two structural systems largely employed in civil construction sector: the steel-concrete composite beams and the alveolar steel beams. Thus, its use allows their advantages to be enhanced, enabling to design even larger spans and to achieve more economical and sustainable solutions. Considering that Brazilian and international standards do not directly specify criteria for the analysis and design of these beams, in this paper it is presented the development and validation of an updated finite element model, using ANSYS software, capable of simulating different failure modes that may occur, such as web-post buckling, Vierendeel mechanism and flexural mechanism. The obtained results presented a good correlation with experimental results from previous works. After the model validation, the effect of the openings on the composite beam was investigated and discussed, and it was concluded that the web-post buckling may limit the structural gains on load capacity, so it is important to adopt opening patterns that enhance the resistance of the beam to this mode of failure.

References listed at the end of the paper:


ABSTRACT: In this research, the multilayered composite plates made of glass/epoxy material were experimentally and numerically investigated under compressive loading conditions. The intact and defected structures were analyzed with the use of finite element method. The influence of the thickness and geometrical imperfection level were carried out in the linear buckling analysis. The nonlinear analysis was performed to determine the influence of the delamination length on the buckling behavior of the plate. The numerical results were validated by experiments. Experimental tests were performed for structures having artificial delamination between laminate layers. The buckling behavior was monitored using the nondestructive and noncontact structural vision-based health monitoring system (the digital image correlation (DIC)). The influence of the different delamination behavior during the tests on the compressive load capacity was determined by a detailed analysis of DIC measurements. The 20% reduction of the compressive load was noticed in the cases with local buckling of delamination.

References listed at the end of the paper:
Muc, A., (2011a), SHM of composite cylindrical multilayered shells with delaminations, Proceeding of the18th International Conference on Composite Materials ICCM18, Jeju, Korea.

ABSTRACT: To analyze thin and thick plates, the paper presents two rectangular finite elements with high accuracy. In these elements, the proposed formulations of the displacement field utilize the Bergan-Wang approach, which depends only on one variable: the plate lateral deflection. This approach ensures that shear-locking problem will not happen as thickness decreases. The degrees of freedom of the proposed elements are twenty-four for the first element and it is named BWRE24, while the second one has thirty-six degrees of freedom and is named BWRE36. To evidence the efficiency of the two elements, a series of numerical examples for an isotropic plate subjected to various loadings and with different boundary conditions have been analyzed. Very good results are obtained suffering no numerical difficulties in case of very thin plates.

References listed at the end of the paper:

ABSTRACT: Passenger safety and low fuel consumption rate are the most important factors that need to be considered when designing modern transportations. This study validates the crash behavior and optimum values of foam-filled structures under the dynamic oblique impact using the Weibull distribution. The optimization method aimed to absorb maximum energy with minimum peak crushing force. Furthermore, the metamodel and optimization techniques such as RBF and NSGA-II were used to ensure accurate validation of the Weibull distribution method. The result showed that the finite element model is comparable to the experimental data in the reference, while the metamodel method, which is directly verified, affects optimization results. The Weibull distribution method shows that the optimum value and the simulation have good accuracy or $R^2>0.85$.

References listed at the end of the paper:


Fang, J., Gao, Y., Sun, G., Qiu, N. & Li, Q. 2015. On design of multi-cell tubes under axial and oblique impact loads. Thin-Walled Structures 95: 115-126.


ABSTRACT: We propose, in this paper, stochastic isogeometric analysis (SIGA) is a type of non-statistic approach in which combines the perturbation technique with the standard isogeometric analysis, in particular for static behavior of functionally graded plates with the uncertain elastic modulus. We assume that the spatial random variation of elastic modulus can be modeled as a two dimensional Gaussian random field in the plane of the plate. The random field is discretized to set of random variables using the integration point method. The system equations of SIGA are created using the NURBS functions for approximation displacement fields in conjunction with the first-order and second-order perturbation expansions of random fields, stiffness matrix, displacement fields. Besides the non-statistic approach, Monte Carlo simulation is presented for validation. The accuracy and appropriateness of the non-statistic approach are demonstrated via comparisons of the present results with those given by the stochastic finite element method in the literature and by the Monte Carlo analysis as well. The numerical examples are employed to investigate the effect of the randomness of elastic modulus and system parameters on the first and second statistical moments of displacement.

References listed at the end of the paper:
Cavdar, O., Bayraktar, A., Cavdar, A. and Adanur, S. (2008), Perturbation based stochastic finite element analysis of the structural systems with composite sections under earthquake forces, Steel Compos. Struct. Steel and Composite Structures, 8(2), 129-144.
Choi, C. and Noh, H. (1996), Stochastic finite element analysis of plate structures by weighted integral method, Structural Engineering...
and Mechanics, 4(6), 703-715.


Hosseini, S.M. and Shahabian, F. (2014), Stochastic analysis of elastic wave and second sound propagation in media with Gaussian uncertainty in mechanical properties using a stochastic hybrid mesh-free method, Structural Engineering and Mechanics, 49(1), 41-64.


The paper considers the effect of imperfect length on the buckling behavior of axially compressed mild steel truncated cone. Three types of initial geometric imperfections with different number of waves along the compressed edge are analyzed, and they are: (i) sinusoidal waves, (ii) triangular waves, and (iii) square waves. A validation of experimental data from previous study and further numerical calculations are provided in this paper. A good repeatability of experimental data was revealed through the test results with only 0% to 7% of error. Numerical simulations were carried out using ABAQUS FE code. It is shown that the buckling load of the cone is differently affected by the shape and amplitude of the imperfection. Apparently, the buckling loads of analyzed cones are less sensitive when imperfection shape is triangular as compared to other imperfection shapes. Furthermore, the effect of number of waves on buckling load of axially compressed cones was investigated for the above three cases. Results indicate that the influence of number of waves on the load carrying capacity of the cone is less significant.
References listed at the end of the paper:

ABSTRACT: This paper presents an exact solution for the boundary-value problem which describes the linear buckling of axially-compressed cylindrical panels with frames attached to the circular edges. The boundary conditions differ from the classical simply supported ones, often assumed for design purposes, in the sense that the torsion resisted by the frames are also taken into account. The quality of the results reported herein may be valuable benchmark data.

References listed at the end of the paper:


https://doi.org/10.1016/j.compstruct.2016.02.023


https://doi.org/10.1016/j.compstruct.2016.02.023


https://doi.org/10.1016/j.compstruct.2016.02.023


ABSTRACT: The influence of crack geometry on the buckling load of axially compressed mild steel cones was presented in this paper. The following geometrical parameter was used: bottom radius-to-top radius ratio, \( r_2/r_1 = 2.0 \); top radius-to-thickness ratio, \( r_1/t = 25 \); axial length-to-bottom radius ratio, \( L/r_2 = 2.24 \); nominal shell thickness, \( t = 1 \text{mm} \); cone angle, \( \beta = 12.6^\circ \). The local buckling phenomenon was investigated through a series of numerical computations (50 \( \leq t \leq 2000 \)). Numerical results show that crack geometry (i.e., length and orientation) influences the buckling strength of the cones differently. For instance, as the crack length increases, the loading capacity of cones drops; cones with a circumferential crack (0°) display the most severe drop. As the crack orientation increases (from 0° to 90°) the buckling strength of the cracked cones with crack length greater than 1 increases. Whereas, for cracked cones with crack length less than 1, increasing the crack orientation has little or no effect on the buckling strength. Hence, it can be said that crack orientation has a secondary effect on the buckling of cracked conical shells.

References listed at the end of the paper:

ABSTRACT: Buckling mode interaction in cold-formed steel (CFS) members must be considered for the structural design, which may lead to a significant reduction of the structural strength, usually recognized as erosion of the limit load. So far, the distortional-global (DG) buckling interaction is not covered by codes, e.g. Brazilian code NBR 14762:2010. The present investigation is aimed at the DG interaction of CFS lipped channel (LC) columns, which is the most usual section. The methodology evolves a parametric analysis, over a single LC column under DG buckling interaction. First, a study of initial geometric imperfection (IGI) sensibility is performed, with the purpose of understanding the influence of the IGI on the column’s behavior. Moreover, the parametric analysis is extended to a set of yielding stress and column lengths, to understand the ultimate load under different types of DG buckling interaction natures. Conclusions on this research have been shown that the actual global buckling equation from the Direct Strength Method is already suitable to cover the DG buckling interaction for the case of lipped channel columns.

References listed at the end of the paper:


HEVA, Y. B. Behaviour and design of cold-formed steel compression members at elevated temperatures, 2009. Thesis, School of Urban Developments Queensland University of Technology.


LAZZARI, J. A. Distortional-Global Interaction In Cold-Formed Steel Lipped Channel Columns: Buckling Analysis, Structural Behavior And Strength, 2020. Master’s Thesis, Civil Engineering Program, Federal University of Rio de Janeiro, COPPE.


YOUNG, B.; DINIS, P. B.; CAMOTIM, D. CFS lipped channel columns affected by L

WINTER, G. Thin

WEMPNER, G. A. Discrete approximations relate

VLASOV, V. Thin


ABSTRACT: Since structural engineering requires highly developed and optimized structures, the thickness dependency is one of the most controversially debated topics. This paper deals with stability analysis of lightweight thin structures combined with arbitrary geometrical imperfections. Generally known design guidelines only consider imperfections for simple shapes and loading, whereas for complex structures the lower-bound design philosophy still holds. Herein, uncertainties are considered with an empirical knockdown factor representing a lower bound of existing measurements. To fully understand and predict expected bearable loads, numerical investigations are essential, including geometrical imperfections. These are implemented into a stand-alone program code with a stochastic approach to compute random fields as geometric imperfections that are applied to nodes of the finite element mesh of selected structural examples. The stochastic approach uses the Karhunen–Loève expansion for the random field discretization. For this approach, the so-called correlation length \( \ell \) controls the random field in a powerful way. This parameter has a major influence on the buckling shape, and also on the stability load. First, the impact of the correlation length is studied for simple structures. Second, since most structures for engineering devices are more complex and combined structures, these are intensively discussed with the focus on constrained random fields for e.g. flange–web-intersections. Specific constraints for those random fields are pointed out with regard to the finite element model. Further, geometrical imperfections vanish where the structure is supported.

References listed at the end of the paper:

ABSTRACT: An efficient numerical method is developed for the simulation of dynamic response and the prediction of the wave propagation in composite plate structures. The method is termed finite wavelet domain method and takes advantage of the outstanding properties of compactly supported 2D Daubechies wavelet scaling functions for the spatial interpolation of displacements in a finite domain of a plate structure. The development of the 2D wavelet element, based on the first order shear deformation laminated plate theory is described and equivalent stiffness, mass matrices and force vectors are calculated and synthesized in the wavelet domain. The transient response is predicted using the explicit central difference time integration scheme. Numerical results for the simulation of wave propagation in isotropic, quasi-isotropic and cross-ply laminated plates are presented and demonstrate the high spatial convergence and problem size reduction obtained by the present method.

ABSTRACT: The contribution addresses the finite element analysis of bending of plates given the Kirchhoff-Love model. To analyze the static deformation of plates with different loadings and geometries, the principle of virtual work is used to extract the weak form. Following deriving the strain field, stresses and resultants may be obtained. For constructing four-node quadrilateral plate elements, the Hermite polynomials defined with respect to the variables in the parent space are applied explicitly. Based on the approximated field of displacement, the stiffness matrix and the load vector in the finite element method are obtained. To demonstrate the performance of the subparametric 4-node plate elements, some known, classical examples in structural mechanics are solved and there are comparisons with the analytical solutions available in the literature.

References listed at the end of the paper:


ABSTRACT: This paper develops a coupling approach which integrates the meshfree method and isogeometric analysis (IGA) for static and free-vibration analyses of cracks in thin-shell structures. In this approach, the domain surrounding the cracks is represented by the meshfree method while the rest domain is meshed by IGA. The present approach is capable of preserving geometry exactness and high continuity of IGA. The local refinement is achieved by adding the nodes along the background cells in the meshfree domain. Moreover, the equivalent domain integral technique for three-dimensional problems is derived from the additional Kirchhoff–Love theory to compute the J-integral for the thin-shell model. The proposed approach is able to address the problems involving through-the-thickness cracks without using additional rotational degrees of freedom, which facilitates the enrichment strategy for crack tips. The crack tip enrichment effects and the stress distribution and displacements around the crack tips are investigated. Free vibrations of cracks in thin shells are also analyzed. Numerical examples are presented to demonstrate the accuracy and computational efficiency of the coupling approach.

References listed at the end of the paper:

ABSTRACT: This work presents a systematic study of discontinuous and nonconforming finite element methods for linear elasticity, finite elasticity, and small strain plasticity. In particular, we consider new hybrid methods with additional degrees of freedom on the skeleton of the mesh and allowing for a local elimination of the element-wise degrees of freedom. We show that this process leads to a well-posed approximation scheme. The quality of the new methods with respect to locking and anisotropy is compared with standard and in addition locking-free conforming methods as well as established (non-) symmetric discontinuous Galerkin methods with interior penalty. For several benchmark configurations, we show that all methods converge asymptotically for fine meshes and that in many cases the hybrid methods are more accurate for a fixed size of the discrete system.

References listed at the end of the paper:
ABSTRACT: In this paper truncated hierarchical B-spline (THB-spline) is coupled with reproducing kernel particle method (RKPM) to blend advantages of the isogeometric analysis and meshfree methods. Since under certain conditions, the isogeometric B-spline and NURBS basis functions are exactly represented by reproducing kernel meshfree shape functions, recursive process of producing isogeometric bases can be omitted. More importantly, a seamless link between meshfree methods and isogeometric analysis can be easily defined which provide an authentic meshfree approach to refine the model locally in isogeometric analysis. This procedure can be accomplished using truncated hierarchical B-splines to construct new bases and adaptively refine them. It is also shown that the THB–RKPM method can provide efficient approximation schemes for numerical simulations and represent a promising performance in adaptive refinement of partial differential equations via isogeometric analysis. The proposed approach for adaptive locally refinement is presented in detail and its effectiveness is investigated through well-known benchmark examples.

References listed at the end of the paper:

ABSTRACT: A beam formulation based on reproducing kernel particle method (RKPM) for the dynamic analysis of stiffened shell structures is presented in this paper. The kinematic description of a beam is obtained based on the Timoshenko beam theory. By using the principle of virtual power, the governing equations of a three-dimensional beam are derived. To obtain the numerical model of stiffened shell structures, two schemes are adopted: one is model stiffeners by the RKPM beam formulation, the other one is model the entire stiffened shell by the RKPM shell formulation. In the first scheme, the coupling model of RKPM shell and beam formulation is obtained by adding the corresponding quantities in their governing equations. In the second scheme, by determining the support domain of a stress point according to which component the stress point is located, the full shell simulation is achieved. The reliability and accuracy of those two schemes are verified by several numerical examples.

References listed at the end of the paper:

ABSTRACT: This paper presents a numerical procedure to couple shell to solid elements by using the Nitsche’s method. The continuity of displacements can be satisfied approximately with the penalty method, which is effective in setting the penalty parameter to a sufficiently large value. When the continuity of only displacements on the interface is applied between shell and solid elements, an unreasonable deformation may be observed near the interface. In this work, the continuity of the stress vector on the interface is considered by employing the Nitsche’s method, and hence a reasonable deformation can be obtained on the interface. The authors propose two types of shell elements coupled with solid elements in this paper. One of them is the conventional MITC4 shell element, which is one of the most popular elements in engineering applications. This approach shows the capability of discretizing the domain of the structure with the different types of elements. The other is the shell element with additional degrees of freedom to represent thickness direction on the interface can be considered. Several numerical examples are presented to examine the fundamental performance of the proposed procedure. The behavior of the proposed simulation model is compared with that of the whole domain discretized with only solid elements.

References listed at the end of the paper:


ABSTRACT: A modified rigid-object formulation is developed, and employed as part of the fluid–object interaction modeling framework from Akkerman et al. (J Appl Mech 79(1):010905, 2012. [https://doi.org/10.1115/1.4005072]) to simulate free vibration and flutter of long-span bridges subjected to strong winds. To validate the numerical methodology, companion wind tunnel experiments have been conducted. The results show that the computational framework captures very precisely the aeroelastic behavior in terms of aerodynamic stiffness, damping and flutter characteristics. Considering its relative simplicity and accuracy, we conclude from our study that the proposed free-vibration simulation technique is a valuable tool in engineering design of long-span bridges.

References listed at the end of the paper:
10. R. P. Selvam, S. Govindaswamy, W. Bosch, Aerodynamic analysis of bridges using FEM and moving grids, Wind and Structures 5 (2, 3), 2002, 257–266. [https://doi.org/10.12989/was.2002.5.2_3.4.275]
finite elements. The semi-components like geometrically e
method and multibody system formalism with a robust integration scheme. Each mechanical system under
slender structures made of composite multilayer and hyperelastic materials, which combines fin
slender structures: A new object
Cristian Guillermo G
Comput Fluids 49(1):93
73. Hsu MC, Akkerman I, Bazilevs Y (2011) Hig
phase
interfaces. In: Proceedi
71. Tezduyar TE (2001) Finite element interface
Eng Mech 135(8):771
66
stabilized finite element method. Comput Methods Appl Mech Eng 190:305
65.
64.
63.
62.
60.
59.
58.
57.
56.
55.
54.
53.
52.
51.
50.
49.
48.
47.
46.
45.
44.
43.
42.
41.
40.
39.
38.
37.
36.
35.
34.
33.
32.
31.
30.
29.
28.
27.
26.
25.
24.
23.
22.
21.
20.
19.
18.
17.
16.
15.
14.
13.
12.
11.
10.
9.
8.
7.
6.
5.


ABSTRACT: With this work, we present a new object-oriented framework to study the nonlinear dynamics of slender structures made of composite multilayer and hyperelastic materials, which combines finite element method and multibody system formalism with a robust integration scheme. Each mechanical system under consideration is represented as a collection of infinitely stiff components, such as rigid bodies, and flexible components like geometrically exact beams and solid-degenerate shells, which are spatially discretized into finite elements. The semi-discrete equations are temporally discretized for a fixed time increment with a
momentum-preserving, energy-preserving/dissipative method, which allows the systematic annihilation of unresolved high-frequency content. As usual in multibody system dynamics, kinematic constraints are employed to render supports, joints and structural connections. The presented ideas are implemented following the object-oriented programming philosophy. The approach, which is perfectly suitable for wind energy or aeronautical applications, is finally tested and its potential is illustrated by means of numerical examples.

References listed at the end of the paper:

Jeferson Wilian Dossa Fernandes, Humberto Breves Coda and Rodolfo Andre Kuche Sanches (Structural Engineering Department, School of Engineering of São Carlos, University of São Paulo, São Carlos, Brazil), “ALE incompressible fluid-shell coupling based on a higher-order auxiliary mesh and positional shell finite element”, Computational Mechanics, Vol. 63, No. 3, pp 555-569, March 2019

ABSTRACT: One of the most employed strategies in finite element analysis of fluid–structure interaction (FSI) problems involves using an arbitrary Lagrangian–Eulerian (ALE) method for the fluid, requiring an additional step to the partitioned coupling algorithm: the dynamic mesh moving. Mesh moving techniques need to avoid excessive element distortion or inversion. In this work, we develop a partitioned FSI algorithm for large displacement shell structures-incompressible flow interaction analysis using the finite element method (FEM). The coupling is performed by a block Gauss–Seidel implicit approach and the fluid mesh is updated by a linear Laplacian smoothing. To save computing time and avoid element inversion during the mesh deformation procedure, we introduce a coarse higher-order auxiliary mesh, which is used only to capture the structural deformation and extend it to the fluid domain. The shell structure is modeled by a FEM formulation with nodal positions and components of an unconstrained vector as degrees of freedom, which avoids the need for dealing with large rotations approximations. We solve the fluid dynamics equations in the ALE description using an implicit time marching temporal integrator and stabilized mixed FEM spatial discretization. Finally, the accuracy and robustness of the proposed method are tested with numerical examples compared to the literature results.

References listed at the end of the paper:


ABSTRACT: Geometrically nonlinear analysis of shell structures is conducted using weak form quadrature elements. A new geometrically exact shell formulation incorporating drilling degrees of freedom is established wherein rotation quaternions in combination with a total Lagrange updating scheme are employed for rotation description. An extended kinematic condition to serve as the drilling rotation constraint, derived from polar decomposition of modified mid-surface deformation gradient, is exactly satisfied in the formulation. Several benchmark examples are presented to illustrate the versatility and robustness of the present formulation.

References listed at the end of the paper:

Kenji Takizawa, Tayfun E. Tezduyar and Takafo K Sasaki (Primarily from: Department of Modern Mechanical Engineering, Waseda University, Shinjuku-ku, Japan), “Isogeometric hyperelastic shell analysis with out-of
plane deformation mapping”, Computational Mechanics, Vol. 63, No. 4, pp 681-700, April 2019

ABSTRACT: We derive a hyperelastic shell formulation based on the Kirchhoff–Love shell theory and
isogeometric discretization, where we take into account the out-of-plane deformation mapping. Accounting for
that mapping affects the curvature term. It also affects the accuracy in calculating the deformed-configuration
out-of-plane position, and consequently the nonlinear response of the material. In fluid–structure interaction
analysis, when the fluid is inside a shell structure, the shell midsurface is what it would know. We also propose,
as an alternative, shifting the “midsurface” location in the shell analysis to the inner surface, which is the
surface that the fluid should really see. Furthermore, in performing the integrations over the undeformed
configuration, we take into account the curvature effects, and consequently integration volume does not change
as we shift the “midsurface” location. We present test computations with pressurized cylindrical and spherical
shells, with Neo-Hookean and Fung’s models, for the compressible- and incompressible-material cases, and for
two different locations of the “midsurface.” We also present test computation with a pressurized Y-shaped tube,
tended to be a simplified artery model and serving as an example of cases with somewhat more complex
geometry.

References listed at the end of the paper:

   Methods Appl Mech Eng 198:3902–3914
   Numer Methods Eng 89:323–336
    fluid–structure interaction simulations of bioprosthesis heart valves using parametric design with T-splines and Fung-type material
    Methods Biomed Eng 34(4):e2958
References listed at the end of the paper: valves, from thermo ranging from Orion spacecraft parachutes to wind turbines, from patient computers. For quarter of a century, these computations brought solution to many classes of complex problems are now also with isogeometric disc computations that have taken place since then. These computations started with finite element discretization and computations in practical engineering applications were already enabled in 1993. We summarize the "enabling practical implementation of the space–time FEM for engineering applications." In fact, space–time computations in practical engineering applications were already enabled in 1993. We summarize the

ABSTRACT: In an article published online in July 2018 it was stated that the algorithm proposed in the article is "enabling practical implementation of the space–time FEM for engineering applications." In fact, space–time computations in practical engineering applications were already enabled in 1993. We summarize the computations that have taken place since then. These computations started with finite element discretization and are now also with isogeometric discretization. They were all in 3D space and were all carried out on parallel computers. For quarter of a century, these computations brought solution to many classes of complex problems ranging from Orion spacecraft parachutes to wind turbines, from patient-specific cerebral aneurysms to heart valves, from thermo-fluid analysis of ground vehicles and tires to turbocharger turbines and exhaust manifolds.

References listed at the end of the paper:


92.


ABSTRACT: In this paper, two eight-node asymmetric solid-shell elements are firstly presented to illustrate the use of traditional finite element technique in G MEM for constructing new finite element formulations. In these two elements, the analytical method is utilized to derive the displacement functions of the basic in-plane modes, which makes the resulted elements free of mesh distortions for these modes. For out-of-plane modes, the Mindlin plate elements CQUAD4 and QTS4 are integrated to calculate the corresponding modal displacement vectors and modal force vectors of solid-shell elements. As a result, the displacement functions of the plate-bending element range up to three orders of magnitude. On the other hand, since the asymmetric elements cannot be applied to frequency analysis, two symmetric solid-shell elements are proposed by using a modal transformation method, in which the in-plane modes are derived from the previous proposed symmetric solid element S-MEM8S and the out-of-plane modes are constructed by plate elements CQUAD4 and QTS4, respectively. Various benchmarks including linear static and frequency analysis are presented to demonstrate the accuracy and efficiency of the presented elements.

References listed at the end of the paper:

Takashi Kuraishi, Kenji Takizawa and Tayfun E. Tezduyar (First author is from: Department of Modern Mechanical Engineering, Waseda University, Tokyo, Japan), “Tire aerodynamics with actual tire geometry, road contact and tire deformation”, Computational Mechanics, Vol. 63, No. 6, pp 1165-1185. June 2019

ABSTRACT: Tire aerodynamics with actual tire geometry, road contact and tire deformation pose tough computational challenges. The challenges include (1) the complexity of an actual tire geometry with longitudinal and transverse grooves, (2) the spin of the tire, (3) maintaining accurate representation of the boundary layers near the tire while being able to deal with the flow-domain topology change created by the road contact and tire deformation, and (4) the turbulent nature of the flow. A new space–time (ST) computational method, “ST-SI-TC-IGA,” is enabling us to address these challenges. The core component of the ST-SI-TC-IGA is the ST Variational Multiscale (ST-VMS) method, and the other key components are the ST Slip Interface (ST-SI) and ST Topology Change (ST-TC) methods and the ST Isogeometric Analysis (ST-IGA). The VMS feature of the ST-VMS addresses the challenge created by the turbulent nature of the flow, the moving-mesh feature of the ST framework enables high-resolution flow computation near the moving fluid–solid interfaces, and the higher-order accuracy of the ST framework strengthens both features. The ST-SI enables moving-mesh computation with the tire spinning. The mesh covering the tire spins with it, and the SI between the spinning mesh and the rest of the mesh accurately connects the two sides of the solution. The ST-TC enables moving-mesh computation even with the TC created by the contact between the tire and the road. It deals with the contact while maintaining high-resolution flow representation near the tire. Integration of the ST-SI and ST-TC enables high-resolution representation even though parts of the SI are coinciding with the tire and road surfaces. It also enables dealing with the tire–road contact location change and contact sliding. By integrating the ST-IGA with the ST-SI and ST-TC, in addition to having a more accurate representation of the tire geometry and increased accuracy in the flow solution, the element density in the tire grooves and in the narrow spaces near the contact areas is kept at a reasonable level. We present computations with the ST-SI-TC-IGA and two models of flow around a rotating tire with road contact and prescribed deformation. One is a simple 2D model for verification purposes, and one is a 3D model with an actual tire geometry and a deformation pattern provided by the tire company. The computations show the effectiveness of the ST-SI-TC-IGA in tire aerodynamics.

References listed at the end of the paper:


D. Schöllhammer and T. P. Fries (Institute of Structural Analysis, Graz University of Technology, Graz, Austria), “Kirchhoff–Love shell theory based on tangential differential calculus”, Computational Mechanics, Vol. 64, No. 1, pp 113-121, July 2019

ABSTRACT: The Kirchhoff–Love shell theory is recasted in the frame of the tangential differential calculus (TDC) where differential operators on surfaces are formulated based on global, three-dimensional coordinates. As a consequence, there is no need for a parametrization of the shell geometry implying curvilinear surface coordinates as used in the classical shell theory. Therefore, the proposed TDC-based formulation also applies to shell geometries which are zero-isosurfaces as in the level-set method where no parametrization is available in general. For the discretization, the TDC-based formulation may be used based on surface meshes implying element-wise parametrizations. Then, the results are equivalent to those obtained based on the classical theory. However, it may also be presented in recent finite element approaches as the TraceFEM and CutFEM where shape functions are generated on a background mesh without any need for a parametrization. Numerical results presented herein are achieved with isogeometric analysis for classical and new benchmark tests. Higher-order convergence rates in the residual errors are achieved when the physical fields are sufficiently smooth.

References listed at the end of the paper:
· 21.
experiments. quadrilateral and triangular meshes. The methods are verified by a convergence analysis in numerical experiments. We present high order surface finite element methods for the linear analysis of seven-parameter shells. The special feature of these methods is that they work with the exact geometry of the shell reference surface which can be given parametrically by a global map or implicitly as the zero level-set of a level set function. Furthermore, a special treatment of singular parametrizations is proposed. For the approximation of the shell displacement parameters we have implemented arbitrary order hierarchical shape functions on quadrilateral and triangular meshes. The methods are verified by a convergence analysis in numerical experiments.
References listed at the end of the paper:


ABSTRACT: Because the medical-image-based geometries used in patient-specific arterial fluid–structure interaction computations do not come from the zero-stress state (ZSS) of the artery, we need to estimate the ZSS required in the computations. The task becomes even more challenging for arteries with complex geometries, such as the aorta. In a method we introduced earlier the estimate is based on T-spline discretization of the arterial wall and is in the form of integration-point-based ZSS (IPBZSS). The T-spline discretization enables dealing with complex arterial geometries, such as an aorta model with branches, while retaining the desirable features of isogeometric discretization. With higher-order basis functions of the isogeometric discretization, we may be able to achieve a similar level of accuracy as with the linear basis functions, but using larger-size and fewer elements. In addition, the higher-order basis functions allow representation of more complex shapes within an element. The IPBZSS is a convenient representation of the ZSS because with isogeometric discretization, especially with T-spline discretization, specifying conditions at integration points is more straightforward than imposing conditions on control points. The method has two main components. 1. An iteration technique, which starts with a calculated ZSS initial guess, is used for computing the IPBZSS such that when a given pressure load is applied, the medical-image-based target shape is matched. 2. A design procedure, which is based on the Kirchhoff–Love shell model of the artery, is used for calculating the ZSS initial guess. Here we increase the scope and robustness of the method by introducing a new design procedure for the ZSS initial guess. The new design procedure has two features. (a) An IPB shell-like coordinate system, which increases the scope of the design to general parametrization in the computational space. (b) Analytical solution of the force equilibrium in the normal direction, based on the Kirchhoff–Love shell model, which places proper constraints on the design parameters. This increases the estimation accuracy, which in turn increases the robustness of the iterations and the convergence speed. To show how the new design procedure for the ZSS initial guess performs, we first present 3D test computations with a straight tube and a Y-shaped tube. Then we present a 3D computation where the target geometry is coming from medical image of a human aorta, and we include the branches in the model.

References listed at the end of the paper:


Jongmin Seo, Daniele E. Schiavazzi, Alison L. Marsden, “Performance of preconditioned iterative linear solvers for cardiovascular simulations in rigid and deformable vessels”, Computational Mechanics, Vol. 64, No. 3, pp 717-739, September 2019

ABSTRACT: Computing the solution of linear systems of equations is invariably the most time consuming task in the numerical solutions of PDEs in many fields of computational science. In this study, we focus on the numerical simulation of cardiovascular hemodynamics with rigid and deformable walls, discretized in space and time through the variational multiscale finite element method. We focus on three approaches: the problem agnostic generalized minimum residual and stabilized bi-conjugate gradient (BICGS) methods, and a recently proposed, problem specific, bi-partitioned (BIPN) method. We also perform a comparative analysis of several preconditioners, including diagonal, block-diagonal, incomplete factorization, multigrid, and resistance based methods. Solver performance and matrix characteristics (diagonal dominance, symmetry, sparsity, bandwidth and spectral properties) are first examined for an idealized cylindrical geometry with physiologic boundary conditions and then successively tested on several patient-specific anatomies representative of realistic cardiovascular simulation problems. Incomplete factorization preconditioners provide the best performance and results in terms of both strong and weak scalability. The BIPN method was found to outperform other methods in patient-specific models with rigid walls. In models with deformable walls, BIPN was outperformed by BICG with diagonal and incomplete LU preconditioners.

References listed at the end of the paper:
ABSTRACT: We present a meshless discretisation method for the solution of the non-linear equations of the von Kármán plate containing folds. The plate has Mindlin–Reissner kinematics where the rotations are independent of the derivatives of the normal deflection, hence discretised with different shape functions. While in cracks displacements are discontinuous, in folds, rotations are discontinuous. To introduce a discontinuity in the rotations, we use an enriched weight function previously derived by the authors for cracks (Barbieri et al. in Int J Numer Methods Eng 90(2):177–195, 2012). With this approach, there is no need to introduce additional degrees of freedom for the folds, nor the mesh needs to follow the folding lines. Instead, the folds can be arbitrarily oriented and have endpoints either on the boundary or internal to the plate. Also, the geometry of the folds can be straight or have kinks. The results show that the method can reproduce the sharp edges of the folding lines, for various folding configurations and compare satisfactorily with analytical formulas for buckling or load-displacement curves from reference solutions.

References listed at the end of the paper:


ABSTRACT: Theoretical and computational aspects of rotation vector and its complement parameterization are examined in detail in this paper. The mutual relationships between the variations of rotation vector and its complement and the spin variable are presented. It shows that the switch of rotation parameter between rotation vector and its complement preserves not only the strains but also the angular velocity and acceleration, and the force vectors and tangent matrices of an element. Two singularity-free corotational shell element formulations are presented. The first formulation is a non-consistent one, in which a simple way only using rotation vector is proposed to modify the exact rotation update approach via the Baker–Campbell–Hausdorff formula, while the second formulation is a consistent one. The novelty is that, following the presented method, the existing singular spatial beam and shell element formulations based on rotation vector parameterization could be modified to be the singularity-free ones with only a few changes. Finally, three numerical examples involving large rotations are analyzed to demonstrate the capability of the presented formulations.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: In the present work, a non-linear finite element model for the analysis of composite and sandwich plates is proposed. The underlying variational formulation is based on the kinematics of the refined zigzag theory (RZT) as well as on a modified version of the two-field Hellinger–Reissner (HR) functional, where the displacements and the transverse shear stresses are involved as independent field variables. In fact, a consistent expression for each shear stress function is obtained by integrating the local equilibrium equations written in terms of derivated strain components. Regardless of the number of material layers, the proposed four-node plate element, which is labeled HR–RZT, exhibits only seven nodal degrees of freedom. The additionally introduced variables are effectively eliminated on the element level. One key advantage of the HR–RZT formulation is the fact that interlayer-continuity of the transverse shear stresses is automatically obtained without resorting to any post-processing procedures. The same applies to the zero stress conditions at the outer surfaces of the laminate. Further, due to the enhanced kinematics, the layerwise distortion of the laminate’s cross-section can also be accurately captured. The performance of the novel element formulation is studied by several numerical applications, where the solutions of the two-dimensional HR–RZT elements are verified by comparison with fully three-dimensional finite element models.
References listed at the end of the paper:

Camiel Adams (1,2), Martin Fagerström (1) and Joris J. C. Remmers (2)
(1) Department of Industrial and Materials Science, Chalmers University of Technology, Gothenburg, Sweden
(2) Department of Mechanical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands
“Efficient modelling of delamination growth using adaptive isogeometric continuum shell elements”.

ABSTRACT: The computational efficiency of CAE tools for analysing failure progression in large layered
composites is key. In particular, efficient approximation and solution methods for delamination modelling are
crucial to meet today’s requirements on virtual development lead times. For that purpose, we present here an
adaptive continuum shell element based on the isogeometric analysis framework, suitable for the modelling of
arbitrary delamination growth. To achieve an efficient procedure, we utilise that, in isogeometric analysis, the
continuity of the approximation field easily can be adapted via so-called knot insertion. As a result, the current
continuum shell provides a basis for an accurate but also computationally efficient prediction of delamination
growth in laminated composites. Results show that the adaptive modelling framework works well and that, in
comparison to a fully resolved model, the adaptive approach gives significant time savings even for simple
analyses where major parts of the domain exhibit delamination growth.

References listed at the end of the paper:
Methods Eng 58:2013–2040
propagation in laminates. Compos Struct 126:196–206
Eng Fract Mech 146:121–138
219211
8. Hughes TJR, Cottrell JA, Bazilevs Y (2005) Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh
Methods Appl Mech Eng 198:3902–3914
References listed at the end of the paper:


Liang Zhang (1,2), Kaijun Dong (3), Mengkai Lu (3,4) and Hongwu Zhang (3)
(1) College of Aerospace Engineering, Chongqing University, Chongqing, People’s Republic of China
(2) State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi’an Jiaotong University, Xi’an, People’s Republic of China
(3) State Key Laboratory of Structural Analysis for Industrial Equipment, Dalian University of Technology, Dalian, People’s Republic of China
(4) Department of Mechanical Engineering and Mechanics, Ningbo University, Ningbo, People’s Republic of China


ABSTRACT: The paper proposes a complementarity computational framework for the wrinkling analysis of pneumatic membranes under follower loads. Geometric and material nonlinearities are separated by using the co-rotational finite element method. A reasonable wrinkling model is proposed based on the constitutive law of bi-modulus materials in the principal stress space. To improve the convergence, a linear complementarity framework is constructed in the local frame and embedded into the global Newton–Raphson iteration. The proposed method requires no extra solution techniques to ensure convergence, compared with other solution strategies, such as a pseudo-dynamic method and a penalty stabilization method. Three benchmark tests are employed to verify the proposed model and method. The numerical results have a good agreement with the existing numerical and experimental data. Importantly, the proposed computational method can even make a more accurate prediction on the displacement response and wrinkling regions than the post-buckling analysis of thin shells in some situation.

References listed at the end of the paper:
Marko Lavrenčič and Boštjan Brank (Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana, Slovenia), “Hybrid-mixed shell quadrilateral that allows for large solution steps and is low-sensitive to mesh distortion”, Computational Mechanics, Vol. 65, No. 1, pp 177-192, January 2020, https://doi.org/10.1007/s00466-019-01759-3

ABSTRACT: We compare three nearly optimal quadrilateral finite elements for geometrically exact inextensible-director shell model. Two of them are revisited and one is novel. The assumed natural strain (ANS) element of Ko et al. (Comput Struct 185:1–14, 2017) shows low sensitivity to mesh distortion and excellent convergence behavior for most types of shell problems. The Hu–Washizu element with ANS shear strains of Wagner and Gruttmann (Int J Numer Methods Eng, 64:635–666, 2005) allows for large solution steps and is computationally fast. However, both formulations have undesirable weak spots, which we clearly identify by a comprehensive set of numerical examples. We show that a straightforward combination of both formulations results in a novel element that synergizes the positive features and eliminates the weak spots of its predecessors.

References listed at the end of the paper:

ABSTRACT: This paper presents a geometrically nonlinear formulation in boundary representation for the isogeometric analysis of solids. The proposed formulation employs the parameterization of the scaled boundary finite element method. Thus, the geometry of the boundary is sufficient to describe the entire domain. In contrast to the scaled boundary finite element method, NURBS basis functions approximate the solution on the boundary and also in the interior of the domain. In this way, the exact geometry of the boundary is preserved and geometrically nonlinear problems are treated without further measures. The formulation is derived for two-dimensional domains with arbitrary number of boundaries. Numerical benchmarks evaluate the accuracy and efficiency of the formulation. Furthermore, the influence of the discretization in the interior of the domain and the performance of complex geometries is studied. The proposed formulation compares well with other numerical methods and is suitable for geometries that are designed in boundary representation.

References listed at the end of the paper:


stochastic structure under three derived through the moment method of random variables. Subsequently, the numerical characteristic values of the random temperature field and that of random dynamic responses are then of random structure subjected to coupling from three fields is addressed in the frame of the finite element method. Based on the proposed dynamic finite element formulation for fracture in elastomers. J Comput Phys 262:244–261


ABSTRACT: Random dynamic analysis of the thin-walled structure subjected to coupling loads from three fields is addressed in the frame of the finite element method. Based on the proposed dynamic finite element equation of the deterministic structure under thermal–structural–acoustic coupling, when the randomness of structural physical parameters, temperature load and fatigue test data is fully considered, the dynamic responses of random structure subjected to coupling loads from three fields are dealt with by random factor method. The numerical characteristic values of the random temperature field and that of random dynamic responses are then derived through the moment method of random variables. Subsequently, the dynamic reliability of the stochastic structure under three-field coupling is evaluated using residual strength model, dynamic stress-
intensity interference theory and the cumulative damage equal principle. Finally, the results from the methodology proposed are compared with that from Monte-carlo method for a case of numerical example, along with an inspection of the impacts of random variables on dynamic analysis results.

References listed at the end of the paper:


Simon Klarmann, Friedrich Gruttmann and Sven Kinkel (First author is from: Lehrstuhl für Baustatik und Baudynamik, RWTH Aachen University, Mies-van-der-Rohe-Str. 1, 52074, Aachen, Germany),

ABSTRACT: This contribution proposes a multiscale scheme for structural elements considering beam kinematics. The scheme is based on a first-order homogenization approach fulfilling the Hill–Mandel condition. Within this paper, special focus is given to the transverse shear stiffness. Using basic boundary conditions, the transverse shear stiffness drastically depends on the size of the representative volume element (RVE). The reason for this size dependency is identified. As a consequence, additional internal constraints are proposed. With these new constraints, the homogenization scheme leads to cross-sectional values independent of the size of the RVE. As they are based on the beam assumptions, a homogeneous material distribution in the length direction yields optimal results. Furthermore, outcomes of the scheme are verified with simple linear elastic benchmark tests as well as nonlinear computations involving plasticity and cross-sectional deformations.

References listed at the end of the paper:

ABSTRACT: This work is devoted to the robust analysis of the effects of geometric nonlinearities on the nonlinear dynamic behavior of rotating detuned (intentionally mistuned) bladed disks in presence of unintentional mistuning (simply called mistuning). Mistuning induces uncertainties in the computational model, which are taken into account by a probabilistic approach. This paper presents a series of novel results of the dynamic behavior of such rotating bladed disks exhibiting nonlinear geometric effects. The structural responses in the time domain are analyzed in the frequency domain. The frequency analysis exhibits responses outside the frequency band of excitation. The confidence region of the stochastic responses all involving nonlinear geometric effects. The structural responses investigated with and without mistuning.

References listed at the end of the paper:


Dongdong Wang, Jiarui Wang and Junchao Wu (Department of Civil Engineering, Xiamen University, Xiamen, 361005, Fujian, China), “Arbitrary order recursive formulation of meshfree gradients with application to superconvergent collocation analysis of Kirchhoff plates”, Computational Mechanics, Vol. 65, No. 3, pp 877-903, March 2020,
ABSTRACT: A general arbitrary order recursive gradient formulation is presented for meshfree approximation. According to this method, an \(n\)th order recursive meshfree gradient is formulated as an interpolation of the \((n-1)\)th order gradients by standard first order meshfree gradients, which finally can be expressed as a successive multiplication of standard first order meshfree gradients. This formulation avoids the complex and costly computation of conventional high order derivatives of meshfree shape functions. One crucial ingredient of the proposed methodology is that the resulting recursive meshfree gradients with a \(p\)th degree basis function not only meet the conventional \(p\)th order consistency conditions for standard gradients, but also satisfy \((p+1)\)th to \((p+n-1)\)th extra high order consistency conditions. This important property leads to superconvergent meshfree collocation algorithms and here we focus on the classical fourth order Kirchhoff plate problems. An accuracy analysis of the proposed recursive gradient meshfree collocation formulation for Kirchhoff plates reveals that superconvergence is simultaneously achieved for both even and odd degrees of basis functions. More specifically, two and four additional orders of accuracy are respectively gained by the proposed method for even and odd degree basis functions, compared with the standard meshfree collocation scheme. Furthermore, the extra high order consistency conditions of recursive meshfree gradients enable superconvergent meshfree collocation analysis of Kirchhoff plates using low order basis functions of less than 4th degree, while the standard meshfree collocation approach requires at least a 4th degree basis function to maintain convergence. The accuracy and efficiency of the proposed methodology are holistically demonstrated by numerical results.

References listed at the end of the paper:

This paper presents an analysis of the vibrational behavior of a rotating viscoelastic sandwich pre-twisted beams with a setting angle and with various viscoelastic stiffness laws. The governing equations of motion are derived using the Lagrange formulation and the assumed modes method. The obtained nonlinear eigenvalue problems are solved by using an iterative nonlinear eigensolver leading to complex eigensolutions composed of damped frequencies and loss factors with high accuracy. Further, the effects of the rotating speed, pre-twist angle, thickness ratio of core layer on the dynamic characteristics are investigated with taking into account the dependence of Young modulus with respect to frequency. Different numerical tests on rotating pre-twisted beams are performed for both isotropic and sandwich materials with a constant then a variable core modulus and the obtained results coincide very well with those provided in literature.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: In this work, a thermodynamically consistent constitutive formulation for the coupled thermomechanical strain gradient plasticity theory is developed in the context of the finite deformation framework. A corresponding finite element solution is presented to investigate the microstructural features of metallic volumes. The developed model is established based on an extra Helmholtz-type partial differential equation, and the nonlocal quantity is calculated in a coupled method based on the equilibrium conditions. This approach is well known for its computational strength, however, it is also commonly accepted that it cannot capture the size effect phenomenon observed in the micro-/nanoscale experiments during hardening. In order to resolve this issue, a modified strain gradient approach which can capture the size effects under the finite deformation is constructed in this work. The shear problem is then solved to carry out the feasibility study of the developed model on the size effect phenomenon. Lastly, a plane strain problem under uniaxial tensile loading with shear bands is examined to perform the mesh sensitivity tests of the model during softening.
References listed at the end of the paper:

- 44. ABAQUS (2016) ABAQUS 2016 documentation. Dassault, Providence

Qingyuan Hu (1), Yang Xia (2), Sundararajan Natarajan (3), Andreas Zilian (4), Ping Hu (2) and Stephane P.A. Bordas (4)

(1) School of Science, Jiangnan University, Wuxi, 214122, People’s Republic of China
(2) School of Automotive Engineering, Dalian University of Technology, Dalian, 116024, People’s Republic of China
(3) Integrated Modelling and Simulation Lab, Department of Mechanical Engineering, Indian Institute of Technology, Madras, Chennai, 600036, India
(4) Institute of Computational Engineering Sciences, Faculty of Sciences, Technology and Medicine, University of Luxembourg, Esch-sur-Alzette, Luxembourg


ABSTRACT: We propose a local type of B-bar formulation, addressing locking in degenerated Reissner–Mindlin shell formulation in the context of isogeometric analysis. Parasitic strain components are projected onto the physical space locally, i.e. at the element level, using a least-squares approach. The formulation allows the flexible utilization of basis functions of different orders as the projection bases. The introduced formulation is much cheaper computationally than the classical $B$ method. We show the numerical consistency of the scheme through numerical examples, moreover they show that the proposed formulation alleviates locking and yields good accuracy even for slenderness ratios of 10s, and has the ability to capture deformations of thin shells using relatively coarse meshes. In addition it can be opined that the proposed method is less sensitive to locking with irregular meshes

References listed at the end of the paper:

ABSTRACT: In this paper we present a low-order solid-shell element formulation—having only degree of freedom (DOFs), i.e., without rotational DOFs. The element has an additional middle node, that allows efficient and accurate analyses of shell structures using elements at extremely high aspect ratio. The formulation is based on the Hu–Washizu variational principle leading to a novel enhancing strain and stress tensor that renders the computation particularly efficient, with improved in-plane and out-of-plane bending behavior (Poisson thickness locking). The middle-node is endowed with only one degree of freedom, in the thickness direction, allowing the assumption of a quadratic interpolation of the transverse displacement. Unlike solid-shell finite elements reported previously in literature and formulated under the hypothesis of plane stress or with enhanced assumed strain parameter, the new solid-shell element here mentioned uses a complete three-dimensional constitutive law and gives an enhanced pinching stress, thanks to the middle-node. Moreover, to handle the various locking problems that usually arise on solid-shell formulation, the reduced integration technique is used as well as the assumed shear strain method. Finally to assess the effectiveness and performance of this new formulation, a set of popular benchmark problems, involving geometric non-linear analysis as well as elastic-plastic behavior has been investigated.

References listed at the end of the paper:
ABSTRACT: We present a novel consistent singularity-free strain-based finite element formulation for the analysis of three-dimensional frame-like structures. Our model is based on a geometrically exact finite-strain beam theory, quaternion parametrization of spatial rotations, assumption that the strain measures are constant along the length of the element and a proper choice of basis for the translational strain vector representation. As it is common for strain-based elements, the present formulation does not suffer from shear locking. A comparison of our results with the results from the literature and a commercial finite element analysis software demonstrates the advantages of the proposed formulation, especially when the structure is subjected to larger shear deformations. This stems from the fact that our model ensures a mathematically consistent updating procedure for all the quantities describing the beam. This aspect is often overlooked, since most of the numerical cases from other studies on this topic engage rather small-shear strains for which the consistent update is not crucial as the number of elements is increased.

References listed at the end of the paper:
In this work, we focus on the family of shell formulations referred to as “solid shells”, where the simulation of shell-type structures is performed by means of a mesh of 3D solid elements, with typically only one element through the thickness. We propose a novel approach for alleviating shear and membrane locking phenomena, which typically appear in thin structures, based on the projection of strains onto discontinuous coarser polynomial spaces defined at element level. In particular, we present and investigate two different formulations based on this approach. Several numerical experiments prove the very good performance of both...
formulations in terms of displacements and stresses. The main advantages of the presented approach compared to existing solid shell formulations are its simplicity and numerical efficiency.

References listed at the end of the paper:
Dana Bishara and Mahmood Jabareen, “A solid–shell formulation based on the assumed natural inhomogeneous strains for modeling the viscoelastic response of electro-active polymers”, Computational Mechanics, Vol. 66, No. 1, pp 1-25, July 2020,

ABSTRACT: In this paper, an advanced low-order solid–shell formulation is presented for modeling electro-active polymers (EAPs). This advanced finite element is of great importance due to the fact that EAP actuators are typically designed as shell-like formations, in which the application of standard finite element formulation will lead to various locking pathologies (e.g. shear locking, trapezoidal locking, volumetric locking, etc.). Thus, for alleviating the various locking pathologies, both the assumed natural inhomogeneous strains (ANIS) and the enhanced assumed strain (EAS) methods are adopted for modifying the strain measure. Within the modified kinematics, a strain energy function that accounts for the elastic and the viscoelastic response as well as the electromechanical coupling is adopted. The developed formulation is implemented in the finite-element software Abaqus for further numerical applications, in which the developed ANIS solid–shell is compared with the classical assumed natural strains solid–shell and the mixed finite element formulation.

References listed at the end of the paper:


Not all references are listed here for brevity.

ABSTRACT: Thin membranes are notoriously sensitive to instabilities under mechanical loading, and need sophisticated analysis methods. Although analytical results are available for several special cases and assumptions, numerical approaches are normally needed for general descriptions of non-linear response and
stability. The paper uses the case of a thin spherical hyper-elastic membrane subjected to internal gas over-pressure to investigate how stability conclusions are affected by chosen material models and kinematic discretizations. For spherical symmetry, group representation theory leads to linearized modes on the uniformly stretched sphere, with eigenvalues obtained from the mechanics of a thin membrane. A complete three-dimensional geometric description allows non-axisymmetric shear modes of the sphere, and such instabilities are shown to exist. When the symmetry of the continuous sphere is broken by discretized models, group representation theory gives predictions on the effects on the critical states. Numerical simulations of the pressurized sphere show and verify stability conclusions for critical states of meshing strategies and hyper-elastic models.

References listed at the end of the paper:


ABSTRACT: This work focuses on the study of several computational challenges arising when trimmed surfaces are directly employed for the isogeometric analysis of Kirchhoff–Love shells. To cope with these issues and to resolve mechanical and/or geometrical features of interest, we exploit the local refinement capabilities of hierarchical B-splines. In particular, we show numerically that local refinement is suited to effectively impose Dirichlet-type boundary conditions in a weak sense, where this easily allows to overcome the issue of over-constraining of trimmed elements. Moreover, we highlight how refinement can alleviate the spurious coupling stemming from disjoint supports of basis functions in the presence of “small” trimmed geometrical features such as thin holes. These phenomena are particularly pronounced in surface models defined by complex trimming patterns and with details at different scales. In this contribution we focus our effort on the analysis of single-patch geometries, where we show through several numerical examples the benefits and computational efficiency of the proposed methodology.

References listed at the end of the paper:

ABSTRACT: In this study, we present a novel finite element approach to simulate crack propagation in shell structures. A local spider-web mesh is placed at the tip of a crack propagating through a global background mesh. Interface shell elements with assumed natural strains are used to connect a non-matching interface between the background mesh and the local spider-web mesh. Interface shell elements are also employed for trimmed shell elements created by cutting shell elements with the crack line. Numerical simulation of crack propagation in shell structures can be easily performed by moving the local spider-web mesh with an incremental crack growth. Numerical experiments show that the present method is very efficient and effective to accurately simulate crack propagation in shell structures without significantly increasing computational burden and implementation complexity of remeshing process.

References listed at the end of the paper:

Jun Yan, Qianqian Sui, Zhirui Fan, Zunyi Duan and Tao Yu, “Clustering-based multiscale topology optimization of thermo-elastic lattice structures”, Computational Mechanics, Vol. 66, No. 4, pp 979-1002, October 2020,

ABSTRACT: A multiscale clustering-based topology optimization for thermo-elastic lattice structures is studied based on the extended multiscale finite element method (EMsFEM). The strain energy of thermo-elastic lattice structures is chosen as the objective function. The microstructural configuration and the macrostructural distribution of the thermo-elastic lattice material are designed through topology optimization concurrently. The K-means clustering-based method is proposed to group the microstructures of the lattice materials. The effects of the number of clusters (groups), magnitude of the thermal loads, size factor of the microstructure, and material volume fraction on the optimization results are discussed. The results show that the clustering-based multiscale design optimization is superior to the classical multiscale design optimization of lattice structures.

References listed at the end of the paper:

ABSTRACT: In this paper layered shells subjected to static loading are considered. The displacements of the Reissner–Mindlin theory are enriched by an additional part. These so-called fluctuation displacements include warping displacements and thickness changes. They lead to additional terms for the material deformation gradient and the Green–Lagrangian strain tensor. Within a nonlinear multi-field variational formulation the
weak form of the boundary value problem accounts for the equilibrium of stress resultants and couple resultants, the local equilibrium of stresses, the geometrical field equations and the constitutive equations. For the independent shell strains an ansatz with quadratic shape functions is chosen. This leads to a significant improved convergence behaviour especially for distorted meshes. Elimination of a set of parameters on element level by static condensation yields an element stiffness matrix and residual vector of a quadrilateral shell element with the usual 5 or 6 nodal degrees of freedom. The developed model yields the complicated three-dimensional stress state in layered shells for elasticity and elasto-plasticity considering geometrical nonlinearity. In comparison with fully 3D solutions present 2D shell model requires only a fractional amount of computing time.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: In this paper, we compare and assess the performance of the standard 3- and 6-node MITC shell elements (Lee and Bathe 2004) with the recently developed MITC triangular elements (Lee et al. 2014, Jeon et al. 2018, Jun et al. 2018) which were based on the partitions of unity approximation, bubble node, or both. The convergence behavior of the shell elements are measured in well-known benchmark tests; four plane stress tests (mesh distortion test, cantilever beam, Cook’s skew beam, and MacNeal beam), two plate tests (Morley’s skew plate and circular plate) and six shell tests (curved beam, twisted beam, pinched cylinder, hemispherical shells with or without hole, and Scordelis-Lo roof). To precisely compare and evaluate the solution accuracy of the shell elements, different triangular mesh patterns and distorted element mesh are adopted in the benchmark problems. All shell finite elements considered pass the basic tests; namely, the isotropy, the patch, and the zero energy mode tests.


ABSTRACT: In this paper, we compare and assess the performance of the standard 3- and 6-node MITC shell elements (Lee and Bathe 2004) with the recently developed MITC triangular elements (Lee et al. 2014, Jeon et al. 2018, Jun et al. 2018) which were based on the partitions of unity approximation, bubble node, or both. The convergence behavior of the shell elements are measured in well-known benchmark tests; four plane stress tests (mesh distortion test, cantilever beam, Cook’s skew beam, and MacNeal beam), two plate tests (Morley’s skew plate and circular plate) and six shell tests (curved beam, twisted beam, pinched cylinder, hemispherical shells with or without hole, and Scordelis-Lo roof). To precisely compare and evaluate the solution accuracy of the shell elements, different triangular mesh patterns and distorted element mesh are adopted in the benchmark problems. All shell finite elements considered pass the basic tests; namely, the isotropy, the patch, and the zero energy mode tests.

References listed at the end of the paper:


ABSTRACT: This paper presents an analysis of the bending, buckling and free vibration of functionally graded sandwich beams resting on elastic foundation by using a refined quasi-3D theory in which both shear deformation and thickness stretching effects are included. The displacement field contains only three unknowns, which is less than the number of parameters of many other shear deformation theories. In order to homogenize the micromechanical properties of the FGM sandwich beam, the material properties are derived on the basis of several micromechanical models such as Tamura, Voigt, Reuss and many others. The principle of virtual works is used to obtain the equilibrium equations. The elastic foundation is modeled using the Pasternak mathematical model. The governing equations are obtained through the Hamilton’s principle and then are solved via Navier
solution for the simply supported beam. The accuracy of the proposed theory can be noticed by comparing it with other 3D solution available in the literature. A detailed parametric study is presented to show the influence of the micromechanical models on the general behavior of FG sandwich beams on elastic foundation.


ABSTRACT: This paper uses the finite element method (FEM) considering geometrically nonlinear strains to study the first ply failure of laminated composite skewed hypar shell roofs through well-established failure criteria along with the serviceability criterion of deflection. Apart from validating the approach through solution of benchmark problems, skewed hypars with different practical parametric variations are studied for failure loads and tendencies. First ply failure zones are also identified to suggest design and non-destructive monitoring guidelines to the practising engineers. Recommendation tables regarding the design approaches to be adopted in specific cases and factor of safety values needed to be imposed on first ply failure load values for varying shell curvatures are also suggested in this paper. Providing practical inputs to design engineers is the main achievement of the present study.

References listed at the end of the paper:


ABSTRACT: In the present research, an attempt is made to obtain a semi analytical solution for both nonlinear natural frequency and forced vibration of embedded functionally graded double layered nanoplates with all edges simply supported based on nonlocal strain gradient elasticity theory. The interaction of van der Waals forces between adjacent layers is included. For modeling surrounding elastic medium, the nonlinear Winkler-Pasternak foundation model is employed. The governing partial differential equations have been derived based on the Mindlin plate theory utilizing the von Karman strain-displacement relations. Subsequently, using the Galerkin method, the governing equations sets are reduced to nonlinear ordinary differential equations. The semi analytical solution of the nonlinear natural frequencies using the homotopy analysis method and the exact solution of the nonlinear forced vibration through the Harmonic Balance method are then established. The results show that the length scale parameters give nonlinearity of the hardening type in frequency response curve and the increase in material length scale parameter causes to increase in maximum response amplitude, whereas the increase in nonlocal parameter causes to decrease in maximum response amplitude. Increasing the material length scale parameter increases the width of unstable region in the frequency response curve.

References listed at the end of the paper:


nanshells based on a new nonlocal strain gradient higher order shell theory”, Thin-Wall. Struct., 129, 251-264.


ABSTRACT: In this study, Eringen nonlocal elasticity theory in conjunction with surface elasticity theory is employed to study nonlinear free vibration behavior of FG nano-plate lying on elastic foundation, on the base of Reddy’s plate theory. The material distribution is assumed as a power-law function and effective material properties are modeled using Mori-Tanaka homogenization scheme. Hamilton’s principle is implemented to derive the governing equations which solved using DQ method. Finally, the effects of different factors on natural frequencies of the nano-plate under hygrothermal situation and various boundary conditions are studied.

References listed at the end of the paper:


Abbas Heydari (Young Researchers and Elite Club, Ardabil Branch, Islamic Azad University, Ardabil, Iran), “Size-dependent damped vibration and buckling analyses of bidirectional functionally graded solid circular nano-plate with arbitrary thickness variation”, Structural Engineering and Mechanics Volume 68, Number 2, October25 2018, pages 171-182 DOI: http://dx.doi.org/10.12989/sem.2018.68.2.171

ABSTRACT: For the first time, nonlocal damped vibration and buckling analyses of arbitrary tapered bidirectional functionally graded solid circular nano-plate (BDFGSCNP) are presented by employing modified spectral Ritz method. The energy method based on Love-Kirchhoff plate theory assumptions is applied to derive neutral equilibrium equation. The Eringen's nonlocal continuum theory is taken into account to capture small-scale effects. The characteristic equations and corresponding first mode shapes are calculated by using a novel modified basis in spectral Ritz method. The modified basis is in terms of orthogonal shifted Chebyshev polynomials of the first kind to avoid employing adhesive functions in the spectral Ritz method. The fast convergence and compatibility with various conditions are advantages of the modified spectral Ritz method. A more accurate multivariable function is used to model two-directional variations of elasticity modulus and mass density. The effects of nanoscale, in-plane pre-load, distributed dashpot, arbitrary tapering, pinned and clamped boundary conditions on natural frequencies and buckling loads are investigated. Observing an excellent agreement between results of current work and outcomes of previously published works in literature, indicates the results’ accuracy in current work.

References listed at the end of the paper:

Ali A. Yazdi (Department of Mechanical Engineering, Quchan University of Technology, P.O. Box 94717-84686, Quchan, Iran), “Large amplitude forced vibration of functionally graded nano-composite plate with piezoelectric layers resting on nonlinear elastic foundation”, Structural Engineering and Mechanics Volume 68, Number 2, October 25, 2018, pages 203-213 DOI: http://dx.doi.org/10.12989/sem.2018.68.2.203
ABSTRACT: This paper presents a study of geometric nonlinear forced vibration of carbon nano-tubes (CNTs) reinforcement composite plates on nonlinear elastic foundations. The plate is bonded with piezoelectric layers. The von Karman geometric nonlinearity assumptions with classical plate theory are employed to obtain the governing equations. The Galerkin and homotopy perturbation method (HPM) are utilized to investigate the effect of carbon nano-tubes volume fractions, large amplitude vibrations, elastic foundation parameters, piezoelectric applied voltage on frequency ratio and primary resonance. The results indicate that the carbon nano-tube volume fraction, applied voltage and elastic foundation parameters have significant effect on the hardening response of carbon nanotubes reinforced composite (CNTC) plates.

References listed at the end of the paper:

ABSTRACT: A comprehensive study was provided to investigate the buckling behavior of the steel plates with and without through-thickness holes subjected to uniaxial compression using ABAQUS. The method was
validated by the results reported in the literature. Using the critical stresses, the buckling coefficients (K_c) were calculated. The effects of inclusion of material nonlinearity, plate thickness (t), aspect ratio (AR), and initial imperfection on buckling resistance of the plate was studied. Besides, the effects of having the hole in the plate were also studied. The diameter of the hole was normalized by dividing by plate breadth and was given in the form of a. Results showed that perforating one hole in the center of a plate increases the plate buckling resistance while the having two holes resulted in a decrease in the plate buckling resistance. The effects of hole eccentricity ( Ecc) on the buckling resistance of the plate was studied. The position of the hole center was normalized by half of the plate breadth and length in X- and Y-directions, respectively. In this study, four cases of boundary conditions were considered, and the corresponding buckling behavior were studied combined with plate aspect ratio. It was observed that the boundary condition of the case I resulted in the highest buckling resistance. Finally, a comparison was made between the buckling behavior of the uniaxially and biaxially loaded plate. It was revealed that the buckling resistance of a biaxially loaded plate is lower half than half of that of the uniaxially loaded plate.

References listed at the end of the paper:


ABSTRACT: In this paper, an extended finite element method is proposed to analyze both geometric and material non-linear behavior of general Functionally Graded Material (FGM) plate-shell type structures. A user defined subroutine (UMAT) is developed and implemented in Abaqus/Standard to study the elasto-plastic behavior of the ceramic particle-reinforced metal-matrix FGM plates-shells. The standard quadrilateral 4-nodes shell element with three rotational and three translational degrees of freedom per node, S4, is extended in the present study, to deal with elasto-plastic analysis of geometrically non-linear FGM plate-shell structures. The elasto-plastic material properties are assumed to vary smoothly through the thickness of the plate-shell type structures. The nonlinear approach is based on Mori-Tanaka model to underline micromechanics and locally determine the effective FGM properties and self-consistent method of Suquet for the homogenization of the stress-field. The elasto-plastic behavior of the ceramic/metal FGM is assumed to follow Ludwik hardening law. An incremental formulation of the elasto-plastic constitutive relation is developed to predict the tangent operator. In order to to highlight the effectiveness and the accuracy of the present finite element procedure, numerical examples of geometrically non-linear elasto-plastic functionally graded plates and shells are presented. The effects of the geometrical parameters and the volume fraction index on nonlinear responses are performed.

References listed at the end of the paper:


Jalal Torabi and Reza Ansari (Department of Mechanical Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran), “Thermally induced mechanical analysis of temperature-dependent FG-CNTRC conical shells”, Structural Engineering and Mechanics Volume 68, Number 3, November10 2018, pages 313-323 DOi: http://dx.doi.org/10.12989/sem.2018.68.3.313

ABSTRACT: A numerical study is performed to investigate the impacts of thermal loading on the vibration and buckling of functionally graded carbon nanotube-reinforced composite (FG-CNTRC) conical shells. Thermomechanical properties of constituents are considered to be temperature-dependent. Considering the shear deformation theory, the energy functional is derived, and applying the variational differential quadrature (VDQ) method, the mass and stiffness matrices are obtained. The shear correction factors are accurately calculated by matching the shear strain energy obtained from an exact three-dimensional distribution of the transverse shear stresses and shear strain energy related to the first-order shear deformation theory. Numerical results reveal that considering temperature-dependent material properties plays an important role in predicting the thermally induced vibration of FG-CNTRC conical shells, and neglecting this effect leads to considerable overestimation of the stiffness of the structure.

References listed at the end of the paper:
Sattar Jedari Salami and Soheil Dariush (First author is from: Department of Mechanical Engineering, Damavand Branch, Islamic Azad University, Damavand, Iran), “Analytical, numerical and experimental investigation of low velocity impact response of laminated composite sandwich plates using extended high order sandwich panel theory”, Structural Engineering and Mechanics Volume 68, Number 3, November 10 2018, pages 325-334 DOI: http://dx.doi.org/10.12989/sem.2018.68.3.325

ABSTRACT: The nonlinear dynamic response of a sandwich plate subjected to the low velocity impact is theoretically and experimentally investigated. The Hertz law between the impactor and the plate is taken into account. Using the Extended High Order Sandwich Panel Theory (EHSAPT) and the Ritz energy method, the governing equations are derived. The skins follow the Third order shear deformation theory (TSDT) that has hitherto not reported in conventional EHSAPT. Besides, the three dimensional elasticity is used for the core. The nonlinear Von Karman relations for strains of skins and the core are adopted. Time domain solution of such equations is extracted by means of the well-known fourth-order Runge-Kutta method. The effects of core-to-skin thickness ratio, initial velocity of the impactor, the impactor mass and position of the impactor are studied in detail. It is found that these parameters play significant role in the impact force and dynamic response of the sandwich plate. Finally, some low velocity impact tests have been carried out by Drop Hammer Testing Machine. The results are compared with experimental data acquired by impact testing on sandwich plates as well as the results of finite element simulation.

References listed at the end of the paper:

ABSTRACT: This paper deals with the dynamic stability of nanocomposite pipes conveying pulsating ferrofluid flow considering structural damping effects, Structural Engineering and Mechanics Volume 68, Number 3, November 2018, pages 359-368 DOI: http://dx.doi.org/10.12989/sem.2018.68.3.359

ABSTRACT: This paper deals with the dynamic stability of nanocomposite pipes conveying pulsating ferrofluid. The pipe is reinforced by carbon nanotubes (CNTs) where the agglomeration of CNTs are considered based on Mori-Tanaka model. Due to the existence of CNTs and ferrofluid flow, the structure and fluid are subjected to axial magnetic field. Based on Navier-Stokes equation and considering the body force induced by magnetic field, the external force of fluid to the pipe is derived. For mathematical modeling of the pipe, the first order shear deformation theory (FSDT) is used where the energy method and Hamilton's principle are used for obtaining the motion equations. Using harmonic differential quadrature method (HDQM) and Bolotin's method, the motion equations are solved for calculating the excitation frequency and dynamic instability region (DIR) of the structure. The influences of different parameters such as volume fraction and agglomeration of CNTs, magnetic field, structural damping, viscoelastic medium, fluid velocity and boundary conditions are shown on the DIR of the structure. Results show that with considering agglomeration of CNTs, the DIR shifts to the lower excitation frequencies. In addition, the DIR of the structure will be happened at higher excitation frequencies with increasing the magnetic field.

References listed at the end of the paper:


Umut Topal, Ebrahim Nazarimofrad and Seyed Ebrahim Sadat Kholerdi (First author is from: Department of Civil Engineering, Faculty of Technology, Karadeniz Technical University, Trabzon, Turkey), “Shear buckling analysis of cross-ply laminated plates resting on Pasternak foundation”, Structural Engineering and
ABSTRACT: This paper presents the shear buckling analysis of symmetrically laminated cross-ply plates resting on Pasternak foundation under pure in-plane uniform shear load. The classical laminated plate theory is used for the shear buckling analysis of laminated plates. The Rayleigh-Ritz method with novel plate shape functions is proposed to solve the differential equations and a computer programming is developed to obtain the shear buckling loads. Finally, the effects of the plate aspect ratios, boundary conditions, rotational restraint stiffness, translational restraint stiffness, thickness ratios, modulus ratios and foundation parameters on the shear buckling of the laminated plates are investigated.

References listed at the end of the paper:


Winkler, E. (1867), Die Lehre von der Elasticitaet und Festigkeit, Prag, Dominicus.

Yaopeng Wu, Erle Lu and Shuai Zhang (School of Civil Engineering, Xi’an University of Architecture and Technology, Xi’an 710055, P R China), “Study on bi-stable behaviors of un-stressed thin cylindrical shells based on the extremal principle”, Structural Engineering and Mechanics Volume 68, Number 3, November 2018, pages 377-384 DOI: http://dx.doi.org/10.12989/sem.2018.68.3.377

ABSTRACT: Bi-stable structure can be stable in both its extended and coiled forms. For the un-stressed thin cylindrical shell, the strain energy expressions are deduced by using a theoretical model in terms of only two parameters. Based on the principle of minimum potential energy, the bi-stable behaviors of the cylindrical shells are investigated. The results indicate that the isotropic cylindrical shell does not have the second stable configuration and laminated cylindrical shells with symmetric or antisymmetric layup of fibers have the second stable state under some confined conditions. In the case of antisymmetric laminated cylindrical shell, the analytical expressions of the stability are derived based on the extremal principle, and the shell can achieve a compact coiled configuration without twist deformation in its second stable state. In the case of symmetric laminated cylindrical shell, the explicit solutions for the stability conditions cannot be deduced. Numerical results show that stable configuration of symmetric shell is difficult to achieve and symmetric shell has twist deformation in its second stable form. In addition, the roll-up radii of the antisymmetric laminated cylindrical shells are calculated using the finite element package ABAQUS. The results show that the value of the roll-up radii is larger from FE simulation than from theoretical analysis. By and large, the predicted roll-up radii of the cylindrical shells using ABAQUS agree well with the theoretical results.

References listed at the end of the paper:

Hamza Guenfoud, Mohamed Himeur, Hassina Ziou and Mohamed Guenfoud (Primarily from: LGCH Laboratory, 8 Mai 1945 University of Guelma, Algeria), “The use of the strain approach to develop a new consistent triangular thin flat shell finite element with drilling rotation”, Structural Engineering and
Mechanics Volume 68, Number 4, November 2018, pages 385-398
DOI: http://dx.doi.org/10.12989/sem.2018.68.4.385

ABSTRACT: In the present paper, we offer a new flat shell finite element. It is the result of the combination of a membrane element and a bending element, both based on the strain-based formulation. It is known that Co plane membrane elements provide poor deflection and stress for problems where bending is dominant. In addition, they encounter continuity and compliance problems when they connect to C1 class plate elements. The reach of the present work is to surmount these problems when a membrane element is coupled with a thin plate element in order to construct a shell element. The membrane element used is a triangular element with four nodes, three nodes at the vertices of the triangle and the fourth one at its barycenter. Each node has three degrees of freedom, two translations and one rotation around the normal. The coefficients related to the degrees of freedom at the internal node are subsequently removed from the element stiffness matrix by using the static condensation technique. The interpolation functions of strain, displacements and stresses fields are developed from equilibrium conditions. The plate element used for the construction of the present shell element is a triangular four-node thin plate element based on Kirchhoff plate theory, the strain approach, the four fictitious node, the static condensation and the analytic integration. The shell element result of this combination is robust, competitive and efficient.

References listed at the end of the paper:


Ali Mazari, Amina Attia, Mohamed Sekkal, Abdelhakim Kaci, Abdelouahed Tounsi, Abdelmoumen Anis Boushala and S.R. Mahmoud (First author is from: Material and Hydrology Laboratory, Faculty of Technology, Civil Engineering Department, University of Sidi Bel Abbes, Algeria), “Bending analysis of functionally graded thick plates with in-plane stiffness variation”, Structural Engineering and Mechanics Volume 68, Number 4, November 25 2018, pages 409-421 DOI: http://dx.doi.org/10.12989/sem.2018.68.4.409

ABSTRACT: In the present paper, functionally graded (FG) materials are presented to investigate the bending analysis of simply supported plates. It is assumed that the material properties of the plate vary through their length according to the power-law form. The displacement field of the present model is selected based on quasi-3D hyperbolic shear deformation theory. By splitting the deflection into bending, shear and stretching parts, the number of unknowns and equations of motion of the present formulation is reduced and hence makes them simple to use. Governing equations are derived from the principle of virtual displacements. Numerical results for deflections and stresses of powerly graded plates under simply supported boundary conditions are presented. The accuracy of the present formulation is demonstrated by comparing the computed results with those available in the literature. As conclusion, this theory is as accurate as other shear deformation theories and so it becomes more attractive due to smaller number of unknowns. Some numerical results are provided to examine the effects of the material gradation, shear deformation on the static behavior of FG plates with variation of material stiffness through their length.

References listed at the end of the paper:
Bachir Bouiadjra, M, Houari, M.S.A. and Tounsi, A. (2012), “Thermal buckling of functionally graded plates according to a four-


ABSTRACT: The free vibration frequency responses of the graded flat and curved (cylindrical, spherical, hyperbolic and elliptical) panel structures investigated in this research consist of the rectangular and tilted planforms under unlike temperature loading. For the numerical implementation purpose, a micromechanical model is prepared with the help of Voigt's methodology via the power-law type of material model. Additionally, to incur the exact material strength, the temperature-dependent properties of each constituent of the graded structure included due to unlike thermal environment. The deformation kinematics of the rectangular/tilted graded shallow curved panel structural is modeled via higher-order type of polynomial functions. The final form of the eigenvalue equation of the heated structure obtained via Hamilton's principle and simultaneously solved numerically using finite element steps. To show the solution accuracy, a series of comparison the results are compared with the published data. Some new results are exemplified to exhibit the significance of power-law index, shallowness ratio, aspect ratio and thickness ratio on the combined thermal eigen characteristics of the regular and tilted graded panel structure.

References listed at the end of the paper:


ABSTRACT: The aim of the present paper deals with free vibration analysis of laminated composite skew plates with single and multiple cut-outs. For complete understanding of the dynamic behavior of laminated skew plates with cut-out a numerical analysis has been carried out by developing a computer code in FOTRAN. Special attention is drawn on the formulation of mass matrix by considering effect of rotary inertia. The results obtained by the finite element formulation using nine noded isoparametric plate bending element are validated by comparing the results from relevant published literature. Few new results on laminated skew plates with cut-out have been presented.

References listed at the end of the paper:


ABSTRACT: In this paper, buckling analysis of hybrid functionally graded plates using a novel four variable refined plate theory is presented. In this theory the distribution of transverse shear deformation is parabolic across the thickness of the plate by satisfying the surface conditions. Therefore, it is unnecessary to use a shear correction factor. The variations of properties of the plate through the thickness are according to a symmetric sigmoid law (symmetric S-FGM). The principle virtual works is used herein to extract equilibrium equations. The analytical solution is determined using the Navier method for a simply supported rectangular plate subjected to axial forces. The precision of this theory is verified by comparing it with the various solutions available in the literature.

References listed at the end of the paper:


ABSTRACT: The modal frequency responses of functionally graded (FG) sandwich doubly curved shell panels are investigated using a higher-order finite element formulation. The system of equations of the panel structure derived using Hamilton's principle for the evaluation of natural frequencies. The present shell panel model is discretised using the isoparametric Lagrangian element (nine nodes and nine degrees of freedom per node). An in-house MATLAB code is prepared using higher-order kinematics in association with the finite element scheme for the calculation of modal values. The stability of the opted numerical vibration frequency solutions for the various shell geometries i.e., single and doubly curved FG sandwich structure are proven via the convergence test. Further, close conformance of the finite element frequency solutions for the FG sandwich structures is found when compared with the published theoretical predictions (numerical, analytical and 3D elasticity solutions). Subsequently, appropriate numerical examples are solved pertaining to various design factors (curvature ratio, core-face thickness ratio, aspect ratio, support conditions, power-law index and
sandwich symmetry type) those have the significant influence on the free vibration modal data of the FG sandwich curved structure.

References listed at the end of the paper:


Hyeon-Jong Hwang, Gao Ma and Chang-Soo Kim (First author is from: Engineering Research Institute, Seoul National Univ., Seoul 151-744, Republic of Korea), “Minimum thickness of flat plates considering construction load effect”, Structural Engineering and Mechanics Volume 69, Number 1, January 10 2019, pages 001-10

DOI: http://dx.doi.org/10.12989/sem.2018.69.1.001

ABSTRACT: In the construction of flat plate slabs, which are widely used for tall buildings but have relatively low flexural stiffness, serviceability problems such as excessive deflections and cracks are of great concern. To prevent excessive deflections at service load levels, current design codes require the minimum slab thickness, but the requirement could be unconservative because it is independent on loading and elastic modulus of concrete, both of which have significant effects on slab deflections. In the present study, to investigate the effects of the construction load of shored slabs, reduced flexural stiffness and moment distribution of early-age slabs, and creep and shrinkage of concrete on immediate and time-dependent deflections, numerical analysis was performed using the previously developed numerical models. A parametric study was performed for various design and construction conditions of practical ranges, and a new minimum permissible thickness of flat plate slabs was proposed satisfying the serviceability requirement for deflection. The proposed minimum slab thickness was compared with current design code provisions and numerical analysis results, and it agreed well with the numerical analysis results.

References listed at the end of the paper

ACI Committee 209 (1992), Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures (ACI 209R-92), American Concrete Institute, Farmington Hills, Michigan, U.S.A.

ACI Committee 318 (2014), Building Code Requirements for Structural Concrete and Commentary (ACI 318-14), American Concrete Institute, Farmington Hills, Michigan, U.S.A.

ACI Committee 347 (2005), Guide for Shoring/Reshoring of Concrete Multistory Buildings (ACI 347.2R-05), American Concrete Institute, Farmington Hills, Michigan, U.S.A.


ABSTRACT: Optimizing composite structures to exploit their maximum potential is a realistic application with promising returns. In this research, simultaneous maximization of the fundamental frequency and frequency separation between the first two modes by optimizing the fiber angles is considered. A high-fidelity design optimization methodology is developed by combining the high-accuracy of finite element method with iterative improvement capability of metaheuristic algorithms. Three powerful nature-inspired optimization algorithms viz. a genetic algorithm (GA), a particle swarm optimization (PSO) variant and a cuckoo search (CS) variant are used. Advanced memetic features are incorporated in the PSO and CS to form their respective variants-RPSOLC (repulsive particle swarm optimization with local search and chaotic perturbation) and CHP (co-evolutionary host-parasite). A comprehensive set of benchmark solutions on several new problems are reported. Statistical tests and comprehensive assessment of the predicted results show CHP comprehensively outperforms RPSOLC and GA, while RPSOLC has a little superiority over GA. Extensive simulations show that the on repeated trials of the same experiment, CHP has very low variability. About 50% fewer variations are seen in RPSOLC as compared to GA on repeated trials.

References listed at the end of the paper:


and frequency separation”, J. Sound Vibr., 146(2), 181-190.
M. Mohammadi and A. Rastgoo (School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran), “Nonlinear vibration analysis of the viscoelastic composite nanoplate with three directionally imperfect porous FG core”, Structural Engineering and Mechanics Volume 69, Number 2, January 10, 2019, pages 131-143 DOI: http://dx.doi.org/10.12989/sem.2019.69.2.131

ABSTRACT: In this study, the nonlinear vibration analysis of the composite nanoplate is studied. The composite nanoplate is fabricated by the functional graded (FG) core and lipid face sheets. The material properties in the FG core vary in three directions. The Kelvin-Voigt model is used to study the viscoelastic effect of the lipid layers. By using the Von-Karman assumptions, the nonlinear differential equation of the vibration analysis of the composite nanoplate is obtained. The foundation of the system is modeled by the nonlinear Pasternak foundation. The Bubnov-Galerkin method and the multiple scale method are used to solve the nonlinear differential equation of the composite nanoplate. The free and force vibration analysis of the composite nanoplate are studied. A comparison between the presented results and the reported results is done and good achievement is obtained. The reported results are verified by the results which are obtained by the Runge-Kutta method. The effects of different parameters on the nonlinear vibration frequencies, the primary, the super harmonic and subharmonic resonance cases are investigated. This work will be useful to design the nanosensors with high biocompatibility.

References listed at the end of the paper:


Yang Gao, Wan-Shen Xiao and Haiping Zhu (Primarily from: State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha 410082, China), “Nonlinear vibration of
functionally graded nano-tubes using nonlocal strain gradient theory and a two-steps perturbation method”, Structural Engineering and Mechanics Volume 69, Number 2, January 10 2019, pages 205-219 DOI: http://dx.doi.org/10.12989/sem.2019.69.2.205

ABSTRACT: This paper analyzes nonlinear free vibration of the circular nano-tubes made of functionally graded materials in the framework of nonlocal strain gradient theory in conjunction with a refined higher order shear deformation beam model. The effective material properties of the tube related to the change of temperature are assumed to vary along the radius of tube based on the power law. The refined beam model is introduced which not only contains transverse shear deformation but also satisfies the stress boundary conditions where shear stress cancels each other out on the inner and outer surfaces. Moreover, it can degenerate the Euler beam model, the Timoshenko beam model and the Reddy beam model. By incorporating this model with Hamilton's principle, the nonlinear vibration equations are established. The equations, including a material length scale parameter as well as a nonlocal parameter, can describe the size-dependent in linear and nonlinear vibration of FGM nanotubes. Analytical solution is obtained by using a two-steps perturbation method. Several comparisons are performed to validate the present analysis. Eventually, the effects of various physical parameters on nonlinear and linear natural frequencies of FGM nanotubes are analyzed, such as inner radius, temperature, nonlocal parameter, strain gradient parameter, scale parameter ratio, slenderness ratio, volume indexes, different beam models.

References listed at the end of the paper:


ABSTRACT: In this paper, a new higher order shear deformation model is developed for static and free vibration analysis of functionally graded beams with porosities: Effect of the micromechanical models, Structural Engineering and Mechanics Volume 69, Number 2, January 10, 2019, pages 231-241
DOI: http://dx.doi.org/10.12989/sem.2019.69.2.231

Lazreg Hadji, Nafissa Zouatnia and Fabrice Bernard (First author is from: Laboratory of Geomatics and Sustainable Development, Ibn Khaldoun University of Tiaret, Algeria). “An analytical solution for bending and free vibration responses of functionally graded beams with porosities: Effect of the micromechanical models”, Structural Engineering and Mechanics Volume 69, Number 2, January 10, 2019, pages 231-241
DOI: http://dx.doi.org/10.12989/sem.2019.69.2.231

ABSTRACT: In this paper, a new higher order shear deformation model is developed for static and free vibration analysis of functionally graded beams with porosities: Effect of the micromechanical models, Structural Engineering and Mechanics Volume 69, Number 2, January 10, 2019, pages 231-241
DOI: http://dx.doi.org/10.12989/sem.2019.69.2.231

References listed at the end of the paper:


ABSTRACT: Accurately determining the natural frequencies and mode shapes of a structural floor is an essential step to assess the floor's human-induced vibration serviceability. In the theoretical analysis, the prestressed concrete floor can be idealized as a multi-span continuous anisotropic plate. This paper presents a new analytical approach to determine the natural frequencies and mode shapes of a multi-span continuous
orthotropic plate. The suggested approach is based on the combined modal and perturbation method, which differs from other approaches as it decomposes the admissible functions defining the mode shapes by considering the intermodal coupling. The implementation of this technique is simple, requiring no tedious mathematical calculations. The perturbation solution is validated with the numerical results.

References listed at the end of the paper:


ABSTRACT: In present study, a novel refined hyperbolic shear deformation theory is proposed for the buckling analysis of thick isotropic plates. The new displacement field is constructed with only two unknowns, as against three or more in other higher order shear deformation theories. However, the hyperbolic sine function is assigned according to the shearing stress distribution across the plate thickness, and satisfies the zero traction boundary conditions on the top and bottom surfaces of the plate without using any shear correction factors. The equations of motion associated with the present theory are obtained using the principle of virtual work. The analytical solution of the buckling of simply supported plates subjected to uniaxial and biaxial loading conditions was obtained using the Navier method. The critical buckling load results for thick isotropic square plates are compared with various available results in the literature given by other theories. From the present analysis, it can be concluded that the proposed theory is accurate and efficient in predicting the buckling response of isotropic plates.

References listed at the end of the paper:

ABSTRACT: More than one longitudinal web stiffener may be economical in the design of plate girders that have considerably high width-to-thickness ratio of webs. In this study, the bend-buckling strength of relatively deep webs with two horizontal lines of flat plate-shaped single-sided stiffeners was numerically investigated. Linear eigenvalue buckling analyses were conducted for specially selected hypothetical models of stiffened web panels, in which top and bottom junctions of a web with flanges were assumed to have simply supported boundary conditions. Major parameters in the analyses were the locations of two longitudinal stiffeners, stress ratios in the web, slenderness ratios and aspect ratios of web panels. Based on the application of assumptions on the combined locations of the two longitudinal web stiffeners, simplified equations were proposed for the bend-buckling coefficients and compared to the case of one longitudinal stiffener. It was found that bend-buckling coefficients can be doubled by adopting two longitudinal stiffeners instead of one longitudinal stiffener. For practical design purposes, additional equations were proposed for the required bending rigidity of the longitudinal stiffeners arranged in two horizontal lines on a web.

References listed at the end of the paper:

Bleich, F. (1952), Buckling Strength of Metal Structures, McGraw-Hill.

Sina Saberi, Parham Memarzadeh and Tadeh Zirakian (Primarily from: Department of Civil Engineering, Najafabad Branch, Islamic Azad University, P.O. Box 85141-43131, Najafabad, Iran), “Study of buckling
stability of cracked plates under uniaxial compression using singular FEM”, Structural Engineering and Mechanics Volume 69, Number 4, February 25, 2019, pages 417-426
DOI: http://dx.doi.org/10.12989/sem.2019.69.4.417

ABSTRACT: Buckling is one of the major causes of failure in thin-walled plate members and the presence of cracks with different lengths and locations in such structures may adversely affect this phenomenon. This study focuses on the buckling stability assessment of centrally and non-centrally cracked plates with small-, intermediate-, and large-size cracks, and different aspect ratios as well as support conditions, subjected to uniaxial compression. To this end, numerical models of the cracked plates were created through singular finite element method using a computational code developed in MATLAB. Eigen-buckling analyses were also performed to study the stability behavior of the plates. The numerical results and findings of this research demonstrate the effectiveness of the crack length and location on the buckling capacity of thin plates; however, the degree of efficacy of these parameters in plates with various aspect ratios and support conditions is found to be significantly different. Overall, careful consideration of the aspect ratio, support conditions, and crack parameters in buckling analysis of plates is crucial for efficient stability design and successful application of such thin-walled members.

References listed at the end of the paper:

ABSTRACT: This research deals with thermo-electro-mechanical buckling analysis of the sandwich nanobeams with face-sheets made of functionally graded carbon nano-tubes reinforcement composite (FG-CNTRC) based on the nonlocal strain gradient elasticity theory (NSGET) considering various higher-order shear deformation beam theories (HSDBT). The sandwich nano-beam with FG-CNTRC face-sheets is subjected to thermal and electrical loads while is resting on Pasternak’s foundation. It is assumed that the material properties of the face-sheets change continuously along the thickness direction according to different patterns for CNTs distribution. In order to include coupling of strain and electrical field in equation of motion, the nonlocal non-classical nano-beam model contains piezoelectric effect. The governing equations of motion are derived using Hamilton principle based on HSDBTs and NSGET. The differential quadrature method (DQM) is used to calculate the mechanical buckling loads of sandwich nano-beam as well as critical voltage and temperature rising. After verification with validated reference, comprehensive numerical results are presented to investigate the influence of important parameters such as various HSDBTs, length scale parameter (strain gradient parameter), the nonlocal parameter, the CNTs volume fraction, Pasternak’s foundation coefficients, various boundary conditions, the CNTs efficiency parameter and geometric dimensions on the buckling behaviors of FG sandwich nano-beam. The numerical results indicate that, the amounts of the mechanical critical load calculated by PSDBT and TSDBT approximately have same values as well as ESDBT and ASDBT. Also, it is worthy noted that buckling load calculated by aforementioned theories is nearly smaller than buckling load estimated by FSDBT. Also, similar aforementioned structure is used to building the nano/micro oscillators.

References listed at the end of the paper:


Abdelillah Benahmed, Bouazza Fahsi, Abdelnour Benzair, Mohamed Zidour, Fouad Bourada and Abdelouahed Tounsi (First author is from: Laboratory de Modélisation et Simulation Multi-échelle, Département de Physique, Faculte des Science Exactes Universite de Sidi Bel Abbes, Algeria), “Critical buckling of functionally graded nanoscale beam with porosities using nonlocal higher-order shear deformation”, Structural Engineering and Mechanics Volume 69, Number 4, February25 2019, pages 457-466

DOI: http://dx.doi.org/10.12989/SSS.2018.21.4.397

ABSTRACT: This paper presents an efficient higher-order nonlocal beam theory for the Critical buckling, of functionally graded (FG) nanobeams with porosities that may possibly occur inside the functionally graded materials (FG) during their fabrication, the nonlocal elastic behavior is described by the differential constitutive model of Eringen. The material properties of (FG) nanobeams with porosities are assumed to vary through the thickness according to a power law. The governing equations of the functionally graded nanobeams with porosities are derived by employing Hamilton’s principle. Analytical solutions are presented for a simply supported FG nanobeam with porosities. The validity of this theory is studied by comparing some of the present results with other higher-order theories reported in the literature. Illustrative examples are given also to show the effects of porosity volume fraction, and thickness to length ratios on the critical buckling of the FG beams.

References listed at the end of the paper:


Mokhtar Nebab, Hassen Ait Atmane, Riadh Bennai, Abdelouahed Tounsi and E.A. Adda Bedia (First author is from: Department of Civil Engineering, Faculty of Civil Engineering and Architecture, University of Hassiba Benbouali of Chlef, Algeria), “Vibration response and wave propagation in FG plates resting on elastic foundations using HSRT”, Structural Engineering and Mechanics, Volume 69, Number 5, March 10, 2019, pages 511-525, http://dx.doi.org/10.12989/sem.2019.69.5.511

ABSTRACT: This paper presents an analytical study of wave propagation in simply supported graduated functional plates resting on a two-parameter elastic foundation (Pasternak model) using a new theory of high order shear strain. Unlike other higher order theories, the number of unknowns and governing equations of the present theory is only four unknown displacement functions, which is even lower than the theory of first order shear deformation (FSDT). Unlike other elements, the present work includes a new field of motion, which introduces indeterminate integral variables. The properties of the materials are assumed to be ordered in the
thickness direction according to the two power law distributions in terms of volume fractions of the constituents. The wave propagation equations in FG plates are derived using the principle of virtual displacements. The analytical dispersion relation of the FG plate is obtained by solving an eigenvalue problem. Numerical examples selected from the literature are illustrated. A good agreement is obtained between the numerical results of the current theory and those of reference. A parametric study is presented to examine the effect of material gradation, thickness ratio and elastic foundation on the free vibration and phase velocity of the FG plate.

References listed at the end of the paper:


ABSTRACT: This paper will compare T3ys and MITC3 elements, both these two elements are three-node triangular plate bending elements with three degrees of freedom per node. The formulation of the T3ys and MITC3 elements is rather simple and has already been widely used. This paper will prove that the shear strain formulation of these two elements is identical even though they are obtained from two different methods. A single element is used to test the formulation of shear strain matrices. Numerical tests for circular plate cases compared with the exact solutions and with DKMT element will complete this review to verify the performances and show the convergence of these two elements.

References listed at the end of the paper:

Xianggang Zhang, Dapeng Deng, Xinyan Lin, Jianhui Yang and Lei Fu (First author is from: Henan Province Engineering Laboratory of Eco-Architecture and the Built Environment, Henan Polytechnic University, Jiaozuo, Henan, China), “Mechanical performance of sand-lightweight concrete-filled steel tube stub column under axial compression”, Structural Engineering and Mechanics, Volume 69, Number 6, pages 627-635, http://dx.doi.org/10.12989/sem.2019.69.6.627
ABSTRACT: In order to study the axial compression performance of sand-lightweight concrete-filled steel tube (SLCFST) stub columns, three circular SLCFST (C-SLCFST) stub column specimens and three SLCFST square (S-SLCFST) stub column specimens were fabricated and static monotonic axial compression performance testing was carried out, using the volume ratio between river sand and ceramic sand in sand-lightweight concrete (SLC) as a varying parameter. The stress process and failure mode of the specimens were observed, stress-strain curves were obtained and analysed for the specimens, and the ultimate bearing capacity of SLCFST stub column specimens was calculated based on unified strength theory, limit equilibrium theory and superposition theory. The results show that the outer steel tubes of SLCFST stub columns buckled outward, core SLC was crushed, and the damage to the upper parts of the S-SLCFST stub columns was more serious than for C-SLCFST stub columns. Three stages can be identified in the stress-strain curves of SLCFST stub columns: an elastic stage, an elastic-plastic stage and a plastic stage. It is suggested that CECS 159:2004 or AJI-1997, based on superposition theory, can be used to design the ultimate bearing capacity under axial compression for C-SLCFST and S-SLCFST stub columns; for varying replacement ratios of natural river sand, the calculated stress-strain curves for SLCFST stub columns under axial compression show good fitting to the test measure curves.
References listed at the end of the paper:
Mohammad H. Bayati Chaleshtari and Mohammad Jafari (Faculty of Mechanical and Mechatronics Engineering, Shahrrood University of Technology, Shahrrood, Iran), “Ant lion optimizer for optimization of...
ABSTRACT: Minimizing the stress concentration around hypotrochoid hole in finite metallic plates under in-plane loading is an important consideration in engineering design. In the analysis of finite metallic plate, the effective factors on stress distribution around holes include curvature radius of the corner of the hole, hole orientation, plate's aspect ratio, and hole size. This paper aims to investigate the impact of these factors on stress analysis of finite metallic plate with central hypotrochoid hole. To obtain the lowest value of stress around a hypotrochoid hole, a swarm intelligence optimization method named ant lion optimizer is used. In this study, with the hypothesis of plane stress circumstances, analytical solution of Muskhelishvili's complex variable method and conformal mapping is employed. The plate is taken into account to be finite, isotropic and linearly elastic. By applying suitable boundary conditions and least square boundary collocation technique, undefined coefficients of stress function are found. The results revealed that by choosing the above-mentioned factor correctly, the lowest value of stress would be obtained around the hole allowing to an increment in load-bearing capacity of the structure.

References listed at the end of the paper:


ABSTRACT: In this study, the problem of axisymmetric deformation of prestressed Föppl-Hencky membrane under constrained deflecting was analytically solved and its closed-form solution was presented. The small-rotation-angle assumption usually adopted in membrane problems was given up, and the initial stress in membrane was taken into account. Consequently, this closed-form solution has higher calculation accuracy and can be applied for a wider range in comparison with the existing approximate solution. The presented numerical examples demonstrate the validity of the closed-form solution, and show the errors of the contact radius, profile and radial stress of membrane in the existing approximate solution brought by the small-rotation-angle assumption. Moreover, the influence of the initial stress on the contact radius is also discussed based on the numerical examples.

References listed at the end of the paper:


Sang-Youl Lee and Jong-Su Jeon (First author is from: Department of Civil Engineering, Andong National University, 1375 Gyeondong-ro, Andong, Gyeongsangbuk-do 36729, Republic of Korea), “Use of bivariate gamma function to reconstruct dynamic behavior of laminated composite plates containing embedded delamination under impact loads”, Structural Engineering and Mechanics, Volume 70, Number 1, April 10 2019, pages 1-11, DOI: http://dx.doi.org/10.12989/sem.2019.70.1.001

ABSTRACT: This study deals with a method based on the modified bivariate gamma function for reconstructions of dynamic behavior of delaminated composite plates subjected to impact loads. The proposed bivariate gamma function is associated with micro-genetic algorithms, which is capable of solving inverse problems to determine the stiffness reduction associated with delamination. From computing the unknown parameters, it is possible for the entire dynamic response data to develop a prediction model of the dynamic response through a regression analysis based on the measurement data. The validity of the proposed method was verified by comparing with results employing a higher-order finite element model. Parametric results revealed that the proposed method can reconstruct dynamic responses and the stiffness reduction of delaminated composite plates can be investigated for different measurements and loading locations.

References listed at the end of the paper:


Behrouz Karami, Maziar Janghorban and Abdelouahed Tounsi (First author is from: Department of Mechanical Engineering, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran), “Wave propagation of functionally graded anisotropic nanoplates resting on Winkler-Pasternak foundation”, Structural Engineering and Mechanics, Volume 70, Number 1, April 10 2019, pages 55-66, DOI: http://dx.doi.org/10.12989/sem.2019.70.1.055

ABSTRACT: This work deals with the size-dependent wave propagation analysis of functionally graded (FG) anisotropic nanoplates based on a nonlocal strain gradient refined plate model. The present model incorporates two scale coefficients to examine wave dispersion relations more accurately. Material properties of FG anisotropic nanoplates are exponentially varying in the z-direction. In order to solve the governing equations for bulk waves, an analytical method is performed and wave frequencies and phase velocities are obtained as a function of wave number. The influences of several important parameters such as material graduation exponent, geometry, Winkler-Pasternak foundation parameters and wave number on the wave propagation of FG anisotropic nanoplates resting on the elastic foundation are investigated and discussed in detail. It is concluded that these parameters play significant roles on the wave propagation behavior of the nanoplates. From the best knowledge of authors, it is the first time that FG nanoplate made of anisotropic materials is investigated, so, presented numerical results can serve as benchmarks for future analysis of such structures.

References listed at the end of the paper:


Ehsan Arshid, Ahmad Reza Khorshidvand and S. Mahdi Khorsandijou (First author is from: Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran), “The effect of porosity on free vibration of SPFG circular plates resting on visco-Pasternak elastic foundation based on CPT, FSDT and TSDT”, Structural Engineering and Mechanics, Vol. 70, No. 1, April 10, 2019, pp 97-112, DOI: http://dx.doi.org/10.12989/sem.2019.70.1.097

ABSTRACT: Using the classical, first order and third order shear deformation plates theories the motion equations of an undrained porous FG circular plate which is located on visco-Pasternak elastic foundation have been derived and used for free vibration analysis thereof. Strains are related to displacements by Sanders relationship. Fluid has saturated the pores whose distribution varies through the thickness according to three physically probable given functions. The equations are discretized and numerically solved by the generalized
differential quadrature method. The effect of porosity, pores distribution, fluid compressibility, viscoelastic foundation and aspect ratio of the plate on its vibration has been considered.

References listed at the end of the paper:
Mohamed Bourada, Abed Bouadi, Abdelmoumen Anis Bousahla, Amel Senouci, Fouad Bourada, Abdelouahed Tounsi and S.R. Mahmoud (First author is from: Material and Hydrology Laboratory, University of Sidi Bel Abbes, Faculty of Technology, Civil Engineering Department, Algeria), “Buckling behavior of rectangular plates under uniaxial and biaxial compression”, Structural Engineering and Mechanics, Vol. 70, No. 1, April 10, 2019, pp 113-123, DOI: http://dx.doi.org/10.12989/sem.2019.70.1.113

ABSTRACT: In the classical stability investigation of rectangular plates the classical thin plate theory (CPT) is often employed, so omitting the transverse shear deformation effect. It seems quite clear that this procedure is not totally appropriate for the investigation of moderately thick plates, so that in the following the first shear deformation theory proposed by Meksi et al. (2015), that permits to consider the transverse shear deformation influences, is used for the stability investigation of simply supported isotropic rectangular plates subjected to uni-axial and bi-axial compression loading. The obtained results are compared with those of CPT and, for rectangular plates under uniaxial compression, a novel direct formula, similar to the conventional Bryan\'s expression, is found for the Euler stability stress. The accuracy of the present model is also ascertained by comparing it, with model proposed by Piscopo (2010).

References listed at the end of the paper:


theory for functionally graded thick rectangular plates on elastic foundation", Geomech. Eng., 12(1), 9-34.


ABSTRACT: A nine node isoparametric plate bending element is used for bending analysis of laminated composite skew cylindrical shell panels. Both thick and thin shell panels are solved. Rotary inertia and shear deformation are incorporated by considering first order shear deformation theory. The analysis is performed considering shallow shell theory. Both shallow and moderately deep skew cylindrical shells are investigated. Skew cylindrical shell panels having different thickness ratios (h/a), radius to length ratios (R/a), ply angle orientations, number of layers, aspect ratio (b/a), boundary conditions and various loading (concentrated, uniformly distributed, linear varying and doubly sinusoidal varying) conditions are analysed. Various new results are presented.

References listed at the end of the paper:


ABSTRACT: In this paper, energy absorption characteristics of circular windowed tubes with different section shapes (circular, ellipse, square, hexagon, polygon and pentagon) are investigated numerically and experimentally. The tube possesses the same material, thickness, height, volume and average cross sectional area which are subjected under axial and oblique quasi-static loading conditions. Numerical model was constructed with FE code ABAQUS/Explicit, the obtained outcome of simulation is in good matching with the experimental data. The energy absorbed, specific energy absorption, crash force efficiency, peak and mean loads along with the collapse modes with their initiation point of simple and windowed tubes were evaluated. The technique for order of preference by similarity ideal solution (TOPSIS) approach was employed for assessing their overall crushing performance. The obtained results confirm that efficacy of crash force indicators have improved by introducing windows and tubes with pentagonal and circular windows achieves the maximum ranking about 0.528 and 0.517, it clearly reveals the above are best window shapes.

References listed at the end of the paper:


Seyed Mashem Alavi and Hamidreza Eipakchi (Faculty of Mechanical and Mechatronics Engineering, Shahrood University of Technology, P.O.Box 316, Shahrood, I.R. Iran). “Geometry and load effects on transient response of a VFGM annular plate: An analytical approach”, Structural Engineering and Mechanics, Vol. 70, No. 2, April 25 2019, pp 179-197, DOI: http://dx.doi.org/10.12989/sem.2019.70.2.179

ABSTRACT: In this article, the effect of different geometrical, materials and load parameters on the transient response of axisymmetric viscoelastic functionally graded annular plates with different boundary conditions are studied. The behavior of the plate is assumed the elastic in bulk and viscoelastic in shear with the standard linear solid model. Also, the graded properties vary through the thickness according to a power law function. Three types of mostly applied transient loading, i.e., step, impulse, and harmonic with different load distribution respect to radius coordinate are examined. The motion equations and the corresponding boundary conditions are extracted by applying the first order shear deformation theory which are three coupled partial differential equations with variable coefficients. The resulting motion equations are solved analytically using the perturbation technique and the generalized Fourier series. The sensitivity of the response to the graded indexes, different transverse loads, aspect ratios, boundary conditions and the material properties are investigated too. The results are compared with the finite element analysis.

References listed at the end of the paper:


functionally graded plates subjected to underwater shock”, J. Sound J. Sound Vibr., 336, 257-274.
Sadd, M.H. (2009), Elasticity Theory, Applications and Numeric, Elsevier Inc., U.S.A.


ABSTRACT: In this paper, a semi-analytical method will be discussed for free vibration analysis of rotating beams with variable cross sectional area. For this purpose, the rotating beam is discretized through applying the transfer matrix method and assumed the axial force is constant for each element. Then, the transfer matrix is derived based on Euler-Bernoulli’s beam differential equation and applying boundary conditions. In the following, the frequencies of the rotating beam with constant and variable cross sections are determined using the transfer matrix method in several case studies. In order to eliminate numerical difficulties in the transfer matrix method, the Riccati transfer matrix is employed for high rotation speed and high modes. The results are compared with the results of the finite elements method and Rayleigh-Ritz method which show good agreement in spite of low computational cost.

References listed at the end of the paper:


ABSTRACT: Using the non-local elasticity theory, Timoshenko beam model is developed to study the non-local buckling of Triple-walled carbon nanotubes (TWCNTs) embedded in an elastic medium under axial compression. The chirality and small scale effects are considered. The effects of the surrounding elastic medium based on a Winkler model and van der Waals/vdW forces between the inner and middle, also between the middle and outer nanotubes are taken into account. Considering the small-scale effects, the governing equilibrium equations are derived and the critical buckling loads under axial compression are obtained. The results show that the critical buckling load can be overestimated by the local beam model if the small-scale effect is overlooked for long nanotubes. In addition, significant dependence of the critical buckling loads on the chirality of zigzag carbon nanotube is confirmed. Furthermore, in order to estimate the impact of elastic medium on the non-local critical buckling load of TWCNTs under axial compression, the use of these findings are important in mechanical design considerations, improve and reinforcement of devices that use carbon nanotubes.

References listed at the end of the paper:


ABSTRACT: In the present article, cross ply laminated composite plates are considered and a simple sinusoidal shear deformation model is tested for analyzing their flexural, stability and dynamic behaviors. The model contains only four unknown variables that are five in the first order shear deformation theory (FSDT) or other higher order models. The in-plane kinematic utilizes undetermined integral terms to quantitatively express the shear deformation influence. In the proposed theory, the conditions of zero shear stress are respected at bottom and top faces of plates without considering the shear correction coefficient. Equations of motion according to the proposed formulation are deduced by employing the virtual work principle in its dynamic version. The analytical solution is determined via double trigonometric series proposed by Navier. The stresses, displacements, natural frequencies and critical buckling forces computed using present method are compared with other published data where a good agreement between results is demonstrated.

References listed at the end of the paper:


ABSTRACT: In this paper, free vibration of Cooper-Naghd micro sandwich cylindrical shell with saturated porous core and reinforced carbon nanotube (CNT) piezoelectric composite face sheets is investigated by using first order shear deformation theory (FSDT) and modified couple stress theory (MCST). The sandwich shell is subjected to magneto-thermo-mechanical loadings with temperature dependent material properties. Energy method and Hamilton's principle are used for deriving of the motion equations. The equations are solved by Navier's method. The results are compared with the obtained results by the other literatures. The effects of various parameters such as saturated porous distribution, geometry parameters, volume fraction and temperature change on the natural frequency of the micro-sandwich cylindrical shell are addressed. The obtained results reveal that the natural frequency of the micro sandwich cylindrical shell increases with increasing of the radius to thickness ratio, Skempton coefficient, the porosity of the core, and decreasing of the length to radius ratio and temperature change.

References listed at the end of the paper:


ABSTRACT: The present paper illustrates a numerical investigation on the failure behaviour of ring-stiffened cylinder subjected to external hydrostatic pressure. The published test data of steel welded ring-stiffened cylinder are surveyed and collected. Eight test models are chosen for the verification of the modelling and FE analyses procedures. The imperfection as the consequences of the fabrication processes, such as initial geometric deformation and residual stresses due to welding and cold forming, which reduced the ultimate strength, are simulated. The results show that the collapse pressure and failure mode predicted by the nonlinear FE analyses agree acceptably with the experimental results. In addition, the failure mode parameter obtained from the characteristic pressure such as interface buckling pressure known as local buckling pressure, overall buckling pressure, and yield pressure are also examined through the collected data and shows a good correlation. A parametric study is then conducted to confirm the failure progression as the basic parameters such as the shell radius, thickness, overall length of the compartment, and stiffener spacing are varied.

References listed at the end of the paper:


ShaoFeng Nie, Tianhua Zhou, Fangfang Liao and Donghua Yang, “Study on axial compressive behavior of quadruple C-channel built-up cold-formed steel columns”, Structural Engineering and Mechanics, Vol. 70, No. 4, May 25 2019, pp 499-511, DOI: https://doi.org/10.12989/sem.2019.70.4.499

ABSTRACT: In this study, the axial compressive behavior of novel quadruple C-channel built-up cold-formed steel columns with different slenderness ratio was investigated, using the experimental and numerical analysis. The axial compressive capacity and failure modes of the columns were obtained and analyzed. The finite element models considering the geometry, material and contact nonlinearity were developed to simulate and analyze the structural behavior of the columns further. There was a great correlation between the numerical analyses and test results, which indicated that the finite element model was reasonable and accurate. Then influence of, slenderness ratio, flange width-to-thickness ratio and screw spacing on the mechanical behavior of the columns were studied, respectively. The tests and numerical results show that due to small slenderness ratio, the failure modes of the specimens are generally local buckling and distortional buckling. The axial compressive strength and stiffness of the quadruple C-channel built-up cold-formed steel columns decrease with the increase of maximum slenderness ratio. When the screw spacing is ranging from 150mm to 450mm, the axial compressive strength and stiffness of the quadruple C-channel built-up cold-formed steel columns change little. The axial compressive capacity of quadruple C-channel built-up cold-formed steel columns increases with the decrease of flange width-thickness ratio. A modified effective length factor is proposed to quantify the axial compressive capacity of the quadruple C-channel built-up cold-formed steel columns with U-shaped track in the ends.

References listed at the end of the paper:


AISI (2007), North American specification for the design of cold-formed steel structural members, Washington, DC, USA.


AS/NZS No. 4600 (2005), Cold-formed Steel Structure, Sydney, Australia.


GB50018 (2002), Technical Code of Cold-formed Thin-wall Steel Structures, Beijing, China.

GB/T228.1 (2010), Metallic materials: Tensile testing: part 1: Method of test at room temperature, Beijing, China.


ABSTRACT: An analytical research on buckling of simply supported thin plate with variable thickness under bi-axial compression is presented in this paper. Combining the perturbation technique, Fourier series expansion and Galerkin methods, the linear governing differential equation of the plate with arbitrary thickness variation under bi-axial compression is solved and the analytical expression of the critical buckling load is obtained. Based on that, numerical analysis is carried out for the plates with different thickness variation forms and aspect ratios under different bi-axial compressions. Four different thickness variation forms including linear, parabolic, stepped and trigonometric have been considered in this paper. The calculated critical buckling loads and buckling modes are presented and compared with the published results in the tables and figures. It shows that the analytical expressions derived by the theoretical method in this paper can be effectively used for buckling analysis of simply supported thin plates with arbitrary thickness variation, especially for the stepped thickness that used in engineering widely.

References listed at the end of the paper:

ABSTRACT: This study aimed to develop a high-order shear deformation theory to predict the free vibration of hybrid cross-ply laminated plates under different boundary conditions. The equations of motion for laminated hybrid rectangular plates are derived and obtained by using Hamilton's principle. The closed-form solutions of anti-symmetric cross-ply and angle-ply laminates are obtained by using Navier's solution. To assess the validity of our method, we used the finite element method. Firstly, the analytical and the numerical implementations were validated for an antisymmetric cross-ply square laminated with available results in the literature. Then, the effects of side-to-thickness ratio, aspect ratio, lamination schemes, and material properties on the fundamental frequencies for different combinations of boundary conditions of hybrid composite plates are investigated. The comparison of the analytical solutions with the corresponding finite element simulations shows the good accuracy of the proposed analytical closed form solution in predicting the fundamental frequencies of hybrid cross-ply laminated plates under different boundary conditions.

References listed at the end of the paper:


ABSTRACT: In the present study, a suitable mathematical model considering parabolic transverse shear strains
for dynamic analysis of laminated composite skew plates under different types of impulse and spatial loads was presented for the first time. The proposed mathematical model satisfies zero transverse shear strain at the top and bottom of the plate. On the basis of the cubic variation of thickness coordinate in in-plane displacement fields of the present mathematical model, a 2D finite element (FE) model was developed including skew transformations in the mathematical model. No shear correction factor is required in the present formulation and damping effect was also incorporated. This is the first FE implementation considering a cubic variation of thickness coordinate in in-plane displacement fields including skew transformations to solve the forced vibration problem of composite skew plates. The effect of transverse shear and rotary inertia was incorporated in the present model. The Newmark-beta scheme was adapted to perform time integration from step to step. The C0 FE formulation was implemented to overcome the problem of C1 continuity associated with the cubic variation of thickness coordinate in in-plane displacement fields. The numerical studies showed that the present 2D FE model predicts the result close to the analytical results. Many new results varying different parameter such as skew angles, boundary conditions, etc. were presented.

References listed at the end of the paper:


ABSTRACT: To analyze the seismic reliability of concrete rectangular liquid storage structures (CRLSSs), assuming that the wall thickness and internal liquid depth of CRLSSs are random variables, calculation models of CRLSSs are established by using the Monte Carlo finite element method (FEM). The principal stresses of the over-ground and buried CRLSSs are calculated under three rare fortification intensities, and the failure probabilities of CRLSSs are obtained. The results show that the seismic reliability increases with the increase of wall thickness, whereas it decreases with the increase of liquid depth. Between the two random factors, the seismic reliability of CRLSSs is more sensitive to the change in wall thickness. Compared with the overground CRLSS, the buried CRLSS has better reliability.

References listed at the end of the paper:


ABSTRACT: This paper aims to develop a quasi-3D shear deformation theory for the study of bending, buckling and free vibration responses of functionally graded (FG) sandwich thick plates. For that, in the present theory, both the components of normal deformation and shear strain are included. The displacement field of the proposed model contains undetermined integral terms and involves only four unknown functions with including stretching effect. Using Navier' technique the solution of the problem is derived for simply supported sandwich plate. Numerical results have been reported, and compared with those available in the open literature were excellent agreement was observed. Finally, a detailed parametric study is presented to demonstrate the effect of the different parameters on the flexural responses, free vibration and buckling of a simply supported sandwich plates.

References listed at the end of the paper:


ABSTRACT: This study presents a comprehensive nonlinear dynamic approach to investigate the linear and nonlinear vibration of sandwich plates fabricated from functionally graded materials (FGMs) resting on an elastic foundation. Higher-order shear deformation theory and Hamilton's principle are employed to obtain governing equations. The Runge–Kutta method is employed together with the commercially available mathematical software MAPLE 14 to solve the set of nonlinear dynamic governing equations. Method validity is evaluated by comparing the results of this study and those of previous research. Good agreement is achieved. The effects of temperature change on frequencies are investigated considering various temperatures and various
volume fraction index values, N. As the temperature increased, the plate frequency decreased, whereas with increasing N, the plate frequency increased. The effects of the side-to-thickness ratio, c/h, on natural frequencies were investigated. With increasing c/h, the frequencies increased nonlinearly. The effects of foundation stiffness on nonlinear vibration of the sandwich plate were also studied. Backbone curves presenting the variation of maximum displacement with respect to plate frequency are presented to provide insight into the nonlinear vibration and dynamic behavior of FGM sandwich plates.

References listed at the end of the paper:


ABSTRACT: Buckling analysis of shape memory alloy (SMA) rectangular plates subjected to uniform and linearly distributed in-plane loads is the main objective in the present paper. Brinson’s model is developed to
express the constitutive characteristics of SMA plate. Using the classical plate theory and variational approach, stability equations are derived. In addition to external in-plane mechanical loads, the plate is subjected to the pre-stresses caused by the recovery stresses that are generated during martensitic phase transformation. Ritz method is used for solving the governing stability equations. Finally, the effects of conditions on the edges, thickness, aspect ratio, temperature and pre-strains on the critical buckling loads of SMA plate are investigated in details.

References listed at the end of the paper:
Åkesson, B. (2007), Plate Buckling in Bridges and Other Structures, CRC Press, U.S.A.

ABSTRACT: The present study aims to analyze the magneto-electro-elastic (MEE) vibration of a functionally graded carbon nanotubes reinforced composites (FG-CNTRC) cylindrical shell. Electro-magnetic loads are applied to the structure and it is located on an elastic foundation which is simulated by visco-Pasternak type. The properties of the nano-composite shell are assumed to be varied by temperature changes. The third-order shear deformation shells theory is used to describe the displacement components and Hamilton’s principle is employed to derive the motion differential equations. To obtain the results, Navier’s method is used as an analytical solution for simply supported boundary condition and the effect of different parameters such as temperature variations, orientation angle, volume fraction of CNTs, different types of elastic foundation and other prominent parameters on the natural frequencies of the structure are considered and discussed in details. Design more functional structures subjected to multi-physical fields is of applications of this study results.

References listed at the end of the paper:


Belmahi, S., Zidour, M., Meradjah, M., Bensattallah, T. and Dihaj, A. (2018), “Analysis of boundary conditions effects on vibration of


ABSTRACT: Considering stress singularities at point support locations, buckling solutions for plates with arbitrary number of point supports are hard to obtain. Thus, new Hp-Cloud shape functions with Kronecker delta property (HPCK) were developed in the present paper to examine elastic buckling of point-supported thin plates in various shapes. Having the Kronecker delta property, this specific Hp-Cloud shape functions were constructed through selecting particular quantities for influence radii of nodal points as well as proposing appropriate enrichment functions. Since the given quantities for influence radii of nodal points could bring about poor quality of interpolation for plates with sharp corners, the radii were increased and the method of Lagrange multiplier was used for the purpose of applying boundary conditions. To demonstrate the capability of the new Hp-Cloud shape functions in the domain of analyzing plates in different geometry shapes, various test cases were correspondingly investigated and the obtained findings were compared with those available in the related literature. Such results concerning these new Hp-Cloud shape functions revealed a significant consistency with those reported by other researchers.

References listed at the end of the paper:


ABSTRACT: This paper investigates the static and dynamic behaviors of imperfect single walled carbon nanotube (SWCNT) modeled as a beam structure by using energy-equivalent model (EEM), for the first time. Based on EEM Young's modulus and Poisson's ratio for zigzag (n, 0), and armchair (n, n) carbon nanotubes (CNTs) are presented as functions of orientation and force constants. Nonlinear Euler-Bernoulli assumptions are proposed considering mid-plane stretching to exhibit a large deformation and a small strain. To simulate the
interaction of CNTs with the surrounding elastic medium, nonlinear elastic foundation with cubic nonlinearity and shearing layer are employed. The equation governed the motion of curved CNTs is a nonlinear integrodifferential equation. It is derived in terms of only the lateral displacement. The nonlinear integrodifferential equation that governs the buckling of CNT is numerically solved using the differential integral quadrature method (DIQM) and Newton's method. The linear vibration problem around the static configurations is discretized using DIQM and then is solved as a linear eigenvalue problem. Numerical results are depicted to illustrate the influence of chirality angle and imperfection amplitude on static response, buckling load and dynamic behaviors of armchair and zigzag CNTs. Both, clamped-clamped (C-C) and simply supported (SS-SS) boundary conditions are examined. This model is helpful especially in mechanical design of NEMS manufactured from CNTs.

References listed at the end of the paper:

(NOTE: Refs. only go to “H”. There are no more in the pdf file. Possibly additional references are missing in the journal article?)

ABSTRACT: This paper studies application of modified couple stress theory and first order shear deformation theory to magneto-electro-mechanical vibration analysis of three-layered size-dependent curved beam. The curved beam is resting on Pasternak's foundation and is subjected to mechanical, magnetic and electrical loads. Size dependency is accounted by employing a small scale parameter based on modified couple stress theory. The magneto-electro-mechanical preloads are accounted in governing equations to obtain natural frequencies in terms of initial magneto-electro-mechanical loads. The analytical approach is applied to investigate the effect of some important parameters such as opening angle, initial electric and magnetic potentials, small scale parameter, and some geometric dimensionless parameters and direct and shear parameters of elastic foundation on the magneto-electro-elastic vibration responses.

References listed at the end of the paper:
https://doi.org/10.1177/1099636217697497.
https://doi.org/10.1007/s1045389X17689930.


ABSTRACT: In this study, the mechanical bending behaviors of functionally graded porous nanobeams are investigated. Four types of porosity which are, the classical power porosity function, the symmetric with mid-plane cosine function, bottom surface distribution and top surface distribution are proposed in analysis of nanobeam for the first time. A comparison between four types of porosity are illustrated. The effect of nano-scale is described by the differential nonlocal continuum theory of Eringen by adding the length scale into the constitutive equations as a material parameter comprising information about nanoscopic forces and its interactions. The graded material is designated by a power function through the thickness of nanobeam. The beam is simply-supported and is assumed to be thin, and hence, the kinematic assumptions of Euler-Bernoulli beam theory are held. The mathematical model is solved numerically using the finite element method. Numerical results show effects of porosity type, material graduation, and nanoscale parameters on the static deflection of nanobeam.

References listed at the end of the paper:


ABSTRACT: Wave propagation analysis of a porous graphene platelet reinforced (GPLR) nanocomposite shell is investigated for the first time. The homogenization of the utilized material is procured by extending the Halpin-Tsai relations for the porous nanocomposite. Both symmetric and asymmetric porosity distributions are regarded in this analysis. The equations of the shell's motion are derived according to Hamilton's principle coupled with the kinematic relations of the first-order shear deformation theory of the shells. The obtained governing equations are considered to be solved via an analytical solution which includes two longitudinal and circumferential wave numbers. The accuracy of the presented formulations is examined by comparing the results of this method with those reported by former authors. The simulations reveal a stiffness decrease in the cases which porosity influences are regarded. Also, one must pay attention to the effects of longitudinal wave number on the wave dispersion curves of the nanocomposite structure.


References listed at the end of the paper:


ABSTRACT: In this investigation, study of the static and dynamic behaviors of functionally graded beams (FGB) is presented using a hyperbolic shear deformation theory (HySDT). The simply supported FG-beam is resting on the elastic foundation (Winkler-Pasternak types). The properties of the FG-beam vary according to exponential (E-FGB) and power-law (P-FGB) distributions. The governing equations are determined via Hamilton's principle and solved by using Navier's method. To show the accuracy of this model (HySDT), the current results are compared with those available in the literature. Also, various numerical results are discussed to show the influence of the variation of the volume fraction of the materials, the power index, the slenderness ratio and the effect of Winkler spring constant on the fundamental frequency, center deflection, normal and shear stress of FG-beam.

References listed at the end of the paper:
ABSTRACT: Probabilistic buckling behavior of sandwich panel considering random system parameters using a radial basis function (RBF) approach is presented in this paper. The random system properties result in an uncertain response of the sandwich structure. The buckling load of laminated sandwich panel is obtained by employing higher-order-zigzag theory (HOZT) coupled with RBF and probabilistic finite element (FE) model. The in-plane displacement variation of core as well as facesheet is considered to be cubic while transverse
displacement is considered to be quadratic within the core and constant in the facesheets. Individual and combined stochasticity in all elemental input parameters (like facesheets thickness, ply-orientation angle, core-thickness and properties of material) are considered to know the effect of different degree of stochasticity, ply-orientation angle, boundary conditions, core thickness, number of laminates, and material properties on global response of the structure. In order to achieve the computational efficiency, RBF model is employed as a surrogate to the original finite element model. The stiffness matrix of global response is stored in a single array using skyline technique and simultaneous iteration technique is used to solve the stochastic buckling equations.

References listed at the end of the paper:


https://doi.org/10.1080/15397734.2016.1238765.


accurate actions. Therefore, the purpose of this paper is to analyze plastic buckling behavior of the micro beam structures by adopting a Conventional Mechanism-based Strain Gradient plasticity (CMSG) theory. The effect of length scale on critical force is considered for three types of boundary conditions, i.e. the simply supported, cantilever and clamped - simply supported micro beams. For each case, the stability equations of the buckling are calculated to obtain related critical forces. The constitutive equation involves work hardening phenomenon through defining an index of multiple plastic hardening exponent. In addition, the Euler-Bernoulli hypothesis is used for kinematic of deflection. Corresponding to each length scale and index of the plastic work hardening, the critical forces are determined to compare them together.

References listed at the end of the paper:


Darvishvand, A. and Zajkani, A. (2019a), “A new model for permanent f...

ABSTRACT: This paper develops a nonlocal strain gradient plate model for damping vibration analysis of smart magneto-electro-viscoelastic nanoplates resting on visco-Pasternak medium. For more accurate analysis of nanoplate, the proposed theory contains two scale parameters related to the nonlocal and strain gradient effects. Viscoelastic effect which is neglected in all previous papers on magneto-electro-viscoelastic nanoplates is considered based on Kelvin–Voigt model. Governing equations of a nonlocal strain gradient smart nanoplate on viscoelastic substrate are derived via Hamilton's principle. Galerkin's method is implemented to solve the governing equations. Effects of different factors such as viscoelasticity, nonlocal parameter, length scale parameter, applied voltage and magnetic potential on damping vibration characteristics of a nanoplate are studied.

References listed at the end of the paper:


ABSTRACT: Present article deals with the static stability analysis of compositionally graded nanocomposite beams reinforced with graphene oxide powder (GOP) is undertaken once the beam is subjected to an induced force caused by nonuniform magnetic field. The homogenized material properties of the constituent material are approximated through Halpin-Tsai micromechanical scheme. Three distribution types of GOPs are considered, namely uniform, X and O. Also, a higher-order refined beam model is incorporated with the dynamic form of the virtual work\textquoterights principle to derive the partial differential motion equations of the problem. The governing equations are solved via Galerkin\textquoterights method. The introduced mathematical model is numerically validated presenting a comparison between the results of present work with responses obtained from previous articles. New results for the buckling load of GOP reinforced nanocomposites are presented regarding for different values of magnetic field intensity. Besides, other investigations are performed to show the impacts of other variants, such as slenderness ratio, boundary condition, distribution type and so on, on the critical stability limit of beams made from nanocomposites.

References listed at the end of the paper:
https://doi.org/10.1016/j.compstruct.2013.08.038. 

M. Arefi and M. Meskini (Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan 87317-51167, Iran), “Application of hyperbolic shear deformation theory to free vibration analysis of functionally graded porous plate with piezoelectric face-sheets”, Structural Engineering and Mechanics, Vol. 71, No. 5, September 10 2019, pp 459-467, DOI: https://doi.org/10.12989/sem.2019.71.5.459 ABSTRACT: In this paper, hyperbolic shear deformation theory is used for free vibration analysis of piezoelectric rectangular plate made of porous core. Various types of porosity distributions for the porous material is used. To obtain governing equations of motion, Hamilton’s principle is used. The Navier’s method is used to obtain numerical results of the problem in terms of significant parameters. One can conclude that free vibration responses are changed significantly with change of important parameters such as various porosities and dimensionless geometric parameters such as thickness to side length ratio and ratio of side lengths. 

References listed at the end of the paper:
https://doi.org/10.1007/s1099636217697497.
https://doi.org/10.1007/s1099636217714181.
https://doi.org/10.1016/j.physb.2017.06.066.
https://doi.org/10.1007/s1099636216642393.
https://doi.org/10.1016/j.compositesb.2011.05.032.
Md I. Ansari\textsuperscript{1}, Ajay Kumar\textsuperscript{2} and Ranja Bandyopadhyaya\textsuperscript{2}

\textsuperscript{1}Department of Architecture, Jamia Millia Islamia, New Delhi- 110025, India
\textsuperscript{2}Department of Civil Engineering, National Institute of Technology Patna, Patna- 800005, India


\textbf{ABSTRACT:} In this paper, an improved mathematical model is presented for the bending analysis of doubly curved functionally graded material (FGM) sandwich rhombic conoids. The mathematical model includes expansion of Taylor’s series up to the third degree in thickness coordinate and normal curvatures in in-plane displacement fields. The condition of zero-transverse shear strain at upper and lower surface of rhombic conoids is implemented in the present model. The newly introduced feature in the present mathematical model is the simultaneous inclusion of normal curvatures in deformation field and twist curvature in strain-displacement equations. This unique introduction permits the new 2D mathematical model to solve problems of moderately thick and deep doubly curved FGM sandwich conoids. The distinguishing feature of present shell from the other shells is that maximum transverse deflection does not occur at its center. The proposed new mathematical model is implemented in finite element code written in FORTRAN. The obtained numerical results are compared with the results available in the literature. Once validated, the current model was employed to solve numerous bending problems by varying different parameters like volume fraction indices, skew angles, boundary conditions, thickness scheme, and several geometric parameters.

References listed at the end of the paper:


ABSTRACT: In this research, the nonlinear static, buckling and vibration analysis of viscoelastic micro-composite beam reinforced by various distributions of boron nitridube nanotube (BNNT) with initial geometrical imperfection by modified strain gradient theory (MSGT) using finite element method (FEM) are presented. The various distributions of BNNT are considered as UD, FG-V and FG-X and also, the extended rule of mixture is used to estimate the properties of micro-composite beam. The components of stress are dependent to mechanical, electrical and thermal terms and calculated using piezoelectricity theory. Then, the kinematic equations of micro-composite beam using the displacement fields are obtained. The governing equations of motion are derived using energy method and Hamilton’s principle based on MSGT. Then, using FEM, these equations are solved. Finally, the effects of different parameters such as initial geometrical imperfection, various distributions of nanotube, damping coefficient, piezoelectric constant, slenderness ratio, Winkler spring constant, Pasternak shear constant, various boundary conditions and three material length scale parameters on the behavior of nonlinear static, buckling and vibration of micro-composite beam are investigated. The results indicate that with an increase in the geometrical imperfection parameter, the stiffness of micro-composite beam increases and thus the non-dimensional nonlinear frequency of the micro structure reduces gradually.

References listed at the end of the paper:


REFERENCES


https://doi.org/10.1016/j.compstruct.2015.03.011.


Mehdi Mohammadimehr*1, Hasan Afshari1,2, M. Salemi1, K. Torabi1,3 and Mojtaba Mehrabi1,3
1Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
2Department of Mechanical Engineering, Khomeinishahr Branch, Islamic Azad University, Khomeinishahr/Isfahan, Iran
3Department of Mechanics, Faculty of Engineering, University of Isfahan, Isfahan, Iran


ABSTRACT: In the present study, buckling and free vibration analyses of annular thin sector plate made of functionally graded materials (FGMs) resting on visco-elastic Pasternak foundation, subjected to external radial, circumferential and shear in-plane loads is investigated. Material properties are assumed to vary along the thickness according to an power law with Poisson’s ratio held constant. First, based on the classical plate theory (CPT), the governing equation of motion is derived using Hamilton’s principle and then is solved using the generalized differential quadrature method (GDQM). Numerical results are compared to those available in the literature to validate the convergence and accuracy of the present approach. Finally, the effects of power-law exponent, ratio of radii, thickness of the plate, sector angle, and coefficients of foundation on the fundamental and higher natural frequencies of transverse vibration and critical buckling loads are considered for various boundary conditions. Also, vibration and buckling mode shapes of functionally graded (FG) sector plate have been shown in this research. One of the important obtained results from this work show that ratio of the frequency of FG annular sector plate to the corresponding values of homogeneous plate are independent from boundary conditions and frequency number.

References listed at the end of the paper:


María E. Marante¹,a, Wilmer J. Barreto¹,2b and Ricardo A. Picón*¹,2
¹Laboratory of Structural Mechanics, Lisandro Alvarado University, Barquisimeto, Venezuela
²Departamento de Obras Civiles y Geología, Facultad de Ingeniería, Universidad Católica de Temuco, Temuco, Chile
“Using a feed forward ANN to model the inelastic behaviour of confined sandwich panels”, Structural Engineering and Mechanics, Vol. 71, No. 5, September 10 2019, pp 545-552, DOI: https://doi.org/10.12989/sem.2019.71.5.545

ABSTRACT: The analysis and design of complex structures like sandwich-panel elements are difficult; the use of finite element method for the analysis is complicated and time consuming when non-linear effects are considered. On the other hand, artificial neural network (ANN) models can capture the non-linear effects and its application requires lesser computational demand. Two ANN models were trained, tested and validated to compute the force for a given displacement of a sandwich-type roof element; 2555 force and element deformation pairs were used for training the ANN models. For the models trained without considering the damping effect, there were two values in the input layer: maximum displacement and current displacement, and for the model considering damping, displacement from the previous step was used as an additional input. Totally, 400 ANN models were trained. Results show that there is a good agreement between the experimental and simulated data, and the models showed a good performance with a mean square error value of 4548.85. Both the ANN models could simulate the inelastic behaviour, loss of rigidity, and evolution of permanent displacements. The models could also interpolate and extrapolate, which enables them to be used as an analysis and design tool for such complex elements.

References listed at the end of the paper:
ASTM E564-06 (2018), Standard Practice for Static Load Test for Shear Resistance of Framed Walls for Buildings, ASTM International, West Conshohocken, PA, USA.

Monchay Panyatong1, Boonme Chinnaboon2 and Somchai Chuheepsakul2
1Department of Civil and Environmental Engineering, Faculty of Engineering, Rajamangala University of Technology Lanna, Chiang Rai, 57120, Thailand
2Department of Civil Engineering, Faculty of Engineering, King Mongkut’s University of Technology Thonburi, Bangkok, 10140, Thailand
ABSTRACT: The paper focuses on bending analysis of the functionally graded (FG) plates with arbitrary shapes and boundary conditions. The material property of FG plates is modelled by using the power law distribution. Based on the first order shear deformation plate theory (FSDT), the governing equations as well as boundary conditions are formulated and obtained by using the principle of virtual work. The coupled Boundary Element-Radial Basis Function (BE-RBF) method is established to solve the complex FG plates. The proposed methodology is developed by applying the concept of the analog equation method (AEM). According to the AEM, the original governing differential equations are replaced by three Poisson equations with fictitious sources under the same boundary conditions. Then, the fictitious sources are established by the application of a technique based on the boundary element method and approximated by using the radial basis functions. The solution of the actual problem is attained from the known integral representations of the potential problem. Therefore, the kernels of the boundary integral equations are conveniently evaluated and readily determined, so that the complex FG plates can be easily computed. The reliability of the proposed method is evaluated by comparing the present results with those from analytical solutions. The effects of the power index, the length to
thickness ratio and the modulus ratio on the bending responses are investigated. Finally, many interesting features and results obtained from the analysis of the FG plates with arbitrary shapes and boundary conditions are demonstrated.

References listed at the end of the paper:


Yang Gao1, Wan-shen Xiao*1 and Haiping Zhu2

1 State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, 410082, China
2School of Computing, Engineering and Mathematics, Western Sydney University, Locked, Bag 1797, Penrith, NSW 2751, Australia


ABSTRACT:
We in this article study nonlinear thermal buckling of bi-directional functionally graded beams in the theoretical framework of a physical neutral surface to derive the size-dependent governing equations combining with the Hamilton’s principle. It should be pointed out that the established model, containing a nonlocal parameter and a strain gradient length scale, is able to account for the influence of nonlocal elastic stress field and the influence of strain gradient stress field. Subsequently, via using an hierarchical group of solutions, the corresponding analytical solution of thermal buckling of beams is obtained with the help of perturbative carried out in detail after validating the present analysis, especially for the effects of a nonlocal parameter, a strain gradient size of the two on the critical thermal buckling temperature of beams.

References listed at the end of the paper:


Steel tube, profile steel ratio and RAC strength were all beneficial to improve the bearing capacity of columns.

Influences of recycled coarse aggregate (RCA) replacement percentage, profile steel ratio, width thickness ratio, stress nephogram, and load were investigated. The finite element analysis and axial bearing capacity of steel reinforced recycled concrete filled square steel tube columns using the ABAQUS software. The study shows that the results of finite element analysis are in good agreement with the experimental results, which verifies the validity of the analytical model. The axial bearing capacity of columns decreased with the increase of RCA replacement percentage. While the increase of wall thickness of square steel tube, profile steel ratio and RAC strength were all beneficial to improve the bearing capacity of columns.
Additionally, the parameter analysis of finite element analysis on the columns was also carried out by using the above numerical model. In general, the SRRC filled square steel tube columns have high bearing capacity and good deformation ability. On the basis of the above analysis, a modified formula based on the American ANSI/AISC 360-10 was proposed to calculate the nominal axial bearing capacity of the columns under axial loads. The research conclusions can provide some references for the engineering application of this kind of columns.

References listed at the end of the paper:
Bekki Hadj*1,2, Benferhat Rabia1,2 and Tahar Hassaine Daouadj1,2
1Département de génie civil, Université Ibn Khaldoun Tiaret; BP 78 Zaaroura, Tiaret, Algérie.
2Laboratoire de Géomatique et Développement Durable, Université de Tiaret, Algérie.


ABSTRACT:
The functionally graded materials (FGM) used in plates contain probably a porosity volume fraction which needs taking into account this aspect of imperfection in the mechanical behavior of such structures. The present work aims of porosity on the bending of simply supported FG plate reposed on the Winkler-Pasternak foundation. A refined the study the effect of the distribution shape of porosity on static behavior of FG plates. It was found that the distribution the mechanical behavior of FG plates, in terms of deflection, normal and shear stress. It can be concluded that the pr resolution of the behavior of flexural FGM plates resting on elastic foundations while taking into account the shape of porosities.

References listed at the end of the paper:


Adim B., T. Hassaine Daouadji, B. Abbas, A. Rabahi (2016) “Buckling and free vibration analysis of laminated composite plates...
https://doi.org/10.1051/meca/2015112.


http://dx.doi.org/10.12989/sem.2015.53.6.1143.


https://doi.org/10.12989/sem.2019.72.1.071

Ali Farajpour1,2, Mergen H. Ghayesh1a and Hamed Farokhi2a
1School of Mechanical Engineering, University of Adelaide, South Australia 5005, Australia
2Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne NE1 8ST, UK

ABSTRACT:
The objective of this paper is to develop a size-dependent nonlinear model of beams for fluid-conveying nanotubes with an initial deflection. The nonlinear frequency response of the nanotube is analysed via an Euler-Bernoulli model. The nanosystem are described utilising the nonlocal strain gradient theory (NSGT). Relative motions at the inner wall of Beskock–Karniadakis model. Formulating kinetic and elastic energies and then employing Hamilton’s approach, the Euler-Bernoulli model is used to solve the governing equations of the nanotube. Furthermore, the Galerkin’s approach is employed for discretisation, and then a continuation scheme is developed for obtaining the frequency response of NSGT nanotubes conveying fluid. The analytical results are derived whereas a softening-hardening nonlinearity is observed for large initial deflections.

References listed at the end of the paper:
functionally graded material (FGM) size-dependent nanoscale beams including the thickness stretching effect", Steel Compos. Struct., 18(2), 425-442. https://doi.org/10.1016/j.scs.2015.18.2.245.


Farzad Ebrahimi*1, Ali Jafari1 and Vinyas Mahesh2
1Department of Mechanical Engineering, Faculty of Engineering, Imam Khomeini International University, Qazvin, Iran
2Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology, Bangalore, India

“Assessment of porosity influence on dynamic characteristics of smart heterogeneous magneto-electro-elastic plates”, Structural Engineering and Mechanics, Vol. 72, No. 1, 2019, pp 113-129, DOI: https://doi.org/10.12989/sem.2019.72.1.113

ABSTRACT: A four-variable shear deformation refined plate theory has been proposed for dynamic characteristics of smart plates made of porous magneto-electro-elastic functionally graded (MEE-FG) materials with various boundary conditions by using an analytical method. Magneto-electro-elastic properties of FGM plate are supposed to vary through the thickness direction and are estimated through the modified power-law rule in which the porosities with even and uneven type are approximated. Pores possibly occur inside functionally graded materials (FGMs) due the result of technical problems that lead to creation of micro-voids in these materials. The variation of pores along the thickness direction influences the mechanical properties. The governing differential equations and boundary conditions of embedded porous FGM plate under magneto-electrical field are derived through Hamilton’s principle based on a four-variable tangential-exponential refined theory which avoids the use of shear correction factors. An analytical solution procedure is used to achieve the natural frequencies of embedded porous FG plate supposed to magneto-electrical field with various boundary condition. A parametric study is led to carry out the effects of material graduation exponent, coefficient of porosity, magnetic potential, electric voltage, elastic foundation parameters, various boundary conditions and plate side-to-thickness ratio on natural frequencies of the porous MEE-FG plate. It is concluded that these parameters play significant roles on the dynamic behavior of porous MEE-FG plates. Presented numerical results can serve as benchmarks for future analyses of MEE-FG plates with porosity phases.

References listed at the end of the paper:


Sandipan N. Thakur1a, Subrata Chakraborty2b and Chaitali Ray2

1Department of Civil Engineering, University Institute of Technology, The University of Burdwan, Burdwan - 713104, India

2Department of Civil Engineering, Indian Institute of Engineering Science and Technology, Shibpur, Howrah - 711103, India


ABSTRACT: Reliability analysis of composite structures considering random variation of involved parameters is quite important as composite materials revealed large statistical variations in their mechanical properties. The reliability analysis of such structures by the first order reliability method (FORM) and Monte Carlo Simulation (MCS) based approach involves repetitive evaluations of performance function. The response surface method (RSM) based metamodeling technique has emerged as an effective solution to such problems. In the application of metamodeling for uncertainty quantification and reliability analysis of composite structures; the finite
element model is usually formulated by either classical laminate theory or first order shear deformation theory. But such theories show significant error in calculating the structural responses of composite structures. The present study attempted to apply the RSM based MCS for reliability analysis of composite shell structures where the surrogate model is constructed using higher order shear deformation theory (HSDT) of composite structures considering the uncertainties in the material properties, load, ply thickness and radius of curvature of the shell structure. The sensitivity of responses of the shell is also obtained by RSM and finite element method based direct approach to elucidate the advantages of RSM for response sensitivity analysis. The reliability results obtained by the proposed RSM based MCS and FORM are compared with the accurate reliability analysis results obtained by the direct MCS by considering two numerical examples.

References listed at the end of the paper:


Ditlevsen, O. and Madsen, H.O. (1996), Structural Reliability Methods, John Wiley and Sons Ltd., Chichester, United Kingdom.


relations. The scattering relation of wave propagation in solid bodies which captures the derivation of the differential equation is conducted, employing extended principle of Hamilton and solved my

R. Ebrahimi Fardshad*1, Y. Mohammadi1 and F. Ebrahimi*2
1Department of Mechanical Engineering, Faculty of Industrial and Mechanical Engineering, Islamic Azad University, Qazvin Branch, Qazvin, Iran
2Department of Mechanical Engineering, Faculty of Engineering, Imam Khomeini International University, Qazvin, Iran


ABSTRACT: In this paper, the magnetic field influence on the wave propagation characteristics of graphene nanosheets is examined within the frame work of a two-variable plate theory. The small-scale effect is taken into consideration based on the nonlocal strain gradient theory. For more accurate analysis of graphene sheets, the proposed theory contains two scale parameters related to the nonlocal and strain gradient effects. A derivation of the differential equation is conducted, employing extended principle of Hamilton and solved my means of analytical solution. A refined trigonometric two-variable plate theory is employed in Kinematic relations. The scattering relation of wave propagation in solid bodies which captures the relation of wave
number and the resultant frequency is also investigated. According to the numerical results, it is revealed that the proposed modeling can provide accurate wave dispersion results of the graphene nanosheets as compared to some cases in the literature. It is shown that the wave dispersion characteristics of graphene sheets are influenced by magnetic field, elastic foundation and nonlocal parameters. Numerical results are presented to serve as benchmarks for future analyses of graphene nanosheets.

References listed at the end of the paper:


Salamat Ullah, Jinghui Zhang and Yang Zhong(Faculty of Infrastructure Engineering, Dalian University of Technology, No.2 Linggong Road, Ganjingzi District, Dalian City, Liaoning Province, P.R.C., 116024, China), “Accurate buckling analysis of rectangular thin plates by double finite sine integral transform method”, Structural Engineering and Mechanics, Vol. 72, No. 4, 2019, pp 491-502, DOI: https://doi.org/10.12989/sem.2019.72.4.491

ABSTRACT:

This paper explores the analytical buckling solution of rectangular thin plates by the finite integral transform method. Although several analytical and numerical developments have been made, a benchmark analytical solution of the complexity of solving high order partial differential equations. In solution procedure, the governing high order partial differential equation with specific boundary conditions is converted into a system of linear algebraic equations and the analytical solution is obtained by numerical integration function which makes the solving procedure much reasonable.

Agreement.

References listed at the end of the paper:


Gholamreza Asgari¹, Gholamhassan Payganeh¹ and Keramat Malekzadeh Fard²

¹Faculty of Mechanical Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran
²Aerospace Research Institute, Malek Ashtar University of Technology, Tehran, Iran

Abstract: The purpose of the present work was to study the dynamic instability of a three-layered, symmetric sandwich beam subjected to a periodic axial load resting on nonlinear elastic foundation. A higher-order theory was used for analysis of sandwich beam with soft core on elastic foundations. In the higher-order theory, the Reddy's third-order theory was used for the face sheets and quadratic and cubic functions were assumed for transverse and in-plane displacements of the core, respectively. The elastic foundation was modelled as nonlinear's type. The dynamic instability regions and free vibration were investigated for simply supported conditions by Bolotin's method. The results showed that the responses of the dynamic instability of the system were influenced by the excitation frequency, the coefficients of foundation, the core thickness, the dynamic and static load factor. Comparison of the present results with the published results in the literature for the special case confirmed the accuracy of the proposed theory.

References listed at the end of the paper:


Bolotin, V.V. (1956), The Dynamic Stability of Elastic Systems, Gostekhizdat, Moscow, Russia.


ABSTRACT:

Wind induced dynamic responses on hyperbolic cooling tower (HCT) shells are complicated functions of structure and wind properties, such as the fundamental frequency $f_{min}$, damping ratio $\zeta$, wind velocity $V$, correlation in meridional direction of the dynamic responses to these four factors are limited and disagree from each other. Following the dynamic equations for soft-core sandwich beams, Sobolinsky and Nurt, S.R. (2004), “Consistent higher-order dynamic equations for soft-core sandwich beams”, AIAA J., 42(2), 374-382.

Jun-Feng ZHANG¹, Qing-Shuai LIU¹, Yao-Jun GE² and Lin ZHAO²

¹School of Civil Engineering, Zhengzhou University, Zhengzhou 450001, China
²State Key Laboratory for Disaster Reduction in Civil Engineering, Tongji University, Shanghai 200092, China

“Studies on the influence factors of wind dynamic responses on hyperbolic cooling tower shells”, Structural Engineering and Mechanics, Vol. 72, No. 5, 2019, pp 541-555, DOI: https://doi.org/10.12989/sem.2019.72.5.541

 wind properties, such as the fundamental frequency $f_{min}$, damping ratio $\zeta$, wind velocity $V$, correlation in meridional direction of the dynamic responses to these four factors are limited and disagree from each other. Following the dynamic equations for soft-core sandwich beams, Sobolinsky and Nurt, S.R. (2004), “Consistent higher-order dynamic equations for soft-core sandwich beams”, AIAA J., 42(2), 374-382.

Jun-Feng ZHANG¹, Qing-Shuai LIU¹, Yao-Jun GE² and Lin ZHAO²

¹School of Civil Engineering, Zhengzhou University, Zhengzhou 450001, China
²State Key Laboratory for Disaster Reduction in Civil Engineering, Tongji University, Shanghai 200092, China

“Studies on the influence factors of wind dynamic responses on hyperbolic cooling tower shells”, Structural Engineering and Mechanics, Vol. 72, No. 5, 2019, pp 541-555, DOI: https://doi.org/10.12989/sem.2019.72.5.541

ABSTRACT:

Wind induced dynamic responses on hyperbolic cooling tower (HCT) shells are complicated functions of structure and wind properties, such as the fundamental frequency $f_{min}$, damping ratio $\zeta$, wind velocity $V$, correlation in meridional direction of the dynamic responses to these four factors are limited and disagree from each other. Following the dynamic equations for soft-core sandwich beams, Sobolinsky and Nurt, S.R. (2004), “Consistent higher-order dynamic equations for soft-core sandwich beams”, AIAA J., 42(2), 374-382.
Ahmed M. El-Kholy, Sherif A. Mourad, Ayman A. Shaheen and Yomna A. Mohamed

1Department of Civil Engineering, Faculty of Engineering, Fayoum University, Kiman Fares, El-Fayoum, 63541, Egypt

2Department of Structural Engineering, Faculty of Engineering, Cairo University, Giza, 12613, Egypt

“Finite element simulation for steel tubular members strengthened with FRP under compression”, Structural Engineering and Mechanics, Vol. 72, No. 5, 2019, pp 569-583, DOI: https://doi.org/10.12989/sem.2019.72.5.569

ABSTRACT: Tubular steel sections are widespread all over the world because of their strength and aesthetic appearance. Tubular steel members may exhibit local buckling such as elephant foot or overall buckling under extreme compression load. Recently, external bonding of fiber reinforced polymers (FRP) sheets for strengthening these members has been explored through experimental research. This paper presents three-dimensional nonlinear finite element analysis (FEA) to investigate the structural behavior of strengthening tubular steel members with FRP against local and overall buckling phenomena. Out-of-roundness and out-of-straightness imperfections were introduced to the numerical models to simulate the elephant foot and overall buckling, respectively. The nonlinear analysis preferences such as the integration scheme of the shell elements, the algorithm for solution of nonlinear equations, the loading procedure, the bisecion limits for the load increments, and the convergence criteria were set, appropriately enough, to successfully track the sophisticated buckling deformations. The agreement between the results of both the presented FEA and the experimental research was evident. The FEA results demonstrated the power of the presented rigorous FEA in monitoring the plastic strain distribution and the buckling phenomena (initiation and propagation). Consequently, the buckling process was interpreted for each mode (elephant foot and overall) into three sequential stages. Furthermore, the influence of FRP layers on the nonlinear analysis preferences and the results was presented.

References listed at the end of the paper:


A new higher-order shear and normal deformation theory for the buckling analysis of new type of FGM sandwich plates (2019)

A simplified analysis method for characterizing unbonded post-tensioned precast wall systems (2008)

Post buckling analysis of sandwich beams with functionally graded faces using a consistent higher order theory (2014)

Size-dependent mechanical behavior of functionally graded trigonometric shear deformable nanobeams including neutral surface position concept (2016)

Effect of thickness stretching and porosity on mechanical response of a functionally graded sandwich plates with free vibration analysis of advanced composite plates (2017)

A novel quasi 3D hyperbolic shear deformation theory for the buckling analysis of new type of FGM sandwich plates (2019)

A simplified analysis method for characterizing unbonded post-tensioned precast wall systems (2008)

References list at the end of the paper:


Yuan Yuan, Ke Zhao and Kuo Xu
School of Mechanical and Precision Instrument Engineering, Xi’an University of Technology, Xi’an, 710048, China

“Enhancing the static behavior of laminated composite plates using a porous layer”, Structural Engineering and Mechanics, Vol. 72, No. 6, 2019, pp 763-774, DOI: https://doi.org/10.12989/sem.2019.72.6.763

ABSTRACT:
The main aim of this paper is enhancing design of traditional laminated composite plates subjected to static loads. In regard, this paper suggests embedding a lightweight porous layer in the middle of laminated composite as the core layer. Based on Modified Couple Stress Theory, the static governing equations of the suggested laminated composite plates with perfect foundation are obtained. A finite element method is also utilized to solve the governing equations of LCPPLs. Furthermore, in compare with perfect cores, the use of porous core bet can offer a considerable reduction in structural weight without a significant difference in their static responses.

References listed at the end of the paper:


requires greater computational cost, thus making it less suitable for practical engineering. To circumvent this
adaptivity, Finite elements based on the partition of unity (PU) approximation have powerful capabilities for
shear locking and showing excellent convergence properties and solution accuracy. However, the enrichment
with the PU approximation results in a significant increase in the number of degrees of freedom; therefore, it
requires greater computational cost, thus making it less suitable for practical engineering. To circumvent this

Hyungmin Jun1,2

1Department of Mechanical System Engineering, Jeonbuk National University, 567 Baekje-daero, Deokjin-gu,
Jeonju-si, Jeollabuk-do 54896, Republic of Korea

2Department of Biological Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue,
Cambridge, MA 02139, USA

“New higher-order triangular shell finite elements based on the partition of unity”, Structural Engineering and
Mechanics, Vol. 73, No. 1, 2020, pp 1-16, DOI: https://doi.org/10.12989/sem.2020.73.1.001

ABSTRACT: Finite elements based on the partition of unity (PU) approximation have powerful capabilities for
p-adaptivity and solutions with high smoothness without remeshing of the domain. Recently, the PU
approximation was successfully applied to the three-node shell finite element, properly eliminating transverse
shear locking and showing excellent convergence properties and solution accuracy. However, the enrichment
with the PU approximation results in a significant increase in the number of degrees of freedom; therefore, it
requires greater computational cost, thus making it less suitable for practical engineering. To circumvent this
disadvantage, we propose a new strategy to decrease the total number of degrees of freedom in the existing PU-based shell element, without loss of optimal convergence and accuracy. To alleviate the locking phenomenon, we use the method of mixed interpolation of tensorial components and perform convergence studies to show the accuracy and capability of the proposed shell element. The excellent performances of the new shell elements are illustrated in three benchmark problems.

References listed at the end of the paper:


Hughes, T.J.R. (2012), The Finite Element Method: Linear Static and Dynamic Finite Element Analysis, Courier Corporation, MA, USA.


Emrah Madenci\(^1\) and Atilla Özütok\(^2\)

\(^1\)Department of Civil Engineering, Faculty of Engineering and Architecture, Necmettin Erbakan University, 42140 Konya, Turkey

\(^2\)Department of Civil Engineering, Faculty of Engineering, KTO Karatay University, 42020 Konya, Turkey


**ABSTRACT:**
This study presents a 4 node, 11 DOF/node plate element based on higher order shear deformation theory for lamina composite plates. The theory accounts for parabolic distribution of the transverse shear strain through the thickness of composite plates are obtained from energy methods using virtual work principle. Differential field equations of composite plates are transformed into the operator form and then transformed boundary conditions with the help of the Gâteaux differential method, after determining that they provide the potential determined by performing variational operations. By using the mixed finite element method, plate element named HOPLT44 was developed. After coding in FORTRAN computer program, finite element matrices were transformed into system matrices and various analyzes verified with those results obtained in the previous work and the new results are presented in tables and graphs.

References listed at the end of the paper:


Vasanth Keshav and Shuvendu N. Patel. (Department of Civil Engineering, BITS Pilani, Pilani Campus, Rajasthan, India-333031)

“Non-Linear dynamic pulse buckling of laminated composite curved panel”, Structural Engineering and Mechanics, Vol. 73, No. 2, 2020, pp 181-190, DOI: https://doi.org/10.12989/sem.2020.73.2.181

ABSTRACT:
In this paper, non-linear dynamic buckling behaviour of laminated composite curved panels subjected to dynamic in using finite element methods. The work is carried out using the finite element software ABAQUS. The curved panel nonlinear dynamic equilibrium equations are solved using the ABAQUS/Explicit algorithm. The effect of aspect ratio studied. The importance of orientation of plies in the direction of loading is also reiterated in this study. Vol’mir’s criterion is used to calculate the dynamic rectangular pulse load of various amplitude and durations and the responses are observed. For particular loading amq is observed beyond which the variation of dynamic buckling load is insignificant. It is also observed that, the value c of loading duration is increased though the reduction is not much after a particular loading duration.

References listed at the end of the paper:
ABSTRACT:

This study aims at investigating the size-dependent free vibration of porous nanoplates when exposed to hygrothermal environment and rested on Kerr foundation. Based on the modified power-law model, material properties of porous functionally graded rectangular plates with general boundary conditions, which is supposed to change continuously along the thickness direction. The generalized nonlocal strain gradient elasticity theory is used as a governing equation. The elastic Kerr foundation, as a highly effective foundation type, is adopted to capture the effect of imperfection and viscoelasticity on the size-dependent free vibration of porous nanoplates. Results show a significant effect on the vibration frequency of FG nanoplates.

References listed at the end of the paper:

This paper investigates the buckling behavior of carbon nanotube-reinforced composite plates supported by Kerr foundation model. In this foundation elastic of Kerr consisting of two spring layers interconnected by a shearing layer. The plates are reinforced by single-walled carbon nanotubes with four types of distributions of uniaxially aligned reinforcement material. The analytical equations are derived and the exact solutions for buckling analyses of such type’s plates are obtained. The mathematical models provided, and the present solutions are numerically validated by comparison with some available results in the literature. Effect of various reinforced plates parameters such as aspect ratios, volume fraction, types of reinforcement, parameters constant factors of Kerr foundation and plate thickness on the buckling analyses of carbon nanotube-reinforced composite plates are studied and discussed.

References listed at the end of the paper:


ABSTRACT: This work treats the axisymmetric buckling of functionally graded (FG) porous annular/circular nanoplates resting on a Kerr foundation based on new hyperbolic shear deformation theory. The nanoplate is located at the elastic medium which is simulated by Kerr foundation with two spring and one shear layer. The material properties of the porous FG nanostructure are assumed to vary through the nanoplate thickness based on power-law rule. Based on two variables refined plate theory, the governing equations are derived by utilizing Hamilton\'s principle. Applying generalized differential quadrature method (GDQM), the buckling load of the annular/circular nanoplates is obtained for different boundary conditions. The influences of different involved parameters such as boundary conditions, Kerr medium, material length scale parameter, geometrical parameters of the nanoplate, and porosity are demonstrated on the nonlinear buckling load of the annular/circular nanoplates.
nanoplates. The results indicate that with increasing the porosity of the nanoplate, the nonlinear buckling load is decreased. In addition, with increasing the material length scale parameter to thickness ratio, the effect of spring constant of Kerr foundation on the buckling load becomes more prominent. The present results are compared with those available in the literature to validate the accuracy and reliability. A good agreement is observed between the two sets of the results.

References listed at the end of the paper:
M. Lori Dehsaraji (1), A.R. Saidi (2) and M. Mohammadi (1)

(1) Department of Mechanical Engineering, Vali-e-Asr University of Rafsanjan, Rafsanjan, Iran
(2) Department of Mechanical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran


ABSTRACT: In this paper, bending-stretching analysis of thick functionally graded piezoelectric rectangular plates is studied using the higher-order shear and normal deformable plate theory. On the basis of this theory, Legendre polynomials are used for approximating the components of displacement field. Also, the effects of both normal and shear deformations are encountered in the theory. The governing equations are derived using the principle of virtual work and variational approach. It is assumed that plate is made of piezoelectric materials with functionally graded distribution of material properties. Hence, exponential function is used to modify mechanical and electrical properties through the thickness of the plate. Finally, the effect of material properties, electrical boundary conditions and dimensions are investigated on the static response of plate. Also, it is shown that results of the presented model are close to the three dimensional elasticity solutions.

References listed at the end of the paper:


Hossein Daemi and Hamidreza Eipakchi (Faculty of Mechanical and Mechatronics Engineering, Shahrood University of Technology, Shahrood, Iran), “Effect of different viscoelastic models on free vibrations of thick cylindrical shells through FSDT under various boundary conditions”, Structural Engineering and Mechanics, Vol. 73, No. 3, pp 319-330, February 10, 2020, https://doi.org/10.12989/sem.2020.73.3.319

ABSTRACT: This paper investigates the free vibrations of cylindrical shells made of time-dependent materials for different viscoelastic models under various boundary conditions. During the extraction of equations, the displacement field is estimated through the first-order shear deformation theory taking into account the transverse normal strain effect. The constitutive equations follow Hooke's Law, and the kinematic relations are linear. The assumption of axisymmetric is included in the problem. The governing equations of thick viscoelastic cylindrical shells are determined for Maxwell, Kelvin–Voigt and the first and second types of Zener's models based on Hamilton's principle. The motion equations involve four coupled partial differential equations and an analytical method based on the elementary theory of differential equations is used for its solution. Relying on the results, the natural frequencies and mode shapes of viscoelastic shells are identified. Conducting a parametric study, we examine the effects of geometric and mechanical properties and boundary conditions, as well as the effect of transverse normal strain on natural frequencies. The results in this paper are compared against the results obtained from the finite elements analysis. The results suggest that solutions achieved from the two methods are ideally consistent in a special range.

References listed at the end of the paper:


Tayfun Dede (1), Maksym Grzywiński (2) and Jacek Selejdak (2)
(1) Karadeniz Technical University, Department of Civil Engineering, Trabzon, Turkey
(2) Czestochowa University of Technology, Faculty of Civil Engineering, 42200 Czestochowa, Poland
“Continuous size optimization of large-scale dome structures with dynamic constraints”, Structural Engineering and Mechanics, Vol. 73, No. 4, pp 397-405, February 25, 2020, https://doi.org/10.12989/sem.2020.73.4.397
ABSTRACT: In this study size optimization of large-scale dome structures with dynamic constraints is presented. In the optimal design of these structure, the Jaya algorithm is used to find minimal size of design variables. The design variables are the cross-sectional areas of the steel truss bar elements. To take into account the constraints which are the first five natural frequencies of the structures, the finite element analysis is coded in Matlab programs using eigen values of the stiffness matrix of the dome structures. The Jaya algorithm and the finite elements codes are combined by the help of the Matlab - GUI (Graphical User Interface) programming to carry out the optimization process for the dome structures. To show the efficiency and the advances of the Jaya algorithm, 1180 bar dome structure and the 1410 bar dome structure were tested by taking into the frequency constraints. The optimal results obtained by the proposed algorithm are compared with those given in the literature to demonstrate the performance of the Jaya algorithm. At the end of the study, it is concluded that the proposed algorithm can be effectively used in the optimal design of large-scale dome structures.

References listed at the end of the paper:
https://doi.org/10.1007/s00158-010-0566-y.
Mahnaz Shamshirzaz (1), Shahin Sharafi (1), Javad Rahmatian (1,2), Sajad Rahmatian (1,3) and Naserodin Sepehry (1,4)
(1) New Technologies Research Center, Amirkabir University of Technology, 424 Hafez Ave, 15875-4413, Tehran, Islamic Republic of Iran
(2) Department of Mechanical Engineering, Razi University of Kermanshah, Tagh Bostan, 67144-15111, Kermanshah, Islamic Republic of Iran
(3) Department of Mechanical Engineering, University of Tehran, 16th Azar St., Enghelab Sq, 1417466191, Tehran, Islamic Republic of Iran
(4) Faculty of Mechanical and Mechatronics Engineering, Shahrood University of Technology, Shahrood, 3619995161, Islamic Republic of Iran

“A semi-analytical mesh-free method for 3D free vibration analysis of bi-directional functionally graded piezoelectric circular structure. The dependent variables have been expanded by Fourier series with respect to the circumferential direction and have been discretized through radial and axial directions based on the mesh-free shape function. The current approach has a distinct advantage. The nonlinear Green-Lagrange strain is employed as the relationship between strain and displacement fields to observe thermal impacts in stiffness matrices. Nevertheless, high order terms have been neglected at the final steps of equations driving. The material properties are assumed to vary continuously in both radial and axial directions simultaneously in accordance with a power law distribution. The convergence and validation studies are conducted by comparing our proposed solution with available published results to investigate the accuracy and efficiency of our approach. After the validation study, a parametric study is undertaken to investigate the temperature effects, different types of polarization, mechanical and electric boundary conditions and geometry parameters of structures on the natural frequencies of functionally graded piezoelectric circular structures.

References listed at the end of the paper:


Mohsen Motezaker (1) and Arameh Eyyazian (2)

(1) School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran

(2) Mechanical and Industrial Engineering Department, College of Engineering, Qatar University, P.O. Box 2713, Doha, Qatar


ABSTRACT: This paper deals with the buckling and optimization of a nanocomposite beam. The amalgamation of nanoparticles was assumed by Mori-Tanaka model. The harmony search optimization algorithm is adaptively improved using two adjusted processes based on dynamic parameters. The governing equations were derived by Timoshenko beam model by energy method. The optimum conditions of the nanocomposite beam-based proposed AIHS are compared with several existing harmony search algorithms. Applying DQ and HS methods, the optimum values of radius and FS were obtained. The effects of thickness, amalgamation, volume percent of CNTs and boundary conditions were assumed. The results show that with increasing the volume percent of CNTs, the optimum radius of the beam decreases while the FS was improved. References listed at the end of the paper:


Yu Hu (1,2), Jian Yang (1,2), Charalampos C. Baniotopoulos (2) and Feiliang Wang (1)
(1) School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
(2) School of Civil Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom

“A comparison of structural performance enhancement of horizontally and vertically stiffened tubular steel wind turbine towers”, Structural Engineering and Mechanics, Vol. 73, No. 5, pp 487-500, March 10, 2020, ABSTRACT: Stiffeners can be utilised to enhance the strength of thin-walled wind turbine towers in engineering practice, thus, structural performance of wind turbine towers by means of different stiffening schemes should be compared to explore the optimal structural enhancement method. In this paper two alternative stiffening methods, employing horizontal or vertical stiffeners, for steel tubular wind turbine towers have been studied. In particular, two groups of three wind turbine towers of 50m, 150m and 250m in height, stiffened by horizontal rings and vertical strips respectively, were analysed by using FEM software of ABAQUS. For each height level tower, the mass of the stiffening rings is equal to that of vertical stiffeners each other. The maximum von Mises stresses and horizontal sways of these towers with vertical stiffeners is compared with the corresponding ring-stiffened towers. A linear buckling analysis is conducted to study the buckling modes and critical buckling loads of the three height levels of tower. The buckling modes and eigenvalues of the 50m, 150m and 250m vertically stiffened towers were also compared with those of the horizontally stiffened towers. The numbers and central angles of the vertical stiffeners are considered as design variables to study the effect of vertical stiffeners on the structural performance of wind turbine towers.

Following an extensive parametric study, these stiffening techniques were compared with each other and it is obtained that the use of vertical stiffeners is a more efficient approach to enhance the stability and strength of intermediate and high towers than the use of horizontal rings.

References listed at the end of the paper:


Ahmad Farokhian (1) and Reza Kolahchi (2)
(1) Mechanical Engineering group, Pardis College, Isfahan University of Technology, Isfahan 84156-83111, Iran
(2) Institute of Research and Development, Duy Tan University, Da Nang 550000, Viet Nam


ABSTRACT: The objective of present paper is assessment of dynamic buckling behavior of an embedded sandwich microplates in thermal environment in which the layers are reinforced through functionally graded carbon nanotubes (FG-CNTs). Therefore, mixture rule is taken into consideration for obtaining effective material characteristics. In order to model this structure much more realistic, Kelvin–Voigt model is presumed and the sandwich structure is rested on visco-Pasternak medium. Exponential shear deformation theory (ESDT) in addition to Eringen's nonlocal theory are utilized to obtain motion equations. Further, differential cubature method (DCM) as well as Bolotin's procedure are used to solve governing equations and achieve dynamic instability region (DIR) related to sandwich structure. Different parameters focusing on volume percent of CNTs, dispersion kinds of CNTs, thermal environment, small scale effect and structural damping and their
influences upon the dynamic behavior of sandwich structure are investigated. So as to indicate the accuracy of applied theories as well as methods, the results are collated with another paper. According to results, presence of CNTs and their dispersion kind can alter system's dynamic response as well.

References listed at the end of the paper:
Farzad Ebrahimi (1), S. Hamed S. Hosseini (1) and Rajendran Selvamani (2)
(1) Department of Mechanical Engineering, Faculty of Engineering, Imam Khomeini International University, Qazvin, Iran
(2) Department of mathematics, Karunya Institute of Technology and Sciences, Coimbatore, India


ABSTRACT: The nonlinear thermo-electro-elastic buckling behavior of viscoelastic nanoplates under magnetic field is investigated based on nonlocal elasticity theory. Employing nonlinear strain-displacement relations, the geometrical nonlinearity is modeled while governing equations are derived through Hamilton’s principle and they are solved applying semi-analytical generalized differential quadrature (GDQ) method. Eringen’s nonlocal elasticity theory considers the effect of small size, which enables the present model to become effective in the analysis and design of nano-sensors and nano actuators. Based on Kelvin-Voigt model, the influence of the viscoelastic coefficient is also discussed. It is demonstrated that the GDQ method has high precision and computational efficiency in the buckling analysis of viscoelastic nanoplates. The good agreement between the results of this article and those available in literature validated the presented approach. The detailed mathematical derivations are presented and numerical investigations are performed while the emphasis is placed on investigating the effect of the several parameters such as electric voltage, small scale effects, elastomeric medium, magnetic field, temperature effects, the viscosity and aspect ratio of the nanoplate on its nonlinear buckling characteristics. It is explicitly shown that the thermo-electro-elastic nonlinear buckling behavior of viscoelastic nanoplates is significantly influenced by these effects. Numerical results are presented to serve as benchmarks for future analyses of viscoelastic nanoplates as fundamental elements in nanoelectromechanical systems.

References listed at the end of the paper:
connectors under fire and a comparison of performance with different types of shear connectors subjected to fire”, Steel Compos.
considering the demand response program in power system”, Appl. Therm. Eng., 149, 1114-1124.
https://doi.org/10.1016/j.apm.2014.11.060.
absorption in tall buildings with braced tube frame system”, Steel Compos. Struct. 34(3), 393-407.
https://doi.org/10.12989/scs.2020.34.3.393.
most influencing parameters on the properties of corroded concrete beams using an Adaptive Neuro-Fuzzy Inference System
concrete strength in presence of furnace slag and fly ash using Hybrid ANN-GA (Artificial Neural Network-Genetic Algorithm)”,
(2019a), “Application of a Hybrid Artificial Neural Network- Particle Swarm Optimization (ANN-PSO) Model in Behavior Prediction
of Channel Shear Connectors Embedded in Normal and High-Strength Concrete”, Appl. Sci., 9(24), 5534.
https://doi.org/10.1007/s00366-019-09930-x.
Shariati, M., Mafipour, M. S., Mehrabi, P., Zandi, Y., Dehghani, D., Bahadori, A., Shariati, A., Trung, N.T., Salih, M.N.A. and Poi-
axial compressive behavior of built-up CFT columns considering different welding lines”, Steel Compos. Struct. 34(3), 377-
391 https://doi.org/10.12989/scs.2020.34.3.377.
quarter cylinder channel considering nanoparticle shape effect”, Powder Technol., 346, 160-170.
Shen, H. S. (2000), “Nonlinear bending of shear deformable laminated plates under transverse and in-plane loads and resting on
elastic foundations”, Compos. Struct., 50(2), 131-142. https://doi.org/10.1016/S0263-8223(00)00088-X.
antisymmetric angle-ply composite and sandwich plates”, Compos. Struct., 64(3-4), 405-417.
https://doi.org/10.12989/sems.2019.70.5.639.
3037. https://doi.org/10.1016/S0020-7683(02)00233-0.
ABSTRACT: The dynamic stability of a functionally graded polymer microbeam reinforced by graphene oxides is investigated. The microbeam is assumed to rest on an elastic substrate and is subjected to various immovable boundary restraints. The weight fraction of graphene oxides nanofillers is graded across the beam thickness. The effective Young’s modulus of the functionally graded substrate and is subjected to various immovable boundary restraints. The weight fraction of graphene oxides nanofillers is graded across the beam thickness. The effective Young’s modulus of the functionally graded

Since the scale effect is taken into account based on modified couple stress theory, then, the Mathieu-Hill equation was solved using Bolotin’s method to predict the principle unstable regions of the FG-GORC microbeams. The numerical results show the effects of the small scale, the graphene oxides nanofillers as well as the elastic substrate on the dynamic stability behaviors of the FG-GORC microbeams.

References listed at the end of the paper:


graphene platelets and carbon nanotubes on the mechanical
properties of epoxy composites”, Carbon, 49(3), 793-803.
https://doi.org/10.1016/j.carbon.2010.01.014.
Hongmei Zhang (1), Yufei Shan (2), Yuanfeng Duan (1), Chung Bang Yun (1) and Song Liu (2)

(1) College of Civil Engineering and Architecture, Zhejiang University, 866, Yuhangtang Road, Hangzhou, 310058, China
(2) Department of Disaster Mitigation for Structures, Tongji University, Shanghai, China

“Vector mechanics-based simulation of large deformation behavior in RC shear walls using planar four-node elements”, Structural Engineering and Mechanics, Vol. 74, No. 1, pp 1-18, April 10, 2020,

ABSTRACT: For the large deformation of shear walls under vertical and horizontal loads, there are difficulties in obtaining accurate simulation results using the response analysis method, even with fine mesh elements. Furthermore, concrete material nonlinearity, stiffness degradation, concrete cracking and crushing, and steel bar damage may occur during the large deformation of reinforced concrete (RC) shear walls. Matrix operations that are involved in nonlinear analysis using the traditional finite-element method (FEM) may also result in flaws, and may thus lead to serious errors. To solve these problems, a planar four-node element was developed based on vector mechanics. Owing to particle-based formulation along the path element, the method does not require repeated constructions of a global stiffness matrix for the nonlinear behavior of the structure. The nonlinear concrete constitutive model and bilinear steel material model are integrated with the developed element, to ensure that large deformation and damage behavior can be addressed. For verification, simulation analyses were performed to obtain experimental results on an RC shear wall subjected to a monotonically increasing lateral load with a constant vertical load. To appropriately evaluate the parameters, investigations were conducted on the loading speed, meshing dimension, and the damping factor, because vector mechanics is based on the equation of motion. The static problem was then verified to obtain a stable solution by employing a balanced equation of motion. Using the parameters obtained, the simulated pushover response, including the bearing capacity, deformation ability, curvature development, and energy dissipation, were found to be in accordance with the experimental observation. This study demonstrated the potential of the developed planar element for simulating the entire process of large deformation and damage behavior in RC shear walls.

References listed at the end of the paper:

GB 50011-2010 (2010), Code for seismic design of buildings, Industry Standard of the People’s Republic of China; Beijing, China.
Saenz, L. P. (1964), Discussion of “Equation for the stress-strain curve of concrete”, Proceeding of American Concrete Institute. 61, 1229-1235.
thickness direction increases the buckling load considerably. This improvement is found to be more significant for the case of thick plates than that of thin plates. Results also show that this stiffening-like effect of the sigmoid function profile is more evident for cases where the in-plane loads are applied along the shorter edge of the plate.

References listed at the end of the paper:


https://doi.org/10.1002/zamm.201000184.
https://doi.org/10.1002/(sici)1097-0207(20001110/30)47:1/3%3c663::aid-nme787%3e3.0.co;2-8.

Fatima Zohra Zaoui (1), Abdelouahed Tounsi (2,3), Djamel Ouinas (1) and Jaime A. Viña Olay (4)
(1) Laboratory of numerical and experimental modeling of the mechanical phenomena, Mechanical Engineering Department, Faculty of sciences and Technology / Ibn Badis University, 27000 Mostaganem, Algeria
(2) Material and Hydrology Laboratory, Civil Engineering Department, Faculty of Technology/Djilali Liabes University, 22000 Sidi Bel Abbes, Algeria
(3) Department of Civil and Environmental Engineering, King Fahd University of Petroleum & Minerals, 31261 Dhahran, Eastern Province, Saudi Arabia
(4) Department of Materials Science and Metallurgical Engineering, Campus of Viesques, University of Oviedo,
33204 Gijón, Spain

ABSTRACT: In this work, a novel higher-order shear deformation theory (HSDT) for static and free vibration analysis of functionally graded (FG) plates is proposed. Unlike the conventional HSDTs, the proposed theory has a novel displacement field which includes undetermined integral terms and contains fewer unknowns. Equations of motion are obtained by using Hamilton's principle. Analytical solutions for the bending and dynamic investigation are determined for simply supported FG plates. The computed results are compared with 3D and quasi-3D solutions and those provided by other plate theories. Numerical results demonstrate that the proposed HSDT can achieve the same accuracy of the conventional HSDTs which have more number of variables.

References listed at the end of the paper:


was.2018.27.4.269
ABSTRACT: The theories having been developed thus far account for higher-order variation of transverse shear strain through the depth of the beam and satisfy the stress-free boundary conditions on the top and bottom surfaces of the beam. A shear correction factor, therefore, is not required. In this paper, the effect of surface on the axial buckling and free vibration of nanobeams is studied using various refined higher-order shear deformation beam theories. Furthermore, these theories have strong similarities with Euler–Bernoulli beam theory in aspects such as equations of motion, boundary conditions, and expressions of the resultant stress. The equations of motion and boundary conditions were derived from Hamilton's principle. The resultant system of ordinary differential equations was solved analytically. The effects of the nanobeam length-to-thickness ratio, thickness, and modes on the buckling and free vibration of the nanobeams were also investigated. Finally, it was found that the buckling and free vibration behavior of a nanobeam is size-dependent and that surface effects and surface energy produce significant effects by increasing the ratio of surface area to bulk at nano-scale. The results indicated that surface effects influence the buckling and free vibration performance of nanobeams and that increasing the length-to-thickness increases the buckling and free vibration in various higher-order shear deformation beam theories. This study can assist in measuring the mechanical properties of nanobeams accurately and designing nanobeam-based devices and systems.

References listed at the end of the paper:


ABSTRACT: Thin films easily wrinkle under compressive loading due to their small bending stiffness resulting from their tiny thickness. For a thin film deposited on a functionally graded substrate with non-uniform stiffness exponentially changes along the length span in this paper, the uniaxial wrinkling problem is solved analytically in terms of hyper–Bessel functions. For infinite, semi-infinite and finite length systems the wrinkling load and wrinkling wavenumber are determined and compared with those in literature. In comparison with a homogeneous substrate–bounded film in which the wrinkling pattern is uniform along the length span, for a functionally graded substrate–film system the wrinkles accumulate around the softer location of the functionally graded substrate. Therefore, the effective length of the film influenced by the wrinkles decreases, the amplitude of the wrinkles on softer regions of the functionally graded substrate grows and the wrinkling load of the functionally graded substrates with higher softening rate decreases more. The results of the current research are expected to be useful in science and technology of thin films and wrinkling of the structures especially living tissues.

References listed at the end of the paper:


ABSTRACT: The bi-axial and shear buckling behavior of laminated hypar shells having rhombic planforms are studied for various boundary conditions using the present mathematical model. In the present mathematical model, the variation of transverse shear stresses is represented by a second-order function across the thickness and the cross curvature effect in hypar shells is also included via strain relations. The transverse shear stresses free condition at the shell top and bottom surfaces are also satisfied. In this mathematical model having a realistic second-order distribution of transverse shear strains across the thickness of the shell requires unknown parameters only at the reference plane. For generality in the present analysis, nine nodes curved isoparametric element is used. So far, there exists no solution for the bi-axial and shear buckling problem of laminated composite rhombic (skew) hypar shells. As no result is available for the present problem, the present model is compared with published suitable results (experimental, FEM, analytical and 3D elasticity) and then it is extended to analyze bi-axial and shear buckling of laminated composite rhombic hypar shells. A C0 finite element (FE) coding in FORTRAN is developed to generate many new results for different boundary conditions, skew angles, lamination schemes, etc. It is seen that the dimensionless buckling load of rhombic hypar increases with an increase in c/a ratio (curvature). Between symmetric and anti-symmetric laminations, the symmetric laminates have a relatively higher value of dimensionless buckling load. The dimensionless buckling load of the hypar shell increases with an increase in skew angle.

References listed at the end of the paper:


Struct., 38, 53–77. https://doi.org/10.1016/S0263-8231(00)00029-X


Zoltán Virág (1) and Károly Jármái (2)

(1) Institute of Mining and Geotechnical Engineering, University of Miskolc H-3515 Miskolc, Egyetemváros, Hungary
(2) Institute of Energy Engineering and Chemical Machinery, University of Miskolc H-3515 Miskolc, Egyetemváros, Hungary


ABSTRACT: The main requirements of modern welded metal structures are the load-carrying capacity (safety), fitness for production, and economy. The primary objective of attaching longitudinal stiffeners is to improve the buckling strength of relatively thin compression panels. This paper gives several comparisons for stiffened plates with different loadings (static, dynamic), different shape of stiffeners (flat, L-shape, trapezoidal), different steel grades, and different welding technologies (SMAW, GMAW, SAW), different costs to show the necessity of a combination of design, fabrication and economic aspects. Safety and fitness for production are guaranteed by fulfilling the design and fabrication constraints. The economy is achieved by minimizing the cost function. It is shown that the optimum sizes depend on the welding technology, the material yield stress, the profile of the stiffeners, the load cycles and the place of the production.

References listed at the end of the paper:

COSTCOMP (1990), Programm zur Berechnung der Schweisskosten. Deutscher Verlag für Schweisstechnik, Düsseldorf.

Eurocode 3 (2005), Design of Steel Structures – Part 1-9: Fatigue; European Committee for Standardization (CEN).


Farkas K., Jármáj K. (2003), Economic Design of Metal Structures, Millpress, Rotterdam.


Yan Cao (1), Xueming Qian (1), Qingming Fan (1) and Farbod Ebrahimi (2)
(1) School of Mechatronic Engineering, Xian Technological University, Xian 710021 China
(2) Islamic Azad University, Tehran, Iran


ABSTRACT: The main purpose of this study is to analyze the effects of external pressure on the vibration and buckling of functionally graded (FG) spherical panels resting on elastic medium. The material characteristics of the FG sphere continuously vary through the thickness direction based on the power-law rule. In accordance with first-order shear deformation shell theory and by the use of Ritz formulation the governing equations are presented. In this regard, the beam functions are applied in two-dimensions for different sets of boundary supports. The Winkler and Pasternak models of elastic foundations are also taken into account. In order to show the validity and applicability of the presented formulation, various comparison studies are given. Furthermore, a diverse range of numerical results is reported to check the impacts of geometrical and material parameters along with external pressure on the vibration and buckling analysis of FG spherical panels.

References listed at the end of the paper:


ABSTRACT: This study presents a practical application of topology optimization (TO) technique to seek the best form of perforated steel plate shear walls (PSPSW) in simple frames. For the numerical investigation, a finite element model is proposed based on the recent particular form of PSPSW that is called the ring-shaped steel plate shear wall. The TO is applied based on the sensitivity analysis to maximize the reaction forces as the objective function considering the fracture tendency. For this purpose, TO is conducted under a monotonic and cyclic loading considering the nonlinear behavior (material and geometry) and buckling. Also, the effect of plate thickness is studied on the TO results. The final material volume of the optimized plate is limited to the material volume of the ring-shaped plate. Finally, an optimized plate is introduced and its nonlinear behavior is investigated under a cyclic and monotonic loading. For a more comprehensive view, the results are compared to the ring-shaped and four usual forms of SPSWs. The material volume of the plate for all the models is the same. The results indicate the strength, load-carrying, and energy dissipation in the optimized plate are increased while the fracture tendency is reduced without changing the material volume.

References listed at the end of the paper:
ATC24 (1992), Guidelines for cyclic seismic testing of components of steel structures for buildings, Applied Technology Council, Redwood City, CA, U.S.A.
REFERENCES


TOSCA (2013), V.8.0, Tosca Structure Documentation, Dassault Systèmes Company, Karlsruhe, Baden-Württemberg, Germany.


Soufiane Abbas (1), Soumia Benguediab (2), Kada Draiche (2), Ahmed Bakora (2) and Mohamed Benguediab(1)

(1) Laboratory of Materials and Reactive Systems (LMRS), University of Sidi Bel Abbes, Faculty of Technology, Mechanical Engineering Department, Algeria

(2) Material and Hydrology Laboratory, University of Sidi Bel Abbes, Faculty of Technology, Civil Engineering Department, Algeria


https://doi.org/10.12989/sem.2020.74.3.365

ABSTRACT: The focus of this paper is to develop an analytical approach based on an efficient shear deformation theory with stretching effect for bending stress analysis of cross-ply laminated composite plates subjected to transverse parabolic load and line load by using a new kinematic model, in which the axial displacements involve an undetermined integral component in order to reduce the number of unknowns and a sinusoidal function in terms of the thickness coordinate to include the effect of transverse shear deformation. The present theory contains only five unknowns and satisfies the zero shear stress conditions on the top and bottom surfaces of the plate without using any shear correction factors. The governing differential equations and its boundary conditions are derived by employing the static version of principle of virtual work. Closed-form solutions for simply supported cross-ply laminated plates are obtained applying Navier's solution technique, and the numerical case studies are compared with the theoretical results to verify the utility of the proposed model. Lastly, it can be seen that the present outlined theory is more accurate and useful than some higher-order shear deformation theories developed previously to study the static flexure of laminated composite plates.

References listed at the end of the paper:


ABSTRACT: In this paper, the meshless local Petrov-Galerkin (MLPG) method is developed for dynamic analysis of nanocomposite cylindrical shell equations of elastic wave motion with nonlinear grading patterns under shock loading. The properties of the nanocomposite cylinder are obtained based on a micro-mechanical model. In this study, four kinds of carbon nanotube reinforcement are considered. The displacements can be approximated using shape functions. The numerical results for the cylindrical shell are compared with the results of the present method and other models. The accuracy of the present formulation and method verifies with analytical solutions. The present method compares well with the finite element method (FEM) and the element free Galerkin (EFG) method. The comparison shows the high capacity and accuracy of the present method to dynamic analysis of non-symmetric cylindrical shell. The capability of the present method to dynamic analysis of non-symmetric cylindrical shell is demonstrated by dynamic analysis of the cylinder with different kinds of grading patterns and an reinforcement. The present method shows high accuracy, efficiency, and capability to dynamic analysis of non-symmetric cylindrical shell, which furnishes a ground for a more flexible design.


ABSTRACT: For the first time, the influence of in-plane magnetic field on wave propagation of Graphene Nano-Platelets (GNPs) polymer composite nanoplates is investigated here. The impact of three- parameter Kerr foundation is also considered. There are two different reinforcement distribution patterns (i.e. uniformly and non-uniformly) while the material properties of the nanoplate are estimated through the Halpin-Tsai model and a rule of mixture. To consider the size-dependent behavior of the structure, Eringen Nonlocal Differential Model (ENDM) is utilized. The equations of wave motion derived based on a higher-order shear deformation refined theory through Hamilton’s principle and an analytical technique depending on Taylor series utilized to find the wave frequency as well as phase velocity of the GNPs reinforced nanoplates. A parametric investigation is performed to determine the influence of essential phenomena, such as the nonlocality, GNPs conditions, Kerr foundation parameters, and wave number on the both longitudinal and flexural wave characteristics of GNPs reinforced nanoplates.


ABSTRACT: Present research is aimed to investigate the free vibration behavior of functionally graded (FG) nanocomposite conical panel reinforced by graphene platelets (GPLs) on the elastic foundation. Winkler-Pasternak elastic foundation surrounds the mentioned shell. For each ply, graphene platelets are randomly oriented and uniformly dispersed in an isotropic matrix. It is assumed that the Volume fraction of GPLs reinforcement could be different from layer to layer according to a functionally graded pattern. The effective elastic modulus of the conical panel is estimated according to the modified Halpin-Tsai rule in this manuscript. Cone is modeled based on the first order shear deformation theory (FSDT). Hamilton’s principle and generalized differential quadrature (GDQ) approach are also used to derive and discrete the equations of motion. Some evaluations are provided to compare the natural frequencies between current study and some experimental and theoretical investigations. After validation of the accuracy of the present formulation and method, natural frequencies and the corresponding mode shapes of FG-GPLRC conical panel are developed for different parameters such as boundary conditions, GPLs volume fraction, types of functionally graded and elastic foundation coefficients.

ABSTRACT: This paper presents a study on the mechanical behavior of buried pipelines crossing faults using experimental and numerical methods. A self-made soil-box was used to simulate normal fault, strike-slip fault and oblique slip fault. The effects of some important parameters, including the displacement and type of fault, the buried depth and the diameter of pipe, on the deformation modes and axial strain distribution of the buried pipelines crossing faults was studied in the experiment. Furthermore, a finite element analysis (FEA) model of spring boundary was developed to investigate the performance of the buried pipelines crossing faults, and FEA results were compared with experimental results. It is found that the axial strain distribution of those buried pipelines crossing the normal fault and the oblique fault is asymmetrical along the fault plane and that of buried pipelines crossing the strike-slip fault is approximately symmetrical. Additionally, the axial peak strain appears near both sides of the fault and increases with increasing fault displacement. Moreover, the axial strain of the pipeline decreases with decreasing buried depth or increasing ratios of pipe diameter to pipe wall thickness. Compared with the normal fault and the strike-slip fault, the oblique fault is the most harmful to pipelines. Based on the accuracy of the model, the regression equations of the axial distance from the peak axial strain position of the pipeline to the fault under the effects of buried depth, pipe diameter, wall thickness and fault displacement were given.


ABSTRACT: The present paper investigates the combination resonance behavior of imperfect spiral stiffened functionally graded (SSFG) cylindrical shells with internal and external functionally graded stiffeners under two-term large amplitude excitations. The structure is embedded within a generalized nonlinear viscoelastic foundation, which is composed of a two-parameter Winkler-Pasternak foundation augmented by a Kelvin-Voigt viscoelastic model with a nonlinear cubic stiffness, to account for the vibration hardening/softening phenomena and damping considerations. With regard to classical plate theory of shells, von-Kármán equation and Hook law, the relations of stress-strain are derived for shell and stiffeners. The spiral stiffeners of the cylindrical shell are modeled according to the smeared stiffener technique. According to the Galerkin method, the discretized motion equation is obtained. The combination resonance is obtained by using the multiple scales method. Finally, the influences of the stiffeners angles, foundation type, the nonlinear elastic foundation coefficients, material distribution, and excitation amplitude on the system resonances are investigated comprehensively.


ABSTRACT: In the present paper, a simple analytical model is developed based on a new refined parabolic shear deformation theory (RPSDT) for free vibration and buckling analysis of orthotropic rectangular plates with simply supported boundary conditions. The displacement field is simpler than those of other higher-order theories since it is modeled with only two unknowns and accounts for a parabolic distribution of the transverse shear stress through the plate thickness. The governing differential equations related to the present theory are obtained from the principle of virtual work, while the solution of the eigenvalue problem is achieved by assuming a Navier technique in the form of a double trigonometric series that satisfy the edge boundary conditions of the plate. Numerical results are presented and compared with previously published results for orthotropic rectangular plates in order to verify the precision of the proposed analytical model and to assess the impacts of several parameters such as the modulus ratio, the side-to-thickness ratio and the geometric ratio on natural frequencies and critical buckling loads. From these results, it can be concluded that the present computations are in excellent agreement with the other higher-order theories.


ABSTRACT: This paper presents a new hyperbolic shear deformation plate theory including the stretching effect for free vibration of the simply supported functionally graded plates in thermal environments. The theory
accounts for parabolic distribution of the transverse shear strains and satisfies the zero traction boundary conditions on the surfaces of the plate without using shear correction factors. This theory has only five unknowns, which is even less than the other shear and normal deformation theories. The present one has a new displacement field which introduces undetermined integral variables. Material properties are assumed to be temperature-dependent, and graded in the thickness direction according to a simple power law distribution in terms of the volume power laws of the constituents. The equation of motion of the vibrated plate obtained via the classical Hamilton’s principle and solved using Navier’s steps. The accuracy of the proposed solution is checked by comparing the present results with those available in existing literature. The effects of the temperature field, volume fraction index of functionally graded material, side-to-thickness ratio on free vibration responses of the functionally graded plates are investigated. It can be concluded that the present theory is not only accurate but also simple in predicting the natural frequencies of functionally graded plates with stretching effect in thermal environments.


ABSTRACT: The steel slit shear wall (SSSW), made by cutting vertical slits in a steel plate, is increasingly used for the seismic protection of building structures. In the domain of thin plate shear walls, the out-of-plane buckling together with the potential fracture developed at slit ends at large lateral deformation may result in degraded shear strength and energy dissipation, which is not desirable in view of seismic design. To address this issue, the present study proposed a new type of SSSW made by intentionally introducing initial out-of-plane folding into the originally flat slitted plate. Quasi-static cyclic tests on three SSSWs with different amplitudes of introduced out-of-plane folding were conducted to study their shear strength, elastic stiffness, energy dissipation capacity and buckling behavior. By introducing proper amplitude of out-of-plane folding into the SSSW fracture at slit ends was eliminated, plumper hysteretic behavior was obtained and there was nearly no strength degradation. A method to estimate the shear strength and elastic stiffness of the new SSSW was also proposed.


ABSTRACT: A finite strip formulation was developed for buckling and free vibration analysis of laminated composite plates based on different shear deformation plate theories. The different shear deformation theories such as Zigzag higher order, Refined Plate Theory (RPT) and other higher order plate theories by variation of transverse shear strains through plate thickness in the parabolic form, sine and exponential were adopted here. The two loaded opposite edges of the plate were assumed to be simply supported and remaining edges were assumed to have arbitrary boundary conditions. The polynomial shape functions are applied to assess the in-plane and out-of-plane deflection and rotation of the normal cross-section of plates in the transverse direction. The finite strip procedure based on the virtual work principle was applied to derive the stiffness, geometric and mass matrices. Numerical results were obtained based on various shear deformation plate theories to verify the proposed formulation. The effects of length to thickness ratios, modulus ratios, boundary conditions, the number of layers and fiber orientation of cross-ply and angle-ply laminates were determined. The additional results on the same effects in the interaction of biaxial in-plane loadings on the critical buckling load were determined as well.


ABSTRACT: The objective of this article is investigation of dynamic response of thick multilayer functionally graded (FG) beam under generalized dynamic forces. The plane stress problem is exploited to describe the constitutive equation of thick FG beam to get realistic and accurate response. Applied dynamic forces are assumed to be sinusoidal harmonic, sinusoidal pulse or triangle in time domain and point load. Equations of motion of deep FG beam are derived based on the Hamilton principle from kinematic relations and constitutive
equations of plane stress problem. The numerical finite element procedure is adopted to discretize the space domain of structure and transform partial differential equations of motion to ordinary differential equations in time domain. Numerical time integration method is used to solve the system of equations in time domain and find the time responses. Numerical parametric studies are performed to illustrate effects of force type, graduation parameter, geometrical and stacking sequence of layers on the time response of deep multilayer FG beams.


Abstract: With the rapid development of rail transit, rail transit noise needs to be paid more and more attention. In order to accurately and effectively analyze the characteristics of low-frequency noise, a prediction model of vibration of box girder was established based on the hybrid FE-SEA method. When the train speed is 140 km/h, 200 km/h and 250 km/h, the vibration and noise of the box girder induced by the vertical wheel-rail interaction in the frequency range of 20-500 Hz are analyzed. Detailed analysis of the energy level, sound pressure contribution, modal analysis and vibration loss power of each slab at the operating speed of 140 km/h. The results show that: (1) When the train runs at a speed of 140 km/h, the roof contributes more to the sound pressure at the far sound field point. Analyzing the frequency range from 20 to 500 Hz: The top plate plays a very important role in controlling sound pressure, contributing up to 70% of the sound pressure at peak frequencies. (2) When the train is traveling at various speeds, the maximum amplitude of structural vibration and noise generated by the viaduct occurs at 50 Hz. The vibration acceleration of the box beam at the far field point and near field point is mainly concentrated in the frequency range of 31.5-100 Hz, which is consistent with the dominant frequency band of wheel-rail force. Therefore, the main frequency of reducing the vibration and noise of the box beam is 31.5-100 Hz. (3) The vibration energy level and sound pressure level of the box bridge at different speeds are basically the same. The laws of vibration energy and sound pressure follow the rules below: web < wing plate < top plate. (4) When the train is running at a higher speed, the noise and vibration of the bridge structure are larger. (5) The hybrid FE-SEA method is used to predict the structural noise of the box beam, which not only improves the efficiency, but also improves the calculation accuracy, thereby expanding the frequency range of the structural noise and improving the prediction accuracy.


Abstract: In this study, the flexural behaviors of full-scale prestressed concrete box girders are experimentally investigated. Four girders were fabricated using two types of concrete (compressive strengths: 50 MPa and 70 MPa) and tested under four-point bending until failure. The measured parameters included the deflection, the stress and strain in concrete and steel bars, and cracks in concrete. The measurement results were used to analyze the failure mode, load-bearing capacity, and deformability of each girder. A finite element model is established to simulate the flexural behaviors of the girders. The results show that the use of high-performance concrete and reasonable combination of prestressed tendons could improve the mechanical performance of the box girders, in terms of the crack resistance, load-carrying capacity, stress distribution, and ductility.


Abstract: This study presents experimental and numerical investigations on circular steel tube confined ultra high performance concrete (UHPC) columns under axial compression. The plain UHPC without fibers was designed to achieve a compressive strength ranged between 150 MPa and 200 MPa. Test results revealed that loading on only the UHPC core can generate a significant confinement effect for the UHPC core, thus leading to an increase in both strength and ductility of columns, and restricting the inherent brittleness of unconfined UHPC. All tested columns failed by shear plane failure of the UHPC core, this causes a softening stage in the axial load versus axial strain curves. In addition, an increase in the steel tube thickness or the confinement index...
was found to increase the strength and ductility enhancement and to reduce the magnitude of the loss of load capacity. Besides, steel tube with higher yield strength can improve the post-peak behavior. Based on the test results, the load contribution of the steel tube and the concrete core to the total load was examined. It was found that no significant confinement effect can be developed before the peak load, while the ductility of post-peak stage is mainly affected by the degree of the confinement effect. A finite element model (FEM) was also constructed in ABAQUS software to validate the test results. The effect of bond strength between the steel tube and the UHPC core was also investigated through the change of friction coefficient in FEM. Furthermore, the mechanism of circular steel tube confined UHPC columns was examined using the established FEM. Based on the results of FEM, the confining pressures along the height of each modeled column were shown. Furthermore, the interaction between the steel tube and the UHPC core was displayed through the slip length and shear stresses between two surfaces of two materials.

ABSTRACT: The present paper employs nonlocal strain gradient theory (NSGT) to study buckling behavior of functionally graded magneto-electro-thermo-elastic (FG-METE) nanoshells under various physical fields. NSGT modeling of the nanoshell contains two size parameters, one related to nonlocal stress field and another related to strain gradients. It is considered that mechanical, thermal, electrical and magnetic loads are exerted to the nanoshell. Temperature field has uniform and linear variation in nanoshell thickness. According to a power-law function, piezo-magnetic, thermal and mechanical properties of the nanoshell are considered to be graded in thickness direction. Five coupled governing equations have been obtained by using Hamilton's principle and then solved implementing Galerkin's method. Influences of temperature field, electric voltage, magnetic potential, nonlocality, strain gradient parameter and FG material exponent on buckling loads of the FG-METE nanoshell have been studied in detail.

ABSTRACT: This papers studies nonlinear stability and post-buckling behaviors of geometrically imperfect metal foam doubly-curved shells with eccentrically stiffeners resting on elastic foundation. Metal foam is considered as porous material with uniform and non-uniform models. The doubly-curved porous shell is subjected to in-plane compressive loads as well as a transverse pressure leading to post-critical stability in nonlinear regime. The nonlocal governing equations are analytically solved with the help of Airy stress function to obtain the post-buckling load-deflection curves of the geometrically imperfect metal foam doubly-curved shell. Obtained results indicate the significance of porosity distribution, geometrical imperfection, foundation factors, stiffeners and geometrical parameters on post-buckling characteristics of porous doubly-curved shells.

ABSTRACT: This article aims to illustrate the damped dynamic responses of layered functionally graded (FG) thick 2D beam under dynamic pulse sinusoidal load by using finite element method, for the first time. To investigate the response of thick beam accurately, two-dimensional plane stress problem is assumed to describe the constitutive behavior of thick beam structure. The material is distributed gradually through the thickness of each layer by generalized power law function. The Kelvin–Voigt viscoelastic constitutive model is exploited to include the material internal damping effect. The governing equations are obtained by using Lagrange's equations and solved by using finite element method with twelve–node 2D plane element. The dynamic equation of motion is solved numerically by Newmark implicit time integration procedure. Numerical studies are presented to illustrate stacking sequence and material gradation index on the displacement-time response of
cantilever beam structure. It is found that, the number of waves increases by increasing the graduation distribution parameter. The presented mathematical model is useful in analysis and design of nuclear, marine, vehicle and aerospace structures those manufactured from functionally graded materials (FGM).


ABSTRACT: This paper attempts to investigate the free vibration of functionally graded material beams with nonuniform width based on the nonlocal elasticity theory. The theoretical formulations are established following the Euler–Bernoulli beam theory, and the governing equations of motion of the system are derived from the minimum total potential energy principle using the nonlocal elasticity theory. In addition, the Differential Quadrature Method (DQM) is applied, along with the Chebyshev-Gauss-Lobatto polynomials, in order to determine the weighting coefficient matrices. Furthermore, the effects of the nonlocal parameter, cross-section area of the functionally graded material (FGM) beam and various boundary conditions on the natural frequencies are examined. It is observed that the nonlocal parameter and boundary conditions significantly influence the natural frequencies of the functionally graded material beam cross-section. The results obtained, using the Differential Quadrature Method (DQM) under various boundary conditions, are found in good agreement with analytical and numerical results available in the literature.


ABSTRACT: This paper provides a semi-analytical approach to investigate the variations of 3D displacement components, electric potential, stresses, electric displacements and transverse vibration frequencies in laminated piezoelectric composite plates based on the scaled boundary finite element method (SBFEM) and the precise integration algorithm (PIA). The proposed approach can analyze the static and dynamic responses of multilayered piezoelectric plates with any number of laminae, various geometrical shapes, boundary conditions, thickness-to-length ratios and stacking sequences. Only a longitudinal surface of the plate is discretized into 2D elements, which helps to improve the computational efficiency. Comparing with plate theories and other numerical methods, only three displacement components and the electric potential are set as the basic unknown variables and can be represented analytically through the transverse direction. The whole derivation is built upon the three dimensional key equations of elasticity for the piezoelectric materials and no assumptions on the plate kinematics have been taken. By virtue of the equilibrium equations, the constitutive relations and the introduced set of scaled boundary coordinates, three-dimensional governing partial differential equations are converted into the second order ordinary differential matrix equation. Furthermore, aided by the introduced internal nodal force, a first order ordinary differential equation is obtained with its general solution in the form of a matrix exponent. To further improve the accuracy of the matrix exponent in the SBFEM, the PIA is employed to make sure any desired accuracy of the mechanical and electric variables. By virtue of the kinetic energy technique, the global mass matrix of the composite plates constituted by piezoelectric laminae is constructed for the first time based on the SBFEM. Finally, comparisons with the exact solutions and available results are made to confirm the accuracy and effectiveness of the developed methodology. What's more, the effect of boundary conditions, thickness-to-length ratios and stacking sequences of laminae on the distributions of natural frequencies, mechanical and electric fields in laminated piezoelectric composite plates is evaluated.


ABSTRACT: In this paper, the deflection and buckling analyses of porous nano-composite piezoelectric plate reinforced by carbon nanotube (CNT) are studied. The equations of equilibrium using energy method are derived from principle of minimum total potential energy. In the research, the non-local strain gradient theory is employed to consider size dependent effect for porous nanocomposite piezoelectric plate. The effects of material length scale parameter, Eringen

ABSTRACT: This study presents an analytical approach to investigate the thermodynamic behavior of functionally graded beam resting on elastic foundations. The formulation is based on a refined deformation theory taking into consideration the stretching effect and the type of elastic foundation. The displacement field used in the present refined theory contains undetermined integral forms and involves only three unknowns to derive. The mechanical characteristics of the beam are assumed to be varied across the thickness according to a simple exponential law distribution. The beam is supposed simply supported and therefore the Navier solution is used to derive analytical solution. Verification examples demonstrate that the developed theory is very accurate in describing the response of FG beams subjected to thermodynamic loading. Numerical results are carried out to show the effects of the thermodynamic loading on the response of FG beams resting on elastic foundation.


ABSTRACT: This manuscript tends to investigate influences of nanoscale and surface energy on a static bending and free vibration of piezoelectric perforated nanobeam structural element, for the first time. Nonlocal differential elasticity theory of Eringen is manipulated to depict the long–range atoms interactions, by imposing length scale parameter. Surface energy dominated in nanoscale structure, is included in the proposed model by using Gurtin–Murdoch model. The coupling effect between nonlocal elasticity and surface energy is included in the proposed model. Constitutive and governing equations of nonlocal-surface perforated Euler–Bernoulli nanobeam are derived by Hamilton’s principle. The distribution of electric potential for the piezoelectric nanobeam model is assumed to vary as a combination of a cosine and linear variation, which satisfies the Maxwell’s equation. The proposed model is solved numerically by using the finite-element method (FEM). The present model is validated by comparing the obtained results with previously published works. The detailed parametric study is presented to examine effects of the number of holes, perforation size, nonlocal parameter, surface energy, boundary conditions, and external electric voltage on the electro-mechanical behaviors of piezoelectric perforated nanobeams. It is found that the effect of surface stresses becomes more significant as the thickness decreases in the range of nanometers. The effect of number of holes becomes significant in the region $0.2 \leq a \leq 0.8$. The current model can be used in design of perforated nano-electro-mechanical systems (PNEMS).

Zhiwei Song, Xiaqiao He, Wei Li and De Xie, “Free vibration analysis of plates with steps and internal line supports by using a modified matched interface and boundary method”, Structural Engineering and Mechanics, Vol. 76, No. 2, 239-250, October 25, 2020, http://dx.doi.org/10.12989/sem.2020.76.2.239

ABSTRACT: This paper deals with free vibration of plates with steps and internal line supports by using a modified matched interface and boundary (MMIB) method. Different kinds of interfaces caused by steps, rigid and elastic line supports and their combinations are taken into account. Detailed MMIB procedures for dealing with these different interfaces are presented. Various examples are chosen to illustrate the accuracy and convergence of MMIB method. Numerical results show that the proposed MMIB is a highly accurate and convergent approach for solving the title issue. This study will extend the application range of MMIB method.


ABSTRACT: In this paper, the mechanical characteristics of the open type hyperbolic-parabolic membrane structure under wind load were investigated. First, the numerical simulation of a typical plane membrane structure was performed based on the Large-Eddy Simulation method. The accuracy of the simulation method
was validated by the corresponding wind tunnel test results. Then, the wind load shape coefficients of open type hyperbolic-parabolic membrane structures are obtained from the series of numerical calculations and compared with the recommended values in the “Technical Specification for Membrane Structures (CECS 158: 2015).” Finally, the influences of the wind directions and wind speeds on the mean wind pressure distribution of open type hyperbolic-parabolic membrane structures were investigated. This study aims to gain a better understanding of the wind-induced response for this type of structure and be useful to engineers and researchers.


ABSTRACT: Until now, a comparative study on fully and partially-connected steel shear walls leading to enhancing strength and stiffness reduction of partially-connected steel plate shear wall structures has not been reported. In this paper a number of 4-story and 8-story steel plate shear walls, are considered with three different connection details of infill plate to surrounding frame. The specimens are modeled using nonlinear finite element method verified excellently with the experimental results and analyzed under monotonic loading. A comparison between initial stiffness and shear strength of models as well as percentage of shear force by model boundary frame and infill plate are performed. Moreover, a comparison between energy dissipation, ductility factor and distribution of Von-Mises stresses of models are presented. According to the results, the initial stiffness, shear resistance, energy dissipation and ductility of the models with beam-only connected infill plates (SSW-BO) is found to be about 53%, 12%, 15% and 48% on average smaller than those of models with fully-connected infill plates (SPSW), respectively. However, performance characteristics of semi-supported steel shear walls (SSWW) containing secondary columns by simultaneously decreasing boundary frame strength and increasing thickness of infill plates are comparable to those of SPSWs. Results show that by using secondary columns as well as increasing thickness of infill plates, the stress demands on boundary frame decreases substantially by as much as 35%. A significant increase in infill plate share on shear capacity by as much as 95% and 72% progress for the 4-story SSW-BO and 8-story SSSW, respectively, as compared with non-strengthened counterparts. A similar trend is achieved by strengthening secondary columns of 4-story SSSW leading to an increase of 50% in shear force contribution of infill plate.


ABSTRACT: Considering inverse cotangential shear strain function, the present paper studies nonlinear stability of nonlocal higher-order refined beams made of metal foams based on Chebyshev-Ritz method. Based on inverse cotangential beam model, it is feasible to incorporate shear deformations needless of shear correction factor. Metal foam is supposed to contain different distributions of pores across the beam thickness. Also, presented Chebyshev-Ritz method can provide a unified solution for considering various boundary conditions based on simply-supported and clamped edges. Nonlinear effects have been included based upon von-karman’s assumption and nonlinear elastic foundation. The buckling curves are shown to be affected by pore distribution, geometric imperfection of the beam, nonlocal scale factor, foundation and geometrical factors.


ABSTRACT: This work presents the formulation of the isogeometric collocation method to solve the strong form equation of a unified and integrated approach of Reissner Mindlin plate theory (UI-RM). In this plate theory model, the total displacement is expressed in terms of bending and shear displacements. Rotations, curvatures, and shear strains are represented as the first, the second, and the third derivatives of the bending displacement, respectively. The proposed formulation is free from shear locking in the Kirchhoff limit and is equally applicable to thin and thick plates. The displacement field is approximated using the B-splines functions, and the strong form equation of the fourth-order is solved using the collocation approach. The convergence properties and accuracy are demonstrated with square plate problems of thin and thick plates with
different boundary conditions. Two approaches are used for convergence tests, e.g., increasing the polynomial degree (NELT = 1×1 with p = 4, 5, 6, 7) and increasing the number of elements (NELT = 1×1, 2×2, 3×3, 4×4 with p = 4) with the number of control variable (NCV) is used as a comparable equivalent variable. Compared with DKMQ element of a 64×64 mesh as the reference for all L/h, the problem analysis with isogeometric collocation on U1-RM plate theory exhibits satisfying results.


ABSTRACT: This paper presents an investigation on the dynamic behavior of SRC columns with built-in cross-shaped steels under impact load. Seven 1/2 scaled SRC specimens were subjected to low-speed impact by a gravity drop hammer test system. Three main parameters, including the lateral impact height, the axial compression ratios and the stirrup spacing, were considered in the response analysis of the specimens. The failure mode, deformation, the absorbed energy of columns, as well as impact loads are discussed. The results are mainly characterized by bending-shear failure, meanwhile specimens can maintain an acceptable integrity. More than 33% of the input impact energy is dissipated, which demonstrates its excellent impact resistance. As the impact height increases, the flexural cracks and shear cracks observed on the surface of specimens were denser and wider. The recorded time-history of impact force and mid-span displacement confirmed the three stages of relative movement between the hammer and the column. Additionally, the displacements had a notable delay compared to the rapid changes observed in the measured impact load. The deflection of the mid-span did not exceed 5.90mm while the impact load reached peak value. The impact resistance of the specimen can be improved by proper design for stirrup ratios and increasing the axial load. However, the cracking and spalling of the concrete cover at the impact point was obvious with the increasing in stiffness.


ABSTRACT: On the basis of nonlocal strain gradient theory, considering the material properties of porous FGM changing with thickness and the influence of moment of inertia, the wave equation of FG nano circular plate is derived by using the first-order shear deformation plate theory, by introducing dimensionless parameters, we transform the equations into dimensionless wave equations, and the dispersion relations of bending wave, shear wave and longitudinal wave are obtained by Laplace and Hankel integral transformation method. The influence of nonlocal parameter, porosity volume fraction, strain gradient parameters and power law index on the propagation characteristics of bending wave, shear wave and longitudinal wave in FG nano circular plate.


ABSTRACT: A state-space method is developed to investigate the time-dependent behaviors of an angle-ply cylindrical shell in cylindrical bending with surface-bonded piezoelectric layers. Both the interfacial diffusion and sliding are considered to describe the properties of the imperfect interfaces. Particularly, a matrix reduction technique is adopted to establish the transfer relations between the elastic and piezoelectric layers of the laminated shell. Very different from our previous paper, in which an approximate numerical technique, i.e. power series expansion method, is used to deal with the time-dependent problems, the exact solutions are derived in the present analysis based on the piezoelectricity equations without any assumptions. Numerical results are finally obtained and the effects of imperfect interfaces on the electro-mechanical responses of the laminated shell are discussed.

ABSTRACT: In current study, surface/interface effects for pull-in voltage and viscous fluid velocity effects on dimensionless natural frequency (DNF) of fluid-conveying piezoelectric nanosensor (FCPENS) subjected to direct electrostatic voltage DC with nonlinear excitation, harmonic force and also viscoelastic foundation (visco-pasternak medium and structural damping) are investigated using Gurtin–Murdoch surface/interface (GMSIT) theory. For this analysis, Hamilton’s principles, the assumed mode method combined with Lagrange–Euler’s are used for the governing equations and boundary conditions. The effects of surface/interface parameters of FCPENS such as Lame’s constants (λ, μ, ρ), residual stress (τ, ρ), piezoelectric constants (e_{31}, e_{33}) and mass density (ρ) are considered for analysis of dimensionless natural frequency respect to viscous fluid velocity U and pull-in voltage V_{in}.

Structural Engineering and Mechanics, Vol. 76, No. 5, 619-629, December 10, 2020,

More papers published in the journal, Mechanics of Composite Materials. (2019 and on)


ABSTRACT: The dynamic response of shear deformable functionally graded (FG) pipes conveying fluid internal fluid is studied to determine the effects of temperature gradient, and to determine the effect of two cases of temperature distributions on their natural frequencies. Assuming that the material properties of the FG pipes obey a power-law distribution and are temperature-dependent, a differential governing equation is obtained using the extended Hamilton’s principle. A wavelet-based element of FG pipes considering shear deformations is developed and used to obtain ordinary differential equations for the system considered.

References listed at the end of the paper:

ABSTRACT: A technique for the numerical analysis of nonlinear dynamic deformation and progressive failure of cylindrical glass-fiber plastic shells is developed with account of their strain-rate-dependent strength characteristics. The kinematic model of deformation of a layer package is based on a nonclassical theory of shells. The geometrical relations are constructed using the simplest quadratic variant of nonlinear elasticity theory. The relationship between the stress and strain tensors in a composite macrolayer is established on the basis of Hooke’s law for an orthotropic body, with account of volatility of the stiffness and strength characteristics of the multilayer package due to a local failure of some elementary layers of the composite and the strain-rate dependence of strength characteristics. An energy-consistent resolving system of dynamics equations for cylindrical shells is obtained as a result of minimization of the functional of total energy of the shell as a three-dimensional body. The numerical method for solving the initial boundary-value problem is based on an explicit variational-difference scheme. The reliability of the technique developed was confirmed by a satisfactory agreement of calculation results with experimental data. For different shell reinforcement structures, qualitative differences in the character and size of failure zones were found, which were calculated by the model considering the strain-rate dependence of strength or their constancy.

References listed at the end of the paper:


ABSTRACT: In this study, the nonlinear buckling of stiffened FGM truncated conical shells resting on an elastic foundation and subjected to a uniform axial compressive load is considered. The shells are reinforced by FGM stringers and rings. Using the analytical approach, FSDT, Galerkin method, geometrical nonlinearity in the von Karman–Donnell sense, and Leknitskii smeared stiffener technique, the governing equations are derived. Closed-form expressions for determining the critical buckling load and for analyzing the postbuckling load–deflection curves are obtained. Finally, the effect of stiffeners, dimensional parameters, semivertex angle, material properties, and foundations on the nonlinear response of FGM truncated conical shells are analyzed and discussed in detail.

References listed at the end of the paper:


ABSTRACT: The optimum paths and orientations for curvilinear and straight fibers in composite cylindrical shells of variable and constant stiffness under external hydrostatic pressure are obtained and compared. The optimization was performed for several length-to-diameter ratios of the shells. Results showed that the buckling pressure of the variable-stiffness shell was by about 30% higher than that of the constant-stiffness one. This increase in the buckling pressure was obtained by locating fibers in the hoop direction in the middle of the cylinder and orienting the fibers toward the longitudinal direction on cylinder edges.

References listed at the end of the paper:


ABSTRACT: The first 3D dynamic problem on forced vibrations of an orthotropic three-layer plate with an asymmetric structure is solved asymptotically. On faces of the package, conditions of the first boundary-value problem of elasticity theory, i.e., the values of corresponding components of the stress tensor, are set. It is assumed that they vary harmonically in time. An asymptotic solution of the internal (external) problem is found. Conditions for the origination of resonance are established. The cases where the solution of the internal problem becomes mathematically exact are indicated, and an illustrative example is given. The question about the conjugation of solutions of the inner and boundary-layer problems is discussed.

References listed at the end of the paper:
ABSTRACT: Based on the applied theory of shells, an energy-consistent resolving system of equations is constructed, and a complex numerical method is developed which, within in the framework of an explicit variational-difference scheme, makes it possible to solve both quasi-static and dynamic problems of nonlinear nonaxisymmetric deformation and buckling of composite cylindrical shells. The quasi-static loading mode is simulated by setting an internal pressure in the form of a linearly increasing function reaching a steady-state value during three periods of vibration of a composite cylindrical shell at the lower form. The critical buckling load is determined by the characteristic kink on the maximum deflection–loading amplitude curve. The reliability of the method developed is substantiated by comparing calculation results with experimental data. The characteristic forms and critical buckling loads of GRP cylindrical shells as functions of the level of preloading by a quasi-static internal pressure and of the subsequent dynamic loading by an external pressure are analyzed for various reinforcement patterns in a wide range of loading rate.

References listed at the end of the paper:

ABSTRACT: To reveal the energy absorbing mechanism of thin-walled circular tubes made of a T700/3234 composite, tests were first conducted to find its material properties, and then quasi-static axial crushing tests were performed to determine the failure modes and were measured by material performance tests, and the damage mechanism and energy absorption characteristics of the tubes. The effects of the mechanism and ply orientations on the failure modes and energy absorption characteristics were further analyzed. Stacked shell finite-element models are developed using the Puck2000 and Yamada Sun failure criteria and are verified by comparing simulation results with test data. The calculated initial peak crushing and mean crushing forces and the specific energy absorption agreed well with test data. The effect of layer sequence on the energy absorption characteristics of the composite circular tubes are compared on the basis of verified finite-element models.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: The natural frequencies of hybrid cross-ply laminated plates are predicted using a high-order shear deformation theory and the three-dimensional finite-element analysis. The equations of motion for simply supported laminated hybrid rectangular plates are derived using the Hamilton principle. Closed-form solutions for antisymmetric cross-ply and angle-ply laminates are found employing the Navier solution. In the finite-element method, eight-node linear interpolation brick elements are used to model the composite plates. First, the analytical and numerical results are validated for an antisymmetric cross-ply square laminate by results available in the literature. Then, the effects of side-to-thickness ratio, aspect ratio, lamination schemes, and material properties on the fundamental frequencies for simply supported carbon/glass hybrid composite plates are investigated. Since no data are available in the literature for hybrid composite plates, the finite-element solution is used for comparison purposes. A comparison of the analytical solution with the corresponding 3D finite-element simulations shows a good accuracy of the proposed analytical solution in predicting the fundamental frequencies of hybrid cross-ply laminated plates.

References listed at the end of the paper:

ABSTRACT: A new refined quasi-3D shear deformation theory for bending, buckling, and free vibration analyses of a functionally graded porous beam resting on an elastic foundation is presented. It involves only three unknown functions, against four or more ones in other shear and normal deformation theories. The stretching effect is naturally taken into account by this theory because of its 3D nature. The mechanical characteristics of the beam are assumed to be graded in the thickness direction according to two different porosity distributions. The differential equation system governing the bending, buckling, and free vibration behavior of porous beams is derived based on the Hamilton principle. The problem is then solved using the Navier solution for a simply supported beam. The accuracy of the present solution is demonstrated by comparing it with other closed-form solutions available in the literature. A detailed parametric study is presented to show the influence of porosity distribution on the general behavior of FG porous beams on an elastic foundation.

References listed at the end of the paper:

ABSTRACT: The objective of this work is to propose a simple efficient finite element, based on Reddy’s third-order shear deformation theory, for analyzing the bending behavior of isotropic and composite laminated plates. It is a 2D isoparametric quadrilateral C0 four-node element with seven degrees of freedom at each node, three translation components, two rotations, and two higher-order rotational degrees. A selective numerical integration technique is introduced for the numerical formulation in order to improve results and to alleviate the locking problem. The formulation is able to take into account the parabolic distribution of transverse shear across the plate thickness in the bending behavior of isotropic and laminated composite plates, both thin and...
thick, without a need for correction factors. The performance and reliability of the formulation proposed are confirmed by comparing the author’s results with those obtained using the 3D elasticity theory, analytical solutions, and other advanced finite-element models.

References listed at the end of the paper:
d'Alembert's principle, the equations of dynamic behavior of the plates are obtained and the conditions for their dynamic deformation modes of the plates are possible. From the principle of virtual power, with account of  the contour of plate. The structural model of a reinforced layer is used. Depending on intensity of the load, various dynamic deformation modes of the plates are possible. From the principle of virtual power, with account of d’Alembert’s principle, the equations of dynamic behavior of the plates are obtained and the conditions for their
Implementation are determined for each of the modes. Analytical expressions for estimation of their limit loads are obtained. The variant of quasi-isotropic and reinforced ellipse plate with a circular hole are given.

References listed at the end of the paper:


ABSTRACT: The stability of loaded circular cylindrical shells made of functionally graded materials and flowed round by a supersonic gas stream is investigated. The effective temperature-dependent properties of the material examined vary across the shell thickness according to a power law. The temperature distribution along its radial coordinate is determined by solving the one-dimensional heat conduction equation. The aerodynamic pressure is evaluated using the quasi-static aerodynamic theory. The behavior of the elastic structure is described by the classical shell theory based on Kirchhoff–Love hypotheses. The geometric and physical relationships, along with the equations of motions, are reduced to a system of eight ordinary differential equations in new unknowns. The boundary-value problem formulated is solved by the Godunov orthogonal sweep method, and the differential equations are integrated using the Runge–Kutta method. The behavior of circular cylindrical shells clamped at both its ends is analyzed at different volume fractions of the functionally graded material. Impact of various combinations of mechanical, thermal, and aerodynamic loads on the boundaries of elastic, thermoelastic, and aeroelastic stability of the shells is evaluated.

References listed at the end of the paper:

8. S. A. Bochkarev and S. V. Lekomtsev, “Research into the panel flutter of cylindrical shells made of a functionally graded material. Impact of various combinations of mechanical, thermal, and aerodynamic loads on the boundaries of elastic, thermoelastic, and aeroelastic stability of the shells is evaluated.”

References listed at the end of the paper:

- J. H. Zhang (1), X. Liu (1) and X. Zhao (2)

(1) School of Science, Lanzhou University of Technology, Lanzhou, P.R. China
(2) Taiyuan Boiler Group Co. Ltd, Taiyuan, P.R. China


ABSTRACT: The dynamic thermal buckling of circular thin plates made of a functionally graded material is investigated by the symplectic method. Based on the Hamilton principle, canonical equations are established in the symplectic space, and the problems of axisymmetric dynamic thermal buckling of the plates are simplified. The buckling loads and modes of the plates are translated into generalized eigenvalues and eigensolutions, which can be obtained by bifurcation conditions. The effects of gradient properties, parameters of geometric shape, and dynamic thermal loads on the critical temperature increments are considered.

J. H. Zhang (1), X. Liu (1) and X. Zhao (2)

(1) School of Science, Lanzhou University of Technology, Lanzhou, P.R. China
(2) Taiyuan Boiler Group Co. Ltd, Taiyuan, P.R. China


ABSTRACT: The dynamic thermal buckling of circular thin plates made of a functionally graded material is investigated by the symplectic method. Based on the Hamilton principle, canonical equations are established in the symplectic space, and the problems of axisymmetric dynamic thermal buckling of the plates are simplified. The buckling loads and modes of the plates are translated into generalized eigenvalues and eigensolutions, which can be obtained by bifurcation conditions. The effects of gradient properties, parameters of geometric shape, and dynamic thermal loads on the critical temperature increments are considered.

References listed at the end of the paper:

ABSTRACT: The nonlinear buckling and postbuckling of a FGM toroidal shell segments surrounded by elastic foundations in a thermal environment and subjected to a torsional load are investigated by using an analytical method. Based on Reddy’s third-order shear deformation shell theory (TSDT) with geometrical nonlinearity in the von Karman sense, the governing equations are derived. Using the Galerkin method and a stress function, closed-form expressions for determining the critical torsional load and postbuckling load—deflection curves are obtained. Effects of the geometrical shape, material properties, temperature field, and foundation parameters on the stability of the shells are examined in detail.

References listed at the end of the paper:

Vlasov method of reduction to ordinary differential equations is employed. To find the natural frequencies of calculate its natural frequencies and to identi

shells, the free vibrations of a thin elastic orthotropic cylindrical panel with free edges is investigated. To

Materials, Vol. 55, No. 5

(3)

(2)

(1)


G. R. Ghulghazaryan (1), L. G. Ghulghazaryan (1,2) and I. I. Kudish (3)

(1) Kh. Abovyans ASPU, Yerevan, Armenia

(2) Institute of Mechanics, NAS of Armenia, Yerevan, Armenia

(3) University of Kettering, Flint, Michigan, USA


ABSTRACT: Using a system of equations corresponding to the classical theory of orthotropic cylindrical shells, the free vibrations of a thin elastic orthotropic cylindrical panel with free edges is investigated. To calculate its natural frequencies and to identify the respective vibration modes, the generalized Kantorovich–Vlasov method of reduction to ordinary differential equations is employed. To find the natural frequencies of
possible types of vibrations, dispersion equations are derived. An asymptotic relation between the dispersion equations of the problem in hand and of an analogous problem for a rectangular plate with free sides is established. Determined is also a relation between the dispersion equations of the problem and of the boundary-value problem for a semi-infinite orthotropic nonclosed circular cylindrical shell with three free edges. With the example of an orthotropic cylindrical panel, the values of dimensionless characteristics of its natural frequencies are derived.

References listed at the end of the paper:
Numerically by the 3D FEM. The influence of material and geometrical parameters of the plate on its critical buckling force is evaluated and discussed.

References listed at the end of the paper:


N. D. Duc, V. H. Nam and N. H. Cuong (First author is from: Advanced Materials and Structures Laboratory, VNU, Hanoi - University of Engineering and Technology, 144 Xuan Thuy, Cau Giay, Hanoi, Vietnam and Infrastructure Engineering Program, VNU, Hanoi - Vietnam-Japan University My Đình 1, Tu Liem, Hanoi, Vietnam and National Research Laboratory, Department of Civil and Environmental Engineering, Sejong University, 209 Neungdongro, Gwangjin-gu, Seoul, 05006, Korea, “Nonlinear Postbuckling of Eccentrically
Oblique-Stiffened Functionally Graded Doubly Curved Shallow Shells Based on Improved Donnell Equations”, Mechanics of Composite Materials, Vol. 55, No. 6, pp 727-742, January 2020

ABSTRACT: The nonlinear buckling and postbuckling of eccentrically oblique-stiffened doubly curved shallow functionally graded shells is investigated based on improved Donnell equations. The improved Lekhnitskii smeared stiffeners technique is employed to found the stiffness matrix of the stiffened shells. The shells are reinforced by eccentrically oblique stiffeners with an arbitrary inclination angle. Using the Galerkin method, an analytical approximate solution for the deflection of reinforced FGM doubly curved shallow shells is obtained. The influence of geometrical parameters, oblique stiffeners, and temperature on the postbuckling behavior of the shells is analyzed.

References listed at the end of the paper:
This fact, in particular, can explain the phenomenon of decreasing of the averaged shear modulus of a fibrous composite with account of tension and compression strains in the transverse direction for a rigid fiber (fiber bundle) represented in the form of a rod with a rectangular cross section and the model of a transversely soft layer with a fixed outer boundary of the periodicity cell of composite for four binder elements introduced into consideration. It is shown that, in loading test specimens with a [±45]$_s$ structure, a continuous rearrangement of the composite structure is possible in both compression and tension. This occurs owing to the realization and continuous changes of internal buckling modes with continuous variations of the parameter of wave formation.

The composite structure is possible in both compression and tension. This occurs owing to the realization and continuous changes of internal buckling modes with continuous variations of the parameter of wave formation.

ABSTRACT: Basalt-fiber-reinforced epoxy (BFRE) composite laminates fabricated using the vacuum infusion process were subjected to axial compression to assess their buckling behavior. The buckling responses of open-hole specimens were compared with those of plain ones. ABAQUS finite-element predictions of BFRE composite buckling agreed well with experimental results. A validated numerical model was used to perform a parametric investigation into the effects of open-hole specimen geometry and boundary conditions of specimens on their buckling behavior. A linear analysis was carried out to estimate the effect of geometric imperfections of specimens on their buckling. Also, glass-fiber-reinforced epoxy specimens were analyzed for their buckling response and compared with that of BFRE ones. The results of this study can be used for buckling-based designs of open-hole composite structures.

References listed at the end of the paper:


F. Aylikci, S. D. Akbarov and N. Yahnioglu (First author is from: Yildiz Technical University, Faculty of Chemical and Metallurgical Engineering, Department of Mathematical Engineering, Davutpasa Campus, 34220, Esenler, Istanbul, Turkey), “3D FEM Analysis of Buckling Delamination of a Piezoelectric Sandwich Rectangular Plate with Interface Edge Cracks”, Mechanics of Composite Materials, Vol. 55, No. 6, pp 797-810, January 2020

ABSTRACT: The problem of local buckling delamination around interface edge cracks in a sandwich PZT/Metal/PZT rectangular thick plate is studied within the scope of the 3D linearized buckling instability theory. Crack faces have an insignificant initial imperfection, and the plate is compressed by uniformly distributed normal forces acting on two opposite ends of the plate. The evolution of the initial imperfection is investigated, and the critical buckling forces for the plate are found. A mathematical modeling of the problem considered is performed using the 3D exact geometrically nonlinear electroelasticity theory within the framework of a piecewise homogeneous body model. The corresponding boundary-value problems are solved numerically by employing a 3D finiteelement method. Numerical results for the critical forces and the effect problem parameters on these forces are presented and discussed.

References listed at the end of the paper:


M. Soltani (1) and B. Asgarian (2)

(1) Department of Civil Engineering, Faculty of Engineering, University of Kashan, Kashan, Iran
(2) Civil Engineering Faculty, K.N.Toosi University of Technology, Tehran, Iran


ABSTRACT: A lateral buckling analysis of simply supported web- and/or flange-tapered I-beams made of axially functionally graded materials and subjected to a uniformly distributed load is performed. The properties of beam material vary continuously along the beam axis, depending on the volume fraction of constituent materials, according to an exponential or power law. Considering the coupling between the lateral displacement and twist angle, equilibrium equations are derived via the energy method in association with the Vlasov thin-walled beam theory. For simply supported beams with free warping, the system of equilibrium equations is transformed into a differential equation in the twist angle. The differential quadrature method is then used to numerically solve the resulting fourth-order differential equation with variable coefficients and to determine the lateral buckling loads. A numerical example is finally considered to study the influence of different parameters — the axial variation of material properties, tapering ratios, and load eccentricities — on the lateral stability of the beams considered. The numerical results of this paper can be used as benchmarks for future studies on axially functionally graded nonprismatic I-beams with pinned-pinned end conditions.

References listed at the end of the paper:


ABSTRACT: The low-velocity impact behavior of polypropylene-core-based sandwich composites reinforced with basalt/epoxy facesheets was investigated by drop-weight impact tests. The impact resistance of composite samples was characterized for various impact energies according to ASTM standards. Also, the effect of facesheet thickness was explored, and the failure and fracture surfaces around the impacted region were analyzed. It was found that the thickness of facesheets played an important role in the impact properties of the honeycombs. Their residual deformation after the impact tests increased as the impact energy grew, but decreased when the number of facesheet layers increased with reducing the penetration depth and perforation.

References listed at the end of the paper:


ABSTRACT: The classical methods of surface damping of bending vibrations of thin-walled structures and a promising integrated version with a damping coating consisting of two layers of a material with pronounced viscoelastic properties and an intermediate thin reinforcing layer of a high-modulus material are discussed. A four-layer finite element for an elongate plate with an integral damping coating is developed taking into account the lateral compression of the damping layers. A system of governing equations of the finite-element method is constructed for analyzing the dynamic response of the plate during its resonant vibrations. Iterative algorithms have been developed to take into account the amplitude dependence of the logarithmic decrements of vibrations of material of the damping layers when determining the damping properties of the plate and determining its vibration eigenmodes and eigenfrequencies with consideration of frequency dependence of the dynamic elastic moduli of the material. Numerical experiments were carried out to test the finite element developed and the iterative algorithms mentioned. The influence of aerodynamic resistance forces on the overall damping level of a cantilever plate with an integral damping coating is assessed.

References listed at the end of the paper:

22. V. V. Khil’chevskii and V. G. Dubeneck, Energy Dissipation in Vibrations of Thin-Walled Structural Elements [in Russian], Kiev, Vishcha Shkola (1977).

ABSTRACT: In a geometrically linear formulation based on the use of variational principles of elasticity theory and the generalized Galerkin method, three approaches to constructing equations of static bending of orthotropic plates with a constant thickness are considered. The displacements of plate points are approximated by polynomials in the transverse coordinate with unknown coefficients of expansion. The application of variational principles leads to the first two approaches for constructing these equations. In the first approach, the force boundary conditions on faces of the plates are not taken into account, but the resulting two-dimensional equations and the corresponding boundary conditions on their edges are consistent, since, according to these equations, any subarea of the plates and the entire structure as a whole are in equilibrium. The two-dimensional equations of statics and boundary conditions constructed in this approach cannot be obtained by the generalized Galerkin method. The simplest theories using this approach are the Reddy–Nemirovskii and the Margueere–Timoshenko–Naghd theories. The third approach takes into account the force boundary conditions on faces of the plates, but the two-dimensional equations and the corresponding boundary conditions on the edges are obtained by the generalized Galerkin method. The homogeneous polynomials in the transverse coordinate are used as weight functions. The two-dimensional equations and boundary conditions obtained in this approach are consistent. The simplest theory that uses this approach is the Ambartsumyan theory. The relevance of the study is determined by the fact that the choice of a simple, but adequate, theory of bending can be of fundamental importance in solving optimization problems for composite plates.

References listed at the end of the paper:

M. Nouri, F. Ashenai-Ghasemi, G. Rahimi-Sherbaf and K. Reza Kashyzadeh, “Experimental and Numerical Study of the Static Performance of a Hoop-Wrapped CNG Composite Cylinder Considering Its Variable Wall Thickness and Polymer Liner”, Mechanics of Composite Materials, Vol. 56, No. 3, pp 339-352, July 2020, ABSTRACT: The static performance of a composite type 4 CNG cylinder was investigated using a finite-element simulation and experimental validation. This cylinder involved a liner hoop wrapped with a fiber impregnated by a suitable resin. Tensile tests were performed on standard specimens to examine the mechanical properties of the composite material. Next, a finite-element simulation was performed to determine the static strength of a natural gas tank based on an appropriate criterion. To this end, using a stress analysis, the von Mises stresses were obtained in different parts of the tank to detect the critical area apt to fail. Then, a safety factor was calculated along composite layers, and components of the 3D stress tensor were determined for the critical layer failing before other layers. Eventually, the static performance of the full-scale tank was investigated using various well-known failure criteria of composite materials. Results indicated that the most accurate criteria should include the effects of compressive strength and 3D components of the shear stress. References listed at the end of the paper:


ABSTRACT: The impact behavior of hybrid composite plates cured at 120°C were examined by dropping weights on them for three hours. Two groups of hybrid composite plates were considered. In the first group (TYPE1), all plies were staked symmetrically or antisymmetrically with orientation angle 0°, but in the second group (TYPE2), plies were staked symmetrically or antisymmetrically with orientation angles 0° and 45°. The plates were subjected to impact loadings with energies of 12, 16, and 20 J. Deflections, contact forces, and absorbed energies were determined and compared for plates in the different groups.

References listed at the end of the paper:


ABSTRACT: Drop-weight tests were conducted to investigate the impact responses of carbon-fiber-reinforced composite laminates under low-velocity impacts. A finite-element model is proposed to describe the failure during impacts. The impact damage behavior of composite laminates with different thicknesses were simulated to analyze their energy absorption ability, and a method for its prediction is presented.

References listed at the end of the paper:


ABSTRACT: In a geometrically linear formulation based on the use of variation principles of elasticity theory, the twodimensional equations of statics and the boundary conditions at the edge of an orthotropic bending plate are obtained within the framework of the classical theory and two low-order nonclassical theories: Reddy–Nemirovskii and Margueere–Timoshenko–Naghdii ones. It is shown that using the hypotheses of the classical theory, the two-dimensional static equations and the corresponding boundary conditions ensure the equilibrium of an arbitrary subarea of the structure and of the entire plate as a rigid whole; within the framework of the Reddy–Nemirovskii theory, this equilibrium is disturbed in moments and forces in the transverse direction; within the framework of the Margueere–Timoshenko–Naghdii theory, the equilibrium is disturbed in the membrane forces and moments. An example of cylindrical bending of rectangular elongate orthotropic and isotropic plates clamped along one longitudinal edge and loaded in the transverse direction on the other longitudinal edge is considered. It is shown that, within the framework of the classical, Reissner, and Ambartsumyan theories, this problem is statically determinate and the shearing force, according to these theories, is determined elementary by the method of sections. According to the Reddy–Nemirovskii theory, this problem is statically indeterminate and has a rather awkward solution. It is demonstrated that, within the framework of the Reddy–Nemirovskii theory, the shearing force is zero on the clamped edge, i.e., the plate as a whole cannot be in equilibrium. In the vicinity of such an edge, there arises a pronounced false boundary effect, which does not take place in reality, because it is located inside the zone of the boundary layer and cannot be calculated by this theory.

References listed at the end of the paper:


ABSTRACT: An attempt has been made to perform a comparative study on advances in the shear deformation theory for analyzing the statics and dynamics of different plates with the use of numerical examples. Initially, shape functions for the displacement field across the plate thickness are compared, and then, the stresses, deflections, and natural frequencies of laminated composite plates are also compared.

References listed at the end of the paper:
https://doi.org/10.1007/s00366-019-00732-1

ABSTRACT: The stochastic eigenvalue problem for free vibrations of functionally graded beams with a random elastic modulus is investigated. The effective material properties and beam cross section are assumed to vary continuously in different directions according to the exponential law. The governing equations for the natural frequency of the functionally graded beams are derived from Hamilton’s principle. In the stochastic finite-element method, the random process was discretized by averaging random variables in each element to increase the accuracy of the natural frequency found. A solution of the stochastic eigenvalue problem formulated was obtained using the perturbation technique in conjunction with the finite-element method. The spectral representation was used to generate a random process to employ the Monte Carlo simulation. A good agreement was obtained between the results of the first-order perturbation technique and the Monte Carlo simulation.

References listed at the end of the paper:

ABSTRACT: A linear free vibration analysis is presented for computing the natural frequencies of a grid-stiffened carbon-nanotube-reinforced composite cylindrical shell. The carbon nanotubes (CNTs) are supposed to be oriented unidirectionally across the shell thickness, and the elastic moduli of the CNT-reinforced polymer composite are calculated using a modified rule of mixtures. In order to obtain the equivalent stiffness parameters of the grid-stiffened cylindrical shell, the smeared stiffness method is employed. The stiffeners are assumed to support the transverse shear loads, bending moments, and axial loads. An analytical method based
on the first-order shear deformation theory is used. To validate the results obtained, a 3-D finite-element model is employed using the ABAQUS CAE software.

References listed at the end of the paper:

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: This article investigates the nonlinear vibration of piezoelectric nanoplate with combined thermoelectric loads under various boundary conditions. The piezoelectric nanoplate model is developed by using the Mindlin plate theory and nonlocal theory. The von Karman type nonlinearity and nonlocal constitutive relationships are employed to derive governing equations through Hamilton's principle. The differential quadrature method is used to discretize the governing equations, which are then solved through a direct iterative method. A detailed parametric study is conducted to examine the effects of the nonlocal parameter, external electric voltage, and temperature rise on the nonlinear vibration characteristics of piezoelectric nanoplates.

References listed at the end of the paper:

Piezoelectric nanoplates


DWBNNT using nonlocal shear deformable shell model

nonlocal Timoshenko beam theory using DQ method

nanoplate systems with various boundary conditions using DQM

uniform voltage distribution embedded in Pasternak elastic mem

on the nonlocal theory


A semi-empirical model for nonlocal plate theory

 Applications of nonlocal elastic shell theory in wave propagation analysis of carbon nanotubes

Nonlinear vibration of embedded SWBNNTs based on nonlocal Timoshenko beam theory


References listed at the end of the paper:


ABSTRACT: We analyze static infinitesimal deformations of doubly curved shells using a third-order shear and normal deformable theory (TSNDT) and delineate effects of the curvilinear length/thickness ratio, a/h, radius of curvature/curvilinear length, R/a, and the ratio of the two principal radii on through-the-thickness stresses, strain energies of the in-plane and the transverse shear and normal deformations, and strain energies of stretching and bending deformations for loads that include uniform normal tractions on a major surface and equal and opposite tangential tractions on the two major surfaces. In the TSNDT the three displacement components at a point are represented as complete polynomials of degree three in the thickness coordinate. Advantages of the TSNDT include not needing a shear correction factor, allowing stresses for monolithic shells to be computed from the constitutive relation and the shell theory displacements, and considering general tractions on bounding surfaces. For laminated shells we use an equivalent single layer TSNDT and find the in-plane stresses from the constitutive relations and the transverse stresses with a one-step stress recovery scheme. The in-house developed finite element software is first verified by comparing displacements and stresses in the shell computed from it with those from either analytical or numerical solutions of the corresponding 3D problems. The strain energy of a spherical shell is found to approach that of a plate when R/a exceeds 10. For a thick clamped shell of aspect ratio 5 subjected to uniform normal traction on the outer surface, the in-plane and the transverse deformations contribute equally to the total strain energy for R/a greater than 5. However, for a cantilever shell of aspect ratio 5 subjected to equal and opposite uniform tangential tractions on the two major surfaces, the strain energy of in-plane deformations equals 95–98% of the total strain energy. Numerical results presented herein for several problems provide insights into different deformation modes, help designers decide when to consider effects of transverse deformations, and use the TSNDT for optimizing doubly curved shells.

References listed at the end of the paper:

· 7 E. Reissner, Small bending and stretching of sandwich type shells, National Advisory Committee for Aeronautics Technical Note No. 1832, 1947.
ABSTRACT: A new, simple method is presented for deriving the instability potential of thin plates, based on the equilibrium conditions and constitutive law for incremental forces considering the geometric nonlinear effect. First, the equations of equilibrium are established for the plate at the last calculated C and current deformed C states, from which the equilibrium equations for the incremental forces at C are derived. Then, the incremental forces are derived as the summation of two parts: (1) the part from the increase of the Cauchy stresses at C to the 2nd Piola-Kirchhoff stresses at C, which are related to the strain increments and derivable from the linear constitutive; and (2) the part by the difference between the 2nd Piola-Kirchhoff and 1st Piola-Kirchhoff stresses, which are related to the cross-sectional forces at C and rigid displacements. Based on the previous concept, the rigid body rule and coordinate indifference of tensor expressions, the constitutive law for incremental forces including the geometric nonlinear effect is derived. Further, by the variational principle, the following instability potentials are derived: δU_w caused by the balance conditions for initial forces, δU_w caused by the constitutive law for incremental forces, and δU_w caused by the rotation of boundary moments. Consequently, the total instability potential is presented for the plate in the virtual work form. The present approach is self-explanatory, which requires only simple integration operations. Moreover, the two essential conditions are satisfied: equilibrium conditions for incremental forces and rigid body rule. Numerical examples are presented to demonstrate the rationality of the present plate theory compared with the conventional one.

References listed at the end of the paper:


ABSTRACT: A trigonometric layerwise shear deformation theory is developed for the flexural analysis of laminated plates. The present theory achieves in-plane displacement continuity, transverse shear stress continuity, and traction-free boundary condition. Hence, botheration of shear correction coefficient is neglected. The governing differential equation and boundary conditions are obtained from the principle of virtual work. Although the present analytical method is bounded to a corner supported boundary condition, it neglects the numerical and computational error. Like first-order shear deformation theory, the present theory possesses five numbers of unknowns. Several numerical predictions are carried out and results are compared with those of other existing numerical approaches.

References listed at the end of the paper:


АБСТРАКТ: Работа концентрируется на определении влияния параметра на демпфирующие свойства композиционных структур (CVSS) представленных в виде слоистых структур. Методика позволяет вычислять демпфирующие свойства на волнах с использованием параметра, определяющего влияние свойств на демпфирование. В работе представлены результаты моделирования демпфирования на основе параметра, характеризующего влияние свойств на демпфирование. Работа также включает в себя анализ демпфирования на основе параметра, характеризующего влияние свойств на демпфирование. В работе представлены результаты моделирования демпфирования на основе параметра, характеризующего влияние свойств на демпфирование. Работа также включает в себя анализ демпфирования на основе параметра, характеризующего влияние свойств на демпфирование. В работе представлены результаты моделирования демпфирования на основе параметра, характеризующего влияние свойств на демпфирование.

ABSTRACT: A hybrid-mixed, four-node, quadrilateral element for the three-dimensional (3D) stress analysis of functionally graded (FG) plates using the method of sampling surfaces (SaS) is developed. The SaS formulation is based on choosing an inside the plate body N, not equally spaced SaS parallel to the middle surface, in order to introduce the displacements of these surfaces as basic plate variables. Such a choice of unknowns, with the consequent use of Lagrange polynomials of the degree N – 1 in the assumed distributions of displacements, strains, and mechanical properties through the thickness leads to a robust FG plate formulation. All SaS are located at Chebyshev polynomial nodes that permit one to minimize uniformly the error due to the Lagrange interpolation. To avoid shear locking and spurious zero-energy modes, the assumed natural strain method is employed. The proposed four-node quadrilateral element passes 3D patch tests for FG plates and exhibits a superior performance in the case of coarse distorted meshes. It can be useful for the 3D stress analysis of thin and thick metal/ceramic plates because the SaS formulation gives an opportunity to obtain the solutions with a prescribed accuracy, which asymptotically approach the 3D exact solutions of elasticity as the number of SaS tends to infinity.

References listed at the end of the paper:

ABSTRACT: Exploiting the anisotropic nature of composite laminates is a driving factor to improve the design regime of multistable structures. The concept of laminate tailoring is being taken a step ahead by allowing variation in fiber angle orientation within the ply planform. Such composite laminates known as variable stiffness (VS) composites have been reported to provide significant improvements in performance over constant stiffness designs. The phenomenon of snapping from one stable state to another is of paramount importance for multistable structures to be used in morphing applications. VS laminates allow the designer to tailor structural response according to the requirements of the morphing mechanism. This work presents a parametric study to explore designs by exploiting the tailoring options in VS laminates, with the objective of requiring low snap-through and snap-back voltages but at the same time enabling high out-of-plane displacements with the effective and efficient use of microfiber composites actuators. The fiber orientation of the layers of the VS laminate is assumed to vary linearly from the center to the edge of the plate. Design spaces of different laminates were investigated by varying the three angle parameters defining the VS laminates. Finite element analyses on snap-through and snap-back actions on the bistable nature of VS laminates were performed using the help of macro fiber composite actuators.

References listed at the end of the paper:

ABSTRACT: The dynamic instability analysis of a simply supported variable angle tow (VAT) composite with delamination around a cutout subjected to periodic axial compression load is investigated. The governing equations of motion for the VAT plate are derived based on first-order shear deformation theory and solved using finite element method. The equations of motion contain time periodic coefficients and their stability is determined using the Bolotin’s approach. A parametric study is carried out to analyze the effect of linearly varying fiber orientation angle on the dynamic instability of VAT laminate with delamination around a circular cutout.

References listed at the end of the paper:

· G. Raju, Z. Wu, B. C. Kim, and P. M. Weaver, Prebuckling and buckling analysis of variable angle tow plates with general boundary conditions, Compos. Struct., vol. 94, no. 9, pp. 2961–2970, 2012.

ABSTRACT: In this work, an effective numerical approach based on the isogeometric analysis (IGA) employing first-order shear deformation theory (FSDT) is proposed and implemented for the static and transient analysis of sandwich composite plates. By using Hamilton’s principle, the governing equation of motion is derived and then discretized using NURBS-based isogeometric approach. The set of governing equations are solved by the Newmark’s time integration scheme. The better performance of the present approach in terms of accuracy and reduced computational cost is ascertained by investigating several numerical examples and comparing the evaluated results with different available results in the literature.

References listed at the end of the paper:

- D. Prabhakara and P. Dutta, Vibration, buckling and parametric instability behaviour of plates with centrally located cutouts subjected to in-plane edge loading (tension or compression), Thin-Walled Struct., vol. 27, no. 4, pp. 287–310, 1997.


The finite element method of twenty plate theories

1990

USA

· Application of the method to thin equations. This review sh

· Which are written in form of ordinary differential equations, and the solution methods used to solve those

· Plate problems. The main objective of this review is to compile an up


ABSTRACT: This study presents a thorough review of the applications of the Kantorovich method to several plate problems. The main objective of this review is to compile an up-to-date list of studies that employ the Kantorovich method, which is a semi-analytical numerical method, to bending, buckling, vibration, and three-dimensional elasticity problems of plates. The reviews highlight the derivations of the governing equations, which are written in form of ordinary differential equations, and the solution methods used to solve those equations. This review should be helpful for researchers and engineers to quickly gain an overview of the application of the method to walled structures.

References listed at the end of the paper:


· Mallikarjuna and T. Kant, A critical review and some results of recently developed refined theories of fiber-reinforced laminated composites and sandwiches, Compos. Struct., vol. 23, pp. 293–312, 1993.


V. Unghakorn and P. Singhathanadgid, Buckling analysis of symmetrically laminated composite plates by the extended Kantorovich method, Compos. Struct., vol. 73, pp. 120–128, 2006.


I. Shufrin, O. Rabinovich, and M. Eisenberger, Buckling of symmetrically laminated rectangular plates with general boundary conditions – A semi analytical approach, Compos. Struct., vol. 82, pp. 521–531, 2008.


A.V. Lopatin and E.V. Morozov, Buckling of the SSCF rectangular orthotropic plate subjected to linearly varying in-plane loading, Compos. Struct., vol. 93, pp. 1900–1909, 2011.


**ABSTRACT:** An analysis is presented for the effect of hydrostatic peripheral loading on the free axisymmetric vibrations of functionally graded moderately thick circular plates on the basis of first-order shear deformation theory. The mechanical properties of the plate material are supposed to vary according to a power-law in both the radial and transverse directions. The numerical solution of the governing differential equation derived by using Hamilton's energy principle for such simply supported and clamped boundary conditions has been obtained employing the harmonic differential quadrature method choosing zeros of Chebyshev–Gauss–Lobatto as the grid points. The effect of different parameters has been analyzed on the frequency parameter for the first three modes of vibration. The critical buckling loads for both the plates have been computed by putting the frequencies to zero. Three-dimensional mode shapes for particular plate have been plotted. Obtained results have been compared.

**References listed at the end of the paper:**

- X.L. Chen and K.M. Liew, Buckling of rectangular functionally graded material plates subjected to nonlinearly distributed in-plane edge loads, Smart Mater. Struct., vol. 13, pp. 1430–1437, 2004

ABSTRACT: In this paper, the effect of the skin configuration on the buckling behavior of stiffened composite panels subjected to uniaxial compression was numerically and experimentally investigated. P-version finite element models containing all the structural details were used to predict the buckling load and buckling mode of stiffened composite panels. The upper and lower ends of the panel were fixed by potting a tin bismuth alloy with melting temperature around 70 °C to get an uniformly loading condition in the test. The alloy could be easily recycled by heating and reutilized later for potting the other test specimens.

References listed at the end of the paper:

ABSTRACT: Based on Reddy’s third-order shear deformation shell theory, this paper studied the nonlinear buckling and postbuckling response of imperfect Sigmoid functionally graded circular cylindrical shells in a thermal environment with an outer surface-bonded piezoelectric actuator. Material properties are temperature dependent and graded in the thickness direction with two shell’s outer surfaces rich of metal and ceramic in the middle (S-FGM). The shell is subjected to uniform external pressure, axial compressive, electrical loads and resting on elastic foundations. The obtained numerical results are validated by comparing with other results reported in the open literature.

References listed at the end of the paper:


ABSTRACT: The paper presents results on the elastoplastic analysis of compact and thin-walled structures via refined beam models. The application of Carrera Unified Formulation (CUF) to perform elastoplastic analysis of isotropic beam structures is discussed. Particular attention is paid to the evaluation of local effects and cross-sectional distortions. CUF allows formulation of the kinematics of a one-dimensional (1D) structure by
employing a generalized expansion of primary variables by arbitrary cross-section functions. Two types of cross-section expansion functions, TE (Taylor expansion) and LE (Lagrange expansion), are used to model the structure. The isotropically work-hardening von Mises constitutive model is incorporated to account for material nonlinearity. A Newton–Raphson iteration scheme is used to solve the system of nonlinear algebraic equations. Numerical results for compact and thin-walled beam members in plastic regime are presented with displacement profiles and beam deformed configurations along with stress contour plots. The results are compared against classical beam models such as Euler–Bernoulli beam theory and Timoshenko beam theory, reference solutions from literature, and three-dimensional (3D) solid finite element models. The results highlight: (1) the capability of the present refined beam models to describe the elastoplastic behavior of compact and thin-walled structures with 3D-like accuracy; (2) that local effects and severe cross-sectional distortions can be detected; (3) the computational cost of the present modeling approach is significantly lower than shell and solid model ones.

References listed at the end of the paper:

ABSTRACT: The active vibration control of a composite plate using discrete piezoelectric patches has been investigated. Based on first order shear deformation theory, a finite element model with the contributions of piezoelectric sensor and actuator patches to the mass and stiffness of the plate was used to derive the state space equation. A global optimization based on LQR performance is developed to find the optimal location of the piezoelectric patches. Genetic algorithm is adopted and implemented to evaluate the optimal configuration. The piezoelectric actuator provides a damping effect on the composite plate by means of LQR control algorithm. A correlation between the patches number and the closed loop damping coefficient is established.

References listed at the end of the paper:


ABSTRACT: The present paper studies the transient response of a functionally graded nanobeam integrated with magnetostrictive layers. The material properties of sandwich nanobeam are temperature dependent and assumed to vary in the thickness direction. In order to consider small-scale effects, the modified couple stress theory is also taken into consideration. Using a unified beam theory that contains various beam models and energy method as well as Hamilton’s principle, the governing motion equations and related boundary conditions are obtained. The obtained results in this paper can be used as sensors and actuators in sensitive applications.

References listed at the end of the paper:


ABSTRACT: The present paper focuses on reliability prediction of composite structure under hygro-thermo-mechanical loading, conditioned by Tsai-Wu failure criterion, where the Monte–Carlo method is used to estimate the failure probability(PT). This model was developed in two steps: first, the development of a deterministic model, based on an analytical and numerical approach, and then, a probabilistic computation. Using the hoop stress for each ply, a sensitivity analysis was performed for random design variables, such as materials properties, geometry, manufacturing, and loading, on composite cylindrical structure reliability. The probabilistic results show the very high increase of failure probability when all parameters are considered.

References listed at the end of the paper:


ABSTRACT: In this paper, a new analytical model for behavior of carbon nanotubes reinforced composite plate (CNTRC) cylinder under non-velocity impact has been presented. Nanotubes aligned, straight and randomly oriented are distributed on rectangular simply supported composite plate. The Mori–Tanaka model is used to obtain effective mechanical properties of composites reinforced with nanotubes consisting of aligned, straight and randomly oriented carbon nanotubes embedded in a polymer matrix. The analytical model based on the first-order shear deformation theory and spring–mass model. The results of analytical model are compared with the results of low velocity impact on fiber-reinforced polymer composites. The results show that the deflection and energy absorption of plate in a randomly oriented distribution is more than aligned straight of carbon nanotubes in the composite layers.

References listed at the end of the paper:


http://journals.sagepub.com/doi/abs/10.1177/0021998317695423


ABSTRACT: An effective methodology is developed to investigate the vibration of the sandwich plate with pyramidal lattice core. Equation of motion of lattice sandwich plate is established by Hamilton's principle. Displacement fields are expressed with a simple method, and the natural frequencies of the lattice sandwich plate are conveniently calculated. The correctness of the analytical method is verified by comparing the present results with published literatures. The effects of structural and material parameters on the vibration characteristics of lattice sandwich plate are analyzed. The present method will be useful for vibration analysis and design of lattice sandwich plates.

References listed at the end of the paper:


ABSTRACT: Large amplitude vibration analysis of functionally graded laminated skew plates in thermal environment has been studied. The mechanical properties are assumed to be temperature-dependent and graded in the thickness direction using power-law distribution in terms of the volume fractions of the constituents. The temperature field is uniformly distributed over the plate surface and varied in the thickness direction only. The nonlinear $C_1$ finite element equations are obtained using Reddy’s HSDT with von-Karman’s strain assumptions. The convergence and comparison studies have been performed to prove the accuracy of the present model. The results listed with different design parameters have been presented.

References listed at the end of the paper:


particular quantities are obtained in the physical domain by applying a numerical inversion technique. Variations of axial displacement, axial stress, lateral deflection, volume fraction field and temperature distribution with axial distance are depicted graphically to show the effects of porosity and laser intensity parameter. Some particular cases are also deduced.

References listed at the end of the paper:


https://doi.org/10.1080/15376494.2017.1341578

ABSTRACT: The present work deals with vibration phenomenon of a homogeneous, isotropic thermoelastic double porous microbeam induced by laser pulse heating, in context of Lord–Shulman theory of thermoelasticity with one relaxation time. Laplace transform technique has been used to obtain the expressions for lateral deflection, axial stress, axial displacement, volume fraction field and temperature distribution. The resulting quantities are obtained in the physical domain by applying a numerical inversion technique. Variations of axial displacement, axial stress, lateral deflection, volume fraction field and temperature distribution with axial distance are depicted graphically to show the effects of porosity and laser intensity parameter. Some particular cases are also deduced.

References listed at the end of the paper:

ABSTRACT: This research is concerned with the analysis of post-buckling of a nano-composite beam reinforced by graphene platelets (GPLs) having geometrical imperfection. GPLs are uniformly and nonuniformly distributed throughout the thickness direction. Different porosity distributions are considered. The elastic properties of the nanocomposite are obtained by employing Halpin-Tsai micromechanics model. The postbuckling load-deflection relation is obtained by solving the governing equations having cubic nonlinearity applying Galerkin's method needless of any iteration process. New results show the importance of porosity coefficient, porosity distribution, GPL distribution, GPL weight fraction, geometrical imperfection, and foundation parameters on nonlinear buckling behavior of porous nanoscale beams. Specially, porosities and GPL reinforcement have a great impact on postbuckling configuration of both ideal and imperfect nanocomposite beams.

References listed at the end of the paper:


on new shear deformation theories

shear deformation theories

new shear deformation theories

foundation

vibration of functionally graded sandwich plate

7225(91)90165

References listed at the end of t

results show that the direction of material gradient and type of gradient have significant effects on the behavior

compared with those of other hyperbolic models

studied and the obtained results are compared with each other. The results of the present hyperbolic model

on phy

B

vibration, and buckling analysis of functionally graded plates by using the isogeometric analysis (IGA)

of functionally graded nanoscale plates resting on elastic foundation


ABSTRACT: In this paper, a new efficient hyperbolic shear deformation theory is presented for the static, free vibration, and buckling analysis of functionally graded plates by using the isogeometric analysis (IGA) approach. The IGA approach can easily formulate C continuous elements by the use of Non-Uniform Rational B-Spline (NURBS) functions. Higher-order shear deformation theory satisfies free shear stress conditions on the top and bottom surfaces of plate and so a shear correction factor is not needed. Equations are derived based on physical neutral surface position. FG plates with in-plane and through-thickness stiffness variations are studied and the obtained results are compared with each other. The results of the present hyperbolic model compared with those of other hyperbolic models, show the efficiency of the present model. Furthermore, the results show that the direction of material gradient and type of gradient have significant effects on the behavior of FG plates, especially in buckling analysis.

References listed at the end of the paper:


having discontinuities

Analytical solutions using displacement potential functions

plates


doi:10.1016/j.compstruct.2014.07.043


ABSTRACT: The static behavior of composites and sandwich plates in thermo-mechanical environment is investigated by a two dimensional (2D) FE model. An efficient higher-order zig-zag theory (HOZT) considering actual through-thickness temperature profile and a least square error (LSE) method to accurately predict the inter-laminar stresses is implemented in this model. The in-plane displacement field is obtained by superposing a cubically varying global displacement field on a zig-zag displacement field having different slopes at each layer. This plate theory represents parabolic through thickness variation of transverse shear stresses, which satisfy the inter-laminar continuity at the layer interfaces and zero transverse shear stress conditions at the top and bottom of the plate. In the present 2D finite element (FE) model, the first derivatives of transverse displacement have been treated as independent variables to circumvent the problem of C1 continuity associated with the above plate theory (HOZT). The accurate through-thickness distribution of temperature is obtained by using a linear zig-zag thermal lamination theory proposed by the authors by using the thermal conduction properties of different constituent layers in the thickness direction. The LSE method is applied at the postprocessing stage to accurately calculate the inter-laminar stresses by the 3D equilibrium equations of the plate problem, after in-plane stresses are calculated. The proposed combined FE model (HOZT+LSE) is implemented to analyze the static behavior of laminated composites and sandwich plates subjected to thermo-mechanical loadings. Many new results are also presented that should be useful for the future reference.

References listed at the end of the paper:


ABSTRACT: Many novel materials exhibit a property of different elastic moduli in tension and compression. One such material is graphene, a wonder material, which has the highest strength yet measured. Investigations on buckling problems for structures with different moduli are scarce. To address this new problem, first, the nondimensional expression of the relation between offset of neutral axis and deflection curve is derived based on the phased integration method, and then using the energy method, load–deflection relation of the rod is determined; second, based on the improved constitutive model for different moduli, large deformation finite element formulations are developed, and combined with the arc-length method, finite element iterative program for rods with different moduli is established to obtain buckling critical loads; third, material mechanical properties testing of graphite, which is the raw material of graphene, is performed to measure the tensile and compressive elastic moduli; moreover, buckling tests are also conducted to investigate the buckling behavior of this kind of graphite rod. By comparing the calculation results of the energy method and finite element method with those of laboratory tests, the analytical model and finite element numerical model are demonstrated to be accurate and reliable. The results show that it may lead to unsafe results if the classic theory was still adopted to determine the buckling loads of those rods composed of a material having different moduli. The proposed models could provide a novel approach for further investigation of nonlinear mechanical behavior for other structures with different moduli.

References listed at the end of the paper:


ABSTRACT: In the present article, a high-order global-local theory with three-dimensional elasticity corrections is employed to trace the local and instantaneous variations of lateral deflections and stress components of sandwich plates with auxetic (negative Poisson ratio) cores under static and dynamic loads. Effects of the auxeticity of the core material on the natural frequencies are evaluated as well. The governing equations are extracted based on Hamilton’s principle. The main novelties of the present research in comparison to the available literature and previous researches of the second author of the present paper are: (i) Presenting a higher-order global-local plate theory with a novel equilibrium-based three-dimensional elasticity corrections, (ii) Incorporation of the transverse flexibility of the core; a fact that is crucial when studying behaviors of thick or soft core sandwich plates, (iii) Frequency and dynamic behavior analyses (in addition to the traditional static analysis) of sandwich plates with soft cores by means of the presented accurate global-local theory, and (iv) Investigation of the negative Poisson ratio (auxeticity) effects of the core material on the static (stress) and dynamic responses and natural frequencies. All these items are accomplished here, for the first time. Since the transverse shear stresses are extracted based on the three-dimensional elasticity theory, in contract the traditional constitutive-based theories, the inter-laminar continuity condition of the transverse shear stresses is met. The verification results show that the presented finite element formulation leads to highly accurate results, even for thick or soft core sandwich plates. A comprehensive parametric study is accomplished to evaluate effects of the auxeticity of the core material and transverse compliance of the core on the resulting displacement and stress distributions, natural frequencies, and dynamic responses. Results reveal that auxeticity of the core material decreases the global and relative stresses and lateral deflections of the face sheets and the core compliance may lead to asynchronous movements of the face sheets and strengthen the local bending and extensions.

References listed at the end of the paper:
functionally graded layers

tempature rise in impact responses of composite plates with embedded SMA wires

doi:

foundations by n

Kapuria

and

Alipour

and

Eremeyev

and

Shariyat

and

Altenbach

and

Sadowski

and

Sadowski

and

Sadowski

and

Shariyat

Auxetic Materials and Structures.


ABSTRACT: In this paper, the size and thermal loads, based on the three dimensional theory of elasticity.

References listed at the end of the paper:


ABSTRACT: In the present work, a finite element approach is developed for the static analysis of curved nanobeams using nonlocal elasticity beam theory based on Eringen formulation coupled with a higher-order
shear deformation accounting for through-thickness stretching. The formulation is general in the sense that it can be used to compare the influence of different structural theories, through static and dynamic analyses of curved nanobeams. The governing equations derived here are solved introducing a 3-nodes beam element. The formulation is validated considering problems for which solutions are available. A comparative study is done here by different theories obtained through the formulation. The effects of various structural parameters such as thickness ratio, beam length, rise of the curved beam, loadings, boundary conditions, and nonlocal scale parameter are brought out on the static bending behaviors of curved nanobeams.

References listed at the end of the paper:

ABSTRACT: In this paper, free vibration behavior of functionally nanofilms resting on a Pasternak linear elastic foundation is investigated. The study is based on third-order shear deformation plate theory with small scale effects and von Karman nonlinearity, in conjunction with Gurtin–Murdoch surface continuum theory. It is assumed that functionally graded (FG) material distribution varies continuously in the thickness direction as a
power law function and the effective material properties are calculated by the use of Mori–Tanaka homogenization scheme. The governing and boundary equations, derived using Hamilton's principle are solved through extending the generalized differential quadrature method. Finally, the effects of power-law distribution, nonlocal parameter, nondimensional thickness, aspect of the plate, and surface parameters on the natural frequencies of FG rectangular nanoplates for different boundary conditions are investigated.

References listed at the end of the paper:


ABSTRACT: Geometrically nonlinear vibration of bi-functionally graded material (FGM) sandwich plates has been carried out by the p-version of the finite element method (FEM). The bi-FGM sandwich plate is made up of two face-sheet layers of two different FGM and one layer of homogeneous core. The nonlinear equations of motion of bi-FGM sandwich plates are establish using the harmonic balance method and solved iteratively by the linearized updated mode method. The effects of amplitude vibration, mechanical properties, geometrical parameters, thickness ratio of bi-FGM layers, and volume fraction exponent on the nonlinear vibration behavior of bi-FGM sandwich plates are plotted and investigated.

References listed at the end of the paper:


ABSTRACT: In this article, two-variable sinusoidal shear deformation theory, nonlocal piezoelectricity relations incorporating with concept of neutral surface are employed for free vibration analysis of a sandwich nano-plate. Due to using the functionally graded materials, the concept of neutral surface must be employed through formulation of the problem. A parametric study is performed to show how natural frequencies of sandwich nano-plate are changed in terms of nonlocal parameter, non-dimensional geometric parameters and inhomogeneous index. Before presentation of full numerical results, a comparison with a valid reference is performed to confirm our formulations and corresponding numerical results.

References listed at the end of the paper:


ABSTRACT: In the present paper, mechanical and thermal buckling analyses of two-directional functionally graded material (2D-FGM) circular plate are investigated. The motion equations have been derived based on the first-order shear deformation theory (FSDT) and power series method has been employed to solve the motion equations. Two different kinds of boundary condition including simply supported and fixed are considered. The material properties are assumed to vary in both transverse and radial directions according to power and exponential laws, respectively. Comparisons with available studies in the literature confirm the high accuracy of the material properties and 2D-FG power indices on the critical buckling load have been studied. It is shown that increase of modulus of elasticity of outer layers of plate due to higher presence of hard phase of FGM, in radius and thickness directions of the plate makes it possible to attain a more solid structure against mechanical buckling loads, while increase of coefficient of thermal expansion and coefficient of thermal conduction of outer layers of plate results in less stability against thermal buckling loads.

References listed at the end of the paper:


ABSTRACT: Accurate zigzag theory is presented for static and free vibration analysis of multilayered functionally graded material (FGM) cylindrical shells and rectangular plates by approximating in-plane displacements as a combination of linear layerwise and cubic global terms. Governing equations of motion are derived using Hamilton’s principle. The theory yields accurate results for displacements, stresses and natural frequencies in simply-supported functionally graded multilayered cylindrical shell panels and rectangular plates. Effect of changing the volume fraction ratio, aspect ratio and thickness of FGM layer between two homogeneous layers are investigated for a number of multilayered shell and plate laminates.

References listed at the end of the paper:


ABSTRACT: In the present paper, the vibrational behavior of sandwich beam with a flexible core and anti-symmetric functionally graded carbon nanotubes face sheet is investigated. Carbon nanotubes are considered as functional graded materials in the thickness of the faces and their properties change along the thickness of the face sheets. For the modeling of sandwich beam behavior, the Euler–Bernoulli theory is used for face sheets and the semi-3D elasticity is used for the core, which allowed us to investigate the flexibility of the core. Differential equations of motions are derived using the virtual displacement principle. In this research, a high-order element is presented for solving equations of motion, and then by using this element, the finite element formulation has been extracted and solved. Numerical results are obtained for various boundary conditions, which include simply support, clamped, free-clamped, and simply support-clamped. Also, different volumes of carbon nanotubes have been investigated for different distributions. The results showed that the distribution of the FG-X pattern carbon nanotube leads to the highest natural frequency of the beam. The main conclusion of this research is that, in most cases the FG-O pattern has the lowest natural frequencies and in some cases the FG-Λ pattern has the lowest natural frequencies. In other words, generally, it can be say that the lowest natural frequencies of the sandwich beam with functionally graded carbon nanotubes faces depend on the boundary conditions, thickness ratio, and also the volume fraction of carbon nanotubes. In this paper also the effect of geometric angles of the beam, such as the thickness of the core and face sheet thickness on natural frequency of the system is also investigated.

References listed at the end of the paper:


ABSTRACT: Finite element modeling approach is used here to investigate the behavior of concentric multi-walled boron-nitride and carbon nanotubes under the compressive loadings. Double-walled and triple-walled concentric boron-nitride and carbon nanotubes with different arrangements and geometries are considered. It is shown that multi-walled boron-nitride nanotubes lose their stabilities at larger compressive forces than other arrangements in which at least one carbon wall exists. Comparing the armchair and zig-zag multi-walled nanotubes, the latter one has larger buckling force than the former one. It is also shown that the nanotubes with smaller radii have larger critical compressive forces than those with larger radii.

References listed at the end of the paper:


Mechanics of Advanced Materials and Structures


https://doi.org/10.1080/15376494.2018.1430263
ABSTRACT: The buckling of carbon nanotube (CNT) under self-weight and resting on elastic foundations is examined in this article. The system is mathematically modeled as nonlocal Euler-Bernoulli beam. Two different numerical schemes are employed to calculate the values of buckling loads, namely power series method (PSM) and differential quadrature method (DQM). Both methods bring out buckling loads which are very close to each other for considered boundary conditions and for chosen values of nonlocal parameter. The spring constant plays an increasing role on the buckling loads for all boundary conditions while the shear constant decreases the buckling loads of cantilevered CNT.

References listed at the end of the paper:

- A. G. Greenhill, “Determination of the greatest height consistent with stability that a vertical pole or mast can be made, and the greatest height to which a tree of given proportions can grow Proc.,” Cambridge Phil. Soc., vol. 4, pp. 65–73, 1881.

ABSTRACT: This paper develops a nonlocal strain gradient plate model for vibration analysis of double-layered graphene sheets under biaxial in-plane mechanical loads. For more accurate analysis of graphene sheets, the proposed theory contains two scale parameters related to the nonlocal and strain gradient effects. In fact, frequency increment due to the strain gradient effect is neglected in all previous papers related to double-layer graphene sheets. Governing equations of a nonlocal strain gradient double-layer graphene sheet on elastic substrate are derived via Hamilton's principle. Galerkin's method is implemented to solve the governing equations for different boundary conditions. Effects of different factors such as in-plane loading, nonlocal parameter, length scale parameter, elastic foundation, interlayer stiffness and boundary conditions on vibration characteristics a double-layer graphene sheet are examined.

References listed at the end of the paper:


Xiaodong Li, Linzhi Wu, Li Ma & Xianqiao Yan, “Compression and shear response of carbon fiber composite sandwich panels with pyramidal truss core embedded in composite sandwich panels with reinforcing joints manufactured by the water jet cutting and interlocking assembly method. The effect of thermal exposure on the out-of-plane compression and shear performance of composite sandwich panels is investigated experimentally. In particular, the out-of-plane compression and shear moduli and strengths of the structures after thermal exposure are predicted theoretically. Experimental results show that the out-of-plane compression and shear performance of composite pyramidal truss core sandwich panels first increase and then decrease with thermal exposure temperature at the thermal exposure of 6 h. The failure modes depend on the particular temperature and time of the applied thermal exposure. As well, the compression and shear performances first increase and then decrease with thermal exposure time at 150°C. However, their compression and shear performances have a decreasing tendency with time for a given 230°C exposure temperature. In addition, the destruction responses of composite
sandwich panels are also investigated and their possible failure modes (including the crushing, delamination and local buckling of struts) are complemented with the analytic results.

References listed at the end of the paper:


ABSTRACT: The paper developed the closed-form solution for the free vibration problem of inhomogeneous orthotropic rectangular plates (IHORPs) resting on the inhomogeneous viscoelastic foundation (IHVEF). The Young’s moduli and density of the orthotropic plate vary continuously with respect to three spatial coordinates, while the characteristics of the viscoelastic foundation vary depending on the in-plane coordinates. The relevant motion equation is obtained using the classical plate theory (CPT) and solved using method of separation of variables. The influences of inhomogeneity of orthotropic materials, inhomogeneity of viscoelastic and elastic foundations on the non-dimensional frequencies (NDFs) of plates are studied in detail.

References listed at the end of the paper:

A selecting procedure of the most influencing random parameters on the dynamic behavior of Carbon NanoTubes (CNT) conveying viscous fluid. The general polynomial chaos and the nonlocal elasticity theory are used and several random parameters that may follow various distribution laws are considered. 


ABSTRACT: Methodological approaches based on the nonlocal beam theory, differential quadrature and internal random coefficients methods are elaborated for parameters uncertainty effects on the dynamic behavior of viscoelastic Carbon NanoTubes (CNT) conveying viscous fluid. The general polynomial chaos and the superposition principle are used and several random parameters that may follow various distribution laws are considered. A selecting procedure of the most influencing random parameters on the dynamic behavior of CNT
is given. The space and multimodal time domains are formulated and frequency and time responses are investigated. Effects of various random parameters on free and forced random vibrations are investigated. References listed at the end of the paper:


ABSTRACT: The influence of magnetic field on size sensitivity of nonlinear vibration of embedded nanobeams is studied based on von Kármán geometric nonlinearity and nonlocal Timoshenko beam theory. Adopting Hamilton's principle, governing equations for nonlinear vibration of nanobeams are derived and then solved by using Differential Quadrature method to obtain nonlinear responses under different boundary conditions. The results reveal that high magnetic flux restrains nonlinear vibration of nanobeams. At higher magnetic flux, the nonlocal effect could be ignored. For soft foundation, nonlinear vibration of embedded nanobeams is independent on its stiffness variation, and the increase of magnetic flux broadens this range.

References listed at the end of the paper:


ABSTRACT: This article focuses on validation phase-field method for simulation of free vibration and buckling of crack plates. The formula is derived from using Reissner-Mindlin plate theory. Validation simulation is carried out by numerically investigating free vibration and buckling of cracked plate with taking the configuration, material property, crack location, and other relevant assumptions as the same with the comparing references. The article shows that phase-field approach can be used to estimate the critical buckling load and frequencies of vibration mode. The article also demonstrates the significant advanced of phase-field method for plates with complex crack geometries.

References listed at the end of the paper:
embedded piezoelectric nanoplates based on visco-


ABSTRACT: In this article, a novel idea of utilizing a non-uniform rational B-spline (NURBS)-based material mesh independently defined with the analysis mesh to represent the material distribution is introduced to free vibration and buckling problems of in-plane bi-directional functionally graded (IBFG) plates. Two power-law material models with the symmetrical and asymmetrical volume fraction distribution are proposed as the first experiment. By applying the $\kappa$-refinement scheme, the $C^0$-continuous condition at symmetrical interfaces of material profiles can be easily achieved, while material gradations are still guaranteed elsewhere due to the outstanding advantage of material NURBS basis functions in controlling continuity. Either the rule of mixture or the Mori–Tanaka scheme is then used to estimate effective material properties. The analysis mesh is constructed by generalized shear deformation theory (GSDT)-based isogeometric analysis (IGA) for exactly modeling geometrical domains and approximately solving unknown solutions in finite element analysis (FEA). Accordingly, the $C^1$-continuous requirement of the Galerkin isogeometric finite element model is simply met owing to the possibility of flexibly fulfilling high-order derivatives and continuity of analysis NURBS functions. Additionally, the present formulation is also completely free from shear correction factors, yet still considering shear deformation influences. Several numerical examples are presented to demonstrate the performance and effectiveness of the proposed method. The effects of material gradations, aspect ratios, and different boundary conditions on IBFG plate responses are examined in detail as well.

References listed at the end of the paper:

distributions are considered as even and uneven models. Porosity volume fraction is incorporated to the power


ABSTRACT: This paper deals with postbuckling of geometrically imperfect functionally graded (FG) nanoplates with porosities based on general higher-order plate model and nonlocal elasticity. Porosity distributions are considered as even and uneven models. Porosity volume fraction is incorporated to the power-
law modeling of FG materials. Employing a general higher-order plate theory with five field variables, it is possible to satisfy shear deformation effects without adding correction factors. The nonlinear governing equations are analytically solved to obtain the postbuckling load-deflection relation of the nanoplate. Obtained results indicate the significance of porosity coefficient, porosity distribution, geometrical imperfection, nonlocality, material composition and geometrical parameters on postbuckling characteristics of size-dependent nanoplates.

References listed at the end of the paper:


ABSTRACT: This paper examines an analytical investigation into nonlinear thermomechanical buckling and postbuckling of ES-FGM truncated conical shells. Shells are reinforced by orthogonal stiffeners. The change of spacing between stringers are taken into account. The governing equations, which are the coupled set of three variable coefficients nonlinear partial differential equations in terms of displacement components, are solved by Galerkin method. The explicit expressions for determining the critical buckling load and analyzing the postbuckling load–deflection curves are obtained. The influences of various parameters such as temperature, stiffeners, foundations, material properties, geometric dimensions on the stability of shells are considered and highlighted.

References listed at the end of the paper:


ABSTRACT: The low velocity impact response of beams made of carbon nanotube (CNT)/short carbon fiber (SCF)-reinforced polymer is investigated based on a hierarchical finite element approach. First, the random distribution of CNTs into the polymer matrix is modeled using a three-phase representative volume element (RVE); and the elastic modulus and density of CNT-reinforced polymer are predicted. In the RVE, the interphase region formed due to the interaction between CNTs and the matrix is considered. Then, reinforcement with SCFs is considered, and the elastic properties of SCF-CNT-polymer hybrid composite are obtained. Finally, the low velocity impact response of composite beams is analyzed.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: This study of bi-FGM sandwich elliptic plates is carried out to investigate the vibration behavior using a curved hierarchical finite element. The plate is made up of two face-sheet layers with two different mixtures of FGM and one layer of homogeneous core. The blending function method is used to describe accurately the geometry of the elliptic plate. The accuracy of the present method is established by the comparisons made with the published results. Contour plots of frequency parameters as functions of the volume fraction exponents and thickness for bi-FGM sandwich plates are carried out.

References listed at the end of the paper:

ABSTRACT: In this article, vibration analysis of single-walled carbon nanotubes (SWCNTs) based on Love's thin shell theory has been investigated along with five sort of boundary conditions (S-S), (C-C), (C-F), (C-SI), and (F-S). Three different shapes such as Armchair, Zigzag, and Chiral are taken into account under the influence of Winkler and Pasternak foundations. The wave propagation approach is employed to formulate the eigenvalue problem. MATLAB software package is used to obtain the vibrational natural frequencies of SWCNTs. The axial modal dependence is measured by the complex exponential functions implicating the axial modal numbers.

References listed at the end of the paper:


ABSTRACT: Low velocity impact response of micro-cantilever beams made of axially functionally graded materials (AFG) is analytically investigated in present research based on the modified couple stress theory.
Taking into account the temperature-dependency, material properties of polymer beam reinforced by carbon nanotubes are estimated using refined rule of mixture. The results are validated with those available in the literature. Finally, the temperature-dependent analysis are carried out to study the influences of material length scale parameter, CNTs distribution, CNTs volume fraction, impact position, impactor initial velocity and impactor radius on the low velocity impact behavior of AFG CNT reinforced micro-cantilever beams.

References listed at the end of the paper:


ABSTRACT: The effects of functional properties of the face sheets as well as the mechanical properties of the core and other constituents, on stress distribution in a simply supported five-layer sandwich plate are investigated. Layerwise theory (LT) is adapted to solve for stress distribution in each layer based on first and third order shear deformation theory (FSDT). Results indicate that LT gives very good estimations on planar stresses in the adhesive layers compared to those of finite element analysis (FEA). The peak in-plane and out-of-plane shear stresses developed at the adhesive interfaces have values much higher than those of the applied load.

References listed at the end of the paper:


ABSTRACT: In this article, a comprehensive study on mechanical behaviors of nonhomogenous nonuniform size-dependent beams is presented. Beam is modeled with axially functionally graded materials with different types of materials and functions for material variation. Also, the beam is assumed with nonuniform cross-section and scale effects are presented by having both strain gradient and nonlocal effects. Nonuniformity is modelled in several ways by having tapered, parabolic and higher-order cross-section variation in both thickness and width directions. By having these assumptions, a great majority of small-scale beams from uniform homogeneous beams to nonuniform axially functionally graded beams are modeled and formulated. For this general beam model, static deformation, stability, and free vibration response, which are the three most important mechanical behaviors of such structures, are investigated. Finite element method in conjunction with numerical integration, Gaussian quadrature method, and Wilson's Lagrangian multiplier are employed to solve different problems investigated in this study by combining different assumptions. In order to show the influence of different parameters on mechanical behavior of such structures, a parametric study is presented and the effects by varying material, cross-section, using different type of functions, etc. on bending, buckling, and free vibration response of size-dependent beams are illustrated. It is seen that by combining different cross-section and material variations through the length, mechanical behavior of nanobeams change significantly which could be a step-forward in optimize designing nanostructures.

References listed at the end of the paper:

ABSTRACT: In this paper, a size-dependent Euler–Bernoulli beam model, which takes the flexoelectricity, piezoelectricity, and dielectricity as well as the surface elasticity into consideration, is established. Theoretical solutions for the static bending deflection of thin beams under different loading (uniformly distributed and concentrated load) and boundary conditions (cantilevered, both ends simply supported, clamped–clamped), are established. Moreover, an iterative finite element algorithm is developed for the analysis of thin flexoelectric beams under any load and boundary conditions. Our numerical results show the direct bulk flexoelectric...
always play the role of stiffening the beams with various boundary conditions, while the residual surface stresses behave either stiffening or softening the nanobeams dependent on boundary conditions. The present investigation also demonstrates the size-dependent effects of flexoelectricity on the bending rigidity and piezoelectricity.

References listed at the end of the paper:


ABSTRACT: In this study, we present the extension of the so-called 7-parameter shell formulation to layered CFRP and functionally graded power-based composite structures using two different parametrizations: (i) the three-dimensional shell formulation, and (ii) the solid shell approach. Both numerical strategies incorporate the use of the Enhanced Assumed Strain (EAS) and the Assumed Natural Strain (ANS) methods to alleviate locking pathologies and are implemented into the FE code ABAQUS. The applicability of the current developments is demonstrated by means of several benchmark examples, whose results are compared with reference solutions using shell elements of ABAQUS, exhibiting an excellent level of accuracy.

References listed at the end of the paper:

ABSTRACT: In this study, metallic pyramidal lattice truss core sandwich structures, including single-layered as well as multi-layered ones, are fabricated from EOS Aluminium AlSi10 Mg, utilizing additive manufacturing method. Out-of-plane and in-plane compression as well as shear tests were carried out in order to measure the stiffness and strength properties of the structures. The out-of-plane compressive strength is determined by buckling of struts, and specimens fail in plastic yielding of face sheets for in-plane tests. And for the shear performance of the specimens, the strength is dominated by the node failure. In addition to experimental testing, finite element models have been developed for simulating the stiffness and strength properties and the numerical results agree well with experimental performance.

References listed at the end of the paper:


ABSTRACT: In this study, metallic pyramidal lattice truss core sandwich structures, including single-layered as well as multi-layered ones, are fabricated from EOS Aluminium AlSi10 Mg, utilizing additive manufacturing method. Out-of-plane and in-plane compression as well as shear tests were carried out in order to measure the stiffness and strength properties of the structures. The out-of-plane compressive strength is determined by buckling of struts, and specimens fail in plastic yielding of face sheets for in-plane tests. And for the shear performance of the specimens, the strength is dominated by the node failure. In addition to experimental testing, finite element models have been developed for simulating the stiffness and strength properties and the numerical results agree well with experimental performance.

References listed at the end of the paper:


ABSTRACT: Finite element (FE) formulation of nanobeams using second-order positive/negative strain gradient theories is presented. The variational statement for beam, written using Hamilton's principle involving virtual work of stress/moment resultants, with C continuity requirement leads to unsymmetric nonlocal terms whereas the symmetrization of the nonlocal terms leads to C continuity requirement. The C continuous FE with proper boundary conditions is accurate for the modeling of nanobeams using second-order strain gradient theories. The negative strain gradient model predicts results matching with the experimental investigations on microbeams. The strain gradient theory based plate FE is also formulated by extending C continuous beam FE formulation.

References listed at the end of the paper:

ABSTRACT: The present work investigates through molecular dynamics finite element method with Tersoff potential the buckling behavior of boron nitride (BN) armchair and zigzag nanotubes under bending. The critical bending buckling angle, moment, and curvature are studied and discussed with respect to the tube length-diameter ratios from 10 to 50. Effects of a Stone-Wales defect in the middle tube on the bending behavior are also examined. The bending buckling mechanism is governed by the local instabilities and bond breaking in the compressive zone of the tubes. Results are useful for the design of nanocomposites and nanodevices with BN nanotubes.

References listed at the end of the paper.


REFERENCES


ABSTRACT: In this work nanopolyurea is used as reinforcement for curved steel plates under low velocity impact loading. Experimental and numerical analysis are used to study the effect of plate curvature and nano particle effects. A drop weight test apparatus is utilized to apply impact loading on bi-layer panels. Experiments show that maximum improvement in energy absorption capacity of nanopolyurea is about 5%. Numerical analysis is carried out using explicit LS-DYNA solver. The results show that by increasing panel radius of curvature, impact force increases; also comparison between numerical and experimental results shows a good agreement.

References listed at the end of the paper:

- M. Irshidat, A. Al-Ostaz, and A. H. D. Cheng, Predicting the response of polyurea coated high hard steel plates to ballistic impact by fragment simulating projectiles. USA: Ole Miss Project, Nano Infrastructure Research Group, University of Mississippi, 2011.

ABSTRACT: The truss and honeycomb sandwich plates with transverse crack and delamination in the facesheets are studied, and an Extended Layerwise/Solid-Element (XLW/SE) method is developed. The governing equations of laminated composite facesheets and cores (truss or honeycomb) are established based on the Extended Layerwise Method (XLWM) and 3D solid elements, respectively. The XLW/SE method can obtain the local stress and displacement fields accurately, considering complicated cores without any assumptions. In the numerical examples, the results obtained by the proposed method are compared with those obtained by the 3D elasticity models, and the good agreements are achieved.

References listed at the end of the paper:


ABSTRACT: A formulation for static and dynamic vibration analysis of composite laminated curved beam is presented by using an efficient domain decomposition method. Multi-segment partitioning strategy is used to accommodate the accurate requirements of responses. The system potential functional is introduced to satisfy the continuity constraints on the segment interfaces. The Chebyshev orthogonal polynomials are used as displacement admissible functions. The theoretical results are verified by comparing with those previously published in literature, and the ones obtained by using the program ABAQUS. Based on the verification, the parametric study of composite laminated curved beam is carried out.

References listed at the end of the paper:


ABSTRACT: This article presents an analytical investigation on the effects of shear stress and compressive stress gradient on the distortional buckling of cold-formed steel channel- and zed-section beams subjected to uniformly distributed transverse load. The study is performed by using the principle of minimum potential energy. It is shown that for beams subjected to a uniformly distributed transverse load the buckling wave coupling in distortional buckling modes caused due to compressive stress gradient is very important, particularly for long beams. The effect of shear stress on the critical stress of distortional buckling exists but only in short beams. For beams longer than 3 m the shear stress effect can generally be ignored.

References listed at the end of the paper:


ABSTRACT: In the present study, the energy absorption capacity of thin-walled end-capped conical geometries is taken into consideration and the collapse of the absorbers under different loading types and strengths is investigated. First, the manual spinning method is utilized in order to manufacture the specimen. The manufacturing geometry quality of the parts is then evaluated. Next, quasi-static load-deflection tests are employed to investigate the collapse process as well as the calculation of energy absorption for conical tubes. Drop experiments are carried out using a free flight drop tower on the conical tubes to obtain the acceleration time-history of the hammer. The time history of hammer velocity change during its collision with the energy absorber, the mean collapse load of the absorber and absorbed energy are calculated. The explicit FE code Abaqus/explicit is employed and validated using dynamic experimental data. Finally, a multi-objective optimization method is used to find the tube geometry which has the maximum energy absorption and specific energy absorption. The results show that the impactor's velocity, as well as the geometrical characteristics of the end-capped conical tubes, have significant effects on the energy absorption and specific energy absorption capacity.

References listed at the end of the paper:

ABSTRACT: A scale-dependent continuum model is presented to investigate the effect of initial in-plane edge displacement on the nonlinear vibration and electromagnetic buckling of magneto-electro-elastic (MEE) ultrathin films using the nonlocal continuum mechanics and the von Kármán's theory of large deflections. The coupled nonlinear governing differential equations are solved employing Galerkin's approach and a perturbation method. Analytical relations are obtained to highlight the impact of initial edge displacement on the nonlinear natural frequencies as well as the buckling electric and magnetic potentials. It is shown that the initial edge displacement plays a crucial role in the nonlinear response of MEE nanofilms.

References listed at the end of the paper:


ABSTRACT: Thermal post-buckling analysis of a geometrically imperfect nanoscale piezoelectric beam under closed circuit condition is performed accounting for the flexoelectricity and surface effects. The flexoelectricity is due to the coupling between electrical polarization and strain gradient. Applying Hamilton's principle, the governing equations and related boundary conditions are derived. The post-buckling load-deflection relation is obtained by solving the governing equations having cubic nonlinearity applying Galerkin's method needless of any iteration process. Obtained results indicate that both the flexoelectricity and surface effects possess notable impact on the post-buckling behavior of the system. Only flexoelectricity yields a considerable difference between the present model and previous investigations on conventional piezoelectric nanobeams. A parametric study has been performed to examine the effects of surface elasticity, flexoelectricity, applied electric voltage, geometrical imperfection, foundation parameters and boundary conditions on post-buckling load of piezoelectric nanobeams.

References listed at the end of the paper:


ABSTRACT: In this study mechanical properties and buckling behavior of laminated cylindrical composite shells embedded with shape memory alloys (SMAs) were investigated. Samples were fabricated by filament winding process. Stacking sequences were ±55°/SMA/±55°. SMAs with shape memory effect used in the form of wire were placed between plies 2 and 3. Moreover, the effect of zero and 5% tensile prestrain and number of SMA wires were studied by embedding zero, four, and six wires in the composite. The results showed that the critical buckling load increased by using four SMA wires and decreased due to increasing the number of SMAs up to six.

References listed at the end of the paper:

ABSTRACT: In conjunction with the Reissner's mixed variational theorem and nonlocal Timoshenko beam theory, we develop a finite element method for the geometrically nonlinear bending analysis of a multiwalled carbon nanotube resting on an elastic foundation and with various boundary conditions. The effects of the van der Waals interaction and the interaction between the multiwalled carbon nanotube and its surrounding medium are considered. Numerical implementation shows that the finite element solutions converge rapidly, and their convergent solutions closely agree with those obtained using the differential quadrature method, based on a strong-form formulation, available in the literature.

References listed at the end of the paper:

The results demonstrate the effectiveness of the present method for the analysis of elastic waves, verified by comparing with the conventional finite element method. The effectiveness of the proposed model is verified by comparing with the conventional finite element method. The effect of material grading pattern is analyzed. The results demonstrate the effectiveness of the present method for the analysis of elastic waves.
propagation in functionally graded solids with axial symmetry and the material composition variation has an important effect on structural wave propagation behavior.

References listed at the end of the paper:


ABSTRACT: In this work, the effects of geometric imperfections on the buckling behavior of thin-walled cylindrical shells under compression were investigated by both experimental and numerical methods. The imperfections were produced by one or two circular cutouts on the shell surface. The configuration of specimens was fabricated by the geometric imperfection parameter $\alpha$, which was calculated using the circular cutout radius $a$, thickness $t$, and cylinder radius $R$. In the experimental investigation, a three-dimensional (3D) Digital Image Correlation Method, an optical instrument which utilized the full-field and noncontact measurement, was employed to obtain 3D displacement and strains, then the test data were analyzed and compared with the correlation technique that can determine the surface displacements of cylindrical shells. The further numerical simulations showed that parameter $\alpha$ played an important role in the buckling strengths of thin-walled specimens. In addition, the visualization effects of the geometric imperfections on the thin-walled shell structures were also demonstrated by using this optical method.

References listed at the end of the paper:


ABSTRACT: In order to further improve the accuracy of the equivalent models of the trapezoidal corrugated core, a 3D homogenization method based on a representative unit cell (RUC) has been developed to obtain a complete set of equivalent properties, which also investigates the influences of the elastic modulus in the thickness direction and different RUCs on the equivalent models that were rarely considered in previous studies. Then free vibration analysis is conducted to further validate the present homogenized models by comparing with the corresponding actual corrugated sandwich structures. Finally, parametric studies are carried out to investigate the influence of the corrugation height and trough angle on the equivalent properties and natural frequencies. Results show that sufficient accuracy of the present homogenized models can be easily obtained by choosing suitable profile geometries and high-quality meshes. Furthermore, the effects of corrugation height and trough angle both play a vital role in the equivalent properties and dynamic behavior of corrugated sandwich structures. Several conclusions are drawn, which may be useful for designing such kinds of sandwich cored structures in the applications.

References listed at the end of the paper:


ABSTRACT: This paper studies free vibrational behavior of porous nanocomposite shells reinforced with graphene platelets (GPLs). GPLs are uniformly and nonuniformly distributed thorough the thickness direction. Different porosity distributions called uniform, symmetric, and asymmetric are considered. The elastic properties of the nanocomposite are obtained by employing Halpin–Tsai micromechanics model. The GPL-reinforced shell is modeled via first order shear deformation theory and Galerkin’s method is implemented to obtain vibration frequencies. New results show the importance of porosity coefficient, porosity distribution, GPL distribution, GPL weight fraction, and geometrical and foundation parameters on vibration behavior of porous nanocomposite shells.

References listed at the end of the paper:

ABSTRACT: In this article, an exact solution is obtained to the time-dependent problem of a laminated orthotropic elastic cylindrical shell bonded to piezoelectric actuator and sensor incorporating interfacial diffusion and sliding subjected to electromechanical loadings. The state-space method is employed to solve this problem. Both the direct and the inverse piezoelectric effects of the piezoelectric material are investigated. The relaxation times and the transient electroelastic fields of displacements, stresses, and electric potential are calculated for three-layered and five-layered smart cylindrical shells. It is found that interfacial diffusion and sliding can effectively reduce the initial high stress concentrations as the evolution time is long enough. The derived solution can be used as benchmark results for various approximate shell theories and numerical methods.

References listed at the end of the paper:
ABSTRACT: Transverse shear stresses have a significant influence on the buckling analysis of laminated structures. Thus, the models violating interlaminar continuity of transverse shear stress will encounter difficulty for the buckling analysis. The postprocessing method by integrating three-dimensional equilibrium equation is also invalid, as the transverse shear stresses obtained from the postprocessing method are unable to be involved in the strain energy. In this paper, a Reddy-type higher-order zig-zag theory is firstly proposed, in which the in-plane displacement field is obtained by superposing the developed zig-zag function on the displacement field of Reddy's theory. To predict accurately the buckling behaviors of laminated composite and sandwich beams, a new equilibrium approach in conjunction with the Hu-Washizu (HW) mixed variational principle has been developed to produce the improved transverse shear stresses. Moreover, the accurate transverse shear stresses can be involved in the strain energy which can actively impact the accuracy of buckling stresses. To assess the performance of the proposed method, the critical loads of the laminated composite and sandwich beams with various configurations have been analyzed. Agreement between the present results and the solutions of layerwise are very good, and the proposed model only includes the four displacement parameters which can illustrate the accuracy and effectiveness of the present model. In addition, new results using all the models considered in this paper have been presented which can serve as a reference for future investigations.

References listed at the end of the paper:

ABSTRACT: The present study aimed at quasi-static compressive test on 6061–O aluminum cylindrical absorbers with internal networking. The cylindrical cellularization was in such a way that a square is welded to a thin-walled cylindrical at the middle of the sides. As one of the design of experiments (DOE) techniques the response surface method (RSM) was used to examine the effect of the parameters on energy absorption, peak force (PF), specific energy absorption per unit mass (SEA) and energy absorption per length (EA). The variables of thickness, height and length of square of the thin-walled cylindrical were considered in three levels. The samples were performed under a quasi-static compressive test at a constant speed of 10 mm/min. Then, the numerical simulation was performed using the finite element software (ABAQUS). The results obtained from the experiments and simulations were consistent. In accordance to the equations obtained from the experimental results, the multi-objective optimization was conducted considering maximum SEA conditions, EA conditions, and minimum PF conditions. The results indicated a direct relationship between thickness and length of square with responses, nonlinear relationship between height and responses, and the effect of thickness was greater than other parameters in all responses. Except for PF response, there was an interaction between the parameters in EA and SEA responses.

References listed at the end of the paper:


ABSTRACT: Time dependent nonlinear dynamic response of new proposed plates made up of functionally graded (FG) basalt/nickel composites have been explored under different dynamic blast loadings. Four different approximations are considered to simulate the FG composite plates made up of basalt/nickel according to rules based on Homogenous-Laminated Model (HLM), Continuous Model (CM), Power-Law Model (PLM), and Sigmoid-Law Model (SLM). Large deflection theory of thin plates has been used to consider the geometric nonlinearity effects. The basalt/nickel FG composite plates under blast loads and extreme environments would be a good option and would find many application areas in the near future.

References listed at the end of the paper:
Li-Hong Yang, Jia Qu, Guo-Cai Yu, Jin-Shui Yang and Lin-Zhi Wu (Harbin Engineering University, Harbin, China), “The effect of strain-rate sensitivity on dynamic response of impulsively loaded sandwich beam”,

- 50 ANSYS 10.0 Commercial Software.
ABSTRACT: A theoretical analysis method is developed to study dynamic responses of clamped strain-rate-sensitive sandwich beam subjected to impulsive loading based on Cowper and Symonds constitutive model. The front sheet of the sandwich beam is normally loaded by a uniformly distributed impulse. The effect of strain-rate sensitivity is characterized by an influence factor independent of time history but related to initial impact kinetic energy. The relationship between this influence factor and initial kinetic energies is analyzed for three different materials. The dynamic response process of sandwich beam is divided into two stages: core compression stage and overall beam deformation stage. The strain-rate sensitivity of materials is considered only in the second stage of dynamic response analysis. From the comparison of the results of sandwich beam with that of monolithic beam, we can conclude that this method of introducing influence factor to characterize the strain-rate-sensitive effect is valid to analyze the dynamic responses of impulsively loaded sandwich beams.

References listed at the end of the paper:

references and includes the important suggestions for the future research in the area of analysis of FG sandwich beams.

References listed at the end of the paper:


S. R. Li, and R. C. Batra, “Relations between buckling loads of functionally graded Timoshenko and homogeneous Euler–Bernoulli beams,” Compos. Struct., vol. 95, pp. 5–9, 2013.


ABSTRACT: In this paper, finite element method is employed to study the free vibration response of the rotating pretwisted carbon nanotube-reinforced composite cylindrical shell in thermal environment. The shells are reinforced by single walled carbon nanotubes (SWCNTs) and the material properties of SWCNTs are considered to be temperature dependent. The dynamic equilibrium equation is derived from Lagrange's equation for moderate rotational speeds for which the Coriolis effect is neglected. Parametric study is performed to investigate the effects of pretwist angles, temperature rise, rotational speed, and volume fraction of CNTs. In addition to this, the representative mode shapes are also presented. References listed at the end of the paper:
ABSTRACT: Frequencies and energies of vibrations for a honeycomb sandwich plate with negative Poisson's ratio are investigated. Based on Reddy's third-order shear deformation plate theory, von Karman type nonlinear theory and Hamilton theory, the equations of motion for the plate are obtained, free vibrations and vibrations with the damping and in-plane force of the plate are considered, respectively. The changes of real parts of the eigenvalues with the damping and in-plane forces of the plate are obtained. In order to obtain the analytic solutions of the frequencies and energies of the plate, lateral free vibrations are considered by using the Hamilton energy method, and we compare the results with that of the previous free vibrations. The potential energies and the total energies variation with parameters of the plate are given. The research results from the two methods show that the change trends of the frequencies and energy of the plate are exactly consistent, but the values of natural frequencies and potential energies are larger in lateral vibrations.

References listed at the end of the paper:


ABSTRACT: A size-dependent annular microplate model is established based on the isotropic flexoelectric theory, which considering the effects of strain gradient, polarization gradient, and microscopic electrical field gradient. The displacement mode of the Kirchhoff plate theory is used to obtain the detailed expressions of the electric enthalpy, dynamic energy, and the work done by external forces. The governing equations, boundary conditions, and initial conditions are derived using the Hamilton's principle. By solving the governing equations with only mechanical and only electrical boundary conditions, the analytical solutions of deflection and polarization in the static direct and converse flexoelectric responses are obtained, respectively. Meanwhile, the free vibration problem is also solved. Finally, based on the analytical solutions, some numerical results are given to illustrate the unique flexoelectric properties of the annular microplate compared with the solid circular microplate and influence of the strain gradient elastic effect on the static direct and converse flexoelectric responses as well as the natural frequency.
References listed at the end of the paper:


ABSTRACT: In this article, electro-elastic deformation of the piezoelectric doubly curved shells is studied. First-order shear deformation theory is used for description of displacement field. The electro-elastic governing equations are derived based on principle of minimum potential energy. The piezoelectric doubly curved shell is subjected to uniform transverse load while is resting on Winkler's foundation. In addition, the piezoelectric doubly curved shell is subjected to applied electric potential. Influence of important parameters such as applied electric potential and Winkler's parameter is studied on the electro-elastic deformations and stress results of the problem.

References listed at the end of the paper:


ABSTRACT: In this manuscript the frequencies of micro and nano fiber–metal laminates circular cylindrical shells based on modified couple stress theory (MCST) have been obtained. Love's first approximation shell theory has been applied to consider the thin cylindrical shell and beam modal function model used to satisfy the governing equations of motion subjected to different boundary conditions. Vibration of micro and nano FML cylindrical shells has been considered for carbon/epoxy, glass/epoxy and aramid/epoxy as composites and for aluminum as metal. Also, the frequencies of the shells have been calculated for different volume fractions of composite section, lay-ups, material length scale parameters, length to radius ratio, axial and circumferential wave numbers. The results have been compared to the other researches and showed excellent agreement with them. Also, the frequencies of aramid reinforced aluminum laminate micro and nano cylinder are more than the other ones.

References listed at the end of the paper:


ABSTRACT: In the present study, Eringen nonlocal theory is employed in Mindlin plate theory to study the free vibration of nano-plates. The hierarchical finite element method based on a curved hierarchical quadrilateral element is developed and applied to free vibration analysis of arbitrary shaped Mindlin nano-plates. Equations of motion for free vibration of arbitrary nano-plate are derived according to the principle of virtual displacements. The convergence and accuracy of the proposed method are demonstrated by comparison with other methods. Finally the effect of aspect ratio, thickness ratio, mode number, and the boundary conditions on the natural frequencies have been studied.

References listed at the end of the paper:
Various boundary conditions using the nonlocal continuum plate model,


ABSTRACT: The typical damage pattern of functionally graded materials (FGM) is a complex three-dimensional crack with delamination and transverse cracks. The extended layerwise method (XLWM) is applied to the static, free vibration and transient response of FGM plates with typical damage pattern in this
paper. In the XLWM of FGM plates, the multiple delaminations and transverse cracks are simulated by displacement assumption in thickness direction and in-plane displacement discretization of extended finite element methods (XFEM), respectively. Numerical examples are provided to validate the proposed method, and the results are compared with those of existing methods and 3D elastic models.

References listed at the end of the paper:

The present study investigates the band gap (BG) characteristics in a fluid-filled coaxial shell system. Elastic and acoustic band gaps are generated in this coaxial shell system with either light or heavy fluid loading. The cylindrical shell walls are assumed to be periodic with a fixed thickness. For light fluid loading, BGs of the fluid shell are determined. Because the loading of the cylindrical shell walls a deformation theory and extended isogeometric approach are utilized to simulate the fluid-structure interaction. Elastic and acoustic band gaps (BGs) are generated in this coaxial shell system with either light or heavy fluid loading. The cylindrical shell walls are assumed to be periodic with a fixed thickness. For light fluid loading, BGs of the fluid shell are determined. Because the
coupling effect of the annular light fluid is so weak that it can be neglected; thus, the inner and outer shell may behave independently. In terms of heavy fluid loading, the confined annular fluid region acts as an effective energy transmission medium that links the two shell motion together. The “hydrodynamic” mass induced by the annular-fluid can be far larger than its actual mass when the annular gap is sufficient narrow. As a result, the fluid inertial loading on the other shell can be quite enormous, rendering the central frequencies of BGs for the coaxial periodic shell system notably decreased. The BG formation mechanism may be attributed to (i) phenomenon of interference of waves reflected by these repeated “periodicity cells”, (ii) cut-off frequencies and (iii) hybrid vibration motion modes of different shell sections, according to various circumferential modes and frequency ranges. The acoustic pressure in the narrow annular region is extremely high, if the filling fluid is dense. However, when the harmonic frequency is located at the BG, the acoustic pressure becomes weaker and weaker along the axial direction of the shell; in contrast, if frequency is in the wave pass bands, the acoustic pressure levels will remain as strong as at the front end of the shell throughout the shell.

References listed at the end of the paper:

ABSTRACT: The present work optimizes Sound Transmission Loss (STL) and weight of double-walled composite cylinder with poroelastic foam employing multi-objective genetic algorithm by offering Variables Chromosome Method (VCM). So, firstly, shell and porous core equations of motion are solved beside acoustic wave equations, simultaneously. Next, optimization of the structure is performed based on VCM in which numbers of outer and inner composite layers are variable. Meanwhile, a number of other design factors such as fiber orientation angles and material types depend on a number of layers that in other researches have been considered constant. Finally, efficiency and reliability of optimized structure are shown.

References listed at the end of the paper:


ABSTRACT: The present work optimizes Sound Transmission Loss (STL) and weight of double-walled composite cylinder with poroelastic foam employing multi-objective genetic algorithm by offering Variables Chromosome Method (VCM). So, firstly, shell and porous core equations of motion are solved beside acoustic wave equations, simultaneously. Next, optimization of the structure is performed based on VCM in which numbers of outer and inner composite layers are variable. Meanwhile, a number of other design factors such as fiber orientation angles and material types depend on a number of layers that in other researches have been considered constant. Finally, efficiency and reliability of optimized structure are shown.

References listed at the end of the paper:


ABSTRACT: The present work optimizes Sound Transmission Loss (STL) and weight of double-walled composite cylinder with poroelastic foam employing multi-objective genetic algorithm by offering Variables Chromosome Method (VCM). So, firstly, shell and porous core equations of motion are solved beside acoustic wave equations, simultaneously. Next, optimization of the structure is performed based on VCM in which numbers of outer and inner composite layers are variable. Meanwhile, a number of other design factors such as fiber orientation angles and material types depend on a number of layers that in other researches have been considered constant. Finally, efficiency and reliability of optimized structure are shown.

References listed at the end of the paper:
elements package. Considered. In addition, the sensitivity of the results to the geometrical and mechanical parameters is studied using the first order shear deformation theory. The viscoelastic behavior is assumed standard linear solid in shear and elastic in bulk. Hamilton's principle is employed to derive governing equations which are five coupled partial differential equations with variable coefficients. Using the perturbation technique and the Fourier series, the equations of motion are solved analytically. Determination of the natural frequencies of the plate with different combinations of boundary conditions including simply supported, clamped, and free are considered. In addition, the sensitivity of the results to the geometrical and mechanical parameters is investigated. The results are compared with those obtained from the literature, classical plate theory, and finite elements package.

References listed at the end of the paper:


ABSTRACT: In this paper, free vibrations analysis of asymmetric viscoelastic annular and circular plates are studied using the first order shear deformation theory. The viscoelastic behavior is assumed standard linear solid in shear and elastic in bulk. Hamilton's principle is employed to derive governing equations which are five coupled partial differential equations with variable coefficients. Using the perturbation technique and the Fourier series, the equations of motion are solved analytically. Determination of the natural frequencies of the plate with different combinations of boundary conditions including simply supported, clamped, and free are considered. In addition, the sensitivity of the results to the geometrical and mechanical parameters is investigated. The results are compared with those obtained from the literature, classical plate theory, and finite elements package.

References listed at the end of the paper:

Yong Zhou, Timo Nyberg, Gang Xiong & Shi Li (First author is from: Hunan Institute of Science and Technology, Yueyang, China), “State space finite element analysis for piezoelectric laminated curved beam

ABSTRACT: A six-variable state vector formulation for static deformation of the laminated curved beam bonded with piezoelectric actuators is deduced. The 2D numerical solution for the piezoelectric laminated curved beams (PLCB) is explored. Then the distributions of the electrical and mechanical fields along the beam thickness direction are investigated analytically. The static shape control is researched for a laminated half circular beam covered with piezoelectric actuators. Comparisons with the available results show the reliability of the proposed method. At the end a spiral laminated piezoelectric structure is analyzed and the parameter study is carried out using the presented method.

References listed at the end of the paper:


ABSTRACT: The paper deals with the nonlinear buckling analysis of imperfect cylindrical shells made of porous metal foam subjected to axial compression. For the metal foam shells, porosities are dispersed by uniform, symmetric, and asymmetric distributions in the thickness direction. Using Donnell shell theory and von-Karman nonlinear kinematics, nonlinear equilibrium equations are derived. The critical buckling load and buckling equilibrium curves for both perfect and imperfect shells are solved by using the Galerkin’s procedure. A comprehensive investigation into the influence of porosity coefficient, imperfections, porosity distribution, and geometry on the buckling behaviors of the cylindrical shell is performed.

References listed at the end of the paper:


H. Huang and Q. Han, Elastoplastic buckling of axially loaded functionally graded material cylindrical shells, Compos. Struct., vol. 117, pp. 135–142, 2014. DOI: 10.1016/j.compstruct.2014.06.018.


ABSTRACT: The subject of the paper is a beam with symmetrically varying mechanical properties in the depth direction. The proposed formulation of the functions of the properties makes a certain generalization in the research of functionally graded materials and allows to describe homogeneous, nonlinearly variable and sandwich structures with the use of only one, consistent analytical model. The individual nonlinear hypothesis for planar cross section is assumed. Basing on the Hamilton’s principle two differential equations of motion are obtained. The system of equations is analytically solved. The results are compared with numerical solutions obtained with FEM.

References listed at the end of the paper:

ABSTRACT: Miura-ori core sandwich structures have aroused considerable research interests as a potential alternative to conventional honeycomb sandwich structures due to various superiorities, e.g., open channels and continuous manufacturing process. Although quasi-static or impact mechanical behaviors have been extensively studied, modal response of Miura-ori core sandwich structures has not been investigated yet. In this paper, carbon-fiber-reinforced Miura-ori core sandwich panels (MSPs) were fabricated with an autoclave processing method. Modal tests were carried out to investigate the structural vibration performances. A finite element analysis of MSPs was developed and validated with the tests results. Fiber orientation influences of both face sheets and core on the natural frequencies were investigated. Furthermore, a parametric study on the modal response of various MSPs models subjected to virtual free vibration was performed, through which the relationships between the fundamental frequencies and the geometric parameters were established. Compared with corrugated core sandwich panel under identical dimension and weight, MSP always possesses higher fundamental frequency, with an increase of 11.7% in the optimum case. It indicates that MSP is much stiffer and could be designed even lighter in aerospace applications.

References listed at the end of the paper:
influences of being at the nanoscale level are modeled with the use of the nonlocal strain gradient.


ABSTRACT: The coupled nonlinear mechanical behavior of nonlocal strain gradient nanotubes subject to distributed excitation forcing is investigated for the first time. Both longitudinal displacements and transverse deflection are taken into consideration in both the continuum-based formulation and the numerical solution. The influences of being at the nanoscale level are modeled with the use of the nonlocal strain gradient theory. The
coupled large amplitude motion characteristics are extracted via Galerkin's approach and a continuation method. The influences of scale coefficients, the slenderness ratio, and the force amplitude of the external forcing on the motion are examined.

References listed at the end of the paper:


ABSTRACT: The present work is devoted to the bending behavior of elastic three-layered microplate with exponentially graded core and piezomagnetic face-sheets using the modified couple stress theory (MCST). The micro piezomagnetic layers are subjected to electric and magnetic potentials and the model is resting on Pasternak’s foundation. To capture size-dependency for a micro sized rectangular microplate, the MCST is used. Numerical investigation of this problem is surveyed for effect of significant parameters of microplate such as micro length scale parameter, in-homogenous index, electric and magnetic potentials, geometrical characteristics and parameters of foundation on results of problem.

References listed at the end of the paper:


ABSTRACT: This paper presents Best Theory Diagrams (BTDs) employing combinations of Maclaurin, trigonometric, and exponential terms to build two-dimensional theories for metallic, multilayered, and functionally graded plates. The BTD is a curve in which the least number of unknown variables to meet a given accuracy requirement is read. The present refined models are Equivalent Single Layer and are implemented by using the Unified Formulation developed by Carrera. The plate theories presented are obtained using the axiomatic/asymptotic method and genetic algorithms. A multiobjective optimization technique is employed to analyze multiple displacements and stresses simultaneously. Closed-form, Navier-type solutions have been obtained in the case of simply supported plates loaded by a bisinusoidal transverse pressure. The influence of trigonometric and exponential terms in the BTDs has been studied for different materials and length-to-thickness ratios. The results show that the addition of such terms can lead to enhanced BTDs in which fewer unknown variables than pure Maclaurin expansions are needed to detect 3D like accuracies.

References listed at the end of the paper:


ABSTRACT: This paper examines the behavior of wrinkling instability of a thermoelectric thin film bonded to substrate. The critical temperature differences for wrinkling occurrence and buckling initiation are obtained. Damage growth following wrinkling is also determined. These critical temperatures can provide guidelines for the design of thermoelectric thin film devices. Numerical results show that the stability of thermoelectric thin film is affected by the electric current. The critical temperature differences become smaller when the electric current density in thermoelectric thin film is higher. Effect of the wavelength of wrinkling on the critical temperature differences of wrinkling occurrence is also identified.

References listed at the end of the paper:
ABSTRACT: This study aims to evaluate the nonlocal small scale parameter for large amplitude vibration of single layered graphene sheets (SLGSs) comparing nonlinear resonant frequencies obtained via nonlocal continuum and molecular dynamics (MD) simulations. Nonlinear governing equations of motion are numerically solved employing the pseudo-spectral method to obtain the frequency response. Results reveal that the calibrated small scale parameter decreases when the vibration amplitude increases. Also, from MD simulations it is seen that for all length sizes after an ultimate vibration amplitude around 31% length size, the graphene sheets start to fracture.

References listed at the end of the paper:

ABSTRACT: The modified couple stress theory (MCST) is utilized to investigate the bending of viscoelastic nanobeams laying on visco-Pasternak elastic foundations based on a new shear and normal deformations beam theory. This model consists of the material length scale coefficient that captures the size impact on small-scale beams. The simply supported beam is made of viscoelastic material, subjected to time harmonic transverse load. The nanobeam is presumed to be laying on double layers of foundations. The first layer is modeled as Kelvin–Voigt viscoelastic model and the second is taken as a shear layer. Based on the proposed beam theory and MCST, the differential motion equations are deduced using Hamilton’s principle. To check the validity of the obtained formulations, the predicted results are compared with those available in the open literature. In addition, the influences of various parameters such as the material length scale parameter, length-to-depth ratio, viscoelastic damping structure, the stiffness and damping coefficients of the viscoelastic substrate, and shear and normal strains on the deflection and stresses are illustrated.

References listed at the end of the paper:


ABSTRACT: In this paper, a finite element formulation, using eight independent parameters and high-order spectral/hp functions, for nonlinear analysis is presented. This formulation allows the use of a third-order thickness stretch kinematics, which also avoids Poisson's locking. Full nonlinear terms up to quadratic in the Green–Lagrange strain tensor are retained. Several nontrivial problems are solved using the presented formulation. A comparison between this formulation and others found in the literature, and with shell and solid elements in commercial codes ABAQUS and ANSYS are presented and the differences are brought out. References listed at the end of the paper.


ABSTRACT: Based on the Donnell shell theory and smeared stiffeners technique, the governing equations of functionally graded annular spherical segments with functionally graded eccentrically stiffeners are derived to investigate the buckling of these structures under compression load and radial pressure. The segment is reinforced by parallel eccentrically functionally graded stiffener system. Approximate solutions are assumed to satisfy the simply supported boundary condition and Galerkin method is applied to obtain closed-form relations of linear buckling loads. Numerical results are given to evaluate effects of stiffeners, volume fraction index and dimensional parameters to the buckling of structure.

References listed at the end of the paper:

Meysam Atashafrooz, Reza Bahaadini & Hamid Reza Sheibani (Sirjan University of Technology, Iran),
“Nonlocal, strain gradient and surface effects on vibration and instability of nanotubes conveying nanoflow”,
Mechanics of Advanced Materials and Structures, Vol. 27, No. 7, pp 586-598, 2020,
https://doi.org/10.1080/15376494.2018.1487611

ABSTRACT: In this paper, the size-dependent vibration and instability of nanoflow-conveying nanotubes with
surface effects using nonlocal strain gradient theory (NSGT) are examined. Hence, based on Gurtin-Murdoch
theory, the nonclassical governing equations are derived by extended Hamilton's principle. To study the small-size effects on the flow field, the Knudsen number is applied. Applying Galerkin's approach, the partial
differential equations converted to ordinary differential equations. The effects of the main parameters like
nonlocal and strain gradient parameters, length to diameter ratio, thickness, surface effects, Knudsen number
and different boundary conditions on the eigenvalue and critical fluid velocity of the nanotube are explained.

References listed at the end of the paper:

conveying fluid molecular dynamics study DOI: 10.1016/j.physe.2016.10.046.


ABSTRACT: In the present research vibration of a porous rectangular plate which is located between two piezoelectromagnetic layers based on two variables sinusoidal shear deformation plate theory and according to nonlocal theory is investigated. The plate is resting on Winkler–Pasternak foundation and was subjected to pre loads. The motion equations have been obtained using Hamilton principle and are solved using analytical Navier's solution method. The effects of porosity coefficient, pores distribution, nonlocal parameter, pre load values, foundation constants and geometric size of the plate have been discussed in details. The results can be used to design more efficient sensors and actuators.

References listed at the end of the paper:


ABSTRACT: In this work, the formulation of a new triangular finite element is presented for static and free vibration of plate bending. The developed element which contains the three essential external degrees of freedom at each of the three corner nodes is based on the Reissner/Mindlin theory and the strain-based approach. This element is based on the linear variation of the three bending strains and constant transverse shear strains. The present element performances are evaluated through several tests related to moderated thick and thin plates with various shapes where it is found to be numerically more efficient than the bilinear element. References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: In this paper, Crush force efficiency (CFE), Specific Energy Absorption (SEA), Energy Absorption per Crush Length (EAL), Maximum and average crush forces of straight and grooved tapered thin-walled tubes with various cross-section shapes (circle, ellipse, square, rectangle, hexagon, and octagon) have been studied. The effects of taper, the groove (as initiator) and their interaction have been presented in the current study using Finite Element Method as a numerical method. The tubes have the same volume, height, average cross-section area, thickness and material and have been subjected to axial and oblique dynamic loading. The results of simulations show that the section's geometry, taper and groove addition have a significant effect on energy absorption behavior and the hexagon cross section have better energy absorption behavior compared with other considered geometries. On the other hand, it was found that the behavior of these structures could improve against dynamic axial and oblique impact loading with the cost-effective geometry modifications. These results could help to improve and choose appropriate energy absorber structure based on desirable crush force and energy absorbing characteristics.
oblique impact loading


ABSTRACT: An accurate and computationally attractive global-local higher-order theory (GLHT) is developed for the linearly elastic analysis of cross-ply multilayered composite plates. The theory is derived using the kinematic assumptions of GLHT in conjunction with the Reissner mixed variational principle. For a low-order linear element, it is difficult to accurately compute the transverse shear stresses even applying the three-dimensional equilibrium equation post-processing technique. The reason for this difficulty is that the higher-order derivatives of displacement variables are included in the transverse shear stress fields after using the post-processing technique. Thus, by employing the Reissner mixed variational principle, the higher-order derivatives of displacement variables have been removed from the transverse shear stress components before the finite element procedure is implemented. Based on the mixed GLHT, a computationally efficient C-type three-node triangular plate element with linear interpolation function is proposed for the analysis of multilayered composite plates. The advantage of the present formulation is that no post-processing approach is needed to calculate the transverse shear stresses while maintaining the computational accuracy of a linear plate element. Performance of the proposed element is assessed by comparing with several benchmark solutions. Numerical results show that the present elements can robustly and accurately predict the displacements and stresses of multilayered composite plates.

References listed at the end of the paper:


ABSTRACT: Thick composite disks are utilized in fast-rotating machines, including turbine disks and flywheels. Dynamic equations of motion for a rotating composite disk have been formulated in a polar coordinate system using Hamilton’s principle, and numerical analysis has been performed by finite element interpolation. The natural frequencies of isotropic and laminated composite disks have been obtained when the rotational speed changes. The effects of transverse shear and rotary inertia on the vibration characteristics of rotating disks have also been investigated.

References listed at the end of the paper.


ABSTRACT: In this article, a multiple-scale perturbation method is employed to analyze nonlinear free vibration of nanoplate incorporating surface effects. Eringen's nonlocal theory as well as surface elasticity theory of Gurtin and Murdoch is used to consider small scale effect by presenting the nonlocal parameter and the surface effects at the top and bottom of the bulk part of the nanoplate as a membrane with different mechanical properties, respectively. A multiple-scale perturbation method is suggested to consider the expansion representing the response to be a function of multiple independent variables, or scales, instead of a
single variable. It also should be mentioned that graphene sheets are considered suitable candidates in nanoplates to increase the mechanical properties of the nanostructures. Employing the Hamilton's principle, the three coupled nonlinear equations of motion are obtained based on Hooke's law and the von Kármán nonlinear strain-displacement relationship. To show the accuracy of the presented method results are compared with literature and a good agreement is observed. Effects of two kinds of boundary conditions SSSH1 and SSSH2, as well as nonlocal parameter, surface residual stress and surface elastic modulus parameter on nonlinear frequency of nanoplate are analyzed. The results illustrate that by increasing the nonlocal parameter the nonlinear frequency shows a decreasing behavior while by increasing the surface residual stress and surface elastic modulus parameter, nanoplate's stiffness increases therefore the nonlinear frequencies increase. Also, it can be mentioned that the surface effects have very small effects on nonlinear frequencies and can be ignored. Therefore, they don't play an important role on the nonlinear fundamental frequencies of nanoplate.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: Two-dimensional thermoelastic analyses of fully clamped functionally graded rectangular plates (FGRPs) by applying a constant in-plane heat flux from one edge were studied by using Finite Difference Method (FDM) and Finite Element Method (FEM) with temperature-dependent material properties. Some differences about 1.5 to 2 times between FDM and the FEM solutions in terms of normal strain, equivalent strain, shear stress, and equivalent stress levels are observed. However, similar distribution characteristics from FDM and FEM analyses are obtained for temperature, displacement, strain, and stress components.


ABSTRACT: The dynamic response of clamped square sandwich panels with layered-gradient closed-cell aluminum foam cores under the impact of metallic foam projectiles is investigated. The present solutions are compared to those results of monolithic solid plates and non-graded monolithic core sandwich panels. The resistance performance of specimens to projectile impact is estimated by the maximum transient central-point deflection of back face-sheet. Results indicate that all the sandwich panels have a better shock resistance performance than the monolithic solid plate with the equivalent mass, and the resistance of sandwich panels to shock loading could be improved by utilizing the layered-gradient cores. The sandwich configuration is demonstrated to be able to effectively contribute to energy absorption and material efficiency, and the positive gradient-core configuration is the best choice in term of specific energy absorption. The strain-rate effect of face-sheet and core materials can mitigate the deformation of the back face-sheet of specimens due to its hardening effect.

References listed at the end of the paper:


ABSTRACT: The strain energy density function method is proposed to study the nonlinear vibration behavior of the fiber-reinforced composite thin plate with strain dependence. First, the material nonlinearity of the fiber-reinforced composite is extended to the vibration field. On the basis of Jones-Nelson nonlinear model, a theoretical model with the consideration of the strain-dependent nonlinearity is established to illustrate the theoretical principle of the strain energy density function method. In the model, the nonlinear elastic moduli in different fiber directions are expressed as a function of the strain energy density. The nonlinear natural frequencies are solved by Ritz method in conjunction with the classical laminated plate theory and Hamilton’s principle, and the nonlinear vibration responses are calculated by Newton–Raphson iteration method. Moreover, a TC300 carbon/epoxy composite plate is taken as a research object. In order to determine the corresponding parameters in the theoretical model, the composite beam specimens are cut off to conduct the stress-strain measurement. The nonlinear natural frequencies and vibration responses of the composite plate under different excitation levels are obtained. The comparisons between the theoretical calculation and experimental test show that the maximum calculation error of the first six natural frequencies with considering the strain-dependent nonlinearity is less than 4.3%, and the maximum calculation error of the resonant responses is less than 12.0% for the third mode and the sixth mode, thus the practicability and reliability of the proposed method have been verified.

References listed at the end of the paper:

validates the analytical model well. Furthermore, deformation mode comparisons were conducted to determine. Good agreement was observed between the numerical results and theoretical solutions, which were explored based on folded element and Minimal Energy Principle. Parametric studies were numerically conducted with different scale ratio, and the influence of wall thickness on mechanical performance was determined. Good agreement was observed between the numerical results and theoretical solutions, which validates the analytical model well. Furthermore, deformation mode comparisons were conducted between


ABSTRACT: This study presents numerical and theoretical investigation for the vertex-based hierarchical honeycomb structure subjected to axial compression. Mechanical behavior as well as predictable formulas were explored based on folded element and Minimal Energy Principle. Parametric studies were numerically conducted with different scale ratio, and the influence of wall thickness on mechanical performance was determined. Good agreement was observed between the numerical results and theoretical solutions, which validates the analytical model well. Furthermore, deformation mode comparisons were conducted between
vertex-based hierarchical honeycomb and other filled-type honeycomb structures. Evident promotion on energy absorption was obtained for vertex-based hierarchical honeycomb.

References listed at the end of the paper:


ABSTRACT: A unified nonlocal formulation is developed for the bending, buckling, and vibration analysis of nanobeams. Theoretical formulations of eighteen nonlocal beam theories are presented by using unified formulation. Small scale effect is considered based on the nonlocal differential constitutive relations of Eringen. The governing equations of motion and associated boundary conditions of the nanobeam are derived using Hamilton's principle. Closed form solutions are presented for a simply supported boundary condition using Navier's solution technique. Numerical results for axial and transverse shear stress are first time presented in this study which will serve as a benchmark for the future research.

References listed at the end of the paper:


ABSTRACT: In this paper, the effects of hygrothermal conditions on various behaviors, such as bending, free vibration, mechanical and thermal buckling, of exponentially graded microplates lying on two-parameter elastic foundations are investigated. The trigonometric four-variable plate theory incorporated to the modified couple stress theory (MCST) is employed to derive the equations of motion. The present MCST contains an internal material length scale parameter, thus it can capture the size effect. The microplate is assumed to be subjected to a temperature rise and moisture concentration which are varied linearly through the thickness of the plate.

Based on an exponential law, the material properties of the microplate are graded only in z direction. The equations of motion are solved analytically to obtain the displacements, stresses, eigenfrequencies and critical buckling load and temperature of the microplates. The present results are validated by comparing them with those previously published. The numerical examples reveal that considering the size effect and/or the elastic foundations leads to an increment in plate stiffness and thereby leads to a decrement in the deflection and an increment in eigenfrequency and buckling loads. It is also shown that the size effect is negligible for the thicker plate.

References listed at the end of the paper:

ABSTRACT: This paper presents an analytical investigation on the free vibration, static buckling and dynamic instability of channel-section beams when subjected to periodic loading. The analysis is carried out by using Bolotin’s method. By assuming the instability modes, the kinetic energy and strain energy of the beam and the loss of the potential of the applied load are evaluated, from which the mass, stiffness and geometric stiffness matrices of the system are derived. These matrices are then used to carry out the analyses of free vibration, static buckling and dynamic instability of the beams. Theoretical formulae are derived for the free vibration frequency, critical buckling moment, and excitation frequency of the beam. The effects of the lateral restraint applied to the flange, the section size of the beam and the static part of the applied load on the variation of dynamic instability zones are also discussed.

References listed at the end of the paper:

· M. Macdonald, M. A. Heiyantuduwa, and J. Rhodes, Recent developments in the design of cold-formed steel members and structures, Thin-Walled Struct., vol. 46, no. 7–9, pp. 1047–1053, 2008.

ABSTRACT: Size-dependent buckling of compressed Bernoulli-Euler nano-beams is investigated by stress-driven nonlocal continuum mechanics. The nonlocal elastic strain is obtained by convoluting the stress field with a suitable smoothing kernel. Incremental equilibrium equations are established by a standard perturbation technique. Higher-order constitutive boundary conditions are naturally inferred by the stress-driven nonlocal integral convolution, equipped with the special bi-exponential kernel. Buckling loads of compressed nano-beams, with kinematic boundary constraints of applicative interest, are numerically calculated and compared with those obtained by the theory of strain gradient elasticity.

References listed at the end of the paper:


ABSTRACT: New theory of higher order for functionally graded (FG) shells, which is based on the expansion of the three-dimensional (3D) equations of elasticity for functionally graded materials (FGMs) into Legendre’s polynomials series is developed here. The stress and strain tensors, the displacement, traction and body force vectors of the 3D equations of elasticity, are expanded into Legendre’s polynomials series in terms of the thickness coordinate. The mechanical parameters that describe the functionally graded material properties are also represented in the form of Legendre’s polynomials series expansion. As result the equations of the 3D elasticity are turned into the infinite number of two-dimensional (2D) equations for the Legendre’s polynomials series expansion coefficients. Considering finite number of the Legendre’s polynomials series coefficients and substituting kinematic relations into generalized Hooke’s law and the obtained result into the equations of motion the differential equations of motion the equations of motion in form of displacements have been obtained. The first order equations for the FG axisymmetric cylindrical plate and spherical shell are considered in more details. Corresponding boundary-value problems are solved using the finite element method (FEM) implemented in the MATEMÁTICA software. The numerical results are presented and discussed.

References listed at the end of the paper:


ABSTRACT: Layerwise theory along with the third-order shear deformation theory (TSDT) and hyperbolic shear deformation theory (HSDT) is used to determine the analytical and finite element analysis (FEA) for adhesive behavior in a uniformly loaded circular plate. Two adhesive layers adhere the core to its surrounding functionally graded face sheets. Results indicate that FEA findings give almost similar estimations on planar stresses compared to analytical solutions based on TSDT and HSDT. However, the out-of-plane shear stresses predicted by HSDT are closer to FEA findings. Additionally, to control plate deflection and stresses in the adhesive layer, it is advisable to choose $E_{core}/E_{foam} ≃ 2$.

References listed at the end of the paper:

- F. Alyilcki, S.D. Akbarov and N. Yahmigol, Buckling delamination of a PZT/Metal/PZT sandwich rectangular thick plate containing interface inner band cracks, Compos. Struct., pp. 1–8, 2018.

**ABSTRACT:** The exact geometry four-node solid-shell element formulation using the sampling surfaces (SaS) method is developed. The SaS formulation is based on choosing inside the shell $N$ not equally spaced SaS parallel to the middle surface in order to introduce the displacements of these surfaces as basic shell unknowns.

Such choice of unknowns with the use of Lagrange basis polynomials of degree $N-1$ in the through-thickness interpolations of displacements, strains, stresses and material properties leads to a very compact form of the SaS shell formulation. The SaS are located at Chebyshev polynomial nodes that make possible to minimize uniformly the error due to Lagrange interpolation. To implement efficient 3D analytical integration, the extended assumed natural strain method is employed. As a result, the proposed hybrid-mixed solid-shell element exhibits a superior performance in the case of coarse meshes. To circumvent shear and membrane locking, the assumed stress and strain approximations are utilized in the framework of the mixed Hu-Washizu variational formulation. It can be recommended for the 3D stress analysis of thick and thin doubly-curved functionally graded shells because the SaS formulation with only Chebyshev polynomial nodes allows the obtaining of numerical solutions, which asymptotically approach the 3D solutions of elasticity as the number of SaS tends to infinity.

**References**

Listed at the end of the paper:


ABSTRACT: Within the framework of Timoshenko beam theory, the buckling of nano sandwich beams is developed. The material properties are assumed to vary arbitrarily in both axial and thickness directions. These types of beams are referred to as bi-directional functionally graded (BDFG) beams. Two types of nano sandwich beams with different material distribution patterns and immovable supports are considered. Since the size effects play a significant role in mechanical behavior of nanostructures, the small-scale effects are captured by Eringen’s nonlocal theory of elasticity. The governing equations are derived using the variational formulation. Symmetric smoothed particle hydrodynamics (SSPH) and the Galerkin method are adopted as numerical solution approaches. As a truly meshless method, the convergence of the SSPH technique mainly depends on the smoothing length value and distribution of particles in the compact support domain of the kernel function. The Revised Super Gauss Function is used as the kernel function and an optimum value for the smoothing length that bears the fastest convergence rate is obtained. The solution methods are verified through benchmark problems found in the literature. Numerical and illustrative results show that various parameters, including the aspect ratio, nonlocal parameter, gradient indexes, and cross-sectional types have significant effects on the buckling responses of BDFG nano sandwich beams.

References listed at the end of the paper:


Qingshan Wang, Kwangnam Choe, Jinyuan Tang, Cijun Shuai & Ailun Wang (First author is from: High Performance Complex Manufacturing, Central South University, Changsha, China), “Vibration analyses of
ABSTRACT: An exact semianalytical method for vibration analysis of general thin and moderately thick laminated composite curved beams with variable curvatures and general boundary conditions is presented. In the framework of the first-order shear deformation theory, the method combines the variational principle and multilevel partition technique. As one of the innovation points, the general boundary conditions are enforced by using the virtual boundary spring technology. Each of the fundamental beam unknowns is then invariantly expanded as Jacobi polynomials. The convergence study and numerical verifications of the laminated composite curved beams with various boundary conditions are carried out.

References listed at the end of the paper:


ABSTRACT: A 3D dynamic finite-element model is proposed in this paper to simulate the damage development process of stitched laminates subjected to low-velocity impact. The strain-based Hashin criteria and a sudden degradation scheme are employed to determine the intra-laminar damage initiation and evolution; a mix-mode bilinear constitutive model is adopted to evaluate the inter-laminar delamination damage. The
predicted numerical results agree well with the available experimental data, thus validating the proposed damage analysis model. Moreover, the influence factors, including the thickness of laminates, stitching density, diameter of stitching thread and strength of stitching thread, are analyzed and discussed in detail.

References listed at the end of the paper:

ABSTRACT: Marine structures are advanced material and structural assemblies that span over different length scales. The classical structural design approach is to separate these length scales. The used structural models are based on classical continuum mechanics. There are multiple situations where the classical theory breaks down. Non-classical effects tend arise when the size of the smallest repeating unit of a periodic structure is of the same order as the full structure itself. The aim of the present paper is to discuss representative problems from different length scales of ship structural design.

References listed at the end of the paper:


ABSTRACT: In this work, nonlocal transient dynamic analysis of laminated composite plates using Reddy’s third-order shear deformation theory (TSDT) and Eringen’s nonlocality is presented. The nonlocal governing equations of TSDT are derived employing the Eringen’s stress-gradient constitutive model considering the dynamic effects. Displacement finite element models are developed using a four-noded rectangular conforming element with 8 degrees of freedom per node. Numerical examples are presented to illustrate the effects of nonlocality on the transient dynamic behavior of laminated composite plates.

References listed at the end of the paper:
ABSTRACT: This research work deals with the analysis of elastic shell structures in the large displacement and rotation field adopting one-dimensional (1D) and two-dimensional (2D) unified models. Namely, higher order beam and shell theories accounting for geometrical nonlinearities are formulated by employing a unified framework based on the Carrera unified formulation (CUF) and a total Lagrangian approach. Thus, a finite element (FE) approximation is used along with a Newton-Raphson method and an arc-length path-following approach to perform nonlinear analyses. Low- to higher order beam and shell theories are used to evaluate the nonlinear equilibrium path, and results are compared between the two models, with reference solutions coming from literature or 2D and three-dimensional (3D) models from NASTRAN. Convergence analyses show how
CUF 1D models are able to describe the geometrical nonlinear behavior of analyzed structure with a lower number of degrees of freedom (DoFs) than 2D and 3D models.

References listed at the end of the paper:

- L. Euler, De Curvis Elasticis, Bousquet, Lausanne and Geneva, 1744.


ABSTRACT: The nonlinear bending behavior of nanocomposite laminated plates with negative Poisson’s ratios (NPR) is reported. Each ply of the plate is made of carbon nanotube-reinforced composites (CNTRCs) and may have different CNT volume fractions and the CNTRC plies are arranged in the thickness direction in a piece-wise functionally graded pattern. The plate is supposed to be rested on a two-parameter elastic foundation and is exposed in a thermal environment. The temperature-dependent material properties of the CNTRCs are evaluated using an extended Voigt (rule of mixture) model. The governing equations for the nonlinear bending of FG-CNTRC laminated plates are based on Reddy’s third order shear deformation plate theory and solved by using a
two-step perturbation approach. Analytical solutions are obtained which include the geometrical nonlinearity in the von Kármán sense, the thermal effects and the plate-foundation interaction. The effect of NPR on the nonlinear bending responses of FG-CNTRC laminated plates under different loading conditions are investigated comparatively according to the graphical results. It is explicitly shown that NPR has a significant effect on the nonlinear bending responses of CNTRC laminated plates.

References listed at the end of the paper:

- H.-S. Shen, Nonlinear bending of shear deformable laminated plates under transverse and in-plane loads and resting on elastic foundations, Compos. Struct., vol. 50, no. 2, pp. 131–142, 2000. DOI: 10.1016/S0263-8220(00)00088-X.


ABSTRACT: Most previous studies of viscoelastic sandwich plates were based on the assumption that damping was only resulting from shear deformation in the viscoelastic core. However, extensive and compressive deformations in the viscoelastic core should also be considered especially for sandwich plates with moderately thick viscoelastic core. This paper presents a finite element formulation for vibration and damping analysis of sandwich plates with moderately thick viscoelastic core based on a mixed layerwise theory. The face layers satisfy the Kirchhoff theory while the viscoelastic core meets a general high-order deformation theory. The viscoelastic core is modeled as a quasi-three-dimensional solid where other types of deformation such as longitudinal extension and transverse compression are also considered. To better describe the distribution of the displacement fields, auxiliary points located across the depth of the sandwich plate are introduced. And based on the auxiliary points, the longitudinal and transverse displacements of the viscoelastic core are interpolated independently by Lagrange interpolation functions. Quadrilateral finite elements are developed and dynamic equations are derived by Hamilton’s principle in the variation form. Allowing for the frequency-dependent characteristics of the viscoelastic material, an iterative procedure is introduced to solve the nonlinear eigenvalue
problem. The comparison with results in the open literature validates the remarkable accuracy of the present model for sandwich plates with moderately thick viscoelastic core, and demonstrates the importance of the higher-order variation of the transverse displacement along the thickness of the viscoelastic core for the improvement of the analysis accuracy. Moreover, the influence of the thickness and stiffness ratios of the viscoelastic core to the face layers on the damping characteristics of the viscoelastic sandwich plate is discussed.

References listed at the end of the paper:

ABSTRACT: In an effort to optimize axially compressed members of a wooden structure, composite 2-D lattice structures were designed and manufactured with wood-plastic composites as the panel and glass fiber reinforced plastic as the core by using a simple insert-glue method. The compressive behavior of composite 2-D lattice structures made of cores with different diameters and inclination angles was investigated. Analytical models were employed to predict the theoretical load capacity, equivalent compressive strength, and failure types of lattice structures. Reinforcing hoops were then made at the two ends of cores according to its force characteristics and failure type.

References listed at the end of the paper:

ABSTRACT: This paper is concerned with evaluating stress intensity factors (SIFs), for a cracked curved beam of rectangular cross section, applying an approach which allows us to estimate the strain energy release rate. The beam is located on an elastic foundation. The out-of-plane vibration of the beam is investigated. This approach requires an additional factor namely correction factor, on the basis of the energy release zone slope to approximate the SIFs. The initial curvature of the beam, however, adds some complication in using this factor. The second part of this study is investigating a numerical approach, namely differential quadrature element method (DQEM), to gain the natural frequencies of the cracked beam. This method is applied to show the application of the SIFs to calculate the compliance of the cracked section for modeling the crack. The other method which is used to obtain the natural frequencies is the finite element method (FEM). The results of these two methods are found to be in good agreement, which shows the precision of the stress intensity factors of the cracked beam.

References listed at the end of the paper:

ABSTRACT: This paper investigates geometrically nonlinear effects due to large deformations over the cross sections of beam-like and shell-like structures. Finite elements are used to provide numerical solutions along with the Newton–Raphson technique and the arc-length method. Refined theories able to capture cross-sectional deformation are constructed by referring to the Carrera unified formulation. Full nonlinear Green-Lagrange strains and second Piola-Kirchoff stresses are employed in a total Lagrangian scenario. The numerical results demonstrate that geometrical nonlinearities play a fundamental role when cross-sectional deformations become significant and theories of structures with nonlinear kinematics are utilized. In other words, this means that the use of refined beam models may be ineffective if geometrical nonlinear relations are not employed. These phenomena become particularly evident in thin-walled/shell-like type structures.

References listed at the end of the paper:
ABSTRACT: The buckling of generally laminated conical shells having thickness variations under axial compression is investigated. This problem usually arises in the filament wound conical shells where the thickness changes through the length of the cone. The thickness may be assumed to change linearly through the length of the cone. The fundamental relations for a conical shell with variable thickness applying thin-walled shallow shell theory of Donnell-type and theorem of minimum potential energy have been derived. Nonlinear terms of Donnell equations are linearized by the use of adjacent-equilibrium criterion. Governing equations are solved using power series method. This procedure enables us to investigate all combinations of classical boundary conditions. The results are verified in comparison with Galerkin method and the available results in the literature. Effects of thickness function coefficient, semi-vertex angle, lamination sequence, length to diameter ratio, and initial thickness of the cone on the buckling load are investigated. It is observed that these parameters have considerable effects on the critical buckling load of a conical shell.

References listed at the end of the paper:

ABSTRACT: This article concerns with the analysis of the frequency range within which Timoshenko’s model can be applied for the study of vibrating beams, possibly without incurring in large engineering approximations. Timoshenko's equations are solved in exact way for all classical boundary conditions; frequencies and modes are compared with exact or asymptotically exact solutions of the elasticity theory based on the plane stress assumptions. The analytical procedures, the comparisons and the related findings show that a threshold could be a useful indication, to a certain extent, but it does not seem generalizable; incidentally, the analytical procedure, naturally provides frequencies falling in what could be defined as a single spectrum of Timoshenko's beam theory.

References listed at the end of the paper:

References listed at the end of the paper:

- MATLAB 8.5.0.197613 (R2015a), The Mathworks Inc. 1984–2015.


ABSTRACT: In the present article, the transient analysis and control of delaminated composite plates under hazardous environmental conditions using active fiber composite (AFC) is discussed. Top and bottom layers of the laminated composite plate are embedded AFC layers. The present investigation utilizes AFC as an actuator and sensor. A finite element model for centrally located delamination is developed and coded in Matlab. The proportional controller is used to control the undesirable response in real time. The transient response of the smart delaminated plate is studied for different temperatures and moisture conditions. The feedback control of the dynamic response is performed with the help of velocity and displacement feedback gain to the AFC actuator. The key observations from the numerical studies are: the dynamic response and the frequency response of composite plate increase due to delamination and also with the increase of the temperature and moisture concentrations. The response reduces when the feedback control loop is activated. So, the overall performance of the delaminated plate structure in hygrothermal environment may be enhanced.

References listed at the end of the paper:


ABSTRACT: In this study, mechanical performance of octagonal structure subjected to out-of-plane compression was investigated theoretically and numerically. Theoretical derivation was carried out according to super folding element, formulas were constructed in terms of relative density, half-wave length, average force, mean stress as well as specific energy absorption (SEA). To validate, full scale numerical finite element (FE) models were created to analyze the mechanical behavior of the present structure computationally. Analytical solutions were in good agreement with computational results. Parametric study shows that different geometric configurations heavily influence the mechanical performances. Detailed comparisons between octagonal and conventional hexagonal honeycomb were performed.

References listed at the end of the paper:


ABSTRACT: In this work, a discontinuous Galerkin formulation for higher-order plate theories is presented. The starting point of the formulation is the strong form of the governing equations, which are derived in the context of the Generalized Unified Formulation and the Equivalent Single Layer approach from the Principle of Virtual Displacements. To express the problem within the discontinuous Galerkin framework, an auxiliary flux variable is introduced and the governing equations are rewritten as a system of first-order partial differential equations, which are weakly stated over each mesh element. The link among neighboring mesh elements is then retrieved by introducing suitably defined numerical fluxes, whose explicit expressions define the proposed Interior Penalty discontinuous Galerkin formulation. Furthermore, to account for the presence of generally curved boundaries of the considered plate domain, the discretisation mesh is built by combining a background grid and an implicit representation of the domain. hp-convergence analyses and a comparison with the results obtained using the Finite Element Method are provided to show the accuracy of the proposed formulation as well as the computational savings in terms of overall degrees of freedom.

References listed at the end of the paper:

• ABAQUS, 6.14 Documentation, Dassault Systèmes, Providence, RI, 2014.

ABSTRACT: With the development of science and technology, finite element analysis technology has gradually become the main means of radial tire analysis. However, most of the theoretical models are mainly analyzed, and there are still some differences between them and the actual tire models. In this article, the constitutive model of Yeoh rubber material is selected for the uniaxial tensile results of various rubber materials used in the tire. The material parameters are determined by the equivalent tensile strain curve of the steel cord. Taking the 12.00R20 tire as an example, with the help of ABAQUS software, a finite element method for the analysis of the tire structure is formed under the working conditions of assembly, punching gas and loading, and the necessary evaluation of the finite element results of the loading condition is also carried out. By analyzing the stress and strain of each part of the tire, the strain ratio can be used as the basis for the further analysis of thermal fatigue, and it also plays a guiding role in improving the design of tire structure.

References listed at the end of the paper:

· J. Zhuang, Modern Automotive Tire Technology, Beijing Institute of Technology Press, Beijing, 2001
· Q. Yu, F. Zhou, and J. Ding, Performance and Structure of Pneumatic Tyres [M], South China University of Technology Press, Guangzhou, 1998.
· J. Zhuang, Tyres of Automobile Tire, Beijing Institute of Technology Press, Beijing, 1996.
ABSTRACT: This work is devoted to the bending analysis of functionally graded piezoelectric plates via quasi-3D trigonometric theory. The governing equations and boundary conditions are derived by using the principle of virtual work. The impact of piezoelectric, electric loading, and gradient index on the displacement, electric displacement, electric potential, and stresses are explored numerically presented and discussed in detail. To check the accuracy and validity of bending results obtained from this analysis of FGP plates, results are compared with the analytical solution obtained by 3D, quasi-3D, and higher order shear deformation theories. Parametric studies are then performed to examine the effects of the thickness of the plate and the electric field on the overall electromechanical response of the FGP plates. The presented results are useful in design processes of smart structures and analysis from piezoelectric materials.

References listed at the end of the paper:

ABSTRACT: Different types of plane transient waves (surfaces of strong or weak discontinuities) are studied in the Mindlin micropolar medium. The theory of discontinuities is used as the method of investigation. The velocities of all types of waves have been obtained with the help of the Hadamard-Thomas conditions of compatibility, and on the each wave front it has been established which from the desired values experience discontinuities and which are continuous ones.

References listed at the end of the paper:


ABSTRACT: The main objective of this study is to perform the free and forced vibration analysis of transversely isotropic and laminated composite parabolic arches with a continuous cross-section variation. The anisotropy of the material of the arch, effects of the rotary inertia, and shear deformations are considered. An efficient unified numerical procedure of the Complementary Functions Method and Laplace transform is applied to solve the strong form of the differential equations that govern the dynamic response of the above structures. The validity and the accuracy of the presented scheme are tested by means of several comparisons with available literature and results of ANSYS. The presented approach has proven to be an accurate and stable numerical method. It is believed that derived results can be used as benchmark solutions for validation of related works in the future.

References listed at the end of the paper:
- K. Chandrashekhara and K.M. Bangera, Free vibration of composites
- ANSYS Swanson Analysis System, Inc., 201 Johnson Road, Houston, PA15342 1300, USA.


Mechanical APDL Theory Reference, 2013, Inc., 275 Technology Drive, Canonsburg, PA 15317.

Mechanical APDL Theory Reference, 2013, Inc., 275 Technology Drive, Canonsburg, PA 15317.


ABSTRACT: Thermal buckling and post-buckling behavior of composite beam reinforced with shape memory alloy (SMA) wires under nonuniform temperature distribution is explored. Thermo-mechanical behavior of SMA wires is formulated by using the one-dimensional Brinson SMA model. Considering von Karman strain–displacement relation, corresponding nonlinear governing equations are obtained and solved analytically. Heat conduction equation is employed and through-the-thickness temperature distribution is obtained by discretization scheme of layerwise method. Influence of SMA-wire positioning across the thickness, temperature distribution, SMA wire pre-straining level and volume fraction of SMAs upon the thermal buckling and post buckling of reinforced beam are examined and discussed in detail.

References listed at the end of the paper:


ABSTRACT: This paper presents the free vibration analysis of a variable stiffness laminated composite sandwich plates. The fiber orientation angle of the face sheets (Skin) is assumed to vary linearly with the x-axis. The problem formulation is based on the higher-order shear deformation plate theory HSDT C coupled with p-version of finite element method. The elements of the stiffness and mass matrices are calculated analytically. The sandwich plate is presented with a uniform mesh of four p-elements and the convergence properties are achieved by increasing the degree p of the hierarchical shape functions. A calculation program is developed to determine the fundamental frequencies for different physical and mechanical parameters such as plate thickness, core to face sheets thickness ratio, orientation angle of curvilinear fibers and boundary conditions. The results obtained show a good agreement with the available solutions in the literature. New comparison study of vibration response of laminated sandwich plate between the straight and curvilinear fibers is presented.

References listed at the end of the paper:
of contact load, damage and absorbed energy were compared to those obtained from intact specimens. At impact energies below 10 J, energy absorption in repaired specimens was higher than the one given in intact laminates, although the measured damage area was found to be greater in the former configuration. For higher impact energies, both damage area and energy absorption in intact specimens were greater than in repaired laminates.

References listed at the end of the paper:
· W. Oudad et al., Effect of the humidity absorption by the adhesive on the performances of bonded composite repairs in aircraft structures, Compos. Part B Eng., vol. 45, no. 8, pp. 3419–3424, 2012.
· J. Renart, J. Costa, A. Turon, S. Mahdi, and A. Rodríguez-Bellido, Effect of the moisture content of the adherents on the fatigue behavior of composite bonded joints, 16th International Conference on Composite Structures, 2011.

ABSTRACT: In this study, the nonlinear vibration analysis of the new generation nanostructures is investigated. The composite nanoplate is fabricated from the functional-graded (FG) core and two lipid layers on top and bottom of the FG core as face sheets. The nonlinear vibration analysis is studied in the presence of the external harmonic excitation force. The porosity effect on the free and force vibration analysis of the composite nanoplate is investigated. The nonlinear elasticity theory is utilized to obtain the nonlinear differential governing equation. The Kelvin–Voigt model is used to model the viscoelastic effect of the lipid layers. The Hamilton’s principle is utilized to obtain the differential governing equation. The Galerkin’s method is used to discrete the nonlinear partial differential governing equation to a nonlinear ordinary differential equation. The multiple scale method is used to solve the ordinary differential equation. The numerical results are compared with the reported results in the literature. A comparison between the presented numerical results and the Runge–Kutta results is done and good agreement is obtained. In the presence and absence of the porosity, the system vibration behavior is studied in the primary and secondary resonance cases. The results show that the porosity distribution types play an important role in the mechanical behavior of the composite nanoplate. Also, the numerical results show that the nonlinear frequency of the system decreases by passing time. This study can be useful to product the sensors and devices at the nanoscale with high biocompatibility.

References listed at the end of the paper:

ABSTRACT: In this study feedback control is applied to control the free vibration response of an isotropic truncated conical shell embedded with magnetostrictive layers. Classical shell theory is applied to derive the
shell vibration equations. The results are derived based on the Galerkin method and the results are compared with published results and the results of finite element software in order to determine the accuracy of using method. The influence of several parameters such as the thickness of magnetostrictive layers, control gain, length and radius of the large edge of the shell on the vibration suppression of fundamental frequency is determined.

References listed at the end of the paper:


ABSTRACT: In this article, the quasistatic penetration tests were investigated on unfilled and polyurethane foam filled honeycomb sandwich panels. Failure mechanisms, specific energy absorption, interaction mechanisms, and some structural responses were studied. Comparing the three types of the foam filled sandwich panels with unfilled type, indicates that the absorbed energy of the first, second, and third type of the panels are 23%, 33%, and 58% more than unfilled ones, respectively. In addition, the results showed the enhancement in the dynamic strength and remarkably decrease in the damage area of the sandwich structure when its honeycomb core was filled with polymer foam.

References listed at the end of the paper:

A. Niknejad and G. Liaghat, Experimental study of Poly-orthan foam filler on hexagonal honeycomb structure behavior under axial load with constant rate, in 10th Iran Aerospace Conference (AERO2011). Tarbiat Modarres University, 2011.


ABSTRACT: Failures of honeycomb sandwich plates are analyzed using experiments and three-dimensional (3D) finite element simulations to understand the failure mechanism. Meanwhile, correlations of the critical load and various physical parameters (e.g., height and thickness of the core) are investigated. The results demonstrated that the core height and skin thickness have significant effects on the compressed load buckling of the honeycomb sandwich plates, the core density is a sub-critical sensitive factor, while wall thickness and spacing of the cell, and the sandwich modulus have negligible effects. Cracking on the adhesive surface is the dominant factor to reduce the buckling critical load of the laminated plate, which leads to failures of sandwich plates. The ultimate failure of the sandwich panel is attributed to severe deformations that lead to local cracking of the entire cemented adhesive surface. Due to the bonding of the adhesive surface defects, the actual loads related to the core height are large enough to cause compressions with local buckling. Hence, the actual loads cannot reflect the performance of the sandwich panels. It is recommended to use panels with appropriate thicknesses below the sandwich and moderate grid density in the design.

References listed at the end of the paper:


ABSTRACT: The governing equations of electro-elastic bending problem are derived for size-dependent electro-elastic analysis of three-layered piezoelectric doubly curved nano shells. The three-layered nano shell is composed of an elastic homogeneous core and two piezoelectric nano layers at top and bottom. The doubly curved piezoelectric nano shell is subjected to applied electric potential and transverse loads. A comparative study is presented for validation of formulation and solution. The influence of nonlocal parameter, applied electric potential, and geometric parameters such as radii of curvature and ratio of thickness is studied on the electro-elastic results of the simply-supported doubly curved nano shell.

References listed at the end of the paper:


ABSTRACT: Recently, “Tangential Displacement Normal Normal Stress” elements were introduced for small-deformation piezoelectric structures. Benefits of these elements are that they are free from shear locking in thin structures and volume locking for nearly incompressible materials. We extend these elements to the large deformation case for electro-active polymers in the framework of an updated Lagrangian method. We observe that convergence does not deteriorate as the material becomes nearly incompressible with growing Lamé parameter $\lambda$, and that the discretization of slender structures by flat volume elements is feasible. The elements are freely available in the open source software package Netgen/NGSolve.

References listed at the end of the paper:

ABSTRACT: This paper proposes a new zig-zag function to develop the refined sinusoidal theory. A refined sinusoidal shear deformation theory can be obtained by including the proposed zig-zag function and meeting the traction-free boundary conditions on the top and the bottom surfaces. Governing equations and boundary conditions are obtained by using the principle of virtual displacement. Using Navier’s method, analytical solutions are presented by solving the boundary value problem. By investigating the typical bending problems of laminated composite and sandwich plates, the effect of various parameters like aspect ratio, thickness ratio and material properties on the bending response of plate is studied in detail. Comparison of the present results with the three-dimensional elasticity solutions and the results calculated using other models published recently in the literature shows that the proposed theory can yield accurately the displacements and stresses of multilayered composite and sandwich plates. Moreover, the accuracy of the displacement and stresses are not impacted by the number of layers and the material properties.

References listed at the end of the paper:


· H. Matsunaga, Thermal buckling of cross-ply laminated composite and sandwich plates according to a global higher-order deformation theory, Compos. Struct., vol. 68, no. 4, pp. 439–454, 2005.

· H. Matsunaga, Thermal buckling of cross-ply laminated composite shallow shells according to a global higher-order deformation theory, Compos. Struct., vol. 81, no. 2, pp. 210–221, 2007.


References listed at the end of the paper:


ABSTRACT: This article presents a model to characterize the lateral expansion of metal cylinder expanded by polymer filler and analyzes the influencing factors to the expansion. Based on the elastoplastic theory of thick-walled cylinder and the Drucker–Prager yield criterion, the expansion model which considers the material properties and dimensions of the filler and the cylindrical shell is constructed. To verify the accuracy of the model, a series of experiments, compared with the model, are conducted under different conditions (different materials of the filler, different thickness, and materials of the cylindrical shell), which illustrates that the proposed model is able to capture the response observed in experimental tests. Meanwhile, it is demonstrated that the relationship between axial stress and radial strain of the expansive specimen is mainly determined by the properties of the cylindrical shell instead of those of the filler, and the expansion decreases with the growth of the hydrostatic pressure.

References listed at the end of the paper:

The concept of lamination parameters.

The invariants in transverse shear are newly proposed in this paper. Next, the optimal laminate configurations for the transverse shear deformation. First, the effect of laminate configuration on the damping characteristics is examined. This paper deals with the damping characteristics of symmetrically laminated plates with transverse shear deformation. To examine the effect of laminate configuration, the concept of specific damping capacity is introduced and the damping characteristics are represented on the lamination parameter plane, where the damped stiffness invariants in transverse shear are newly proposed in this paper. Next, the optimal laminate configurations for the cantilevered laminated plates with maximal damping are determined taking into account the transverse shear effect by using differential evolution in which laminate parameters are used as intermediate design variables. The relation between the laminate configurations and the damping characteristics is discussed based on the concept of lamination parameters.
References listed at the end of the paper:

11 Kaneyama SA, Arai M. Optimal design of symmetrically laminated plates for damping characteristics using lamination parameters. Compos Struct. 2015;132:885–897.10.1016/j.composites.2015.06.076


ABSTRACT: A previously developed carbon fibre-reinforced addition-type polyimide composite material was exposed to temperatures of 240, 270 and 300 °C in air for 3000 h to study its long-term stability in terms of its compressive strength. The in-plane shear modulus, compressive failure mode and transverse crack density were also evaluated to determine whether a degradation process induces a decrease in the compressive strength of a high-temperature polymer matrix composite having a laminated configuration of [90/0]. The carbon fibre-reinforced polyimide composite exhibited excellent thermal stability in terms of its compressive strength after being subjected to ageing at 240 °C for 3000 h and at 270 °C for 2000 h, with degradation becoming significant at 300 °C. The compressive strength decreased only when the surface degradation caused the 90° plies sandwiching the 0° plies to degrade severely.

ABSTRACT: Evolution of the laminated woven natural fiber fabric-reinforced polymer composite structures makes a way to the development of the non-uniform laminated composite structures in order to achieve the stiffness variation throughout the structure. An attempt is made in this work to carry out the experimental and numerical investigations on the dynamic characteristics of the thickness-tapered laminated woven jute/epoxy and woven aloe/epoxy composite plates. The governing differential equations of motion for the thickness-tapered laminated composite plate are developed using the h-p version FEM based on higher order shear deformation theory. The validation of the present finite element formulation is carried out by comparing the natural frequencies obtained using the finite element formulation with those natural frequencies determined experimentally. The developed model is further validated with the available literature works on tapered composite plate to confirm the efficiency of h-p version FEM. This work also explores the study of the vibrational characteristics of composite plates under the influence of plant fiber’s transverse isotropic material characteristics and porosity associated with plant fiber composites through the elastic constants evaluated in the author’s previous work. Also the influences of aspect ratios, ply orientations, and taper angles under various end conditions on the natural frequencies of the woven jute/epoxy composite plate are studied using the present finite element formulation. The forced vibration response of the thickness-tapered laminated woven jute/epoxy composite plate under the harmonic force excitation is carried out considering CFCF and CFFF end conditions.

References listed at the end of the paper:


ABSTRACT: The compressive response of 3D woven textile composites (3DWTC), that consist of glass fiber tows and an epoxy matrix material, is studied using a finite element (FE)-based mechanics model. A parametric Representative Unit Cell (RUC) model is developed in a fully three-dimensional setting with geometry and textile architecture for modeling the textile microstructure. The RUC model accounts for the nonlinear behavior of the fiber tows and matrix. The computational model is utilized to predict the compressive strength of 3DWTC and its dependence on various geometrical and material parameters. The finite element model is coupled with a probabilistic analysis tool to provide probabilistic estimates for 3DWTC compressive strength. The reported results are found to be in good agreement with experimental data.

References listed at the end of the paper:

- Awaï M, Butt UN. 3D preforms in the world of composites -- a review. Faisalabad, Pakistan: National Textile University; 2003.

ABSTRACT: The low-velocity impact responses of cross-ply CFRP composite plates are investigated experimentally and are simulated using the finite element code LS-DYNA. An experimental test was initially performed and two different modeling approaches were then employed to model the composite plates. In the first numerical modeling approach, solid elements are utilized for the composite layers, whereas in the second, shell elements are used. The numerical model using the shell elements shows a good correlation with the experimental results, while the impact damage in the form of delamination is predicted more precisely using solid elements.

References listed at the end of the paper:


ABSTRACT: Recently, the approximate methods based on continuous models have been developed to perform structural analysis of composite lattice structures due to their relative simplicity and computational efficiency. This paper defines the modified effective stiffness considering the directionally dependent mechanical properties to an intersection of ribs and mode shape function of a composite lattice cylinder. It subsequently presents an approximate method based on the continuous model of conducting a buckling analysis of the composite lattice cylinder with various boundary conditions under uniform compression. This method considers the coupled buckling mode as well as the global and local buckling modes. The validity of the present method is verified by comparing the results of the finite element analysis. In addition, a parametric analysis is performed to investigate the effects of the design parameters on the critical load and buckling mode shape of the composite lattice cylinder based on the present method. Finally, we apply the present method to perform the optimization of a composite lattice cylinder for a high-speed vehicle to minimize the mass. Consequently, it is concluded that the present method is very suitable to optimization of composite lattice cylinders due to their relative simplicity and computational efficiency.

References listed at the end of the paper:

ABSTRACT: X-ray computed tomography images were used to obtain cross-sectional images of a unidirectional carbon fiber-reinforced plastic constructed by X-ray computed tomography images”, Advanced Composite Materials, Vol. 28, No. 4, pp 347-363, 2019, https://doi.org/10.1080/09243046.2018.1555387

Takuya Takahashi, Masahito Ueda, Keisuke Iizuka, Akinori Yoshimura & Tomohiro Yokozeki, “Simulation on kink-band formation during axial compression of a unidirectional carbon fiber-reinforced plastic constructed by X-ray computed tomography images”.

References listed at the end of the paper:


ABSTRACT: For the past 30 years, wind turbine blades have increased in size to improve energy capturing efficiency and reduce the costs of wind energy. At the same time, the power ratings of wind turbine blades have also increased continuously. As wind turbine blade sizes increase, blade weights need to be reduced to mitigate the structural loads on those blades. Recently, researchers at General Electric Co. proposed a new wind turbine blade concept, which is called fabric-covered. The design is composed of metal or composite spars, ribs, and covering fabrics that work to decrease the blade’s overall weight. The present study investigates the structural designs of fabric-covered wind turbine blades and their feasibility by analyzing static and buckling conditions based on two extreme design load cases. Three types of blade structures are proposed to compare blade weight reduction rates and stiffness. The structural properties of the blade sections calculated via VABS are compared with those of the reference model, i.e. the NREL-5MW wind turbine blade. The analytic results show that the proposed fabric-covered blade structure equipped with a rear spar in this study is able to reduce the weight of the reference blade over 36%, satisfying the structural requirements.

References listed at the end of the paper:


ABSTRACT: Fiber-reinforced composites are the materials of choice in numerous advanced applications in the fields such as automotive, aerospace, and marine as compared to conventional engineering materials. In this context, the influence of reinforcement architecture on the static mechanical performance of composite leaf spring was investigated. Reinforcement in the form of E-Glass chopped fibers, uni-directional (UD), bi-directional (2D) woven, and 3D orthogonal woven preforms were used to prepare composite leaf spring with identical fiber volume fraction and composite processing conditions. Composite leaf springs were analyzed for tensile properties, load-deflection behavior, strain rate sensitivity, hysteresis behavior (Damping), and relaxation behavior. Performance of 3D woven-based composite leaf spring was significantly better than chopped, UD, and 2D counterparts in terms of energy absorption, strain rate sensitivity, hysteresis damping (energy dissipation), and relaxation behavior. Overall 3D composite leaf spring shows a high potential for leaf spring application.

References listed at the end of the paper:
- Cheah LW: Cars on a diet: the material and energy impacts of passenger vehicle weight reduction in the US. Doctoral dissertation, Massachusetts Institute of Technology (2010)
- Kumar N, Das D. Fibrous biocomposites from nettle (Girardinia diversifolia) and poly (lactic acid) fibers for automotive dashboard panel application. Compos Part A. 2017;130:54–63.
containing thermal effects, the constitutive equation of the piezoelectric plate reinforced with BNNTs is set up.

ABSTRACT: Subjected to axial dynamic load, the dynamic stability of piezoelectric plate reinforced with boron nitride nanotube (BNNT) is investigated. Recurring to classical thin plate theory and piezoelectric theory containing thermal effects, the constitutive equation of the piezoelectric plate reinforced with BNNTs is set up.
Adopting ‘XY’ rectangle model, the material constants are reckoned. Afterwards the dynamic control equation of the structure is deduced through Lagrangian equation and resolved by using the Bolotin method. In numerical calculations, the influence of temperature, voltage, boundary condition, volume fraction, material property and static loading parameter on the principal instability region of BNNTs reinforced piezoelectric plate are discussed in detail.

References listed at the end of the paper:
Compos Mater. References listed at the end of the paper:


ABSTRACT: The failure of laminated composites under out-of-plane loadings is experimentally and numerically investigated. For flexure failure prediction, a modified failure criterion is proposed. A progressive failure algorithm is developed for numerical analyses. In experiments, quasi–isotropic and cross-ply laminated composites are fabricated by using unidirectional carbon fiber and glass fabric prepregs. Three-point bending test is performed and the accuracy of the failure algorithm is verified with experimental results. In addition, the flexure failure behaviors are compared with those of a commercial finite element analysis program using the other failure criteria such as maximum strain, maximum stress, and Tasi–Wu.


ABSTRACT: The effect of varying temperature on the compressive properties of a Nomex honeycomb core reinforced with small diameter composite tubes and rods has been investigated experimentally. Compression tests have been undertaken on a commercially-available Nomex core reinforced with tubes or rods at temperatures between 20 and 140 °C. Tests were also undertaken on unreinforced Nomex cores in order to assess the benefits associated with localized reinforcement of the core. Compression tests on the unreinforced cores have shown that the strength decreased steadily with increasing temperature, passing from 4.8 MPa at room temperature to 3.8 MPa at 140 °C. Similarly, the specific energy absorption (SEA) of the plain core samples decreased slightly from 22.3 to 18.9 kJ/kg over this range of temperatures. Reinforcing the cores with either rods or tubes had a positive effect on the compressive properties of the cores over the range of temperatures considered. For example, the room temperature compression strengths of the rod reinforced cores were 70% higher than those of the plain core. Similarly, at 140°C, the rod-reinforced systems were 20% stronger than the plain core. Finally, the energy-absorbing capacity of the tube reinforced cores was higher than that of the rod-reinforced cores.

References listed at the end of the paper:


ABSTRACT: Progressive crushing tests of a unidirectionally laminated carbon fiber-reinforced plastic (CFRP) rectangular plate were carried out to reveal its continuous fracture behavior and energy absorption. Three types of trigger geometry, chamfer, steeple, and V-shaped, were machined on each specimen. A film-embedded V-shaped trigger was also prepared to investigate the effect of initial cracks on the energy absorption. The initial fracture behavior strongly affected the ensuing stable fracture process. The V-shaped trigger specimen was robust as the gauge length varied, in contrast to the chamfer and steeple trigger specimens which absorbed less
energy with a longer gauge length. A column-like pillar was observed between the fronds during the crushing.

Fiber fractures were observed periodically at 50–100 μm lengths in the pillar section, which coincides with the length of the kink band in CFRP ultimate compressive failures. The pillar thickness was a dominant factor in the energy absorption of unidirectional CFRP.

References listed at the end of the paper:

ABSTRACT: This paper defines the modified effective stiffness considering the direction-dependent mechanical properties to an intersection of ribs and mode shape function of a composite lattice cylindrical panel. It subsequently presents an approximate method based on the continuous model of conducting a buckling analysis of the composite lattice cylindrical panel with various boundary conditions under uniform compression. This method considers the coupled buckling mode as well as the global and local buckling modes. We verify the validity of the present method by comparing the results of the finite element analysis. In addition, parametric and sensitivity analyses are performed to investigate the effects of the design parameters on the buckling characteristics based on the present method. The results allow a database to be obtained on the buckling characteristics by design parameters. Finally, the present method is applied to optimizing a composite lattice cylindrical panel for wing box design to minimize the mass. Consequently, it is concluded that the present method is very suitable for an optimization involved in the buckling analysis of composite lattice cylindrical panels due to their relative simplicity and computational efficiency.

References listed at the end of the paper:

ABSTRACT: In this study, we aimed to predict various impact failure behavior of cylindrical CFRPs with multiscale analyses using individual properties of fiber, interface, and resin including strain-rate dependence. We conducted compressive impact tests for the cylindrical CFRPs using split Hopkinson pressure bar (SHPB) method. Tests were carried out under four different compressive condition: radial direction and axial direction compressive tests for CFRP-H in which the fiber was aligned in the hoop direction and CFRP-L in which the fiber was aligned in the axial direction. Strengths in Hashin damage theory used in the macroscale analyses were determined by microscale analyses. Failure envelope in transverse direction and fiber-axial shear strength were obtained by 3D periodical unit cell analyses with considering the strain-rate dependence of resin strength. In addition, tensile and compressive strengths in fiber-axial direction were determined using the simultaneous fiber failure model and the fiber microbuckling model, respectively. Results of macroscale SHPB analyses were compared to test results. In terms of fracture process, analysis results did not match to test results because we conducted simulations without considering fracture energy. In terms of failure strength, failure load and failure occurred point, we could confirm rather good agreement between analysis results and test results.

References listed at the end of the paper:

ABSTRACT: The effects of specimen geometry on the Poisson’s ratio of a quasi-isotropic carbon-fiber-reinforced polymer laminate were examined using compression tests. In particular, the divergence of the apparent Poisson’s ratio from the theoretical value was experimentally determined for a decreasing specimen width/thickness ratio (b/t). The observed tendency was then confirmed by simulations using a finite element analysis (FEA). The FEA was performed using a 3D model of the specimens to investigate the strain and stress distribution. In the evaluation of the apparent Poisson’s ratio, the strain in the width direction was shown to vary under the condition of low b/t. The FEA results revealed that changes to the width strain were caused by cross-sectional deformation under compressive loading, resulting from differences in layer angles and stiffness between the outermost and inner layers.

References listed at the end of the paper:

- prEN 2850: aerospace series carbon thermosetting resin, unidirectional laminates- compression test parallel to the fibre direction.

Advanced Composite Materials, Vol. 30, No. 1, pp 96-110, 2021,

More papers published in the journal, Composites Science and Technology. (2019 and on)

Google the string, “Composites Science and Technology”, then click on the entry,
“Composites Science and Technology – ScienceDirect.com” and on that screen click on “All issues”

Ying Wang, Yuan Chai, Costas Soutis and Philip J. Withers (Primarily from: Henry Moseley X-ray Imaging Facility, Henry Royce Institute for Advanced Materials, School of Materials, University of Manchester, M13 9PL, UK), “Evolution of kink bands in a notched unidirectional carbon fibre-epoxy composite under four-point
bending”, Composites Science and Technology, Vol. 172, pp 143-152, 1 March 2019, https://doi.org/10.1016/j.compscitech.2019.01.014
ABSTRACT: Kink-band nucleation and propagation has been monitored over time in three dimensions (3D) by time-lapse X-ray computed tomography (CT) in the compressive zone of a blunt notched unidirectional (UD) T800 carbon fibre/epoxy composite under in situ four-point bending (FPB). The kink bands that develop from micro-buckling are classified into two types, namely type 1 and type 2 by analogy with Euler buckling. Type 1 (shear) kink bands accommodate a lateral displacement of the fibres either side of the kink band; whereas type 2 kinks comprise conjugate pairs forming chevrons (accompanied by a tilt if the bands are wedge-shaped). In the central plane of the sample the kink bands lie in the plane of bending, whereas near the side surfaces the lack of lateral constraint means that type 2 kink band pairs protrude out of the surface (normal to the bending plane) from the notch corners down the sides of the sample. Moreover, a comparison of CT scans during loading and after unloading shows that geometries measured post-mortem on cross-sections may not be wholly representative, with the angle of the broken fibre segments within the kink bands reduced by 10–20° and the curvature of buckled fibres almost halved. The novelty of this work relates to the observation of the nucleation and propagation of fibre kink bands in three dimensions and the definition and quantification of kink band variables that could lead to more accurate modelling and simulation of compressive behaviour.

ABSTRACT: Pultruded glass fiber reinforced polymer (GFRP) fluted-core sandwich panel is easily made and is a lightweight construction for protective structures. Blast-resistant doors are designed and constructed through combining three pultruded fluted-core sandwich panels framed by steel beams. With weight of 98.34 kg, the composite door is much lighter compared with traditional steel and concrete protective doors. Blast resistances of the composite protective doors are investigated by explosion testing. In current research, when the scaled distance is not smaller than 1.494 m/kg, the door panel exhibits excellent anti-blast ability without any damage. When the scaled distance is less than 1.357 m/kg, the structure damage is firstly characterized by the fluted-core shear and finally featured by the flexural failure of the delaminated sandwich panel. Including the deflection induced by the shear deformation of the fluted-core, dynamic one-way sandwich slab theory is proposed to predict the dynamic responses. The predictions are in agreement with the experimental results with acceptable errors. The dynamic theory can predict the critical scaled distance for the composite door based on core-shear failure criterion and the prediction is well consistent with the experiments. An equivalent static load model is suggested. Through the research, it is concluded that constructing protective door through pultruded GFRP fluted-core sandwich panels is a convenient, weight-saving and cost-saving way.

ABSTRACT: In current composite design, stacking sequence symmetry around the laminate mid-plane is an unarguable constraint to avoid warpage during manufacturing. However, several load cases induce unevenly distributed stresses through the laminate thickness, such that symmetric laminates may not be the optimal solution. In this paper, we explore the damage resistance to out-of-plane low velocity impact loading of an unsymmetrical laminate with zero extension-bending coupling matrix ([B]), thereby assuring no undesired coupling deformations during mechanical or thermal loads. Using impact and quasi-static indentation tests, C-scan inspection and numerical modelling, we compare the damage pattern between an unsymmetrical laminate with ply clustering at the impacted face and a laminate with ply clustering at the non-impacted face (produced by flipping the former laminate upside down). The laminate with clusters at the impacted side exhibits better damage resistance for lower impact energies. More importantly, the location of the damage events obeys the
predictions assumed when the laminate was designed, demonstrating the room for improvement by tailoring unsymmetrical laminates to particular load cases.

ABSTRACT: A carbon fiber-reinforced composite foldcore based on curved-crease origami was designed and fabricated using a hot press molding method. The fabrication process based on curved-crease origami reduces the abrupt change in fiber direction and is more suitable for continuous fiber-reinforced composites. The analytical models based on differential and integral method for predicting the compressive stiffness and strength of curved-crease origami foldcores were developed first and a three-dimensional failure mechanism map was constructed. The compressive properties and failure modes of carbon fiber reinforced composite curved-crease origami foldcores were investigated through experiments and finite element analysis (FEA). A reasonable agreement among the analytical models, experiments, and FEA results was observed. The dominant failure mode in the curved-crease origami foldcores could change from buckling to crushing with the wall thickness of foldcores increasing when subjected to compressive loads. The novel curved-crease origami design with open core channels has potential to applications for lightweight multifunctional structures, such as fuselage panels of airplane.

ABSTRACT: The dynamic response and the failure of the different composite structures subjected to impulsive loadings are performed experimentally with metallic foam projectile. The composite lattice core based sandwich structure is reinforced with polyurethane foam and shows a significant improvement in impulsive mitigation. The effects of core and loading intensity are carried out to identify and quantify the dynamic response, failure mode, and energy absorption efficiency of the composite structures. The results show that the foam filled lattice sandwich has an outperformed deflection resistance and remains better intact due to the loading transferring and weak effect of localization of the out-of-plane deflection. Although the energy absorption efficiency per unit mass of the lattice/foam sandwich is lower, the energy absorption capacity of the structure is confirmed to have been improved significantly, and the difference in the efficiency decreases noticeably with the increasing impulsive intensities. Both the sandwich structures have superior performance of impulsive resistance in comparison with the composite laminate.

ABSTRACT: Microbuckling is an important failure mode for fibre reinforced composites loaded under compression and the topic has received substantial attention of the research community. This effort led to a good understanding of the basic mechanisms behind the microbuckling phenomenon. However in spite of the well-developed theory, the ability to accurately predict failure loads and other related properties based on available data has not been attained yet. This may be attributed to a number of factors, arising at different scales. Consequently, numerous computational models and methods were put forward in the literature to approach this objective and this survey attempts to provide an overview of these developments. A concise reminder of the phenomenology and theoretical basis is also included to make the present survey self-contained.

ABSTRACT: This paper presents a defect severity concept for characterising fibre misalignments commonly found in practical composites. Drawing an analogy with brittle fracture from sharp defects, we show that compressive failure is governed by regions with clusters of misaligned fibres and that failure occurs from a
critical region most favourable to initiating a kink-band. Based on a large database of measured fibre misalignments, a defect severity model is proposed. The initiation and progression of kink-bands are also analysed using a finite element model.

References listed at the end of the paper:
13 D. Wilhelmsson, L.E. Asp, R. Gutkin, F. Edgren, Fibre waviness induced bending in compression tests of unidirectional NCF composites, Proceedings of the 21st European Conference on Composite Materials ICCM21, Xi’an, China (2017)
fabrication of carbon nanotubes (CNTs) reinforced composite shells, the slitting technique is employed to measure the released strains. Then, the elements of the stiffness matrix are obtained accomplishing an extensive computational modeling in ANSYS commercial software. The obtained results of experimental and computational parts are correlated using a MATLAB programming code, and residual stresses are calculated by calibration factors. Additionally, a statistical analysis is carried out to analyze the influence of mentioned parameters in overall scale. The experimental results had a good agreement with the analytical ones. Finally, this study highlights the complexity and the multifaceted characteristic of residual stresses development in terms of mentioned parameters in CNT-reinforced carbon fiber composite shells.


ABSTRACT: Compression failure by fiber kinking limits the structural applications of fiber composites. Fiber kinking is especially prevalent in laminates with holes and cutouts. The latter behavior is characterized by strain localization in the matrix material and fiber rotations. To study fiber kinking on the level of the individual constituents, a homogenization of fiber composites is presented. It is based on a total Lagrangian formulation, making it independent of fiber rotations. It accounts for the microstructure of the composite, including fiber-matrix interfacial decohesion, and enables all types of material behavior of the constituents. The response of each constituent of the composite is modeled separately and the global response is obtained by an assembly of all contributions. The model is implemented as a user-defined material model (UMAT) in ABAQUS and used for multiscale modeling of notched unidirectional plies subjected to compression. The model performs well in agreement with a finite element model of an explicit discretization of the microstructure and literature results. The simulations predict the formation of a kink band in near 0-degree plies and show that the open-hole compression strength is sensitive to fiber-matrix interfacial decohesion. The present work suggests a convenient and computationally efficient tool for simulating the elastic-plastic behavior of fiber composites on the fiber-matrix level and predicting the compressive strength of laminates. Also see:

Vedad Tojaga, Selcuk Hazar, Sören Östlund
Corrigendum to “Compressive failure of fiber composites containing stress concentrations: Homogenization with fiber-matrix interfacial decohesion based on a total Lagrangian formulation” [CSTE (2019) 107758]
Composites Science and Technology, Volume 185, 5 January 2020, Pages 107886

References listed at the end of the paper:
ABSTRACT: The tailor folding method is proposed to make an all-fiber reinforced polymer (CFRP) honeycomb core with continuous fibers is fabricated automatically from a continuous plain woven prepreg to reinforce the constraints of fiber reinforced polymer (CFRP) hexagon honeycomb core. Using this method, a CFRP honeycomb core with continuous fibers is fabricated automatically from a continuous plain woven prepreg to reinforce the constraints of fiber reinforced polymer (CFRP) hexagon honeycomb core.
ABSTRACT: The mechanical response and damage sequence of composite materials are nowadays still a topic of ongoing research. However, many parameters influencing their overall behavior are still not thoroughly taken into consideration. The effect of multiaxial stresses, the distinction between balanced and unbalanced configurations and the influence of the number of off-axis layers are just a few to mention. Experimental data regarding the effect of all these parameters on the damage progression in composites is of great importance, since it is proven that commonly used failure criteria, neglecting the occurring damage mechanisms, cannot always predict the material response. In this work, a study of the influence of all these parameters is attempted, by testing carbon/epoxy laminates with different off-axis angles to account for different multiaxiality. Both balanced and unbalanced laminates are taken into account, considering the lack of experimental evidence in literature regarding the latter case, and significant differences between the two lay-ups are reported for the first time. Finally, the influence of the number of the off-axis layers on the mechanical response in conjunction with the previous parameters is also studied through elaborate damage observations.

Amin Khodadadi (1), Gholamhossein Liaghat (1,2), Hamed Ahmadi (1), Ahmad Reza Bahramian (3) and Omid Razmkhah (4)
(1) Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran
(2) School of Mechanical & Aerospace Engineering, Kingston University, London, England, United Kingdom
(3) Department of Polymer Engineering, Tarbiat Modares University, Tehran, Iran
(4) Department of Mechanical Engineering, Coventry University, United Kingdom


ABSTRACT: This study aims to investigate the impact performance of composite panels consisting of plain-woven Kevlar fabric and rubber matrix. A finite element (FE) model in conjunction with experimental tests was developed to simulate the response of neat fabric and composite under impact loading. Each warp and weft yarn of fabric was individually modeled and combined with rubber matrix network to form the composite. To understand the effect of natural rubber on impact resistance of Kevlar/rubber composites, two types of rubber with different formulation were considered and their mechanical properties were obtained by split Hopkinson pressure bar tests and assigned to the model. Numerical results showed good agreement with the experimental data for both neat fabric and composite. It was shown that rubber matrix improves the ballistic performance of Kevlar fabric by keeping composite flexibility. High hardness rubber matrix composite has higher energy absorption capacity compared to the low hardness rubber matrix composite, due to presence of stronger intermolecular chains. Additionally, deformation and damage mechanism of fabric and composite were investigated under impact loading. The results were presented, discussed and commented upon.

Kalliopi-Artemi Kalteremidou (1), Mohammad Hajikazemi (2), Wim Van Paepegem (2), Danny Van Hemelrijck (1) and Lincy Pyl (1)
(1) Department of Mechanics of Materials and Constructions, Vrije Universiteit Brussel, Pleinlaan 2, 1050, Brussels, Belgium
(2) Department of Materials, Textiles and Chemical Engineering, Ghent University, Technologiepark Zwijnaarde 46, 9052, Ghent, Belgium


ABSTRACT: The mechanical response and damage sequence of composite materials are nowadays still a topic of ongoing research. However, many parameters influencing their overall behavior are still not thoroughly taken into consideration. The effect of multiaxial stresses, the distinction between balanced and unbalanced configurations and the influence of the number of off-axis layers are just a few to mention. Experimental data regarding the effect of all these parameters on the damage progression in composites is of great importance, since it is proven that commonly used failure criteria, neglecting the occurring damage mechanisms, cannot always predict the material response. In this work, a study of the influence of all these parameters is attempted, by testing carbon/epoxy laminates with different off-axis angles to account for different multiaxiality. Both balanced and unbalanced laminates are taken into account, considering the lack of experimental evidence in literature regarding the latter case, and significant differences between the two lay-ups are reported for the first time. Finally, the influence of the number of the off-axis layers on the mechanical response in conjunction with the previous parameters is also studied through elaborate damage observations.

Antonio Alessandro Deleo, James O’Neil, Hiromi Yasuda, Marco Salviato and Jinkyu Yang (Department of Aeronautics and Astronautics, University of Washington, Seattle, WA 98195, USA), “Origami-based

ABSTRACT: Deployable structures are typically made of thin membranes and slender elements, which often require foldable – yet stiff – mechanical properties. The use of carbon fiber reinforced polymer (CFRP) composites for such deployable structures has been limited due to the their rigid and unfoldable nature in general. Here, we design, fabricate, and demonstrate foldable – yet stiff – structures made of CFRP composites. To achieve this, we leverage origami design principles based on the Tachi-Miura-Polyhedron (TMP) architecture. To manufacture TMP structures, we devise a unique vacuum-bag-only composite fabrication method by using compliant urethane epoxies impregnated into woven glass fiber layers on which pre-made CFRP tiles are positioned. We show the resulting structures feature self-deployability, high compactness, and deterministic force–displacement characterization. Potential applications of the proposed composite origami are abundant, including deployable habitats for space exploration and disaster relief, deployable solar arrays and antennas, actively-controlled aerodynamic surfaces, and impact mitigation structures.


ABSTRACT: The ceramic particle reinforced foam-filled carbon fiber reinforced composites sandwich unit cell subjected to quasi-static and dynamic compressions are studied experimentally. The weight fraction of the ceramic particle is discussed to analyze its effect on the failure and energy absorption of the composite cells. The results show that the failure modes and energy absorption mechanisms of the cell are influenced significantly by the strain rate and ceramic particle reinforcement effects. The cluster of the particle makes the strut experience node failure under impulsive loadings, not the strut buckling and fracture shown at other cells. The mechanical property, especially the plateau stress, is enhanced noticeably as the foam is reinforced with the higher weight fraction of ceramic particles. The filling foams improve the impact resistance of the cells by transmitting less impulses and absorbing more energy. With a higher energy absorption efficiency, the foam-filled cell with higher weight fraction of ceramic particle has the highest energy absorption capacity under the quasi-static compression. Under the impulsive loading, the increasing ceramic particles can reduce the transmitted impulse, but cannot absorb additional energy.


ABSTRACT: This work studies the relation of the strain fields, final failure patterns and the apparent flexural modulus in CFRP laminates subjected to quasi-static indentation (QSI) with the in-plane multidirectional loading state
produced. QSI tests could be utilised for evaluating the degradation process in composites under low-velocity impacts (LVI) whenever analogous damage initiation and propagation are expected. Then, the research is focused on the LVI and QSI response of [±45]₉, squared-plates simply-supported in a circular steel window. Similar levels of internal energy are found in the most notable events during the loading process, what supports the comparable final failure patterns observed. Nevertheless angle-ply laminates under LVI present non-negligible higher levels of apparent rigidity, opening the possibility of a certain effect of the strain rate on the impact response. Besides, [0 90], configurations are taken into consideration for reviewing the effect on the results of the stacking sequence out of the simply-supported region. A strong influence on the internal energy is found, being 41.7% higher in angle-ply than in cross-ply laminates. The analytical estimation of the multiaxial apparent linear response of the laminate combined with the measured strains are utilised for the qualitative description of the experimental final failure modes. The deformation fields in QSI testing are acquired by Digital Image Correlation techniques and strain gauges, completing the analysis with the results of a finite element approach. The variation of the apparent flexural modulus with the in-plane loading direction leads to non-simmetrical strain fields and lower out-of-plane displacements in the stiffer direction.


ABSTRACT: This study investigates the post-impact flexural collapse modes of Divinycell H-100 PVC foam core with woven carbon fiber reinforced polymer (CFRP) face sheet composite sandwich structure. Effects of low temperature and impact energy on flexural collapse modes are predicted analytically and validated experimentally. Low-velocity impact tests with 4 J and 8 J impact energy are performed at three different temperatures: 23 °C, -30 °C and -70 °C. Impacted specimens subsequently undergo three-point bending test to identify flexural collapse modes. Analytical models portray indentation, core shear and face wrinkling as the main competing failure modes, whereby the dominant mechanism is dependent on pre-existing impact damage, face sheet thickness, environmental temperature and bending configuration. Results reveal that thick face sheet specimens collapse mainly by indentation or core shear. However, thin face sheet specimens display different collapse mechanisms namely core tensile failure and debonding, which are attributed to degraded tensile strength of back face sheet and impact-induced interfacial debonding at extreme low temperature. This work aims to provide fundamental understanding on the relationship of low temperature and failure modes, so as to guide future design of composites for Arctic applications.


ABSTRACT: The development and certification of aeronautical composite structures is still largely based on the pyramid of tests. This approach is extremely costly in terms of number of tests, especially at the level of coupons. Moreover, these tests are highly conservative, under uniaxial loading, and do not represent the actual behavior at structure scale. To overcome these drawbacks, a new methodology has been developed at the Institut Clément Ader, which uses a complex loading test rig for technological specimens. This research focuses on the combined loading after impact of CFRP plates and highlights a specific behavior quite different from the usual CAI (Compression After Impact) response at the scale of coupons. In particular, compression, shear and combined shear/compression loadings were applied to large Carbon Fiber Reinforced Plastics (CFRP) laminated plates and the interaction of the impact damage with the post-buckling behavior has been investigated.

ABSTRACT: In the quest to improve the compression after impact (CAI) strength of thin laminates, ply-hybrid laminates (where plies of different thicknesses are mixed) have been used in a previous study to mitigate the fibre failure and, consequently, improve the CAI strength. In the same study, hybrid laminates were proposed following qualitative design rules. In this paper, we systematically look for hybrid stacking sequences with improved damage tolerance by virtually testing all the laminates in a defined design space. While the laminates in the design space are made of intermediate and thick ply grades, the baseline laminate has only intermediate grade plies. Using an in-house numerical model, we virtually tested, (impact and CAI at two impact energies), all the candidate stacking sequences. The best hybrid laminates considerably improved the CAI strength over the baseline (31% and 40% improvement for the symmetric and unsymmetrical hybrid laminates, respectively). One of the best hybrid laminates was then manufactured and tested experimentally to validate the approach. Through virtual testing, this study demonstrates the benefits of using ply thickness hybrid laminates and the feasibility of optimizing the stacking sequence for impact damage tolerance.


ABSTRACT: A mesoscale model for fibre kinking onset and growth in a three-dimensional framework is developed and validated against experimental results obtained in-house as well as from the literature. The model formulation is based on fibre kinking theory i.e. the initially misaligned fibres rotate due to compressive loading and nonlinear shear behaviour. Furthermore, the physically-based response is computed in a novel and efficient way using finite deformation theory. The model validation starts by correlating the numerical results against compression tests of specimens with a known misalignment. The results show good agreement of stiffness and strength for two specimens with low and high misalignment. Fibre kinking growth is validated by simulating the crushing of a flat coupon with the fibres oriented to the load direction. The numerical results show very good agreement with experiments in terms of crash morphology and load response.


ABSTRACT: Defects such as out-of-plane wrinkles are known to strongly affect in-plane strength but there has been very little research on their effect on out-of-plane properties. Experimental and numerical studies of multi-directional curved-beam laminates were thus carried out to understand the effects of out-of-plane wrinkles on through-thickness tensile strength. The initially selected layup saw free-edge delamination interacting with transverse cracking, which is undesirable. After suppressing the free-edge delamination by dispersing the plies near the specimen surfaces, through-thickness tensile failure was observed near the mid-plane. The effects of out-of-plane wrinkles could be studied with this appropriate layup, showing a 16% reduction in strength. A High-fidelity Finite Element Method (Hi-FEM) has been used to distinguish between the different failure modes and to understand the effects of wrinkles. Good agreement was achieved between the numerical and experimental results in terms of through-thickness tensile strengths and delamination locations.


ABSTRACT: The electromechanical response of nanofiller-modified polymers subject to high-rate elastic loading has been little explored. In this paper, we address this gap by studying the piezoresistive response and mechanical properties of epoxy modified by three different kinds of carbon nanofillers when subject to high-rate elastic loading. Specifically, long high aspect-ratio epoxy rods were modified by carbon black, carbon nanofibers, and multi-walled carbon nanotubes and impacted in a split Hopkinson pressure bar. Electrical measurements during this loading reveal that the piezoresistive effect can be used to track elastic wave propagation in real-time, resistivity changes occur at the speed of sound of the nanofiller-modified epoxy, and the piezoresistive effect can be used to monitor stress wave properties. Further, dynamic modulus testing
revealed that carbon nanofillers have a positive influence on the dynamic stiffness. These results show that piezoresistivity can be employed to provide real-time insight into the elastodynamics of self-sensing nanocomposites.


ABSTRACT: Very thin carbon fiber composite shells can withstand large bending curvatures without failure. The resulting high tensile and compressive strains require accurate modeling of the fiber-dominated non-linear effects to predict the mechanical response. To date, no universal modeling technique can precisely capture the behavior of such structures. In this work, successful representation of composite’s response was achieved by utilizing single fiber tension and compression experimental data, implemented to extend a basal-plane-realignment based non-linear carbon fiber material model. Numerical techniques were adopted to model the bending behavior of unidirectional carbon fiber composites that was recorded in a comprehensive experimental campaign. Observations show that high material non-linearity leads to a non-negligible neutral-axis shift and drastic reduction of bending modulus due to compressive softening. Tensile fiber failure is the driving mechanism in thin shells flexure allowing for elastic compressive strains of up to 3% without micro-buckling. As a result, a remarkable flexibility in thin shells is realized. With increasing thickness, the elastic flexibility is reduced as the failure-driving mode switches to compressive micro-buckling.

References listed at the end of the paper:
8 Northolt M.G., Veldhuizen L.H., Jansen H., Tensile deformation of carbon fibers and the relationship with the modulus for shear between the basal planes, Carbon, 29 (8) (1991), pp. 1267-1279, 10.1016/0008-6223(91)90046-L
13 Barnet F., Norr M., A three-dimensional structural model for a high modulus pan-based carbon fibre, (1976), pp. 93-99, 10.1017/S004666390000197
15 Yokozeki T., Ogasawara T., Ishikawa T., Effects of fiber nonlinear properties on the compressive strength prediction of unidirectional carbon-fiber composites, Compos. Sci. Technol., 65 (14) (2005), pp. 2140-2147, 10.1016/j.compscitech.2005.05.005
17 Budiansky B., Micromechanics, Comput. Struct., 16 (1-4) (1983), pp. 3-12, 10.1016/0045-7949(83)90141-4


ABSTRACT: Graded foams show great potential in impact protection and blast resistance applications but a limited experimental study on their compressive behavior has been reported. Thus, this paper investigates the gradient effect on the compressive behavior of foams experimentally and numerically. The cell size graded foam (SGF) and the cell-wall thickness graded foam (TGF) are both built by the Voronoi method and then fabricated by the additive manufacturing technique. Meanwhile, uniform foams with different cell sizes (SUF) and cell-wall thicknesses (TUF) are also produced to be compared with graded foams. Quasi-static and dynamic compressive tests are conducted respectively by using a universal testing device and a direct-impact Hopkinson pressure bar. Experimental results reveal that SGFs deform continuously from lower to higher density regions and hence possess a gradually increasing plateau stage in the stress-strain curve. TGFs show three stepwise plateau stages because of their three layers with different cell-wall thicknesses. Moreover, SUFs and TUFs with constant relative density present similar mechanical properties despite their different cell morphologies. Several empirical formulae are proposed for uniform foams and fit well with experimental data. Further simulation is verified by experimental results and indicates that TGFs with adequate layers also possess a gradually increasing plateau stage just like SGFs. It means that the strength of each layer in a graded foam depends on its local density rather than cell morphology.


ABSTRACT: A bistable composite tape-spring (CTS) is stable in both the extended and coiled configurations, with fibres oriented at ±45°. It is light weight and multifunctional, and has attracted growing interest in shape-adaptive and energy harvesting systems in defence-, civil- and, especially aerospace engineering. The factors governing its bistability have been well-understood, but there is limited research concerning the mechanics of structural failure: here, we investigate the shear failure mechanisms in particular. We perform in-situ neutron diffraction on composite specimens using the ENGIN-X neutron diffractometer at Rutherford Appleton Laboratory (STFC, UK), and shear failure is characterised at both macroscopic and microscopic scales. Elastic and viscoelastic strain evolutions at different strain levels reveal the fundamentals of micromechanical shear failure, and their temperature dependency. Multiscale shear failure mechanisms are then proposed, which will benefit the optimisation of structural design to maintain structural integrity of CTS in aerospace applications.

ABSTRACT: Owing to an excellent packaging efficiency and the possibility of jointless folding, origami-inspired composites have attracted great interest in aerospace, flexible electronics, robotics and other applications. Considering the complexity of origami patterns, novel fabrication methods are needed to manufacture the vast array of foldable-composite structures. In this study, a cost-effective compression molding technique is employed to develop origami-inspired fiber-reinforced foldable-composite structures. The manufacturing technique is demonstrated for two typical composite geometries, namely, an origami-inspired triangulated cylinder with a spiral configuration and a single-DOF reverse-fold flat flasher design. The folding operation is achieved through elastic hinges that separate the different architected stiffened regions of the composite. Flexural coupons are fabricated to investigate the behavior of the elastic hinges and establish the practical minimum width of the elastic hinge for rapid recovery after unloading. Mechanical tests on the cylindrical flexible structure show a consistent recovery of 90% of the original length after several loading cycles. The resulting cylindrical structure exhibited easy deployment and collapse properties. Finally, the flasher design (a box-like structure that flattens once deployed), exhibited a deployment radius equivalent to 4 times that of the folded state, as well as 98% recovery of its surface area.


ABSTRACT: Smart and wearable strain sensors have sparked enormous research interests in various applications of flexible electronic devices. For this topic, it remains a huge challenge to acquire wide sensing range, high sensitivity, superior durability and fast response synergistically. Herein, we present an ultra-sensitive and durable strain sensor with sandwich structure to address the issues, which is mainly composed of the composite of carbon black (CB)/aligned thermoplastic polyurethane (TPU) fibrous mat and the Ecoflex. The CB/TPU/Ecoflex strain sensor (CTESS) is prepared via decorating CB nanoparticles onto the aligned electrospun TPU fibrous mats by ultrasonication, then encapsulated with Ecoflex to develop a sandwich structure. This structure provides effective protection for the conductive CB/TPU fibrous network, endowing the strain sensor with excellent sensing performances, including low detection limit (0.5% strain), wide response range (up to 225% strain), ultrahigh sensitivity (maximum gauge factor of 3186.4 at strain of 225%), fast response time (70 ms) and favorable repeatability even after 5000 stretching/releasing cycles. CTESS also shows an excellent anti-interference capability to external humidity and temperature. The CTESS is then assembled as artificial electronic skins to monitor various human motions, exhibiting great application prospects in next-generation wearable electronics.

Hui Li, Wenyu Wang, Xintong Wang, Qingkai Han, Jinquo Liu, Zhaoye Qin, Jian Xiong and Zhongwei Guan, “A nonlinear analytical model of composite plate structure with an MRE function layer considering internal magnetic and temperature fields”, Composites Science and Technology, Vol. 200, Article 108445, 10 November 2020, https://doi.org/10.1016/j.compscitech.2020.108445

ABSTRACT: To better exert the vibration suppression effect of magnetorheological elastomer (MRE) embedded into a composite structure with structural and functional integration advantage, this study proposes a nonlinear analytical model of such composite plate with an MRE function (MREF) layer, accounting for internal magnetic and temperature fields for the first time. Initially, a 9-layer fiber metal laminated (FML) plate with the MREF composites, consisting of two layers of metal protective skins, two layers of fiber-reinforced polymer (FRP) and one layer of MREF, is taken as an example to describe such a modelling method. Nonlinear expressions of elastic moduli of MRE and FRP involving thermal and magnetic fitting coefficients are also proposed, followed by derivation of the energy expressions of the constituent layers by the Rayleigh-Ritz method. After the free and forced vibrations are solved, the identification procedure of fitting coefficients is described and some literature results are employed to preliminarily validate this model without consideration of internal magnetic field or temperature field or both. Finally, dynamic experiments under different magnetic and
More papers published in the journal, International Journal of Steel Structures. (2019 and on)
Google the string: “International Journal of Steel Structures”, then click on the entry: “International Journal of Steel Structures – Springer – Springer Link”; then click on “Browse Volumes & Issues”

Jing Ji, Zhichao Xu, Liangqin Jiang, Chaqing Yuan, Yunfeng Zhang, Lijian Zhou and Shilong Zhang, “Nonlinear buckling analysis of H-type honeycombed composite column with rectangular concrete-filled tube flanges”, International Journal of Steel Structures, Vol. 18, No. 4, pp 1153-1166, November 2018

ABSTRACT: This paper is concerned with the nonlinear analysis on the overall stability of H-type honeycombed composite column with rectangular concrete-filled steel tube flanges (STHCC). The nonlinear analysis was performed using ABAQUS, a commercially available finite element (FE) program. Nonlinear buckling analysis was carried out by inducing the first buckling mode shape of the hinged column to the model as the initial imperfection with imperfection amplitude value of L/1000 and importing the simplified constitutive model of steel and nonlinear constitutive model of concrete considering hoop effect. Close agreement was shown between the experimental results of 17 concrete-filled steel tube (CFST) specimens and 4 I-beams with top flanges of rectangular concrete-filled steel tube (CFSFB) specimens conducted by former researchers and the predicted results, verifying the correctness of the method of FE analysis. Then, the FE models of 30 STHCC columns were established to investigate the influences of the concrete strength grade, the nominal slenderness ratio, the hoop coefficient and the flange width on the nonlinear stability capacity of STHCC column. It was found that the hoop coefficient and the nominal slenderness ratio affected the nonlinear stability capacity more significantly. Based on the results of parameter analysis, a formula is proposed to predict the nonlinear stability capacity of STHCC column which laid the foundation of the application of STHCC column in practical engineering.

References listed at the end of the paper:
ABSTRACT: Steel cylindrical tanks are widely used for the storage of hazardous substances of which leakage must be prevented under any circumstances. However, the dynamic response of the steel cylindrical liquid storage tank depends sensitively on the fluid–structure interaction and the vibration of the tank structure and necessitates clarification for the safety of the tank structure. This paper presents the results of shaking table tests performed to examine the dynamic behavior of a scaled cylindrical steel tank model considering the presence or not of fixed roof and added mass at the top of the tank for various fluid levels. The test results confirm the occurrence of both beam-type and oval-type vibration modes and show that the larger content of liquid inside the container amplified the acceleration along the height of the cylindrical tank. The oval-type vibration modes are seen to be more dominant in case of large water-to-structure mass ratio.

References listed at the end of the paper:


Minwo Park and Dong-Ho Choi, “A four-variable first-order shear deformation theory considering the variation of in-plane rotation of functionally graded plates”, International Journal of Steel Structures, Vol. 18, No. 4, pp 1265-1283, November 2018
ABSTRACT: This paper presents a four-variable first-order shear deformation theory considering in-plane rotation of functionally graded plates. In recent studies, a simple first-order shear deformation theory was developed and extended to functionally graded plates. It has only four variables, separating the deflection into bending and shear parts, while the conventional first-order shear deformation theory has five variables. However, this simple first-order shear deformation theory only provides good predictions for simply supported plates since it does not consider in-plane rotation varying through the thickness of the plates. The present theory also has four variables, but considers the variation of in-plane rotation such that it is able to correctly predict the responses of the plates with any boundary conditions. Analytical solutions are obtained for rectangular plates with various boundary conditions. Comparative studies demonstrate the effects of in-plane rotation and the accuracy of the present theory in predicting the responses of functionally graded plates.

References listed at the end of the paper:


Changyong Liu, Qing Hu, Yuyin Wang and Sumei Zhang, “In-plane stability of concrete-filled steel tubular parabolic truss arches”, International Journal of Steel Structures, Vol. 18, No. 4, pp 1306-1317, November 2018
ABSTRACT: For determining the in-plane buckling resistance of a concrete-filled steel tubular (CFST) arch, the current technical code GB50923-2013 specifies the use of an equivalent beam-column method which ignores the effect of rise-to-span ratio. This may induce a gap between the calculated result and actual stability capacity. In this study, a FE model is used to predict the buckling behavior of CFST truss arches subjected to uniformly distributed loads. The influence of rise-to-span ratio on the capacity of truss arches is investigated, and it is found that the stability capacity reduces as rise-to-span ratio declines. Besides, the calculations of equivalent slenderness ratio for different truss sections are made to consider the effect of shear deformation. Moreover, based on FE results, a new design equation is proposed to predict the in-plane strength of CFST parabolic truss arches under uniformly distributed loads.

References listed at the end of the paper:


Ralph Raymond Santos, Sung-Jun Cho and Jong-Sup Park, “Ultimate strength of 10MW wind turbine tower considering opening, stiffener, and initial imperfection”, International Journal of Steel Structures, Vol. 18, No. 4, pp 1318-1324, November 2018

ABSTRACT: This paper evaluates the effects of door opening, collar stiffener, and initial imperfection on the ultimate strength of a 10 MW wind tower. The lower segment of the tower was modeled to investigate the ultimate strength using steel cylindrical shell elements of finite element program ABAQUS. The wind tower was classified into three categories; without opening nor stiffener (C1), with opening but no stiffener (C2), and with opening and stiffener (C3). The C2 and C3 were further divided into long axis and short axis categories depending on the position of the opening. Result from linear and nonlinear analyses shows that the bigger the opening the bigger the reduction in strength and the same thing goes for the initial imperfection ratio or ovality of the shell. Also, there is a significant decreased in strength as the initial imperfection ratio increases by as high as 18.08%.
References listed at the end of the paper:


Asmita Rokaya and Jeongho Kim, “An accurate analysis for sandwich steel beams with graded corrugated core under dynamic impulse”, International Journal of Steel Structures, Vol. 18, No. 5, pp 1541-1559, December 2018

ABSTRACT: This paper addresses the dynamic loading characteristics of the shock tube onto sandwich steel beams as an efficient and accurate alternative to time consuming and complicated fluid structure interaction using finite element modeling. The corrugated sandwich steel beam consists of top and bottom flat substrates of steel 1018 and corrugated cores of steel 1008. The corrugated core layers are arranged with non-uniform thicknesses thus making sandwich beam graded. This sandwich beam is analogous to a steel beam with web and flanges. Substrates correspond to flanges and cores to web. The stress–strain relations of steel 1018 at high strain rates are measured using the split-Hopkinson pressure. Both carbon steels are assumed to follow bilinear strain hardening and strain rate-dependence. The present finite element modeling procedure with an improved dynamic impulse loading assumption is validated with a set of shock tube experiments, and it provides excellent correlation based on Russell error estimation with the test results. Four corrugated graded steel core arrangements are taken into account for core design parameters in order to maximize mitigation of blast load effects onto the structure. In addition, numerical study of four corrugated steel core placed in a reverse order is done using the validated finite element model. The dynamic behavior of the reversed steel core arrangement is compared with the normal core arrangement for deflections, contact force between support and specimen and plastic energy absorption.

References listed at the end of the paper:


Hongjun Liang, Yiyian Lu, Jiayue Hu and Jifeng Xue, “Experimental study an confinement analysis on RC stub columns strengthened with circular CFST under axial load”, International Journal of Steel Structures, Vol. 18, No. 5, pp 1577-1588, December 2018

ABSTRACT: As the excellent mechanical performance and easy construction of concrete filled steel tubes (CFST) composite structure, it has the potential to be used to strengthen RC pier columns. Therefore, tests were conducted on 2 reinforcement concrete (RC) stub columns and 9 RC columns strengthened with circular CFST under axial loading. The test results show that the circular CFST strengthening method is effective since the mean bearing capacity of the RC columns is increased at least 3.69 times and the ductility index is significantly improved more than 30%. One of the reasons for enhancement is obvious confinement provided by steel tube
besides the additional bearing capacity supplied by the strengthening materials. From the analysis of the enhancement ratio, the strengthening structure has at least an extra 20% amplification except for taking full advantage of the strength of the strengthening material. Through the analysis of confining stress provided by steel tube and the stress–strain relationship of confined concrete, it is found that the strength of the core concrete can be increased by 21–33% and the ultimate strain can be enhanced to beyond 15,000 με.

References listed at the end of the paper:


ABSTRACT: Quantitatively modeling and propagating all sources of uncertainty stand at the core of seismic fragility assessment of structures. This paper investigates the effects of various sources of uncertainty on seismic responses and seismic fragility estimates of single-layer reticulated domes. Sensitivity analyses are performed to examine the sensitivity of typical seismic responses to uncertainties in structural modeling parameters, and the results suggest that the variability in structural damping, yielding strength, steel ultimate strain, dead load and snow load has significant effects on the seismic responses, and these five parameters should be taken as random variables in the seismic fragility assessment. Based on this, fragility estimates and fragility curves incorporating different levels of uncertainty are obtained on the basis of the results of incremental dynamic analyses on the corresponding set of 40 sample models generated by Latin Hypercube Sampling method. The comparisons of these fragility curves illustrate that, the inclusion of only ground motion uncertainty is inappropriate and inadequate, and the appropriate way is incorporating the variability in the five identified structural modeling parameters as well into the seismic fragility assessment of single-layer reticulated domes.

References listed at the end of the paper:


ABSTRACT: This paper presents a Finite Element (FE) study on Lean Duplex Stainless Steel stub column with built-up sections subjected to pure axial compression with column web spacing varied at different position across the column flanges. The thicknesses of the steel sections were from 2 to 7 mm to encompass a range of section slenderness. The aim is to study and compare the strength and deformation capacities as well as the failure modes of the built-up stub columns. The FE results have been compared with the un-factor design strengths predicted through EN1993-1-4 (2006) + A1 (2015) and ASCE8-02 standards, Continuous Strength Method (CSM) and Direct Strength Method (DSM). The results showed that the design rules generally under predict the bearing capacities of the specimens. It’s been observed that the CSM method offers improved mean resistance and reduced scatter for both classes of cross-sections (i.e. slender and stocky sections) compared to the EN1993-1-4 (2006) + A1 (2015) and ASCE 8-02 design rules which are known to be conservative for stocky cross-sections.

References listed at the end of the paper:


ABSTRACT: It has been demonstrated that the buckling-restrained steel plate shear wall (SPSW) is an efficient and economic lateral load-resisting system exhibiting high performance on initial stiffness, ductility, shear resistance, and energy dissipation capacity. In present study, a novel partially connected buckling-restrained SPSW is presented to reduce the stiffness requirement for the vertical boundary elements. Meanwhile, nonlinear finite element (FE) analysis is performed to evaluate the behavior of the proposed shear wall system so that a large expense of conducting additional test can be saved. The experimental results from the literature and the test conducted by the authors are used to establish the validation of FE models. Based on the validated FE models, a further extensive parametric study is carried out to investigate the effect of initial imperfection, stiffness of boundary elements, slenderness ratio (Height/Thickness) of the infill panel, aspect ratio (Height/Width) of the infill panel, RC cover panel thickness and bolt spacing on the behavior of the partially connected buckling-restrained SPSW.

References listed at the end of the paper:

- ACI (American Concrete Institute). (2011). Building code requirements for structural concrete and commentary, ACI 318, Farmington Hills, MI, USA.
- Astaneh-Asl, A. (2001). Seismic behavior and design of steel shear walls. In SEOANC Seminar, Structural Engineers Associate of Northern California, San Francisco, USA.

ABSTRACT: This paper presented the numerical studies on the dynamic crushing behaviors of the aluminum foam filled energy absorption connectors. The finite element (FE) model was firstly constructed and the accuracy of the FE model was verified by comparing the force–displacement curves from FE analyses with those from tests and analytical predictions. The numerical results revealed that the deformation mode of the connector under dynamic crushing evidently differed from that under quasi-static loading mainly due to the inertia effect. Besides, the energy absorption capacity was also improved when the dynamic crushing load was applied. Then, the parametric studies on the effects of crushing velocity–time history, angle between flat plate and pleated plate as well as pleated plate thickness on the energy absorption enhancements of the connectors were conducted. Based on the numerical results, two empirical equations were derived in terms of various parameters to predict the energy absorption enhancements of aluminum foam and pleated plate, which could be employed to obtain the force–displacement functions of the connectors under dynamic crushing.

References listed at the end of the paper:

ABSTRACT: This study presents an optimal shape generation method of local steel unit plates in arch-grid structures by using buckling load factor. ETABS software is utilized for a computational modeling of arch-grid to consider buckling analysis. According to the present optimal shape generation method, first, some shape types of a horizontal unit cell plate of arch-grid are assumed as initial designs. Second, they are analyzed through ETABS in terms of their buckling capacities. At the same time, appropriate vertical column bar sizes are achieved with respect to maximal stress of steel material and buckling load factor. Third, the generated arch-
grid are combined to achieve optimal conditions of width and height of a given arch-grid structure, which shows the best structural feasibility to resist a given building. The arch-grid structure is extended by considering four different cases: a combined grid, an extended grid, a multi-story grid and a pyramid grid to verify the effectiveness of the present optimal shape generation method of steel arch-grid as numerical examples.

References listed at the end of the paper:

References listed at the end of the paper:


https://doi.org/10.1139/t04-037


https://doi.org/10.1139/l78-037


ABSTRACT: In this article, the axial buckling load of an axisymmetric cylindrical shell with nonuniform thickness and initial imperfection is determined analytically with the initial imperfection by using the first order shear deformation theory. The imperfection is considered as an axisymmetric continuous radial displacement. The strain-displacement relations are defined using the nonlinear von Karman formulas. The constitutive equations obey Hooke’s law. The equilibrium equations are nonlinear ordinary differential equations with variable coefficients. The stability equations are determined from them. The stability equations are a system of coupled linear ordinary differential equations with variable coefficients. The results are compared with the finite element method and some other references.

References listed at the end of the paper:
ABSTRACT: Laterally and torsionally unrestrained steel I-section beams are susceptible to torsional deformations between supports; therefore, according to Part 1-1 of Eurocode 3, they need to be designed to resist lateral-torsional buckling. Eurocode’s steelwork design criteria require safety checking based on two stability interaction formulae utilizing the so-called equivalent uniform moment factors and the cross-section resistance formula that, in the case of moment gradient, refer to the beam end section. Uncoupling the beam stability resistance criterion and the cross-section resistance criterion may result in a nonuniform safety assessment of I-section beams. Finite element simulations of the beam resistance for different moment gradient ratios are performed. Verification of the buckling resistance is conducted by varying the following parameters: the slenderness ratio, the location of maximum end moments about both axes and the section depth-to-width ratio (i.e., considering rolled I- and H-sections). The variation in the accuracy of the current Eurocode resistance evaluation method is identified, and an approach for a better equalization of the safety predictions is suggested by considering different values of the most important factors influencing the stability performance of steel I-section beams.

References listed at the end of the paper:

Chuangze Xu, Yuaniong Yang, Xin Tang and Jiepeng Liu [Primarily from: Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education, Chongqing, China], “Experimental research on static behavior of stiffened T-shaped concrete-filled steel tubular stubs subjected to concentric axial loading”, International Journal of Steel Structures, Vol. 19, No. 2, pp 591-602, April 2019

ABSTRACT: Eight stiffened T-shaped concrete-filled steel tubular (CFST) columns and one non-stiffened T-shaped CFST column were tested subjected to axial compressive load in this paper. The mechanical property and failure mode of the specimens were studied. The influences of steel ratio, concrete strength and sectional size were investigated on the axial compressive performance of the specimens. A numerical program was developed to calculate concentric load-shortening curves of T-shaped CFST columns based on experimental results. The confined concrete distribution in T-shaped section and the stiffened tube’s local buckling were considered in the numerical program. A good agreement between calculating results and experimental results was obtained. Besides, a design formula of bearing capacity of stiffened T-shaped CFST columns was put forward by considering favorable effect of stiffeners.

References listed at the end of the paper:


Behzad Mohammadzadeh and Hyuk Chun Noh (Department of Civil and Environmental Engineering, Sejong University, Seoul, South Korea), “An analytical and numerical investigation on the dynamic responses of steel
plates considering the blast loads”, International Journal of Steel Structures, Vol. 19, No. 2, pp 603-617, April 2019

ABSTRACT: This study involves an analytical approach to investigate the dynamic responses of plates subjected to blast and impulsive loads. Navier’s approach was employed in order to obtain the equations for displacements and moments. The method validity was evaluated by making comparisons between the analytical and the numerical predictions of the plate time histories and the maximum displacement. A small discrepancy among the results proved the validity of the proposed analytical formulae. The effects of the plate aspect ratio, the thickness, and the charge weight on the plate deflection due to the blast loads were investigated by employing analytical and numerical approaches. The plate displacement changed linearly with respect to the charge weight, whereas it had a nonlinear variation for the plate thickness.

References listed at the end of the paper:
ABSTRACT: This paper presents a comparative study on the composite structure of Corrugated Steel Plate (CSP) with normal and rubberized concrete. One CSP-normal-concrete plate and two CSP arch structures composited with different concretes are established. A theoretical section-property deduction is derived, which demonstrated that the flexural rigidity of such composite structure increased notably. Static and dynamic mechanical experiments are also conducted. Experimental results agree with expectations, and the measured results on plate structures verified the effectiveness of the analytical and numerical solutions. Comparing the deflection of two composite arches shows that the rubberized concrete composite arch has smaller flexural and compressive stiffnesses, resulting in larger deflection. The rubberized concrete composite arch has higher steel stress, lower concrete stress and better energy-dissipating capacity compared with the normal concrete composite arch. Therefore, the CSP-rubberized concrete composite structure is more suitable for anti-shock and earthquake-resistant structures.

References listed at the end of the paper:


ABSTRACT: A novel unified theory for distortion analysis of thin-walled hollow section has been proposed based on the Hellinger–Reissner variational principle to account for distortional shear deformation effects. Based on the proposed theory, a finite segment model has been developed and the method for determining the distortion functions of the cross-section has been proposed. The rationality of approaches for determining distortional shear stress has been analysed and it is concluded that Bredt’s pure distortion does not exist in the single-cell hollow section. Comparisons and analyses have been performed between the proposed theoretical model and the existing four groups of theories in distortion analysis of thin-walled hollow section. Effects of distortional warping shear stress on the shear deformation has been investigated and the results indicate that the distortional shear deformation effect results in a decrease of the distortional warping stresses and shear stresses but an increase of the transverse bending stresses. The numerical study indicates that the distortional shear deformation effects can be ignored and the first derivative of the distortion angle can be employed as the distortional warping function for the conventional hollow sections of bridge structures.

References listed at the end of the paper:

ABSTRACT: Steel-reinforced concrete-filled square steel tubular (SRCFST) column has been acknowledged as a progressive form from the steel–concrete composite system, having a higher load-bearing capacity. Aiming at laying the foundations for SRCFST full-scale research after fire exposure, this paper has studied the axial compression behavior of SRCFST stub columns after different modes of fire exposure. To start with, temperature distributions, failure patterns and load–strain relationships of four existing SRCFST columns were experimentally analyzed. Based on this, numerical models of square SRCFST columns with sufficient correctness and effectiveness were established for further holistically examining impacts of fire duration time, yield strength of steel tube, compressive strength of concrete, confinement index, section steel index and sectional dimensions on residual strength of SRCFST columns. The results indicate that residual strength of square SRCFST columns decrease significantly with fire duration time, sectional dimensions and section steel index, while yield strength of steel, compressive strength of concrete and confinement index exert negligible effects. Afterwards, predictive formulas that can calculate residual strength index of square SRCFST columns under different patterns of fire exposure were proposed.

References listed at the end of the paper:

In this study, experimental and numerical investigations of the effect of different boundary supports for rare, rarely studied in the literature due to its difficult experimental simulation. For large structures such as shell

**ABSTRACT:**

Behavior of Stiffened and Unstiffened Cylindrical Shells

Oussama Temami

- 8
- 135
- 159
- 171
- 183
- 195
- 207
- 219
- 231
- 243
- 255
- 267
- 279
- 291
- 303
- 315
- 327
- 339
- 351
- 363
- 375
- 387
- 400
- 412
- 424
- 436
- 448
- 460
- 462
- 464
- 466
- 468
- 470
- 472
- 474
- 476
- 478
- 480
- 482
- 484
- 486
- 488
- 490
- 492
- 494
- 496
- 498
- 500
- 502
- 504
- 506
- 508
- 510
- 512
- 514
- 516
- 518
- 520
- 522
- 524
- 526
- 528
- 530
- 532
- 534
- 536
- 538
- 540
- 542
- 544
- 546
- 548
- 550
- 552
- 554
- 556
- 558
- 560
- 562
- 564
- 566
- 568
- 570
- 572
- 574
- 576
- 578
- 580
- 582
- 584
- 586
- 588
- 590
- 592
- 594
- 596
- 598
- 600
- 602
- 604
- 606
- 608
- 610
- 612


ABSTRACT: The effect of boundary conditions is very important in the analysis of cylindrical shells, and is rarely studied in the literature due to its difficult experimental simulation. For large structures such as shell roofs, the type of boundary supports is among the major factors that can minimize the stresses and deflections. In this study, experimental and numerical investigations of the effect of different boundary supports for stiffened and unstiffened cylindrical shells were conducted. Two different models of the stiffened and unstiffened cylindrical shells with different boundary conditions, “pinned and with rigid diaphragms”, were studied. It was shown that by using rigid diaphragms for cylindrical shells, the deflections are minimized by 80%, and by (45–50) % for the stiffened cylindrical shells. From the experimental investigations and the
numerical results obtained, the efficiency of the proposed boundary support types for cylindrical shells is confirmed, which can result in economic benefits.

References listed at the end of the paper:


ABSTRACT: In this paper, the behavior of slender steel delta girders (SDG) is investigated both analytically and numerically. In the analytical analysis, closed-form equations for cross-section properties of SDG are derived. They are then compared with solutions obtained numerically. Using these cross-section properties, the theoretical elastic lateral-torsional buckling (LTB) strength of these girders is determined and compared with results obtained from a finite element analysis. The results show that the theoretical LTB equation derived for general open monosymmetric I-sections can be applied to these delta girders. Additionally, it is shown that a simplified expression for the coefficient of monosymmetry $\beta$ derived for I-sections can be used in the computation of LTB strength for SDG. A parametric study is then performed to demonstrate the effectiveness of SDG in achieving a favorable strength-to-weight ratio when compared to standard I-section members. Based on the results of this parametric study, it is recommended that the height and width of the delta region of the cross-section be equal to two-fifth the height of the web and three-quarter the width of the compression flange, respectively.

References listed at the end of the paper:
Haifeng Li, Jun Luo, Feng Han, Jiexin Luo, “Experimental Study on Seismic Behavior of New Steel Box Bridge Piers with Embedded Energy Dissipation Shells”, International Journal of Steel Structures, Vol. 19, No. 3, pp 952-969, June 2019

ABSTRACT: An investigation was conducted to evaluate the seismic behavior of a new type of steel box-section bridge piers with embedded energy dissipation shell plates. In this study, two sets of the new steel box-section bridge piers were designed and pseudo-static tests were carried out on ten steel box bridge piers under constant axial force, with a horizontal cyclic load on top of the piers. The change regularities of the failure mode, the patterns of local buckling, the load–displacement hysteresis curve and its curve skeletons, and the load–strain hysteresis curves of the specimens were analyzed. The rules of horizontal stiffener spacing on embedded shell plates, the axial compression ratio, the embedded shell strength, and the layout of longitudinal ribs in the box-section wallboards were obtained to evaluate their influence on the seismic behavior of the new-type steel piers. The test results indicated that, after installing the embedded shells, the deformation ability of steel box-section bridge piers was enhanced and their ductility was improved. The effects of axial compression ratio and the space of transverse stiffeners in embedded shells on the seismic behavior of the new steel piers were significant. When the space of the horizontal stiffeners on the embedded shells and the axial compression ratio become smaller, the bearing capacity and ultimate displacement capability of the specimens would be greater, the descent segment of the curve skeleton would be more gradual, and the deformability and ductility of the new-type steel piers would be better. The effects of setting longitudinal stiffening ribs and enhanced embedded shell strength on the bearing capacity and ductility of the steel box bridge piers were relatively small. Based on the experimental results, calculation equations were established for stable bearing capacity and maximum deformation of the new-type steel piers, under the constant axial force and horizontal cyclic loading, in order to promote their seismic design.

References listed at the end of the paper:
Abstract: With the progress in metallurgical technique and steel production process, the strength of structural steels can be improved, along with other material properties, including higher toughness and better weldability. Meanwhile, there are numerous potential civil structural applications for high strength steel (HSS), such as large-span space frames, transfer truss in high-rise buildings, as well as truss bridges. The mechanical behavior of structural members made up from HSS must be closely investigated and quantified before HSS can be widely used in engineering structures. In this paper experiments on six Q550 HSS I-section beams under moment gradient (MG) and four Q550 HSS I-section beams under patch loading (PL) were carried out, to investigate the local buckling behavior of I-section beams subjected to different loading conditions. The failure modes, critical local buckling strengths, ultimate strengths, load–deformation curves, load–strain curves and moment–rotation curves of the specimens were obtained. The test results of ultimate strengths were further compared with the design results in accordance with the available design methods in current specifications, ANSI/AISC 360-16, Eurocode 3, AS 4100-1998, AIJ LSD 2010 and GB 50017-2003. Accounting for material nonlinearity, geometric imperfection and residual stress, finite element models were established and verified with the existing test results, which were used for the parametric analysis of two series of 240 beams. The parametric investigation focused on the effects of the material properties and component plate slenderness on the ultimate strengths of I-section beams under MG and the ones under PL. The comparisons between the parametric analysis results, test results and the design results from ANSI/AISC 360-16 and Eurocode 3 were also conducted.

References listed at the end of the paper:


using the explicit dynamic method was developed based on ABAQUS software to analyse pipeline lateral differences. Numerical simulations are an effective and easy way to obtain the deformation and stress distribution of a post-buckling pipeline with a low cost. A relatively accurate and convenient simulation model using the explicit dynamic method was developed based on ABAQUS software to analyse pipeline lateral


ABSTRACT: Deep-sea pipelines exhibit lateral global buckling under high temperature and pressure differences. Numerical simulations are an effective and easy way to obtain the deformation and stress distribution of a post-buckling pipeline with a low cost. A relatively accurate and convenient simulation model using the explicit dynamic method was developed based on ABAQUS software to analyse pipeline lateral
global buckling. In pipeline global buckling analysis, the dynamic variation of soil resistance as the pipeline moves laterally, the optimized computational length and the use of smooth initial imperfection profiles influence the accuracy of the simulation results. These three key factors were discussed here, and calculation methods were proposed. A CEL simulation model with improved boundary conditions that reduce the influence of wave reflection with a low calculation time cost was built to calculate the variation dynamics of soil resistance throughout the buckling process. Different computational lengths for pipelines with different parameters were simulated, and a fitting function to obtain an optimized computational length was proposed. A method to build the profiles of a pipeline with smooth imperfections was developed. Based on these analyses of the three impact factors, a relatively accurate and convenient simulation model for pipeline global lateral buckling analysis was established. Finally, an engineering case was evaluated to show the application of the simulation model and to test the reliability of this model.

References listed at the end of the paper:
Yasser Sharifi (1), Mahmoud Hosseinpour (1), Adel Mohgbeli (1) and Jojjat Sharifi (2)
(1) Department of Civil Engineering, Vali-e-Asr University of Rafsanjan, Rafsanjan, Iran
(2) Department of Computer Engineering, Vali-e-Asr University of Rafsanjan, Rafsanjan, Iran


ABSTRACT: A new model based on Artificial Neural Network (ANN) was established as a trustworthy technique for predicting ultimate lateral torsional buckling (LTB) capacity of castellated steel beams. The required information for training, validating and testing of the developed model obtained from a reliable database. Consequently, a new formulation based on the ANN has been offered for predicting the failure load of castellated steel beams exposed to LTB. All parameters which may affect the LTB capacity of castellated beams were considered for presentation of this formula. Then, outcomes of the proposed formula were compared with predictions of Australian Standard (AS4100) for LTB capacity of castellated beams. This comparison indicated that proposed formula has a good performance for prediction of ultimate strength in castellated beams subjected to LTB. At the end, Garson’s algorithm has been established as a sensitivity analysis to determine importance of each input in the proposed formula.

References listed at the end of the paper:


ABSTRACT: To study the dynamic response characteristics and failure process of single-layer spherical reticulated shells under impact loads at different loading points, impact dynamic analysis and experimental study are conducted on the K6 single-layer reticulated shell structure. First, the basic theory of numerical calculation and the model parameters are described. Then, dynamic response analysis under impact load is done by choosing different impact points. Finally, the impact test is performed on a large-scale shell model, dynamic response data of key members and nodes of shell structure are obtained, and the shell deformation and destruction process is recorded by a high-speed camera. The results show that the structural dynamic response gradually increases farther from the base point under the same impact force. The nearer the impact point is, the earlier the response occurs, and the larger the corresponding amplitude will be. The apex is the most unfavorable impact loading point, and the member at the apex should be strengthened for impact resistant design of the reticulated shell. The transmission time of the impact dynamic response from the impact site to the entire reticulated shell is short.

References listed at the end of the paper:

ABSTRACT: The hollow flange beams are designed to take the advantages of hot-rolled steel sections in which area is concentrated away from the neutral axis and the ease of installation associated with cold-formed sections. The present study deals with the flexural behaviour of hollow flange channel beam sections by Finite Element modeling using the general purpose finite element software ABAQUUS. A Parametric study is carried out by varying the flat width/thickness ratio, depth of the beam, depth of the hollow flange and length of the beam. The effects of distortional buckling on hollow flange channel beam are studied and finite element model results are compared with AS/NZS 4600:2005 code for cold-formed steel structures. It is found that code based design is economic for hollow flange beams which fail in lateral distortional buckling alone.

References listed at the end of the paper:
Wei-bin Yuan (1,2), Yue-ting Shen (1), Nan-ting Yu (3) and Zhao-shui Bao (1)

(1) College of Civil Engineering and Architecture, Zhejiang University of Technology, Hangzhou, China
(2) Key Laboratory of Civil Engineering Structures & Disaster Prevention and Mitigation Technology of Zhejiang Province. Hangzhou, China
(3) School of Engineering, University of Plymouth, Plymouth, UK

"An Analytical Solution of Local–Global Interaction Buckling of Cold-Formed Steel Channel-Section Columns", International Journal of Steel Structures, Vol. 19, No. 5, pp 1578-1591, October 2019,
https://doi.org/10.1007/s13296-019-00232-4

ABSTRACT: This paper presents an analytical approach to predict the critical load of global buckling with locally buckled channel-section columns under axial compressive loads. The effect of local deformation before global buckling is considered. The analysis is performed by using the Rayleigh–Ritz method. The analytical solution is validated by using the nonlinear finite element analysis method. Parametric study is also performed for different sections including different values of slenderness ratio, height-thickness ratio and width-height ratio. The comparison between the present approach and those taken from Chinese and American standards demonstrates that the present model provides a good approach for predicting the critical loads of steel columns involving local and global buckling interaction.

References listed at the end of the paper:
ABSTRACT: In these days, closed form solutions to estimate the strength increment in the local buckling strength due to the rotational stiffness of the closed-section ribs have been proposed through theoretical approaches using the energy methods and parametric numerical analysis. In this paper, the correlations between the local buckling strength of longitudinally stiffened plates and the rotational restraint stiffness of closed-sections ribs were thoroughly investigated through numerical analyses. Three-dimensional finite element models of longitudinally stiffened plates were obtained using ABAQUS, and a series of comprehensive parametric numerical analyses were conducted in order to reveal the influential design parameters for required rotational stiffness of closed-section ribs for reaching converged buckling strengths. Then, a simplified design equation for the required rotational stiffness for the stiffened plate buckling strength has been proposed, which are applicable for both flat and curved plates to achieve optimum design sections. The comparative study and trend analysis showed that the proposed design methods have a good correlation with the numerical analysis results. Finally, a series of design examples demonstrate a design process of the longitudinally stiffened plates with closed-section ribs by using the proposed design equations.

References listed at the end of the paper:


**ABSTRACT:** To accurately simulate the collapse process of long-span spatial grid structures, certain key parameters should be treated carefully. In the present study, the effects of the strain rate and the damage and fracture parameters were analyzed. A numerical simulation shows the following information: (1) First, the Cowper-Symonds model is utilized to simulate the rate-dependent material properties, illustrating that the strain rate effect can be overlooked for a progressive collapse simulation. (2) Then, the constant failure strain method is used for a damage and fracture simulation. The first fracture of the members is postponed, and the final failure patterns are therefore quite different with an increase in the initial damage-equivalent plastic strain. (3) And, the progressive collapse pattern is unaffected while the fracture is delayed or prevented with a greater equivalent plastic strain of the final failure. These results can provide a reference for determining the damage and fracture parameters. (4) Finally, the equivalent plastic strain of the initial damage is relevant to the stress triaxiality. After considering the stress triaxiality, there is a significant difference compared with the constant failure strain model. The stress triaxiality must therefore be considered.

References listed at the end of the paper:

Direct Strength Design of Cold-Formed Steel Members Using Constrained Spline Finite Strip Method",
International Journal of Steel Structures, Vol. 19, No. 6, pp 1801-1813, December 2019,
https://doi.org/10.1007/s13296-019-00249-9

ABSTRACT: Direct strength method (DSM) for the design of cold-formed steel members recommends finite strip method (FSM) for calculating the elastic buckling stresses corresponding to local, distortional and global buckling, which are considered to be the basic input parameters for design. This paper presents application of constrained spline finite strip method (cSFSM) developed by authors for calculating pure elastic buckling stresses in DSM and hence predicting the ultimate member capacity in uniform flexure and axial compression. The elastic buckling stresses are determined for a specified set of experiments available in literature using cSFSM by considering different end conditions and failure modes and the elastic stress values are applied in DSM for calculating ultimate member capacity. For beams with simply supported-warping free ends and columns with simply supported-warping fixed ends, the DSM evaluated results using cSFSM produces results comparable with experiments. The results obtained by the comparison of DSM with experiments were not satisfactory for fixed columns and beams with simply supported-warping fixed ends.

References listed at the end of the paper:
was paid to the new type of SRC co
they fundamentally focused on the columns with the simple arrangement of steel section, and a few attention
parameters affecting the seismic behavior of the SRC columns. Important progress has been made by
addressed. In addition, the discussion and summary of the axia
codes of design, bond slip behavior, analytical confinement material models, and finite element analysis, are
comparative studies between
publications regarding the SRC columns. Firstly, the analytical studies of the SRC columns, including
sectional
Yao, Z., & Rasmussen, K. J. R. (2011a). Material and geometric nonlinear isoparametric spline finite strip analysis of perforated thin-
Yao, Z., & Rasmussen, K. J. R. (2011b). Material and geometric nonlinear isoparametric spline finite strip analysis of perforated thin-
Young, B., & Rasmussen, K. J. R. (2006). Compression tests of fixed-ended and pin-ended cold-formed lipped channels. Research


ABSTRACT: The composite steel reinforced concrete (SRC) columns with the form of partial or full encasement of the steel section in the reinforced concrete (RC) have attracted pervasive attention due to their advantages compared to the conventional RC columns. This paper aims to summarize the representative publications regarding the SRC columns. Firstly, the analytical studies of the SRC columns, including comparative studies between available codes to address the philosophy of design and the limits in the available codes of design, bond slip behavior, analytical confinement material models, and finite element analysis, are addressed. In addition, the discussion and summary of the axial behavior of the SRC columns and the important parameters affecting the axial behavior of these types of columns were included. It also attempts to cover the parameters affecting the seismic behavior of the SRC columns. Important progress has been made by the previous studies in the SRC columns under the axial load and the combination of axial and seismic loads, but they fundamentally focused on the columns with the simple arrangement of steel section, and a few attention was paid to the new type of SRC columns with rotated cross-shaped steel section whose webs coincide with the
diagonal lines of the columns’ section. Due to the lack of study and the brittle failure of the columns with lightweight and high strength concrete, more studies should still be made to know the behavior of the SRC columns. The paper concludes with suggestions for the future studies to enhance the effectiveness of the SRC columns.

References listed at the end of the paper:


ABSTRACT: In this paper a new regression relation for nonlinear ultimate buckling resistance of the cones with rectangular cutouts is presented. For this purpose, the effective geometry parameters and material properties such as the length, thickness, large diameter and angle of the cone, the length, width and location of cutout, the modulus of elasticity, yield stress and plastic properties are considered. Then using response surface method, 288 design of experiment is considered and a regression relation for predict the ultimate buckling resistance is proposed. To validate the results, two types of real experiment are presented and the results show that there is good agreement between the experimental tests and proposed relation. Then the effects of changing the various parameters on the ultimate buckling resistance of the cone are investigated. The results show that locating the cutout near the large diameter of the cone has more influence than locating near the small diameter. Also, the location of cutout has more influence at higher values of thickness. In addition, decreasing the length of the cone or increasing the diameter of the cone increase the ultimate buckling resistance and increasing the angle of cone decrease the ultimate buckling resistance of the cone.

References listed at the end of the paper:


ABSTRACT: In this paper, a primary dataset of mainshock–aftershock sequences is constructed from the Pacific Earthquake Engineering Research Center. This is followed by the collection of 342 groups of mainshock–aftershock ground motions for the dynamic time history analysis of a single-layer reticulated dome in the full process domain. According to the change curves between the characteristic factors and acceleration amplitudes, four different levels of influence (i.e. no influence, slight influence, significant influence and...
collapse under aftershocks) of multiple earthquakes on the seismic responses of a single-layer reticulated dome are defined. On this basis, a shaking-table test of a single-layer reticulated dome model, taking aftershocks into consideration, is conducted to obtain the full failure history under multiple earthquakes intuitively. Spherical joints are located accurately, using total station surveying equipment and lead screws during model processing. Experimental results verify the above four levels of influence of multiple earthquakes and provide a dependable reference for seismic design.

References listed at the end of the paper:


Lanhui Guo (1,2), Jian Hou (2), Zhiguo Li (3) and Sumei Zhang (4)

(1) Shanxi Key Laboratory of Safety and Durability of Concrete Structures, Xijing University, Xi’an, China

(2) School of Civil Engineering, Harbin Institute of Technology, Harbin, China

(3) Jilin Research and Design Institute of Building Science, Changchun, China

(4) School of Civil Engineering, Harbin Institute of Technology, Shenzhen, China

ABSTRACT: As a kind of new lateral resistance member, buckling restrained steel plate shear walls (BRSPSWs) possess good ductility and energy dissipation ability, which begin to be used in buildings. In the use of BRSPSWs, it is hard to simulate BRSPSWs in high-rise buildings using shell elements due to convergence problems. Hence, a simplified analysis model for BRSPSWs is needed by engineers. In this paper, the finite element analysis of BRSPSWs under cyclic loads was done. The available experimental results are applied to validate the accuracy of finite element analysis results. Then the behavior of typical BRSPSW under cyclic loads is analyzed. Also, the influence of bolt distance, reinforced concrete (RC) panels’ thickness, height-to-thickness ratio and span-to-height ratio of steel plate on the hysteretic behavior of BRSPSWs is studied. The analytical results show that the bolt distance and RC panel thickness have obvious influence on the energy dissipation ability. At last, a simplified model is proposed, which can be used to simulate the hysteretic behavior of BRSPSWs instead of shell element in high-rise buildings.

References listed at the end of the paper:
ABSTRACT: Vibration analysis of a thin circular cylindrical shell with closure is conducted using finite element method (FEM). Theoretically, shell vibrates in different axial modes, $n$; circumferential modes, $n$; and any of their combinations with corresponding modal frequencies. The present FEM results are verified by the results reported in the literature using various shell theories. The eigenvalues of the shell are extracted using block Lanczos and subspace iteration methods, in order to investigate their computational efficacy. Further, the effect of adding various types of closures at one end of the circular cylindrical shell such as flat, cone, and dome, on the modal frequencies are investigated. The two aspect ratios (length to radius ratio) of shell with closure, broad, and slender are considered for this study. The effect of the ratio of the thickness of the closure to the thickness of shell wall on the frequency is also investigated. For the shell with the closure, the vibration modes can be cylinder, closure, or combined cylinder and closure. The modal frequency of the cylindrical shell is significantly affected by the closure. The lowest frequency is observed in the flat type of closure in both the broad and slender cylindrical shells in comparison to the non-closure, dome, and cone type of the closures.

References listed at the end of the paper:


ABSTRACT: This study establishes an improved analytical method (IAM) to investigate the dynamic characteristics of composite box beam with corrugated webs (CBBCW), and the IAM has comprehensively considered the effects of several factors, such as the shear lag, interfacial slip, shear deformation and rotational inertia of CBBCW in combination with the characteristics of CBBCW. Further, based on the Hamilton principle, the vibration differential equation and boundary conditions for CBBCW have been deduced. Finally, an IAM for calculating the dynamic characteristics of CBBCW was proposed. Based on the IAM developed in this study, the natural frequencies of multiple CBBCW cases with different spans, shear connection degrees and boundary conditions have been calculated. The results calculated by the IAM have been compared with those calculated by the finite element method and by the general beam theory. The comparison verifies the effectiveness of the IAM and obtains some conclusions that are meaningful to engineering design, i.e. the shear lag effect of CBBCW increases with increasing shear connection degree and also increases with increasing order of the vibration mode, the shear lag effect of the CBBCW is up to 6.2% in the first five orders of the vibration modes and the effect cannot be ignored. In the first- and second-order vibration modes of the CBBCW cases, the maximum interface slip effect of CBBCW is 28.42% and therefore cannot be ignored. On the other hand, the shear lag effect of CBBCW is usually lower than those of ordinary composite box beam with the same web thickness.

References listed at the end of the paper:


ABSTRACT: This paper presents numerical works and multi-objective optimization of the energy absorbing connectors which was employed to dissipate blast/impact energy through curved plates and aluminum foam. Finite element models of the energy absorbing connectors under dynamic crushing load were established and validated with the impact loading tests. Then, the parametric studies were conducted to reveal the influences of crushing velocity, angle \(\theta\), curved plate thickness as well as length and height of aluminum foam on the energy absorbing characteristics. Increasing crushing velocity was shown to improve the absorbed energy of the connector owing to the strain rate enhancement and change of deformation mode. In addition, the absorbed energy could also be increased via increasing curve plate thickness, length and height of aluminum foam as well as decreasing angle \(\theta\). The multi-objective optimization was conducted by employing the non-dominated sorting genetic algorithm II. It was noted that the specific energy absorption and peak crushing force were conflicting with each other.

References listed at the end of the paper:


ABSTRACT: In this study, a new analytical method is presented to estimate the shear capacity of diagonally stiffened steel–concrete composite plate girders. This method is formulated based on tension field action in steel girder web and failure mechanism of concrete slab deck. To validate the accuracy of the proposed method, the obtained results are compared with three-dimensional finite element analysis of composite plate girders with different configuration of stiffeners. The results of analytical and numerical investigations indicate that the proposed method can accurately estimate the ultimate shear capacity of composite plate girders. In addition, it is shown that the diagonal stiffeners on one hand can reduce the buckling effects of shear panel of girders and on the other hand can increase the strength of elastic shear buckling and ultimate shear capacity of girders well in comparison with the unstiffened thin steel plate girders.

References listed at the end of the paper:


Aliakbar Hayatdavoodi, Mohammad Nazari and Alireza Javadi Pordesari (First author is from: Department of Civil Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran), “Investigation on the Collapse Behavior of Diagonal Stiffened Composite Plate Girders Subjected to Shear Loading”, International Journal of Steel Structures, Vol. 20, No. 2, pp 386–399, April 2020,

ABSTRACT: This paper presents experimental findings of carbon fibre reinforced polymer (CFRP) strengthened cold-formed steel built-up channels subjected to axial load. In order to sensitively detect the buckling strengths and failure modes, twenty-four built-up columns were tested in which twelve columns were unadorned and another twelve columns were strengthened using CFRP sheets. The columns were tested for ultimate load, lateral displacement and failure modes. Tension coupon tests were conducted to determine the material properties of test specimens. The experimental results were compared with the design load calculated according to AISI S100-16 specification and are found to be in good agreement. It is established that the use of CFRP for strengthening increases the ultimate load and delays the buckling.

References listed at the end of the paper:

Abdulkadir Cüneyt Aydın, Zeynep Yama Elif Agcakoca, Mahmut Killic, Mahyar Maali and Ali Aghazadeh Dizaji (First author is from: Department of Civil Engineering, Engineering Faculty, Atatürk University, 25030, Erzurum, Turkey), “CFRP Effect on the Buckling Behavior of Dented Cylindrical Shells”, International Journal of Steel Structures, Vol. 20, No. 2, pp 425–435, April 2020,

ABSTRACT: Considering that the use of thin-walled shells is expanding every day, it is important to examine the problem of instability in this form of structure. Many steel structures such as high-water tanks, water and oil reservoirs, marine structures, and pressure vessels, including shell elements, are under stress tension. In addition, shell elements are subject to instability owing to the loads applied. Ten thin-walled cylindrical shell specimens in two groups with different dent depths of t and 2t, and the different dent number subject to uniform external pressure were tested in the present research (t is the thickness of cylindrical shell). The samples were modified to include either one or two dent line with amplitudes of h/3 in height (h the height of cylinder shell). Moreover, CFRP Strips on the dent depth was used in one of the groups. The results of testing under different theories and codes are compared.

References listed at the end of the paper:
Seo Haeng Lee, Geun Woo Park and Jung-Han Yoo (First author is from: Department of Architecture, Seoul National University of Science and Technology, Seoul, 01811, Korea), “Analytical Study of Shear Buckling Behavior of Trapezoidal and Sinusoidal Corrugated Web Girders”, International Journal of Steel Structures, Vol. 20, No. 2, pp 525-537, April 2020, ABSTRACT: In this study, nonlinear finite element analysis was performed in order to identify the effects of variables that compose sinusoidal webs, and to analyze the effects of the ratio ($\beta$) of the length of the horizontal panel to the length of the tilted panel, one of the variables that compose trapezoidal webs. Based on the analysis models with high accuracy that were validated by earlier studies, variables were analyzed depending on the shape of webs. In addition, equations suggested by earlier studies were analyzed based on the validated models using the results of the analysis of variables. It was found that the equation in Eurocode is more conservative than other equations suggested by earlier studies.

References listed at the end of the paper:


This paper presents an analytical study on the dynamic instability of castellated columns subjected to axial excitation loading. By assuming the instability modes, the kinetic energy and strain energy of the columns and the loss of the potential of the axially applied load are evaluated, from which the mass matrix, stiffness matrix, and geometric stiffness matrix of the system are derived. These matrices are then used for deriving dynamic equations and carrying out the analysis of dynamic instability of castellated columns by using Bolotin's method. The analytical expression for determining the critical excitation frequency of the columns is derived, which takes account for not only the shear influence of web openings but also the rotary inertia effect on the transverse vibration of the columns. Numerical examples are also provided for illustrating the dynamic instability behaviour of castellated columns when subjected to axial excitation loading. The results show that the consideration of the shear effect in castellated columns results in a shaft of the dynamic instability zone to low frequency side and a reduction of the width of the dynamic instability zone. The shear effect on the dynamic instability zone becomes more significant in the short column than in the long column, and in the wide flange column than in the narrow flange column.

References listed at the end of the paper:


ABSTRACT: High-height columns become more economically viable when designed with thin-walled open cross-sections. For such structural release, there is the occurrence of the flexion-torsion phenomenon and the evident loss of lateral stiffness, which can be reduced with the presence of bracing by lintels spaced at height. In the case of road bridges and overhead cranes, there is a low traffic speed, characterizing internal forces that allow the use of cross-sections folded into C and Z-shaped sheet metal, as well as double-T-shaped welded metal sections. In this sense, this paper is intended to contribute to the advancement of the Continuous Medium Technique (CMT) formulation through the Wall Panel Theory (WPT) applied to the thin-walled columns. Through the WPT applied to thin-walled sections, it is possible to express the system of differential equations of the static problem, characterizing the rigidity of the core column via matrix [J] and bracing by matrix [S]. In item 2.3, the inclusion of the dynamic portion in the WPT is performed, thus providing the determination and characterization of the first seven vibration modes of the abovementioned column. Finally, this paper provides the structural engineer with a manual verification tool (via CMT) of static or dynamic modeling for thin-walled columns using commercial software. In this paper we used software ANSYS 2019 R1 (student version) for such numerical checks and validations.

References listed at the end of the paper:
The reticulated shell is also influenced by bending angle of bowed member. On the one hand, member imperfection can be neglected when nodal deviation is large enough. Load is affected by member imperfection, while magnitude of nodal deviation also affects load. Load is sensitive to nodal deviation, and member imperfection, the effect of member imperfection on load is considered is extremely sensitive to nodal deviation. For reticulated shell with larger nodal deviation and member imperfection, the effect of member imperfection on load-carrying capacity is closely related to the magnitude of nodal deviation. Load-carrying capacity of shell with smaller nodal deviation is obviously affected by member imperfection, while not sensitive to member imperfection for reticulated shell with larger one. Member imperfection can be neglected when nodal deviation is large enough. Load-carrying capacity of reticulated shell is also influenced by bending angle of bowed member. On the whole, load-carrying capacity of...
ABSTRACT: Based on precise transfer matrix method (PTMM), the analytical model of the double-walled steel cylindrical shell was setup by taking into account of the annular plate and interlayer water. Under the linear sweep frequency excitation or the fixed frequency excitation, an experimental model of the double-walled steel cylindrical shell has been designed, which is performed to gain the natural frequencies, forced vibration in air and water, underwater acoustic radiation. The analytical model was established to calculate natural frequencies, vibration acceleration level and sound pressure level and compare with the relevant experimental results. The compared results show that analytical results coincide with the experimental value and prove that the analytical model established by PTMM is reliable and credible. Meanwhile, the forced vibration behaviour of measuring positions at inner and outer shells was investigated both theoretically and experimentally. Effects of different types of external excitations on the vibration and sound radiation of the double-walled cylindrical shell are discussed. As to acoustic radiation, the acoustic excitation plays a leading role in the low-frequency range. The force excitation is a major contributor in middle-high frequency range conversely.

References listed at the end of the paper:


Fei Wu, Xiaoting Xiao, Qian Liu and Jianghuai Tong, “Effects of Matching Conditions Between Crocheted Mesh Tube and Metal Tube on Crushing Behaviour and Energy Absorption of Interlayer Tubes”, International Journal of Steel Structures, Vol. 20, No. 4, pp 1151-1164, August 2020,

ABSTRACT: This paper focuses on comparing the quasi-static crushing mechanical behaviour and energy absorption characteristics of four types of interlayer tubes formed by combining mesh tube and 304 tube with two different interface matching methods (tight fit and metallurgical bonding). The deformations and energy absorptions of interlayer tubes are still dominated by 304 tube. The mesh tube and metallurgical points are able to induce and improve the deformation of 304 tube by changing its axial crushing stress state, thus, affecting the shapes and quantities of its folds, changing its deformation behaviours and modes, and finally forming interlayer tubes with different mechanical behaviours and energy absorption characteristics. The tight fit interlayer tubes exhibit better mechanical behaviour and energy absorption compared with the hollow 304 tube. The sintering interlayer tubes matching by metallurgical bonding can further improve the mechanical behaviours and energy absorptions of interlayer tubes and present more stable crushing deformations and stronger bearing capacities. It is an effective method to improve the mechanical behaviours and energy absorption characteristics of interlayer tubes by changing interface matching modes.

References listed at the end of the paper:
mo Attenuation and the effectiveness of these elements on the overall seismic behavior is studied. Seven nonlinear shear wall structural system with and without outriggers. The outrigger panels are placed in 20th, 30th, and 40th floors. The outriggers could significantly reduce the lateral drifts and seismic demand on the VBEs by redistributing some of the demands on vertical boundary elements (VBE). Placement of additional SPSW panels in the structure acting as outriggers could significantly reduce the lateral drifts and seismic demand on the VBEs by redistributing some of the overturning forces to adjacent columns. In this paper, a 40-story building is evaluated using steel plate shear wall structural system with and without outriggers. The outrigger panels are placed in 20th, 30th, and 40th story levels and the effectiveness of these elements on the overall seismic behavior is studied. Seven nonlinear shear wall structural systems with added outriggers are compared to the base case without outriggers. The results show that the addition of outriggers can significantly improve the seismic performance of the building, reducing both the lateral drifts and the seismic demand on the building.
time history analyses are carried out and the seismic performance of the structural system with outriggers is compared to the performance of the system without outriggers. The results indicate a significant reduction in lateral drifts and VBE seismic demands when the system is augmented with steel plate outrigger panels.

References listed at the end of the paper:

ABSTRACT: The fire accidents casually happen during operation of ship, which would influence the load carrying capacity of stiffened panel of ship structures due to the thermal load. The present paper aims to understand the influence of thermal loads on the collapse behaviour of stiffened panels under longitudinal compressive load. Considering the heating and cooling down processes, the collapse behaviours of the stiffened panels under combined in-plane displacement and heat loads representative of fire accident are simulated in the FE (finite element) analysis herein. Firstly, the thermal load is considered to investigate the stress state of the stiffened panels during heating and cooling processes. It is found that the stiffened panels would collapse during thermal loads for the structure with large heated zone. After that, the longitudinal compression loads are applied to assess the collapse strength of the stiffened panels. The parametric studies including different geometrical dimensions and areas of heat zone are performed in detail to quantify the effects of heat loads on the collapse behaviours of stiffened panels. It is found that the expansion could produce biaxial stress state that depends on not only in-plane stiffness but also collapse modes, and for stiffened panels with various heated area the cooling down to room temperature induce similar ultimate strength to that without considering heat loads.

References listed at the end of the paper:

A systematic parametric study has been conducted to investigate the behaviour of lean duplex stainless steel semi-elliptical hollow section members subjected to torsion, using finite element software, Abaqus. The finite element models were initially validated with reliable experimental results; upon which parametric study was conducted. Effects of various key parameters such as aspect ratio, curve length, size and thickness of cross-section were studied. Based on the finite element study, sections of higher aspect ratio, curve length, larger size, and higher thickness were found to have more torque carrying capacity. Available design equations for plates under shear loading were checked for their applicability to the design of semi-elliptical hollow sections subjected to torsion. An attempt has also been made to develop design equations for lean duplex stainless steel semi-elliptical hollow section under torsion, based on EN 1993-1-4: 2006 + A1. Additionally, design equations based on deformation based method (in line with continuous strength method) were also proposed. The proposed equations were found to give reliable results for design of lean duplex stainless steel semi-elliptical hollow section members under torsion.

References listed at the end of the paper:


ABSTRACT: A systematic parametric study has been conducted to investigate the behaviour of lean duplex stainless steel semi-elliptical hollow section members subjected to torsion, using finite element software, Abaqus. The finite element models were initially validated with reliable experimental results; upon which parametric study was conducted. Effects of various key parameters such as aspect ratio, curve length, size and thickness of cross-section were studied. Based on the finite element study, sections of higher aspect ratio, curve length, larger size, and higher thickness were found to have more torque carrying capacity. Available design equations for plates under shear loading were checked for their applicability to the design of semi-elliptical hollow sections subjected to torsion. An attempt has also been made to develop design equations for lean duplex stainless steel semi-elliptical hollow section under torsion, based on EN 1993-1-4: 2006 + A1. Additionally, design equations based on deformation based method (in line with continuous strength method) were also proposed. The proposed equations were found to give reliable results for design of lean duplex stainless steel semi-elliptical hollow section members under torsion.
Profiled steel sheets with very high depth. The analysis encompassed determination of the ultimate limit strength, material nonlinearity and contact analysis in the support zones was applied for the strength calculation. Influence on structural strength. In this research, the finite element method analysis with geometrical and testing. However, catalogues provide little data about the support conditions at the ends that may have influence on structural strength. In this research, the finite element method analysis with geometrical and material nonlinearity and contact analysis in the support zones was applied for the strength calculation of a profiled steel sheet with very high depth. The analysis encompassed determination of the ultimate limit strength.
and serviceability limit strength with limited deflection. All analyses were conducted for surface load applied over the area of one sheet. Thereat, influence of several factors related to support conditions was considered: friction on the supports, support width, and number of fasteners. Failure mechanisms were also analysed. Obtained results were compared with other sources and methods, like analytical solution, manufacturer’s software, and catalogue data. Results of the research showed that behaviour and strength of those elements depend to the great extent on end support detailing, which cannot be encompassed by classical calculation methods and linear analysis. Significance of the support conditions was proven, and attention was paid on absence of such data in published catalogues.

References listed at the end of the paper:


ABSTRACT: Concrete sandwiched double steel tubular (CSDST) columns have improved ductility under cyclic loads. Two CSDST columns are investigated in this paper (1) CSDST-CS with Circular outer tube and Square inner tube and (2) CSDST-CC with Circular outer tube and Circular inner tube. The confinement of concrete between the annular spaces of the inner and outer tubes is very important for their behaviour. To the authors’ knowledge, the literature is scarce on a validated concrete confinement model for CSDST. In this paper, the concrete confinement mechanism in CSDST columns is explained based on thick-walled cylinder theory and a semi-analytical equation is developed. Hollowness ratio of the cross-section, width to thickness
ratio of the outer steel tube, strength of the outer steel tube and sandwiched concrete strength are identified as the main parameters influencing the confinement effect in CSDST. The proposed equation is extended to CSDST-CS with inner square tube approximated as an equivalent circular tube. This assumption is validated by conducting tests on short column specimen under axial compression. With outer tubes being the same, concrete confinement effect in CSDST-CS, CSDST-CC and concrete filled steel tubular column (CFST) are 18%, 20% and 30%, respectively. This study has demonstrated that the presence of double steel tubes does not improve the concrete confinement in CSDST compared to CFST. Further, this study presents a modification to the design equations of EN 1994-1-2 2005-1-1 (Eurocode 4: Design of composite steel and concrete structures Part 1–1: General rules and rules for buildings. European Committee for Standardization, Brussels, 2004) for CFST columns to CSDST stub columns by incorporating the effect of hollowness.

References listed at the end of the paper:


ABSTRACT: Perforated steel plate shear walls (PSPSWs) are requested for passing the equipment and creating the accessing spaces. Also, the studies showed the PSPSWs enhance the ductility. In this paper, topology optimization (TO) is used to introduce a new form of the PSPSW in the moment frames based on the strain energy as the objective function. The TO is conducted using the sensitivity analysis, SIMP method and method of moving asymptotes. Four amounts of aspect ratio (0.67, 1.0, 1.5 and 2.0) and three plate thicknesses (2 mm, 4 mm and 8 mm) are defined in the TO and their effects are considered in the results. For a comprehensive study, the results of TO are compared with the three usual forms of PSPSW with circular holes and a previous optimized model. The material volume is equal for the plates with the identical aspect ratio and plate thickness. The cyclic behavior of all the models is investigated and compared in terms of strength, energy dissipation and fracture tendency. The analytic hierarchy process (AHP) is applied to score and determine the best model and form. The AHP method illustrated that the optimized models have a better performance. The results of the AHP method show that the optimized model in this study obtained 22.07% of the score from 100%, while the scores of the prior optimized model and three traditional models are 20.67%, 19.36%, 19.06% and 18.84%, respectively.

References listed at the end of the paper:


ABSTRACT: The rack column is one of the essential elements in the pallet rack system. However, due to its distinctive perforation feature, it is challenging to analyze its stability using traditional theories for cold-formed steel structures. In this paper, we are interested in the comparison analysis of strength prediction on the perforated columns using finite element method (FEM), regression analysis (RA) and artificial neural network (ANN) methods respectively. First, a refined finite element (FE) model considering the perforation and nonlinearity behavior was generated and calibrated against the experimental results. Subsequently, the validated FE model was used to perform the parametric analysis for the different holes in columns. Given experimental and simulated data, a regression model with an equivalent thickness was proposed for the design strength prediction of thin-walled steel perforated sections. For comparison of the RA model, two powerful tools such as the FEM and ANN are also employed to predict the design strength of different perforated sections. Four indicators were used to assess the accuracy and generalization performance of the three models, including the root mean square error, the mean absolute percentage error, the correlation coefficient and the mean relative percentage. The obtained results show that although they both have good consistency, FEM still slightly outperforms the other two models. Since the values calculated from ANN and regression models are usually smaller than the experimental data, they are reasonably recommended as effective and safer design tools than FEM models from the perspective of engineering applications.

References listed at the end of the paper:

- ANSYS Inc. (2010). ANSYS mechanical APDL structural analysis guide. ANSYS release 13.0, USA.

ABSTRACT: Wind energy has become one of the most widely used alternative energy sources in recent years due to its clean and renewable character. In the context of increasing demand for new facilities, the cost of a wind turbine is a key factor for the success of new wind farms. The reduction of the amount of material used to build the wind turbine tower is one way to reduce the project cost. This work presents a methodology for the minimization of the weight of the tubular steel towers of wind turbines using a metaheuristic optimization algorithm. The diameters of the cross-section at the base and the top of the conical tower are considered as continuous design variables. Due to constructional aspects, the tower is manufactured in many segments, which wall thicknesses are taken as discrete design variables. Besides the dead load, the design considers the action of wind load, which is taken as an equivalent static force determined using the Brazilian standard NBR6123. The
design constraints considered in this work are the maximum admissible displacements at the top of the tower under service condition, the tower's lowest natural frequency and the safety criteria for steel structures defined by the Brazilian standard NBR8800. The mixed-integer nonlinear optimization problem formulated for the structural design in this work is solved using the quantum particle swarm optimization algorithm (QPSO). On average, the QPSO solution was 12% lighter than designs based on other well-established algorithms in a comparative study. Nonetheless, no significant improvement was observed concerning the standard particle swarm optimization.

References listed at the end of the paper:
ABSTRACT: Cold-formed thin-walled steel hollow flange beam (HFB) has been emerged and utilised structurally. It is composed of one or two closed flanges with high torsional stiffness and relatively flexible web. Hence, the global stability of such beam has greatly been improved compared with conventional I-beams with flat flanges, due to their superior torsional stiffness and stability. However, under concentrated loading, local flange deformation occurs easily at the load-action-region, because the tubular flange is hollow even if stiffeners are attached to the webs. Up-to-date, rather than filling the tubular flange with concrete, there is not any relevant literature or reports on how to improve the local buckling state of the hollow flange I-beams. Accordingly, in this paper, a stiffened compression rectangular hollow flange beam (SCHFB) is presented, from which the web penetrates the bottom wall of the top tubular flange until it reaches its top wall. By doing so, several concentrated loads may be applied safely on the beams or the segmental lunching technique may successfully be used to erect the beam in its place. This paper examines experimentally this stiffened beam and then extends to use the finite element modelling to replicate the actual behaviour of the beam. A numerical comparison between the SCHFB, conventional CHFB and I-beam shows that the ultimate bearing capacity and ductility are significantly enhanced in the case of SCHFB compared with the other two beams. Additionally, the SCHFB has been found to own better local deformation performance than that of the CHFB. However, with the span increase, the vertical concave deformation, lateral deformations at top flange and vertical deformations of top flange plate of the tubes of the SCHFB and CHFB may approach each other. So, the SCHFB becomes the best choice for short-span beams under either concentrated or distributed loading.

References listed at the end of the paper:
Jun Wu, Yongfeng Luo and Lei Wang, “Geometric Imperfection Distributions of Existing Reticulated Shells: Theoretical and Experimental Analysis”, International Journal of Steel Structures, Vol. 20, No. 5, pp 1606-1617, October 2020,

ABSTRACT: Geometric imperfection is one of the most disadvantageous factors that impair mechanical behaviors of existing reticulated shell structures. However, the available consistent mode methods and statistical methods which usually applied in designing structures can hardly estimate the actual geometric imperfection distribution for existing structures, because these methods use the assumed imperfections. In this paper, a Markov Random Field (MRF) theoretical model of existing reticulated shells is established by introducing the theory of probabilistic graphical model. The unit of graphic model named node clique are proposed to deduct the geometric state function of reticulated shells, based on the local Markov property. Then the inversion function along with its iterative equation is established to predict geometric imperfection distribution of existing reticulated shells. The MRF method makes the predicted distribution of the numerical model as consistent as possible with its corresponding actual structure, and only a few measurement nodes are needed as known conditions. An experimental structure of K6 single-layer reticulated shell is built to verify the proposed theory by comparing the calculated geometric imperfection distribution results with the actual measured data. Meanwhile, the significance level of the calculated results between MRF and traditional stochastic method is analyzed, which shows MRF method can effectively predict the geometric imperfections of single layer reticulated shells.

References listed at the end of the paper:
SCS sandwich shells were also analyzed and discussed in detail. It was noted that the concrete debris can be restrained by the face steel plates with good ductility. Numerical results against existing blast test. The displacement histories, damage of concrete and remaining fatigue life. Structure and Infrastructure Engineering, 3(3), 245–255.


ABSTRACT: The steel–concrete–steel sandwich structures are usually composed of concrete core and face steel plates. This paper presented the dynamic response of the curved steel–concrete–steel (SCS) sandwich shells subjected to blast loading. The bolts were employed to connect the face steel plates and the concrete. Numerical model was established based on LS-DYNA and the accuracy of the modelling method was verified against existing blast test. The displacement histories, damage of concrete and energy absorption capability of the shell were obtained from the numerical calculations and discussed. Different failure modes of the curved SCS sandwich shell under various loads were obtained from numerical results, i.e., local deformation of the shell for the case of close-in detonations and buckling of steel plates for the case of far-field detonations. It was noted that the concrete debris can be restrained by the face steel plates with good ductility. Numerical results showed that the energy absorption from concrete is higher under close-in detonations on the ground. The effects of charge weight, steel plate thickness, concrete thickness and rise height on the dynamic response of curved SCS sandwich shells were also analyzed and discussed in detail. The curved SCS sandwich shell with thicker
back steel plate showed better blast resistant performance. Moreover, the damage of curved shell was more serious if the rise height to span ratio ($R_h$) is beyond the range of 0.16–0.25.

References listed at the end of the paper:


buildings and bridges in recent years, because of their properties, such as high strength and stiffness, good

ABSTRACT: Concrete-filled steel tubular (CFT) columns have been widely used as structural members in buildings and bridges in recent years, because of their properties, such as high strength and stiffness, good

ductility, and convenience for construction. In CFT columns, the bearing capacity of columns is inversely related to buckling, therefore, buckling is of particular importance at these sections, the AISC Code uses effective bending rigidity ($EI_{b}$) to calculate the critical buckling load in concrete filled steel columns, to apply the effect of reducing concrete confinement, the AISC code provides a maximum value of 0.9 of the reduced concrete confinement coefficient for the equation. Effective bending rigidity ($EI_{b}$), this relationship is provided in AISC code for circular and square sections, therefore, the effect of the column shape geometry on the core concrete confinement is very influential and changes the effective bending rigidity ($EI_{b}$) of the section. The AISC code does not provide a coefficient to consider the type of cross-sectional geometry in CFT columns, therefore, in this study, three groups experimental, numerical (FEM) and theoretical were used to provide critical buckling load correction, finally, it was concluded that the critical buckling load for the cross-section (L) shape due to the lower confinement of the concrete core is 20.07% lower than the AISC code equation, also with a 67% increase in slenderness ratio, the critical buckling load decreased by 14.52%.

References listed at the end of the paper:


ABSTRACT: This paper reports the results of a numerical investigation on the influence of local buckling on the ultimate strength and design of locally fixed-end and globally pined-end stainless steel lipped channel columns in compression. The elastic buckling load is a key parameter in predicting the design strength of stainless steel lipped channel columns. Elastic buckling loads under simple–simple, clamped–clamped and experimental boundary conditions have been compared. To extend the data, a finite element model of stainless steel lipped channel columns has been developed and verified against the test data. Parametric studies on the stainless steel lipped channel columns were performed. The test results are compared with the strength predictions from direct strength method (DSM), indicating that DSM included in North American specification is unsafe, but the DSM proposed by Becque et al. is conservative. A modified DSM equation was proposed and has been proven to accurately predict the ultimate capacities of the stainless steel lipped channel columns in compression.

References listed at the end of the paper:

- Li, Z., & Schafer, B. W. (2010). Buckling analysis of cold-formed steel members with general boundary conditions using CUFSM conventional and constrained finite strip methods.

ABSTRACT: Stainless steel has superior corrosion resistance, fire resistance, and maintenance compared to carbon steel as a structural material. Although austenitic stainless steel (STS304) has mainly been used as structural steel material, lean duplex stainless steel, STS329FLD with lower nickel component (reduced to 0.5–1.0% in KS) has recently been developed as a substitute for austenitic stainless steel. Since duplex stainless steel is less costly and has excellent corrosion resistance compared with austenitic stainless steel, its use is expected to increase in the field of industry and infrastructure. However, there have been little data to apply this duplex stainless steel member to structural use. This paper presents an experimental and numerical investigation on the structural behaviors of austenitic stainless steel (STS304 TKC) and lean duplex stainless steel (STS329FLD TKC) circular columns subjected to concentrically axial compression. Test specimens were fabricated with four types of column lengths and slender ratios and were tested with both fixed ends. Duplex stainless steel (STS329FLD TKC) material showed higher yield stress and tensile strength than those of austenitic stainless steel (STS304 TKC). The results such as buckling shapes (local and global buckling) and ultimate strengths through additional parametric analysis were investigated and were compared with those predicted by current design codes [American Society of Civil Engineers (ASCE) and Eurocode (EC 3)] and by design equations of previous studies. Modified buckling equations were recommended considering the initial imperfection factor and limiting slenderness of two types of stainless steel circular columns and the accuracy of buckling strength prediction was improved.

References listed at the end of the paper:

- American Society of Civil Engineers (ASCE). (2002). Specification for the design of cold-formed stainless steel structural members. SEI/ASCE-8-02, USA.

**ABSTRACT:** The damage evolutions of square concrete-filled steel tubular (CFT) columns were experimentally studied by the axial compression cyclic loading test and the acoustic emission (AE) monitoring technique. Based on the mechanical analysis and damage observations, the limit damage states, i.e. inner concrete cracking, confinement of steel tube, yielding and buckling of steel tube, weld seam splitting and inner concrete spalling were verified. The released strain energy due to the damage of CFT column was monitored by the AE technique and analyzed by the peak frequency classification method. The results show that the buckling of steel tube is the damage state with the maximum load carrying capacity for CFT columns. Most of the released strain energy were detected by the AE signals with the peak frequency between 30 and 75 kHz and most of the strain energy were released after the buckling of the steel tube.

**References listed at the end of the paper:**
ABSTRACT: The American Institute of Steel Construction provides design equations for the lateral torsional buckling (LTB) of beams under fire. However, these equations are limited only to prismatic beams. Stepped beam factors are introduced by researchers that accounts the change in cross-sections of beams to determine capacities of stepped beams under normal temperatures. This paper assesses the validity of the stepped beam factors for the LTB capacities of stepped I-beams located at its midspans integrated to the AISC equation for beams under high temperatures. A set of numerical studies using finite element analysis program, ABAQUS, was conducted to assess the buckling behavior of stepped beams. The analysis is composed of heat-transfer analysis that evaluates the change in material properties of steel as heat propagates the material from $20^\circ$C to $800^\circ$C; and Static Riks analysis where the beams are applied with uniform end moments. Correlation between the results from the stepped beam equations and the simulated data from ABAQUS has been done. The comparison between data showed that the proposed equation generated conservative estimates with an average percentage difference of 11.48% for inelastic LTB, whilst, 2.07% for the elastic LTB. In addition, the ratio of the increase in strength and increase in volume of stepping of beams shows that the flange width of the stepped beam controls its efficiency in lateral torsional buckling capacity. Overall, the results of this research proved that the existing stepped beam equations can be used in calculating the structural capacity of stepped beams at midspan under both normal and elevated temperatures.

References listed at the end of the paper:


ABSTRACT: This paper deals with experimental investigations into in-plane stability of fixed concrete-filled steel tubular (CFST) parabolic arches. Three CFST arches with the same span but different rise-to-span ratios were tested under five-point symmetrical concentrated loads over the full span. All applied loads were controlled in synchronization. The test results show that the test arches buckled in an antisymmetric failure mode and the section positions with the maximum deformation were slightly different for three test arches. It is found that the bearing capacity of CFST arches decreased significantly with the decline of rise-to-span ratios,
and the outer steel tube provided significant confinement effects on the core concrete after the load reaches 80% of the load-carrying capacity. Moreover, comparisons between the test and finite element results indicate that the existing beam-element modeling method can predict the in-plane stability performance of CFST arches very well.

References listed at the end of the paper:

Seong-Wook Han, Yeun Chul Park Ho-Kyung Kim and Doobyong Bae, “Evaluating Local Buckling Strength of HSB460 Steel Tubular Columns”, International Journal of Steel Structures, Vol. 20, No. 6, pp 2086-2093, December 2020, https://doi.org/10.1007/s13296-020-00435-0

ABSTRACT: High performance steels for bridges (HSB), as adopted by the Korean Design Standard (KDS), having a yield strength greater than 350 MPa have recently been developed. Notably, HSB460, which has a minimum yield strength of 460 MPa, does not exhibit a yield plateau beyond yielding and exhibits strain hardening. Such characteristics could provide advantages by absorbing the greater strain energy of steel members and increasing the local buckling strength, which may help develop more economic bridge designs. However, the current KDS for compression members of steel tubular columns was established based on the results of axial load tests for conventional structural steel having yield strengths from 250 to 350 MPa, which
exhibits a yield plateau. Three-dimensional finite element analyses adopting actual stress-strain curve of HSB460 were subsequently carried out to evaluate the buckling strength, by considering the ovality, welding residual stresses, and the cross-section sizes. It was confirmed that HSB460 steel tubular columns could have larger margins compared to the current KDS, primarily due to advantages from strain hardening with no yield plateau. As such, with regards to local buckling, the proposed design guidelines for HSB460 steel is expected to enable a more economic bridge design.

References listed at the end of the paper:


International Journal of Steel Structures, Vol. 20, No. 6, pp 2086-2093, December 2020,

More papers published in the journal, ASME Journal of Mechanical Design. (2019 and on)

Google the string: “Journal of Mechanical Design”, then click on the entry:
“Journal of Mechanical Design – The American Society of Mechanical…..”, then find “Browse All Issues”


ABSTRACT: Origami folding provides a novel method to transform two-dimensional (2D) sheets into complex functional structures. However, the enormity of the foldable design space necessitates development of algorithms to efficiently discover new origami fold patterns with specific performance objectives. To address
this challenge, this work combines a recently developed efficient truss finite element model with a ground structure-based topology optimization framework. A nonlinear mechanics model is required to model the sequenced motion and large folding common in the actuation of origami structures. These highly nonlinear motions limit the ability to define convex objective functions, and parallelizable evolutionary optimization algorithms for traversing nonconvex origami design problems are developed and considered. The ability of this framework to discover fold topologies that maximize targeted actuation is verified for the well-known “Chomper” and “Square Twist” patterns. A simple twist-based design is also discovered using the verified framework. Through these case studies, the role of critical points and bifurcations emanating from sequenced deformation mechanisms (including interplay of folding, facet bending, and stretching) on design optimization is analyzed. In addition, the performance of both gradient and evolutionary optimization algorithms are explored, and genetic algorithms (GAs) consistently yield solutions with better performance given the apparent nonconvexity of the response-design space.

References listed at the end of the paper:

Based Devices Using an Energy Visualization Approach

Jacob Greenwood

References

applicability of the proposed method.

Also,

rotation angles, and neutral axis configuration and cross loading conditions, which lead to asymmetry of tangent operator. Performance measures are displacements and penalty and Lagrange multiplier methods. The developed adjoint DSA metho

curved Kirchhoff beams. In multipatch models, a rotational junction continuity condition is imposed using discretization of the global displa

ABSTRACT: This paper presents a configuration and sizing design optimization method for large deformation planar compliant mechanisms, using a continuum-based adjoint design sensitivity analysis (DSA) approach for built-up structures. Under the total Lagrangian formulation, the Jaumann strain formulation using the discretization of the global displacement field is employed to account for the finite deformation of arbitrarily curved Kirchhoff beams. In multipatch models, a rotational junction continuity condition is imposed using penalty and Lagrange multiplier methods. The developed adjoint DSA method can handle nonconservative loading conditions, which lead to asymmetry of tangent operator. Performance measures are displacements and rotation angles, and neutral axis configuration and cross-sectional thickness are considered as design variables. Also, analytical design sensitivity expressions for the rotation continuity condition are derived. Various compliant mechanisms including path-generators and an angular rotator are synthesized to demonstrate the applicability of the proposed method.

References listed at the end of the paper:

(Cannot easily cut and paste them)


ABSTRACT: This paper presents a configuration and sizing design optimization method for large deformation planar compliant mechanisms, using a continuum-based adjoint design sensitivity analysis (DSA) approach for built-up structures. Under the total Lagrangian formulation, the Jaumann strain formulation using the discretization of the global displacement field is employed to account for the finite deformation of arbitrarily curved Kirchhoff beams. In multipatch models, a rotational junction continuity condition is imposed using penalty and Lagrange multiplier methods. The developed adjoint DSA method can handle nonconservative loading conditions, which lead to asymmetry of tangent operator. Performance measures are displacements and rotation angles, and neutral axis configuration and cross-sectional thickness are considered as design variables. Also, analytical design sensitivity expressions for the rotation continuity condition are derived. Various compliant mechanisms including path-generators and an angular rotator are synthesized to demonstrate the applicability of the proposed method.

References listed at the end of the paper:

(Cannot easily cut and paste them)
ABSTRACT: In many origami-based applications, a device needs to be maintained in one or more fold states. The origami stability integration method (OSIM) presented in this paper provides an approach for graphically combining various techniques to achieve stability. Existing stability techniques are also categorized into four groups based on whether they are intrinsic or extrinsic to the origami pattern and whether they exhibit gradual or non-gradual energy storage behaviors. These categorizations can help designers select appropriate techniques for their application. The paper also contains design considerations and resources for achieving stability. Finally, two case studies are presented which use the OSIM and the technique categorization to conceptualize stability in origami-based devices.


ABSTRACT: Compliant constant-force mechanisms (CCFMs), which provide a near constant-force output over a range of displacement, can benefit many applications. This work proposes a novel large-stroke CCFM (abbreviated as B2CCFM) that utilizes the second buckling mode of flexible beams. Two general nondimensionalized metrics, one describing the variation of output force and the other describing the operational displacement, are proposed to effectively characterize the performances of various CCFMs. Based on the general metrics, design formulas that can help designers quickly find suitable B2CCFM design for a specific application are obtained. A kinetostatic model for B2CCFM is also provided based on the chained beam constraining model to verify B2CCFM designs. An example accompanied with a prototype is presented to verify this novel CCFM and the effectiveness of the design formulas. The experimental results show that the B2CCFM example outputs a constant-force in a range as large as 45% of the beam length with variation less than 4.7%. The nondimensionalized metrics were demonstrated in comparison of several CCFMs, and the comparison results show the superior performances of B2CCFMs.


ABSTRACT: Flat-foldable origami tessellations are periodic geometric designs that can be transformed from an initial configuration into a flat-folded state. There is growing interest in such tessellations, as they have inspired many innovations in various fields of science and engineering, including deployable structures, biomedical devices, robotics, and mechanical metamaterials. Although a range of origami design methods have been developed to generate such fold patterns, some non-trivial periodic variations involve geometric design challenges, the analytical solutions to which are too difficult. To enhance the design methods of such cases, this study first adopts a geometric-graph-theoretic representation of origami tessellations, where the flat-foldability constraints for the boundary vertices are considered. Subsequently, an optimization framework is proposed for developing flat-foldable origami patterns with four-fold (i.e., degree-4) vertices, where the boundaries of the unit fragment are given in advance. A metaheuristic using particle swarm optimization (PSO) is adopted for finding optimal solutions. Several origami patterns are studied to verify the feasibility and effectiveness of the proposed design method. It will be shown that in comparison with the analytical approach and genetic algorithms (GAs), the presented method can find both trivial and non-trivial flat-foldable solutions with considerably less effort and computational cost. Non-trivial flat-foldable patterns show different and interesting folding behaviors and enrich origami design.


More papers published in the journal, Steel and Composite Structures. (2019 and on)
Google the string, “Steel and Composite Structures”, then click on the entry, “Steel and Composite Structures” - Techno Press”, then on your screen click on “Table of Contents” (near the top of your screen) and choose the particular issue.


ABSTRACT: A coupled method, that combines the Ritz method and the finite element (FE) method, is proposed to solve the vibration problem of rectangular thin and thick plates with general boundary conditions. The eigenvalue partial differential equation(s) of the plate is (are) first reduced to a set of eigenvalue ordinary differential equations by the application of the Ritz method. The resulting eigenvalue differential equations are then reduced to an eigenvalue algebraic equation system using the finite element method. The natural boundary conditions of the plate problem including the free edge and free corner boundary conditions are also implemented in a simple and accurate manner. Various boundary conditions including simply supported, clamped and free boundary conditions are considered. Comparisons with existing numerical and analytical solutions show that the proposed mixed method can produce highly accurate results for the problems considered using a small number of Ritz terms and finite elements. The proposed mixed Ritz-FE formulation is also compared with the mixed FE-Ritz formulation which has been recently proposed by the present author and his co-author. It is found that the proposed mixed Ritz-FE formulation is more efficient than the mixed FE-Ritz formulation for free vibration analysis of rectangular plates with Levy-type boundary conditions.


ABSTRACT: The paper is devoted to the stability analysis of a simply supported five layer sandwich beam. The beam consists of five layers: two metal faces, the metal foam core and two binding layers between faces and the core. The main goal is to elaborate a mathematical and numerical model of this beam. The beam is subjected to an axial compression. The nonlinear hypothesis of deformation of the cross section of the beam is formulated. Based on the Hamilton’s principle the system of four stability equations is obtained. This system is approximately solved. Applying the Bubnov-Galerkin’s method gives an ordinary differential equation of motion. The equation is then numerically processed. The equilibrium paths for a static and dynamic load are derived and the influence of the binding layers is considered. The main goal of the paper is an analytical description including the influence of binding layers on stability, especially on critical load, static and dynamic paths. Analytical solutions, in particular mathematical model are verified numerically and the results are compared with those obtained in experiments.


ABSTRACT: In this study, the semi-analytical finite strip method is adopted to examine the free vibration of cylindrical shells made up of functionally graded material. The properties of functionally graded shells are assumed to be temperature-dependent and vary continuously in the thickness direction according to a simple power law distribution in terms of the volume fraction of ceramic and metal. The material properties of the shells and stiffeners are assumed to be continuously graded in the thickness direction. Theoretical formulations based on the smeared stiffeners technique and the classical shell theory with first-order shear deformation theory which accounts for through thickness shear flexibility are employed. The finite strip method is applied to five different shell theories, namely, Donnell, Reissner, Sanders, Novozhilov, and Teng. The approximate procedure is compared favorably with three-dimensional finite elements. Finally, a detailed numerical study is carried out to bring out the effects of power-law index of the functional graded material, stiffeners, and geometry of the shells on the difference between various shell theories. Finally, the importance of choosing the shell theory in simulating the functionally graded cylindrical shells is addressed.

ABSTRACT: Position of a circular or elliptical cutout within an orthotropic plate has great influence on its buckling behavior. This paper aims at finding the optimal position (both location and orientation) of a single circular/elliptical cutout, within an orthotropic rectangular plate, that maximizes the critical buckling load. We consider linear buckling of simply supported orthotropic plates under uniaxial edge loads. To obtain the optimal positions of the cutouts, we have employed a MATLAB optimization routine coupled with buckling computation in ANSYS. Our results show that the position of the cutout that maximizes the buckling load has great dependence on the material properties, laminate configurations, and the geometrical parameters of the plate. These optimal results, for a number of plate geometries and cutout sizes, are reported in this paper. These results will be useful in the design of perforated orthotropic plates against buckling failure.


ABSTRACT: A high-order nonlocal strain gradient model is developed for wave propagation analysis of porous FG nanoplates resting on a gradient hybrid foundation in thermal environment, for the first time. Material properties are assumed to be temperature-dependent and graded in the nanoplate thickness direction. To consider the thermal effects, uniform, linear, nonlinear, exponential, and sinusoidal temperature distributions are considered for temperature-dependent FG material properties. On the basis of the refined-higher order shear deformation plate theory (R-HSDT) in conjunction with the bi-Helmholtz nonlocal strain gradient theory (B-HNSGT), Hamilton’s principle is used to derive the equations of wave motion. Then the dispersion relation between frequency and wave number is solved analytically. The influences of various parameters (such as temperature rise, volume fraction index, porosity volume fraction, lower and higher order nonlocal parameters, material characteristic parameter, foundations components, and wave number) on the wave propagation behaviors of porous FG nanoplates are investigated in detail.


ABSTRACT: This paper presents a combined numerical, experimental, and theoretical study on the behavior of the concrete-filled double circular steel tubular (CFDT) stub columns under axial compressive loading. Four groups of stub column specimens were tested in this study to find out the effects of the concrete strength, steel ratio and diameter ratio on the mechanical behavior of CFDT stub columns. Nonlinear finite element (FE) models were also established to study the stresses of different components in the CFDT stub columns. The change of axial and transverse stresses in the internal and external steel tubes, as well as the change of axial stress in the concrete sandwich and concrete core, respectively, was thoroughly investigated for different CFDT stub columns with the same steel ratio. The influence of inner-to outer diameter ratio and steel ratio on the ultimate bearing capacity of CFDT stub columns was identified, and a reasonable section configuration with proper inner-to outer diameter ratio and steel ratio was proposed. Furthermore, a practical formula for predicting the ultimate bearing capacity was proposed based on the ultimate equilibrium principle. The predicted results showed satisfactory agreement with both experimental and numerical results, indicating that the proposed formula is applicable for design purposes.


ABSTRACT: The research on the confinement behavior of ultra high performance concrete without and with the use of steel fibers (UHPC and UHPFRC) has been extremely limited. In previous studies, authors experimentally investigated the axially compressive behavior of circular steel tube confined concrete (STCC) short and intermediate columns with the employment of UHPC and UHPFRC. Under loading on only the concrete core, the confinement effect induced by the steel tube was shown to significantly enhance the ultimate stress and its corresponding strain of the concrete core. Therefore, this paper develops a simplified stress-strain
ABSTRACT: Properties of AFS vary with the changes in the face-sheet materials. Hence, the performance of AFS can be optimized by selecting face-sheet materials. In this work, three types of face-sheet materials representing elastic-perfectly plastic, elastic-plastic strain hardening and purely elastic materials were employed to study their effects on the flexural behavior and failure mechanism of AFS systematically. Result showed face-sheet materials affected the failure mechanism and energy absorption ability of AFS significantly. When the foam cores were sandwiched by aluminum alloy 6061, the AFS failed by facesheet yielding and crack without collapse of the foam core, there was no clear plastic platform in the Load-Displacement curve. When the foam cores were sandwiched by stainless steel 304 and carbon fiber fabric, there were no face-sheet crack and the sandwich structure failed by core shear and collapse, plastic platform appeared. Energy absorption abilities of steel and carbon fiber reinforced AFS were much higher than aluminum alloy reinforced one. Carbon fiber was suggested as the best choice for AFS for its light weight and high performance. The versus model for circular STCC columns using UHPC and UHPFRC with compressive strength ranging between 150 MPa and 200 MPa. Based on the regression analysis of previous test results, formulae for predicting peak confined stress and its corresponding strain are proposed. These proposed formulae are subsequently compared against some previous empirical formulae available in the literature to assess their accuracy. Finally, the simplified stress - strain model is verified by comparison with the test results.

Wei Liang, Jiangfeng Dong and Qingyuan Wang (First author is from: School of Architecture and Environment, Sichuan University, No. 24 South Section 1, Yihuan Road, Chengdu, 610065, China), “Axial compressive behavior of concrete-filled steel tube columns with stiffeners”, Steel and Composite Structures Volume 29, Number 2, October 25 2018, pages 151-159 DOI: http://dx.doi.org/10.12989/scs.2018.29.2.151

ABSTRACT: In order to reduce the deformation and delay the local buckling of concrete filled steel tube (CFST) columns, strengthening the structures with stiffeners is an effective method. In this paper, a new stiffening method with inclined stiffeners was used to investigate the behaviors of short CFST columns under axial compression. Besides, a three-dimensional nonlinear finite element (FE) model was applied to simulate the mechanical performances, including the total deformation, local buckling, and stress-strain relationship. Revised constitutive models of stiffened steel tube and confined concrete are proposed. A good agreement was achieved between the test and FE results. Furthermore, the calculated results of load capacity by using a simplified method also show a good correlation with experimental data.

Wen-Yang Liu, Guo-Qiang Li and Jian Jiang (First author is from: College of Engineering, Heilongjiang Bayi Agricultural University, Daqing, China), “Capacity design of boundary elements of beam-connected buckling restrained steel plate shear wall”, Steel and Composite Structures Volume 29, Number 2, October 25 2018, pages 231-242 DOI: http://dx.doi.org/10.12989/scs.2018.29.2.231

ABSTRACT: As a lateral load resisting component, buckling restrained steel plate shear walls (BRW) have excellent energy dissipating capacity. Similar to thin steel plate shear walls, the mechanical behavior of BRWs depends on the boundary elements (adjacent beams and columns) which need adequate strength and stiffness to ensure the complete yielding of BRWs and the emergence of expected plastic collapse mechanism of frame. This paper presents a theoretical approach to estimate the design forces for boundary elements of beam-connected BRW (i.e., The BRW is only connected to beams at its top and bottom, without connections to columns) using a fundamental plastic collapse mechanism of frame, a force transferring model of beamconnected BRW and linear beam and column analysis. Furthermore, the design method of boundary beams and columns is presented. The proposed approach does not involve nonlinear analyses, which can be easily and efficiently used to estimate the design forces of beams and columns in a frame with BRWs. The predicted design forces of boundary elements are compared with those from nonlinear finite element analyses, and a good agreement is achieved.

Wei Xiao, Chang Yan, Weibo Tian, Weiping Tian and Xuding Song (First author is from: Key Laboratory for Special Area Highway Engineering of Ministry of Education, Chang\'an University, Shanxi 710064 Xi'an China), “Effects of face-sheet materials on the flexural behavior of aluminum foam sandwich”, Steel and Composite Structures Volume 29, Number 3, November 10 2018, pages 301-318 DOI: http://dx.doi.org/10.12989/scs.2018.29.3.301

ABSTRACT: Properties of AFS vary with the changes in the face-sheet materials. Hence, the performance of AFS can be optimized by selecting face-sheet materials. In this work, three types of face-sheet materials representing elastic-perfectly plastic, elastic-plastic strain hardening and purely elastic materials were employed to study their effects on the flexural behavior and failure mechanism of AFS systematically. Result showed face-sheet materials affected the failure mechanism and energy absorption ability of AFS significantly. When the foam cores were sandwiched by aluminum alloy 6061, the AFS failed by facesheet yielding and crack without collapse of the foam core, there was no clear plastic platform in the Load-Displacement curve. When the foam cores were sandwiched by stainless steel 304 and carbon fiber fabric, there were no face-sheet crack and the sandwich structure failed by core shear and collapse, plastic platform appeared. Energy absorption abilities of steel and carbon fiber reinforced AFS were much higher than aluminum alloy reinforced one. Carbon fiber was suggested as the best choice for AFS for its light weight and high performance. The versus
strength ratio of face sheet to core was suggested to be a significant value for AFS structure design which may determine the failure mechanism of a certain AFS structure.


ABSTRACT: Steel girders are the structural members often used for passing long spans. Mostly being subjected to patch loading, or concentrated loading, steel girders are likely to face sudden deformation or damage e.g., web breathing. Horizontal or vertical stiffeners are employed to overcome this phenomenon. This study aims at assessing the feasibility of a machine learning method, namely the support vector machines (SVM) in predicting the patch loading resistance of longitudinally stiffened webs. A database consisting of 162 test data is utilized to develop SVM models and the model with best performance is selected for further inspection. Existing formulations proposed by other researchers are also investigated for comparison. BS5400 and other existing models (model I, model II and model III) appear to yield underestimated predictions with a large scatter; i.e., mean experimental-to-predicted ratios of 1.517, 1.092, 1.155 and 1.256, respectively; whereas the selected SVM model has high prediction accuracy with significantly less scatter. Robust nature and accurate predictions of SVM confirms its feasibility of potential use in solving complex engineering problems.

Helong Wu, Sritawat Kitipornchai and Jie Yang (First author is from: School of Civil Engineering, the University of Queensland, Brisbane, St. Lucia 4072, Australia), “Free vibration of thermo-electro-mechanically postbuckled FG-CNTRC beams with geometric imperfections”, Steel and Composite Structures Volume 29, Number 3, November 10 2018, pages 319-332 DOI: http://dx.doi.org/10.12989/scs.2018.29.3.319

ABSTRACT: This paper investigates the free vibration of geometrically imperfect functionally graded carbon nanotube-reinforced composite (FG-CNTRC) beams that are integrated with two surface-bonded piezoelectric layers and subjected to a combined action of a uniform temperature rise, a constant actuator voltage and an in-plane force. The material properties of FG-CNTRCs are assumed to be temperature-dependent and vary continuously across the thickness. A generic imperfection function is employed to simulate various possible imperfections with different shapes and locations in the beam. The governing equations that account for the influence of initial geometric imperfection are derived based on the first-order shear deformation theory. The postbuckling configurations of FG-CNTRC hybrid beams are determined by the differential quadrature method combined with the modified Newton-Raphson technique, after which the fundamental frequencies of hybrid beams in the postbuckled state are obtained by a standard eigenvalue algorithm. The effects of CNT distribution pattern and volume fraction, geometric imperfection, thermo-electro-mechanical load, as well as boundary condition are examined in detail through parametric studies. The results show that the fundamental frequency of an imperfect beam is higher than that of its perfect counterpart. The influence of geometric imperfection tends to be much more pronounced around the critical buckling temperature.

Jianghui Dong, Xing Ma, Yan Zhuge and Julie E. Mills (School of Natural and Built Environments, University of South Australia, Adelaide, SA 5095, Australia), “Contact buckling behaviour of corrugated plates subjected to linearly varying in-plane loads”, Steel and Composite Structures Volume 29, Number 3, November 10 2018, pages 333-348 DOI: http://dx.doi.org/10.12989/scs.2018.29.3.333

ABSTRACT: An analytical method is developed for analysing the contact buckling response of infinitely long, thin corrugated plates and flat plates restrained by a Winkler tensionless foundation and subjected to linearly varying in-plane loadings, where the corrugated plates are modelled as orthotropic plates and the flat plates are modelled as isotropic plates. The critical step in the presented method is the explicit expression for the lateral buckling mode function, which is derived through using the energy method. Simply supported and clamped edges conditions on the unloaded edges are considered in this study. The acquired lateral deflection function is applied to the governing buckling equations to eliminate the lateral variable. Considering the boundary conditions and continuity conditions at the border line between the contact and non-contact zones, the buckling coefficients and the corresponding buckling modes are found. The analytical solution to the buckling coefficients is also expressed through a fitted approximate formula in terms of foundation stiffness, which is verified through previous studies and finite element (FE) method.
ABSTRACT: Thermal buckling behavior of porous functionally graded nanobeam integrated with piezoelectric sensor and actuator based on the nonlocal higher-order shear deformation beam theory is investigated for the first time. Its material properties are assumed to be temperature-dependent and varying along the thickness direction according to the modified power-law rule. Note that the porosity with even type is considered herein. The equations of motion are obtained through Hamilton's principle. The influences of several parameters (such as type of temperature distribution, external electric voltage, material composition, porosity, small-scale effect, Ker foundation parameters, and beam thickness) on the thermal buckling of FG nanobeam are investigated in detail.

ABSTRACT: An efficient and free of shear locking finite element model is developed and employed to study free vibration of tapered bidirectional functionally graded material (BFGM) beams. The beam material is assumed to be formed from four distinct constituent materials whose volume fraction continuously varies along the longitudinal and thickness directions by power-law functions. The finite element formulation based on the first-order shear deformation theory is derived by using hierarchical functions to interpolate the displacement field. In order to improve efficiency and accuracy of the formulation, the shear strain is constrained to constant and the exact variation of the cross-sectional profile is employed to compute the element stiffness and mass matrices. A comprehensive parametric study is carried out to highlight the influence of the material distribution, the taper and aspect ratios as well as the boundary conditions on the vibration characteristics. Numerical investigation reveals that the proposed model is efficient, and it is capable to evaluate the natural frequencies of BFGM beams by using a small number of the elements. It is also shown that the effect of the taper ratio on the fundamental frequency of the BFGM beams is significantly influenced by the boundary conditions. The present results are of benefit to optimum design of tapered FGM beam structures.
nanotube reinforced composite beams and experimental tensile test to obtain the mechanical properties of nanocomposite”, Steel and Composite Structures Volume 29, Number 3, November10 2018, pages 405-422 DOI: http://dx.doi.org/10.12989/scs.2018.29.3.405

ABSTRACT: In this research, experimental tensile test and manufacturing of carbon nanotube reinforced composite beam (CNTRC) is presented. Also, bending, buckling, and vibration analysis of CNTRC based on various beam theories such as Euler-Bernoulli, Timoshenko and Reddy beams are considered. At first, the experimental tensile tests are carried out for CNTRC and composite beams in order to obtain mechanical properties and then using Hamilton's principle the governing equations of motion are derived for Euler Bernoulli, Timoshenko and Reddy theories. The results have a good agreement with the obtained results by similar researches and it is shown that adding just two percent of carbon nanotubes increases dimensionless fundamental frequency and critical buckling load as well as decreases transverse deflection of composite beams. Also, the influences of different manufacturing processes such as hand layup and industrial methods using vacuum pump on composite properties are investigated. In these composite beams, glass fibers used in an epoxy matrix and for producing CNTRC, CNTs are applied as reinforcement particles. Applying two percent of CNTs leads to increase the mechanical properties and increases natural frequencies and critical buckling load and decreases deflection. The obtained natural frequencies and critical buckling load by theoretical method are higher than other methods, because there are some inevitable errors in industrial and hand layup method. Also, the minimum deflection occurs for theoretical methods, in bending analysis. In this study, Young's and shear moduli as well as density are obtained by experimental test and have not been used from the results of other researches. Then the theoretical analysis such as bending, buckling and vibration are considered by using the obtained mechanical properties of this research.


ABSTRACT: Free vibration analysis of super-elliptical composite thin plates was investigated. Plate is formed by symmetrical quasi-isotropic laminates. Rayleigh-Ritz method was used for parametric analysis based on the governing differential equations of Classical Laminated Plate Theory (CLPT). Simply supported and clamped boundary conditions at the periphery of plates were considered. Parametric study was performed for the effect of different lamination type, aspect ratio, thickness and super-elliptical power on natural frequencies. Convergence study and validation of isotropic case were achieved. A number of design parameters like different dimensions, structure systems, panel sizes, panel thicknesses, laminate sequences, boundary conditions and loading conditions must be considered in the production of composite ships. The number of possible combinations practically may be so high that a parametric study should be carried out in order to determine the optimum design parameters rapidly during the preliminary design stage. The use of Rayleigh-Ritz method could make this parametric study possible. Thereby it might be decreasing the consumption of time, material and labor. Certain results for some different super-elliptical powers presented in tabulated form in Appendix for designers as well.

Fathollah Taheri-Beherooz and Milad Omidi (School of Mechanical Engineering, Iran University of Science and Technology, Tehran, 16846-13114, Iran), “Buckling of axially compressed composite cylinders with geometric imperfections”, Steel and Composite Structures Volume 29, Number 4, November25 2018, pages 557-567 DOI: http://dx.doi.org/10.12989/scs.2018.29.4.557

ABSTRACT: Cylindrical shell structures buckle at service loads which are much lower than their associated theoretical buckling loads. The main source of this discrepancy is the presence of various imperfections which are created on the cylinder body during different processes as manufacturing, handling, assembling and machining. Many cylindrical shell structures are still designed against buckling based on the experimental data introduced by NASA SP-8007 as conservative lower bound curves. This study employed the numerical based Linear Buckling mode shape Imperfection (LBMI) method and modified it using a stochastic method to assess the effect of geometrical imperfections in more details on the buckling of cylindrical shells with and without the cutout. The comparison of results with those obtained from the numerical Simple Perturbation Load Imperfection (SPLI) method for cylinders with and without cutout revealed a good correlation. The effect of two parameters of size and number of cutouts on the buckling load was investigated using the linear buckling
and Modified LBMI methods. Results confirmed that in cylinders with a small cutout inserting geometrical imperfection using either SPLI or modified LBMI methods significantly reduced the value of the predicted buckling load. However, in cylinders with larger cutouts, the effect of the cutout is dominant, thus considering geometrical imperfection had a minor effect on the buckling loads predicted by both SPLI and modified LBMI methods. Furthermore, the modified LBMI method was employed to evaluate the combination effect of cutout numbers and size on the buckling load. It is shown that in small cutouts, an increasing in the cutout size up to a certain value resulted in a remarkable reduction of the buckling load, and beyond that limit, the buckling loads were constant against D/R ratios. In addition, the cutout number shows a more significant effect on decreasing the buckling load at small D/R ratios than large D/R ratios.

References listed at the end of the paper:
Khot, N.S. (1968), “On the influence of initial geometric imperfections on the buckling and postbuckling behavior of fiber-reinforced cylindrical shells under uniform axial compression (No. AFFDL-TR-68-136)”, Air force flight dynamics lab wright-otterson AFB OH.
**ABSTRACT:** This research presents an investigation on the thermal buckling resistance of FGM plates having parabolic thickness variation, Steel and Composite Structures Volume 29, Number 5, December 10 2018, pages 591-602 DOI: http://dx.doi.org/10.12989/scs.2018.29.5.591

This research presents an investigation on the thermal buckling resistance of FGM plates having parabolic-concave thickness variation exposed to uniform and gradient temperature change. An analytical approach is employed to derive the governing equations for the problem. The effects of various parameters, such as material properties, thickness variation, and temperature, on the thermal buckling behavior of the FGM plates are investigated. The results are validated by comparing them with existing studies and show good agreement. The study provides valuable insights into the thermal buckling behavior of FGM plates, which can be useful for designing structures with improved thermal stability.

Mohammed Arefi and Ashraf M. Zenkour (First author is from: Faculty of Mechanical Engineering, Department of Solid Mechanics, University of Kashan, Kashan 87317-51167, Iran), “Size-dependent vibration and electro-magneto-elastic bending responses of sandwich piezomagnetic curved nanobeams”, Steel and Composite Structures Volume 29, Number 5, December 10 2018, pages 579-590 DOI: http://dx.doi.org/10.12989/scs.2018.29.5.579

ABSTRACT: Size-dependent free vibration responses and magneto-electro-elastic bending results of a three layers piezomagnetic curved beam rest on Pasternak's foundation are presented in this paper. The governing equations of motion are derived based on first-order shear deformation theory and nonlocal piezo-elasticity theory. The curved beam is containing a nanocore and two piezomagnetic face-sheets. The piezomagnetic layers are imposed to applied electric and magnetic potentials and transverse uniform loadings. The analytical results are presented for simply-supported curved beam to study influence of some parameters on vibration and bending results. The important parameters are spring and shear parameters of foundation, applied electric and magnetic potentials, nonlocal parameter and radius of curvature of curved beam. It is concluded that the increase in radius of curvature tends to an increase in the stiffness of curved beam and consequently natural frequencies increase and bending results decrease. In addition, it is concluded that with increase of nonlocal parameter of curved beam, the stiffness of structure is decreased that leads to decrease of natural frequency and increase of bending results.

Puneet Kumar and J. Srinivas (Department of Mechanical Engineering, National Institute of Technology Rourkela, Rourkela-769008, India), “Transient vibration analysis of FG-MWCNT reinforced composite plate resting on foundation”, Steel and Composite Structures Volume 29, Number 5, December 10 2018, pages 569-578 DOI: http://dx.doi.org/10.12989/scs.2018.29.5.569

ABSTRACT: This paper aims to investigate the transient vibration behavior of functionally graded carbon nanotube (FG-CNT) reinforced nanocomposite plate resting on Pasternak foundation under pulse excitation. The plate is considered to be composed of matrix material and multi-walled carbon nanotubes (MWCNTs) with distribution as per the functional grading concept. The functionally graded distribution patterns in nanocomposite plate are explained more appropriately with the layer-wise variation of carbon nanotubes weight fraction in the thickness coordinate. The layers are stacked up in such a way that it yields uniform and three other types of distribution patterns. The effective material properties of each layer in nanocomposite plate are obtained by modified Halpin-Tsai model and rule of mixtures. The governing equations of an illustrative case of simply-supported nanocomposite plate resting on the Pasternak foundation are derived from third order shear deformation theory and Navier’s solution technique. A converge transient response of nanocomposite plate under uniformly distributed load with triangular pulse is obtained by varying number of layer in thickness direction. The validity and accuracy of the present model is also checked by comparing the results with those available in literature for isotropic case. Then, numerical examples are presented to highlight the effects of distribution patterns, foundation stiffness, carbon nanotube parameters and plate aspect ratio on the central deflection response. The results are extended with the consideration of proportional damping in the system and found that nanocomposite plate with distribution III have minimum settling time as compared to the other distributions.
ABSTRACT: This article derived a hybrid coupling technique using the higher order displacement polynomial and three soft computing techniques (teaching learning based optimization, particle swarm optimization, and artificial bee colony) to predict the optimal stacking sequence of the layered structure and the corresponding frequency values. The higher-order displacement kinematics is adopted for the mathematical model derivation considering the necessary stress and strain continuity and the elimination of shear correction factor. A nine nodded isoparametric Lagrangian element (eighty-one degrees of freedom at each node) is engaged for the discretisation and the desired model equation derived via the classical Hamilton\'s principle. Subsequently, three soft computing techniques are employed to predict the maximum natural frequency values corresponding to their optimum layer sequences via a suitable home-made computer code. The finite element convergence rate including the optimal solution stability is established through the iterative solutions. Further, the predicted
optimal stacking sequence including the accuracy of the frequency values are verified with adequate comparison studies. Lastly, the derived hybrid models are explored further to by solving different numerical examples for the combined structural parameters (length to width ratio, length to thickness ratio and orthotropy on frequency and layer-sequence) and the implicit behavior discuss in details.

Ali Kemal Baltac (Akdeniz University, Engineering Faculty, Civil Engineering Department, Division of Mechanics, 07058, Antalya-Turkey), “Numerical approaches for vibration response of annular and circular composite plates”, Steel and Composite Structures Volume 29, Number 6, December 2018, pages 759-770 DOI: http://dx.doi.org/10.12989/scs.2018.29.6.759

ABSTRACT: In the present investigation, by using the two numerical methods, free vibration analysis of laminated annular and annular sector plates have been studied. In order to obtain the main equations two different shell theories such as Love's shell theory and first-order shear deformation theory (FSDT) have been used for modeling. After obtaining the fundamental equations in briefly, the methods of harmonic differential quadrature (HDQ) and discrete singular convolution (DSC) are used to solve the equation of motion. Accuracy, convergence and reliability of the present HDQ and DSC methods were tested by comparing the existing results obtained by different methods in the literature. The effects of some geometric and material properties of the plates are investigated via these two methods. The advantages and accuracy of the HDQ and DSC methods have also been examined with different grid numbers and shell theory. Some results for laminated annular plates and laminated circular plates were also been supplied.


ABSTRACT: In this paper, two different computational methods, called Rayleigh-Ritz and collocation are developed to estimate the ultimate strength of composite plates. Progressive damage behavior of moderately thick composite laminated plates is studied under in-plane compressive load and uniform lateral pressure. The formulations of both methods are based on the concept of the principle of minimum potential energy. First order shear deformation theory and the assumption of large deflections are used to develop the equilibrium equations of laminated plates. Therefore, Newton-Raphson technique will be used to solve the obtained system of nonlinear algebraic equations. In Rayleigh-Ritz method, two degradation models called complete and region degradation models are used to estimate the degradation zone around the failure location. In the second method, a new energy based collocation technique is introduced in which the domain of the plate is discretized into the Legendre-Gauss-Lobatto points. In this new method, in addition to the two previous models, the new model named node degradation model will also be used in which the material properties of the area just around the failed node are reduced. To predict the failure location, Hashin failure criteria have been used and the corresponding material properties of the failed zone are reduced instantaneously. Approximation of the displacement fields is performed by suitable harmonic functions in the Rayleigh-Ritz method and by Legendre basis functions (LBFs) in the second method. Finally, the results will be calculated and discussions will be conducted on the methods.

Kheira Soltani, Aicha Bessaim, Mohammed Sid Ahmed Houari, Abdelhakim Kaci, Mohamed Benguediab, Abdelouahed Tounsi and Mohammed Sh Alhodaly (First author is from: Department of Mechanical Engineering, Faculty of Technology, University of Sidi Bel Abbes, Algeria), “A novel hyperbolic shear deformation theory for the mechanical buckling analysis of advanced composite plates resting on elastic foundations”, Steel and Composite Structures Volume 30, Number 1, January 2019, pages 13-29 DOI: http://dx.doi.org/10.12989/scs.2019.30.1.013

ABSTRACT: This work presents the buckling investigation of functionally graded plates resting on two parameter elastic foundations by using a new hyperbolic plate theory. The main advantage of this theory is that, in addition to including the shear deformation effect, the displacement field is modelled with only four unknowns and which is even less than the first order shear deformation theory (FSDT) and higher-order shear deformation theory (HSDT) by introducing undetermined integral terms, hence it is unnecessary to use shear correction factors. The governing equations are derived using Hamilton’s principle and solved using Navier's
steps. The validation of the proposed theoretical model is performed to demonstrate the efficacy of the model. The effects of various parameters like the Winkler and Pasternak modulus coefficients, inhomogeneity parameter, aspect ratio and thickness ratio on the behaviour of the functionally graded plates are studied. It can be concluded that the present theory is not only accurate but also simple in predicting the critical buckling loads of functionally graded plates on elastic foundation.

Jakkamputi Lakshmipathi and Rajamohan Vasudevan (First author is from: School of Mechanical and Building sciences Engineering, Vellore Institute of Technology (VIT), Chennai 600127, Tamil Nadu, India), “Dynamic characterization of a CNT reinforced hybrid uniform and non-uniform composite plates”, Steel and Composite Structures Volume 30, Number 1, January 10 2019, pages 31-46 DOI: http://dx.doi.org/10.12989/scs.2019.30.1.031

ABSTRACT: In the present study, the various dynamic properties of MWCNT embedded fiber reinforced polymer uniform and tapered composite (MWCNT-FRP) plates are investigated. Various configurations of a tapered composite plate with ply-drop off and uniform composite plate have been considered for the development of the finite element formulation and experimental investigations. First order shear deformation theory (FSDT) has been used to derive the kinetic and potential energy equations of the hybrid composite plates by including the effect of rotary inertia, shear deformation and non-uniformity in thickness of the plate. The governing equations of motion of FRP composite plates without and with MWCNT reinforcement are derived by considering a nine-node rectangular element with five degrees of freedom (DOF) at each node. The effectiveness of the developed finite element formulation has been demonstrated by comparing the natural frequencies and damping ratio of FRP composite plates without and with MWCNT reinforcement obtained experimentally. Various parametric studies are also performed to study the effect of CNT volume fraction and CNT aspect ratio of the composite plate on the natural frequencies of different configurations of CNT reinforced hybrid composite plates. Further the forced vibration analysis is performed to compare the dynamic response of the various configurations of MWCNT-GFRP composite plate with GFRP composite plate under harmonic excitations. It was observed that the fundamental natural frequency and damping ratio of the GFRP composite plate increase approximately 8% and 37% respectively with 0.5wt% reinforcement of MWCNT under CF CF boundary condition. The natural frequencies of MWCNT-GFRP hybrid composite plates tend to decrease with the increase of MWCNT volume fraction beyond 2% due to agglomeration of CNT's. It is also observed that the aspect ratio of the CNT has negligible effect on the improvement of dynamics properties due to randomly orientation of CNT's.

Maksym Grzywiński, Tayfun Dede and Yaprak Isit İzdemir (The first author is from: Czestochowa University of Technology, Faculty of Civil Engineering, 42200 Czestochowa, Poland), “Optimization of the braced dome structures by using Jaya algorithm with frequency constraints”, Steel and Composite Structures Volume 30, Number 1, January 10 2019, pages 47-55 DOI: http://dx.doi.org/10.12989/scs.2019.30.1.047

ABSTRACT: The aim of this paper is to present new and an efficient optimization algorithm called Jaya for the optimum mass of braced dome structures with natural frequency constraints. Design variables of the bar cross-section area and coordinates of the structure nodes were used for size and shape optimization, respectively. The effectiveness of Jaya algorithm is demonstrated through three benchmark braced domes (52-bar, 120-bar, and 600-bar). The algorithm applied is an effective tool for finding the optimum design of structures with frequency constraints. The Jaya algorithm has been programmed in MATLAB to optimize braced dome.

Mohammad Rezaiee-Pajand, Ahmad Aftabi Sani and Seyed Mojtaba Hozhabrossadati (First author is from: Department of Civil Engineering, Ferdowsi University of Mashhad, Iran), “Deflection of axially functionally graded rectangular plates by Green's function method”, Steel and Composite Structures Volume 30, Number 1, January 10 2019, pages 057-67 DOI: http://dx.doi.org/10.12989/scs.2019.30.1.057

ABSTRACT: This paper deals with the static analysis of axially functionally graded rectangular plates. It is assumed that the flexural rigidity of the plate varies exponentially along one of the plate's in-plane dimensions. Both an analytical approach and a numerical method are utilized to solve the problem. The analytical solution is obtained by using the Green's function method. To employ this approach, the adjoint boundary value problem is established. Then, exact solutions for deflection of the plate for different boundary conditions are found. In another way, a finite element formulation for the problem is developed. In order to demonstrate the validity of the Authors' formulation, the results obtained via both mentioned schemes are compared with each other for
functionally graded plates and with results of previously published works for homogeneous plates. The effect of plate parameters on the response of the plate is also investigated. To remind the research background, a brief review on the application of Green's function method in plates' analysis and functionally graded plates is also presented.


ABSTRACT: Numerous problems have always vexed engineers with buckling, corrosion, bending, and overloading in damaged steel structures. The present study aims to study the possible effects of Carbon Fiber Reinforced Polymer (CFRP) for strengthening deficient Steel Square Hollow Section (SHS) columns. To this end, the effects of axial loading, stiffness values, axial displacement, the shape of deficient on the length of steel SHS columns were evaluated based on a detailed parametric study. Ten specimens were tested to failure under axial compression in laboratory and simulated by using Finite Element (FE) analysis based on numerical approach. The results indicated that the application of CFRP sheets resulted in reducing stress in the damage location and preventing or retarding local deformation around the deficiency location appropriately. In addition, the retrofitting method could increase loading the carrying capacity of specimens.


ABSTRACT: The behavior of a new Three-Tube Buckling-Restrained Brace (TTBRB) with circumference pre-stress (σ,,pre) in core tube are investigated through a verified finite element model. The TTBRB is composed of one core tube and two restraining tubes. The core tube is in the middle to provide the axial stiffness, to carry the axial load and to dissipate the earthquake energy. The two restraining tubes are at inside and outside of the core tube, respectively, to restrain the global and local buckling of the core tube. Based on the yield criteria of fringe fiber, a design method for restraining tubes is proposed. The applicability of the proposed design equations are verified by TTBRBs with different radius-thickness ratios, with different gap widths between core tube and restraining tubs, and with different levels of σ,,pre. The outer and inner tubes will restrain the deformation of the core tube in radius direction, which causes circumference stress (σ,) in the core tube. Together with the σ,,pre in the core tube that is applied through interference fit of the three tubes, the yield strength of the core tube in the axial direction is improved from 160 MPa to 235 MPa. Effects of gap width between the core tube and restraining tubes, and σ,, on hysteretic behavior of TTBRBs are presented. Analysis results showed that the gap width and the...
shaped beams with different width-to-thickness ratios was also proposed, which compares well with the experimental results.


ABSTRACT: A new form of composite column, concrete-filled round-ended steel tubes (CFRTs), has been proposed as piers or columns in bridges and high-rise building and has great potential to be used in civil engineering. Hence, the objective of this paper presents an experimental and numerical investigation on the flexural behavior of CFRTs through combined experimental results and ABAQUS standard solver. The failure mode was discussed in detail and the specimens all behaved in a very ductile manner. The effect of different parameters, including the steel ratio and aspect ratio, on the flexural behavior of CFRTs was further investigated. Furthermore, the feasibility and accuracy of the numerical method was verified by comparing the FE and experimental results. The moment vs. curvature curves of CFRTs during the loading process were analyzed in detail. The development of the stress and strain distributions in the core concrete and steel tube was investigated based on FE models. The composite action between the core concrete and steel tube was discussed and clarified. In addition, the load transfer mechanism of CFRT under bending was introduced comprehensively. Finally, the predicted ultimate moment according to corresponding designed formula is in good agreement with the experimental results.


ABSTRACT: One of the most important design criteria in underground structure is to design lightweight protective layers to resist significant blast loads. Sandwich blast resistant panels are commonly used to protect underground structures. The front face of the sandwich panel is designed to resist the blast load and the core is designed to mitigate the blast energy from reaching the back panel. The design is to allow the sandwich panel to be repaired efficiently. Hence, the underground structure can be used under repeated blast loads. In this study, a novel sandwich panel, named RC panel - Helical springs - RC panel (RHR) sandwich panel, which consists of normal strength reinforced concrete (RC) panels at the front and the back and steel compression helical springs in the middle, is proposed. In this study, a detailed 3D nonlinear numerical analysis is proposed using the nonlinear finite element software, AUTODYN. The accuracy of the blast load and RHR Sandwich panel modelling are validated using available experimental results. The results show that the proposed finite element model can be used efficiently and effectively to simulate the nonlinear dynamic behaviour of the newly proposed RHR sandwich panels under different ranges of free air blast loads. Detailed parameter study is then conducted using the validated finite element model. The results show that the newly proposed RHR sandwich panel can be used as a reliable and effective lightweight protective layer for underground structures.

M. Heidari-Rarani and M. Kharratzadeh (Department of Mechanical Engineering, Faculty of Engineering, University of Isfahan, 81746-73441, Isfahan, Iran), “Buckling behavior of composite cylindrical shells with cutout considering geometric imperfection”, Steel and Composite Structures Volume 30, Number 4, February25 2019, pages 305-313 DOI: http://dx.doi.org/10.12989/scs.2019.30.4.305

ABSTRACT: Creating different cutout shapes in order to make doors and windows, reduce the structural weight or implement various mechanisms increases the likelihood of buckling in thin-walled structures. In this study, the effect of cutout shape and geometric imperfection (GI) is simultaneously investigated on the critical buckling load and knock-down factor (KDF) of composite cylindrical shells. The GI is modeled using single perturbation load approach (SPLA). First, in order to assess the finite element model, the critical buckling load of a composite shell without cutout obtained by SPLA is compared with the experimental results available in the literature. Then, the effect of different shapes of cutout such as circular, elliptic and square, and perturbation load imperfection (PLI) is investigated on the buckling behavior of cylindrical shells. Results show that the critical buckling load of a shell without cutout decreases by increasing the PLI, whereas increasing the PLI does
not have a great impact on the critical buckling load in the presence of cutout imperfection. Increasing the cutout area reduces the effect of the PLI, which results in an increase in the KDF.

Şeref D. Akbaş (Department of Civil Engineering, Bursa Technical University, Yıldırım Campus, Yıldırım, Bursa 16330, Turkey), “Nonlinear behavior of fiber reinforced cracked composite beams”, Steel and Composite Structures Volume 30, Number 4, February 25 2019, pages 327-326
DOI: http://dx.doi.org/10.12989/scs.2019.30.4.327
ABSTRACT: This paper presents geometrically nonlinear behavior of cracked fiber reinforced composite beams by using finite element method with and the first shear beam theory. Total Lagrangian approach is used in the nonlinear kinematic relations. The crack model is considered as the rotational spring which separate into two parts of beams. In the nonlinear solution, the Newton-Raphson is used with incremental displacement. The effects of fibre orientation angles, the volume fraction, the crack depth and locations of the cracks on the geometrically nonlinear deflections of fiber reinforced composite are examined and discussed in numerical results. Also, the difference between geometrically linear and nonlinear solutions for the cracked fiber reinforced composite beams.

DOI: http://dx.doi.org/10.12989/scs.2019.30.4.337
ABSTRACT: The objective of this paper is to investigate the confinement coefficient of concrete-filled square stainless steel tubular (CFSSST) stub columns under axial loading. A fine finite 3D solid element model was established, which utilized a constitutive model of stainless steel considering the strain-hardening characteristics and a triaxial plastic-damage constitutive model of concrete with features of the parameter certainty under axial compression. The finite element analysis results revealed that the increased ultimate bearing capacity of CFSSST stub columns compared with their carbon steel counterparts was mainly due to that the composite action of CFSSST stub columns is stronger than that of carbon steel counterparts. A further parametric study was carried out based on the verified model, and it was found that the stress contribution of the stainless steel tube is higher than the carbon steel tube. The stress nephogram was simplified reasonably in accordance with the limit state of core concrete and a theoretical formula was proposed to estimate the ultimate bearing capacity of square CFSSST stub columns using superposition method. The predicted results showed satisfactory agreement with both the experimental and FE results. Finally, the comparisons of the experimental and predicted results using the proposed formula and the existing codes were illustrated.

Ying Qin, Yong-Wei Li, Yu-Sen Su, Xu-Zhao Lan, Yuan-De Wu and Xiang-Yu Wang (Key Laboratory of Concrete and Prestressed Concrete Structures of Ministry of Education, School of Civil Engineering, Southeast University, Nanjing, China), “Compressive behavior of profiled double skin composite wall”, Steel and Composite Structures Volume 30, Number 5, March 10 2019, pages 405-416, DOI: http://dx.doi.org/10.12989/scs.2019.30.5.405
ABSTRACT: Profiled composite slab has been widely used in civil engineering due to its structural merits. The extension of this concept to the bearing wall forms the profiled composite wall, which consists of two external profiled steel plates and infill concrete. This paper investigates the structural behavior of this type of wall under axial compression. A series of compression tests on profiled composite walls consisting of varied types of profiled steel plate and edge confinement have been carried out. The test results are evaluated in terms of failure modes, load-axial displacement curves, strength index, ductility ratio, and load-strain response. It is found that the type of profiled steel plate has influence on the axial capacity and strength index, while edge confinement affects the failure mode and ductility. The test data are compared with the predictions by modern codes such as AISC 360, BS EN 1994-1-1, and CECS 159. It shows that BS EN 1994-1-1 and CECS 159 significantly overestimate the actual compressive capacity of profiled composite walls, while AISC 360 offers reasonable predictions. A method is then proposed, which takes into account the local buckling of profiled steel plates and the reduction in the concrete resistance due to profiling. The predictions show good correlation with the test results.
Selcuk Bas (Department of Civil Engineering, Faculty of Engineering, Bartin University, 74100 Bartin, Turkey), “Lateral torsional buckling of steel I-beams: Effect of initial geometric imperfection”, Steel and Composite Structures Volume 30, Number 5, March10 2019, pages 483-492
DOI: http://dx.doi.org/10.12989/scs.2019.30.5.483
ABSTRACT: In the current study, the influence of the initial lateral (sweep) shape and the cross-sectional twist imperfection on the lateral torsional buckling (LTB) response of doubly-symmetric steel I-beams was investigated. The material imperfection (residual stress) was not considered. For this objective, standard European IPN 300 beam with different unbraced span was numerically analyzed for three imperfection cases: (i) no sweep and no twist (perfect); (ii) three different shapes of global sweep (half-sine, full-sine and full-parabola between the end supports); and (iii) the combination of three different sweeps with initial sinusoidal twist along the beam. The first comparison was done between the results of numerical analyses (FEM) and both a theoretical solution and the code lateral torsional buckling formulations (EC3 and AISC-LRFD). These results with no imperfection effects were then separately compared with three different shapes of global sweep and the presence of initial twist in these sweep shapes. Besides, the effects of the shapes of initial global sweep and the inclusion of sinusoidal twist on the critical buckling load of the beams were investigated to unveil which parameter was considerably effective on LTB response. The most compatible outcomes for the perfect beams were obtained from the AISC-LRFD formulation; however, the EC-3 formulation estimated the P. load conservatively. The high difference from the EC-3 formulation was predicted to directly originate from the initial imperfection reduction factor and high safety factor in its formulation. Due to no consideration of geometric imperfection in the AISC-LFRD code solution and the theoretical formulation, the need to develop a practical imperfection reduction factor for AISC-LRFD and theoretical formulation was underlined. Initial imperfections were obtained to be more influential on the buckling load, as the unbraced length of a beam approached to the elastic limit unbraced length (N). Mode-compatible initial imperfection shapes should be taken into account in the design and analysis stages of the I-beam to properly estimate the geometric imperfection influence on the P. load. Sweep and sweep.twist imperfections led to 10% and 15% decrease in the P. load, respectively, thus; well-estimated sweep and twist imperfections should considered in the LTB of doubly-symmetric steel I-beams.

ABSTRACT: This paper is dedicated to nonlinear static and free vibration analysis of Uniform Distributed Carbon Nanotube Reinforced Composite (UD-CNTRC) structures under in-plane loading. The authors have suggested an efficient six-node triangular element. Mixed Interpolation of Tensorial Components (MITC) approach is employed to alleviate the membrane locking phenomena. Moreover, the behavior of the well-known LST element is considerably improved by applying an additional linear interpolation on the strain fields. Based on the rule of mixture, the properties of CNTRC are obtained. In this study, only the uniform distributed CNTs are employed through the thickness direction of element. To achieve the natural frequencies and shape modes, the eigenvalue problem is also solved. Using Total Lagrangian Principles, large amplitude free vibration is considered based on the first normalized mode shape of structure. Different well-known plane problem benchmarks and some proposed ones are studied to validate the accuracy and capability of authors' formulations. In addition, the effects of length to the height ratio of beam, CNT's characteristics, support conditions and normalized amplitude parameter on the linear and nonlinear vibration parameters are investigated.

Ahmad Soleimani, Kia Dastani, Amin Hadi and Mohamad Hasan Naei (First author is from: School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran), “Effect of out-of-plane defects on the postbuckling behavior of graphene sheets based on nonlocal elasticity theory”, Steel and Composite Structures Volume 30, Number 6, March25 2019, pages 517-534
DOI: http://dx.doi.org/10.12989/scs.2019.30.6.517
ABSTRACT: In this paper, the effects of inevitable out-of-plane defects on the postbuckling behavior of single-layered graphene sheets (SLGSs) under in-plane loadings are investigated based on nonlocal first order
shear deformation theory (FSDT) and von-Karman nonlinear model. A generic imperfection function, which takes the form of the products of hyperbolic and trigonometric functions, is employed to model out-of-plane defects as initial geometrical imperfections of SLGSs. Nonlinear equilibrium equations are derived from the principle of virtual work and variational formulation. The postbuckling equilibrium paths of imperfect graphene sheets (GSs) are presented by solving the governing equations via isogeometric analysis (IGA) and Newton-Raphson iterative method. Finally, the sensitivity of the postbuckling behavior of GS to shape, amplitude, extension on the surface, and location of initial imperfection is studied. Results showed that the small scale and initial imperfection effects on the postbuckling behavior of defective SLGS are important and cannot be ignored.

Ying Qin, Yong-Wei Li, Xu-Zhao Lan, Yu-Sen Su, Xiang-Yu Wang and Yuan-De Wu (Key Laboratory of Concrete and Prestressed Concrete Structures of Ministry of Education, and National Prestress Engineering Research Center, School of Civil Engineering, Southeast University, Nanjing, China.), “Structural behavior of the stiffened double-skin profiled composite walls under compression”, Steel and Composite Structures, Volume 31, Number 1, April 10 2019, pages 1-12, http://dx.doi.org/10.12989/scs.2019.31.1.001

ABSTRACT: Steel-concrete composite walls have been proposed and developed for applications in various types of structures. The double-skin profiled composite walls, as a natural development of composite flooring, provide structural and architectural merits. However, adequate intermediate fasteners between profiled steel plates and concrete core are required to fully mobilize the composite action and to improve the structural behavior of the wall. In this research, two new types of fasteners (i.e., threaded rods and vertical plates) were proposed and three specimens with different fastener types or fastener arrangements were tested under axial compression. The experimental results were evaluated in terms of failure modes, axial load versus axial displacement response, strength index, ductility index, and load-strain relationship. It was found that specimen with symmetrically arranged thread rods sustained more stable axial strain than that with staggered arranged threaded rods. Meanwhile, vertical plates are more suitable for practical use since they provide stronger confinement to profiled steel plate and effectively prevent the steel plate from early local buckling, which eventually enhance the composite action and increase the axial compressive capacity of the wall. The calculation methods were then proposed and good agreement was observed between the test results and the predicted results.

Qiuwei Wang, Qingxuan Shi, Zhaodong Xu and Hanxin He (First author is from: State Key Laboratory of Green Building in Western China, Xi'an University of Architecture and Technology, No. 13 Yanta Road, Xi'an, P.R. China), “Axial capacity of reactive powder concrete filled steel tube columns with two load conditions”, Steel and Composite Structures, Volume 31, Number 1, April 10 2019, pages 23-25, http://dx.doi.org/10.12989/scs.2019.31.1.013

ABSTRACT: Reactive powder concrete (RPC) is a type of ultra-high strength concrete that has a relatively high brittleness. However, its ductility can be improved by confinement, and the use of RPC in composite RPC filled steel tube columns has become an important subject of research in recent years. This paper aims to present an experimental study of axial capacity calculation of RPC filled circular steel tube columns. Twenty short columns under axial compression were tested and information on their failure patterns, deformation performance, confinement mechanism and load capacity were presented. The effects of load conditions, diameter-thickness ratio and compressive strength of RPC on the axial behavior were further discussed. The experimental results show that: (1) specimens display drum-shaped failure or shear failure respectively with different confinement coefficients, and the load capacity of most specimens increases after the peak load; (2) the steel tube only provides lateral confinement in the elastic-plastic stage for fully loaded specimens, while the confinement effect from steel tube initials at the set of loading for partially loaded specimens; (3) confinement increases the load capacity of specimens by 3% to 38%, and this increase is more pronounced as the confinement coefficient becomes larger; (4) the residual capacity-to-ultimate capacity ratio is larger than 0.75 for test specimens, thus identifying the composite columns have good ductility. The working mechanism and force model of the composite columns were analyzed, and based on the twin-shear unified strength theory, calculation methods of axial capacity for columns with two load conditions were established.
ABSTRACT: This paper presents the results of an experimental study to investigate the mechanical behavior of partially encased composite columns confined by CFRP under axial compression. The results show that the high strength encased composite column exhibits brittle post peak behavior and low ductility but has acceptable compressive resistance. The high strength concrete encased composite column subjected to early spalling and initial flexural cracking due to its brittle nature that may degrade the stiffness and ultimate resistance. The analytical study compares the current code methods (ACI 318, Eurocode 4, AISC 360 and Chinese JGJ 138) in predicting the compressive resistance of the high strength concrete encased composite columns to verify the accuracy. The plastic design resistance may not be fully achieved. A database including the concrete encased composite column under centered and eccentric compression is established to verify the predictions using the proposed elastic, elastoplastic and plastic methods. Image-oriented intelligent recognition tool-based fiber element method is programmed to predict the load resistances. It is found that the plastic method can give an accurate prediction of the load resistance for the encased composite column using normal strength concrete (20-60 MPa) while the elastoplastic method provides reasonably conservative predictions for the encased composite column using high strength concrete (60-120 MPa).

Kallol Barua and Anjan K. Bhowmick (Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Canada). “Nonlinear seismic performance of code designed perforated steel plate shear walls”, Steel and Composite Structures, Volume 31, Number 1, April 10 2019, pages 85-98, http://dx.doi.org/10.12989/scs.2019.31.1.085

ABSTRACT: Nonlinear seismic performances of code designed Perforated Steel Plate Shear Walls (P-SPSW) were studied. Three multi-storey (4-, 8-, and 12-storey) P-SPSWs were designed according to Canadian seismic provisions and their performance was evaluated using time history analysis for ground motions compatible with Vancouver response spectrum. The selected code designed P-SPSWs exhibited excellent seismic performance with high ductility and strength. The current code equation was found to provide a good estimation of the shear strength of the perforated infill plate, especially when the infill plate is yielded. The applicability of the strip model, originally proposed for solid infill plate, was also evaluated for P-SPSW and two different strip models were studied. It was observed that the strip model with strip widths equal to center to center diagonal distance between each perforation line could reasonably predict the inelastic behavior of unstiffened P-SPSWs. The strip model slightly underestimated the initial stiffness; however, the ultimate strength was predicted well. Furthermore, applicability of simple shear-flexure beam model for determination of fundamental periods of P-SPSWs was studied.

Jiongfeng Liang, Guangwu Zhang, Jianbao Wang and Minghua Hu (First author is from: State Key Laboratory Breeding Base of Nuclear Resources and Environment, East China Institute of Technology, Nanchang, P.R. China). “Mechanical behaviour of partially encased composite columns confined by CFRP under axial compression”, Steel and Composite Structures, Volume 31, Number 2, April 25 2019, pages 125-131, http://dx.doi.org/10.12989/scs.2019.31.2.125

ABSTRACT: This paper presents the results of an experimental study to investigate the mechanical behavior of partially encased composite columns confined by CFRP under axial compression. The results show that the failure of the partially encased composite columns confined by CFRP occurred due to rupture of the CFRP followed by local buckling of the steel flanges. External wrapping of CFRP effectively delayed the local buckling of the steel flanges. The load carrying capacity of the column increased with the application of CFRP sheet. And the enhancement effect of the column was increased with the number of CFRP layer.

ABSTRACT: This paper reports on the energy absorption characteristics of a lattice-web reinforced composite sandwich cylinder (LRCSC) which is composed of glass fiber reinforced polymer (GFRP) face sheets, GFRP lattice webs, polyurethane (PU) foam and ceramsite filler. Quasi-static compression experiments on the LRCSC manufactured by a vacuum assisted resin infusion process (VARIP) were performed to demonstrate the feasibility of the proposed cylinders. Compared with the cylinders without lattice webs, a maximum increase in the ultimate elastic load of the lattice-web reinforced cylinders of approximately 928% can be obtained. Moreover, due to the use of ceramsite filler, the energy absorption was increased by 662%. Several numerical simulations using ANSYS/LS-DYNA were conducted to parametrically investigate the effects of the number of longitudinal lattice webs, the number of transverse lattice webs, and the thickness of the transverse lattice web and GFRP face sheet. The effectiveness and feasibility of the numerical model were verified by a series of experimental results. The numerical results demonstrated that a larger number of thicker transverse lattice webs can significantly enhance the ultimate elastic load and initial stiffness. Moreover, the ultimate elastic load and initial stiffness were hardly affected by the number of longitudinal lattice webs.

Feng Zhou and Ben Young (First author is from: State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University, Shanghai 200092, China), “Combined bending and web crippling of aluminum SHS members”, Steel and Composite Structures, Volume 31, Number 2, April 25 2019, pages 173-185, http://dx.doi.org/10.12989/scs.2019.31.2.173

ABSTRACT: This paper presents experimental and numerical investigations of aluminum tubular members subjected to combined bending and web crippling. A series of tests was performed on square hollow sections (SHS) fabricated by extrusion using 6061-T6 heat-treated aluminum alloy. Different specimen lengths were tested to obtain the interaction relationship between moment and concentrated load. The non-linear finite element models were developed and verified against the experimental results obtained in this study and test data from existing literature for aluminum tubular sections subjected to pure bending, pure web crippling, and combined bending and web crippling. Geometric and material non-linearities were included in the finite element models. The finite element models closely predicted the strengths and failure modes of the tested specimens. Hence, the models were used for an extensive parametric study of cross-section geometries, and the web slenderness values ranged from 6.0 to 86.2. The combined bending and web crippling test results and strengths predicted from the finite element analysis were compared with the design strengths obtained using the current American Specification, Australian/New Zealand Standard and European Code for aluminum structures. The findings suggest that the current specifications are either quite conservative or unconservative for aluminum square hollow sections subjected to combined bending and web crippling. Hence, a bending and web crippling interaction equation for aluminum square hollow section specimens is proposed in this paper.


ABSTRACT: This paper presents the semi-analytical development of the dynamic instability behavior and the dynamic response of functionally graded (FG) cylindrical shallow shell panel subjected to different type of periodic axial compression. First, in prebuckling analysis, the stresses distribution within the panels are determined for respective loading type and these stresses are used to study the dynamic instability behavior and the dynamic response. The prebuckling stresses within the shell panel are the same as applied in-plane edge loading for the case of uniform and linearly varying loadings. However, this is not true for the case of parabolic loadings. The parabolic edge loading produces all the stresses. . . (remainder is missing)

Rusian Kanischev and Vincent Kvocak (Department of Steel and Timber Structures, Institute of Structural Engineering, Civil Engineering Faculty, Technical University of Kosice, Vysokoskolska 4, 042 00 Kosice, Slovakia), “Local buckling of rectangular steel tubes filled with concrete”, Steel and Composite Structures, Volume 31, Number 2, April 25 2019, pages 201-216, http://dx.doi.org/10.12989/scs.2019.31.2.201

ABSTRACT: This scientific paper provides a theoretical, numerical and experimental analysis of local stability of axially compressed columns made of thin-walled rectangular concrete-filled steel tubes (CFSTs), with the consideration of initial geometric imperfections. The work presented introduces the theory of elastic critical stresses in local buckling of rectangular wall members under uniform compression. Moreover, a numerical
calculation method for the determination of the critical stress coefficient is presented, using a differential equation for a slender wall with a variety of boundary conditions. For comparison of the results of the numerical analysis with those collected by experiments, a new model is created to study the behaviour of the composite members in question by means of the ABAQUS computational-graphical software whose principles are based on the finite element method (FEM). In modelling the analysed members, the actual boundary and loading conditions and real material properties are taken into account, obtained from the experiments and material tests on these members. Finally, the results of experiments on such members are analysed and then compared with the numerical values. In conclusion, several recommendations for the design of axially compressed composite columns made of rectangular concrete-filled thin-walled steel tubes are suggested as a result of this comparison.


ABSTRACT: This study deals with the nonlinear static analysis of functionally graded carbon nanotubes reinforced composite (FG-CNTRC) truncated conical shells subjected to axial load based on the classical shell theory. Detailed studies for both nonlinear buckling and post-buckling behavior of truncated conical shells. The truncated conical shells are reinforced by single-walled carbon nanotubes which alter according to linear functions of the shell thickness. The nonlinear equations are solved by both the Airy stress function and Galerkin method based on the classical shell theory. In numerical results, the influences of various types of distribution and volume fractions of carbon nanotubes, geometrical parameters, elastic foundations on the nonlinear buckling and post-buckling behavior of FG-CNTRC truncated conical shells are presented. The proposed results are validated by comparing with other authors.

S. Masoud Marandi, Mohsen Botshekanan Dehkordi and S. Hassan Nourbakhsh (Faculty of Engineering, Shahrekord University, Shahrekord, Iran), “An extension of a high order approach for free vibration analysis of the nano-scale sandwich beam with steel skins for two types of soft and stiff cores”, Steel and Composite Structures, Volume 31, Number 3, May 10 2019, pages 261-276, http://dx.doi.org/10.12989/scs.2019.31.3.261

ABSTRACT: The study investigates the free vibration of a nano-scale sandwich beam by an extended high order approach, which has not been reported in the existing literature. First-order shear deformation theory for steel skins and so-called high-order sandwich panel theory for the core are applied. Next, the modified couple stress theory is used for both skins and cores. The Hamilton principle is utilized for deriving equations and corresponding boundary conditions. First, in the study the three-mode shapes natural frequencies for various material parameters are investigated. Also, obtained results are evaluated for two types of stiff and soft cores and isotropic, homogenous steel skins. In the research since the governing equations and also the boundary conditions are nonhomogeneous, therefore some closed-form solutions are not applicable. So, to obtain natural frequencies, the boundary conditions are converted to initial conditions called the shooting method as the numerical one. This method is one of the most robust approaches to solve complex equations and boundary conditions. Moreover, three types of simply supported on both sides of the beam (S-S), simply on one side and clamp supported on the other one (S-C) and clamped supported on both sides (C-C) are scrutinized. The parametric study is followed to evaluate the effect of nano-scale grain geometrical configurations for skins, core and material property change for cores as well. Results show that natural frequencies increase by an increase in skins thickness and core Young modulus and a decrease in beam length, core thickness as well. Furthermore, differences between obtained frequencies for soft and stiff cores increase in higher mode shapes; while, the more differences are evaluated for the stiff one.


ABSTRACT: This paper investigates the parametric instability (PI) of multilayered composite conical shells (MLCCSSs) under axial load periodically varying the time, using the first order shear deformation theory (FOSDT). The basic equations for the MLCCSSs are derived and then the Galerkin method is used to obtain the
ordinary differential equation of the motion. The equation of motion converted to the Mathieu-Hill type differential equation, in which the DI is examined employing the Bolotin's method. The expressions for left and right limits of dimensionless parametric instability regions (PIRs) of MLCCSs based on the FOSDT are obtained. Finally, the influence of various parameters; lay-up, shear deformations (SDs), aspect ratio, as well as loading factors on the borders of the PIRs are examined.


ABSTRACT: Pure torsion loading conditions were not frequently occurred in practical engineering, but the torsional researches were important since it's the basis of mechanical property researches under complex loading. Then a 3D finite element model with precise material constitutive models was established, and the effectiveness was verified with test data. Parametric studies with varying factors as steel yield strength, concrete strength and sectional height-width ratio, were performed. Internal stress state and the interaction effect between encased steel tube and the core concrete were analyzed. Results indicated that due to the confinement effect between steel tube and core concrete, the torsional strength of CFT columns was greatly improved comparing to plain concrete columns. The steel ratio would greatly influence the torque share between the steel tube and the core concrete. Then the torsional strength calculation formulas for core concrete and the whole CFT column were proposed. The proposed formula could be simpler and easier to use with guaranteed accuracy. Related design codes were more conservative than the proposed formula, but the proposed formula presented more satisfactory agreement with experimental results.


ABSTRACT: In this paper, a geometrically nonlinear meshfree analysis of 3D various forms of shell structures using the double director shell theory with finite rotations is proposed. This theory is introduced in the present method to remove the shear correction factor and to improve the accuracy of transverse shear stresses with the consideration of rotational degrees of freedom. The present meshfree method is based on the radial point interpolation method (RPIM) which is employed for the construction of shape functions for a set of nodes distributed in a problem domain. Discrete system of geometrically nonlinear equilibrium equations solved with the Newton-Raphson method is obtained by incorporating these interpolations into the weak form. The accuracy of the proposed method is examined by comparing the present results with the accurate ones available in the literature and good agreements are found.


ABSTRACT: In this paper, buckling analyses of composite plate reinforced by Graphen plateletate (GPL) is studied. The Halpin- Tsai model is used for obtaining the effective material properties of nano composite plate. The nano composite plate is modeled by Third order shear deformation theory (TSDT). The elastic medium is simulated by Winkler model. Employing nonlinear strains-displacements, stress-strain, the energy equations of plate are obtained and using Hamilton's principal, the governing equations are derived. The governing equations are solved based on Navier method. The effect of GPL volume percent, geometrical parameters of plate and elastic foundation on the buckling load are investigated. Results showed that with increasing GPLs volume percent, the buckling load increases.


ABSTRACT: We in this paper study nonlinear bending of a functionally graded porous nanobeam subjected to multiple physical load based on the nonlocal strain gradient theory. For more reasonable analysis of nanobeams made of porous functionally graded magneto-thermo-electro-elastic materials (PFGMTEEMs), both constituent
materials and the porosity appear gradient distribution in the present expression of effective material properties, which is much more suitable to the actual compared with the conventional expression of effective material properties. Besides the displacement function regarding physical neutral surface is introduced to analyze mechanical behaviors of beams made of FGMs. Then we derive nonlinear governing equations of PFGMTEEMs beams using the principle of Hamilton. To obtain analytical solutions, a two-step perturbation method is developed in nonuniform electric field and magnetic field, and then we use it to solve nonlinear equations. Finally, the analytical solutions are utilized to perform a parametric analysis, where the effect of various physical parameters on static bending deformation of nanobeams are studied in detail, such as the nonlocal parameter, strain gradient parameter, the ratio of nonlocal parameter to strain gradient parameter, porosity volume fraction, material volume fraction index, temperature, initial magnetic potentials and external electric potentials.


ABSTRACT: This article presents a unified mathematical model to investigate free and forced vibration responses of perforated thin and thick beams. Analytical models of the equivalent geometrical and material characteristics for regularly squared perforated beam are developed. Because of the shear deformation regime increasing in perforated structures, the investigation of dynamical behaviors of these structures becomes more complicated and effects of rotary inertia and shear deformation should be considered. So, both Euler-Bernoulli and Timoshenko beam theories are proposed for thin and short (thick) beams, respectively. Mathematical closed forms for the eigenvalues and the corresponding eigenvectors as well as the forced vibration time response are derived. The validity of the developed analytical procedure is verified by comparing the obtained results with both analytical and numerical analyses and good agreement is detected. Numerical studies are presented to illustrate effects of beam slenderness ratio, filling ratio, as well as the number of holes on the dynamic behavior of perforated beams. The obtained results and concluding remarks are helpful in mechanical design and industrial applications of large devices and small systems (MEMS) based on perforated structure.


ABSTRACT: This work presents a dynamic investigation of functionally graded (FG) plates resting on elastic foundation using a simple quasi-3D higher shear deformation theory (quasi-3D HSDT) in which the stretching effect is considered. The culmination of this theory is that in addition to taking into account the effect of thickness extension ($\varepsilon \neq 0$), the kinematic is defined with only 4 unknowns, which is even lower than the first order shear deformation theory (FSDT). The elastic foundation is included in the formulation using the Pasternak mathematical model. The governing equations are deduced through the Hamilton's principle. These equations are then solved via closed-type solutions of the Navier type. The fundamental frequencies are predicted by solving the eigenvalue problem. The degree of accuracy of present solutions can be shown by comparing it to the 3D solution and other closed-form solutions available in the literature.


ABSTRACT: Current paper deals with thermoelastic static and free vibrational behaviors of axisymmetric thick cylinders reinforced with functionally graded (FG) randomly oriented graphene subjected to internal pressure and thermal gradient loads. The heat transfer and mechanical analyses of randomly oriented graphene-reinforced nanocomposite (GRNC) cylinders are facilitated by developing a weak form mesh-free method based on moving least squares (MLS) shape functions. Furthermore, in order to estimate the material properties of GRNC with temperature dependent components, a modified Halpin-Tsai model incorporated with two efficiency parameters is utilized. It is assumed that the distributions of graphene nano-sheets are uniform and FG along the radial direction of nanocomposite cylinders. By comparing with the exact result, the accuracy of the developed method is verified. Also, the convergence of the method is successfully confirmed. Then we
investigated the effects of graphene distribution and volume fraction as well as thermo-mechanical boundary conditions on the temperature distribution, static response and natural frequency of the considered FG-GRNC thick cylinders. The results disclosed that graphene distribution has significant effects on the temperature and hoop stress distributions of FG-GRNC cylinders. However, the volume fraction of graphene has stronger effect on the natural frequencies of the considered thick cylinders than its distribution.


ABSTRACT: Spiral spacing effect on axial compressive behavior of reinforced concrete filled steel tube (RCFST) stub column is experimentally investigated in this paper. A total of twenty specimens including sixteen square RCFST columns and four benchmarked conventional square concrete filled steel tube (CFST) columns are fabricated and tested. Test variables include spiral spacing (spiral ratio) and concrete strength. The failure modes, load versus displacement curves, compressive rigidity, axial compressive strength, and ductility of the specimens are obtained and analyzed. Especially, the effect of spiral spacing on axial compressive strength and ductility is investigated and discussed in detail. Test results show that heavily arranged spirals considerably increase the ultimate compressive strength but lightly arranged spirals have no obvious effect on the ultimate strength. In practical design, the effect of spirals on RCFST column strength should be considered only when spirals are heavily arranged. Spiral spacing has a considerable effect on increasing the post-peak ductility of RCFST columns. Decreasing of the spiral spacing considerably increases the post-peak ductility of the RCFSTs. When the concrete strength increases, ultimate strength increases but the ductility decreases, due to the brittleness of the higher strength concrete. Arranging spirals, even with a rather small amount of spirals, is an economical and easy solution for improving the ductility of RCFST columns with highstrength concrete. Ultimate compressive strengths of the columns are calculated according to the codes EC4 (2004), GB 50936 (2014), AIJ (2008), and ACI 318 (2014). The ultimate strength of RCFST stub columns can be most precisely evaluated using standard GB 50936 (2014) considering the effect of spiral confinement on core concrete.


ABSTRACT: In cold-formed steel (CFS) structures, such as trusses, wall frames and columns, the use of back-to-back built-up CFS angle sections are becoming increasingly popular. In such an arrangement, intermediate fasteners are required at discrete points along the length, preventing the angle-sections from buckling independently. Limited research is available in the literature on the axial strength of back-to-back built-up CFS angle sections. The issue is addressed herein. This paper presents the results of 16 experimental tests, conducted on back-to-back built-up CFS screw fastened angle sections under axial compression. A nonlinear finite element model is then described, which includes material non-linearity, geometric imperfections and explicit modelling of the intermediate fasteners. The finite element model was validated against the experimental test results. The validated finite element model was then used for the purpose of a parametric study comprising 66 models. The effect of fastener spacing on axial strength was investigated. Four different cross-sections and two different thicknesses were analyzed in the parametric study, varying the slenderness ratio of the built-up columns from 20 to 120. Axial strengths obtained from the experimental tests and finite element analysis were used to assess the performance of the current design guidelines as per the Direct Strength Method (DSM); obtained comparison showed that the DSM is over-conservative by 13% on average. This paper has therefore proposed improved design rules for the DSM and verified their accuracy against the finite element and test results of back-to-back built-up CFS angle sections under axial compression.


ABSTRACT: In this paper, wave propagation is studied and analyzed in double-layered nanotubes systems via the nonlocal strain gradient theory. To the author's knowledge, the present paper is the first to investigate the wave propagation characteristics of double-layered porous nanotubes systems. It is generally considered that the material properties of nanotubes are related to the porosity and hygro-thermal effects. The governing equations
of the double-layered nanotubes systems are derived by using the Hamilton principle. The dispersion relations and displacement fields of wave propagation in the double nanotubes systems which experience three different types of motion are obtained and discussed. The results show that the phase velocities of the double nanotubes systems depend on porosity, humidity change, temperature change, material composition, non-local parameter, strain gradient parameter, interlayer spring, and wave number.


ABSTRACT: Hollow steel-reinforced concrete-filled GFRP tubular member is a new kind of composite members. Firstly set the mold in the GFRP tube (non-bearing component), then set the longitudinal reinforcements with stirrups (steel reinforcement cage) between the GFRP tube and the mold, and filled the concrete between them. Through the axial compression test of the hollow steel-reinforced concrete-filled GFRP tubular member, the working mechanism and failure modes of composite members were obtained. Based on the experiment, when the load reached the ranges of 55-70% $P_u$ ($P_u$-ultimate load), white cracks appeared on the surface of the GFRP tubes of specimens. At that time, the confinement effects of the GFRP tubes on core concrete were obvious. Keep loading, the ranges of white cracks were expanding, and the confinement effects increased proportionally. In addition, the damages of specimens, which were accompanied with great noise, were marked by fiber breaking and resin cracking on the surface of GFRP tubes, also accompanied with concrete crushing. The bearing capacity of the axially compressed components increased with the increase of reinforcement ratio, and decreased with the increase of hollow ratio. When the reinforcement ratio was increased from 0 to 4.30%, the bearing capacity was increased by about 23%. When the diameter of hollow part was decreased from 55mm to 0, the bearing capacity was increased by about 32%.


ABSTRACT: In this research, the dynamic instability region (DIR) of the sandwich nano-beams are investigated based on nonlocal strain gradient elasticity theory (NSGET) and various higher order shear deformation beam theories (HSDBTs). The sandwich piezoelectric nano-beam is including a homogenous core and face-sheets reinforced with functionally graded (FG) carbon nanotubes (CNTs). In present study, three patterns of CNTs are employed in order to reinforce the top and bottom face-sheets of the beam. In addition, different higher-order shear deformation beam theories such as trigonometric shear deformation beam theory (TSDBT), exponential shear deformation beam theory (ESDBT), hyperbolic shear deformation beam theory (HSDBT), and Aydogdu shear deformation beam theory (ASDBT) are considered to extract the governing equations for different boundary conditions. The beam is subjected to thermal and electrical loads while is resting on Visco-Pasternak foundation. Hamilton principle is used to derive the governing equations of motion based on various shear deformation theories. In order to analysis of the dynamic instability behaviors, the linear governing equations of motion are solved using differential quadrature method (DQM). After verification with validated reference, comprehensive numerical results are presented to investigate the influence of important parameters such as various shear deformation theories, nonlocal parameter, strain gradient parameter, the volume fraction of the CNTs, various distributions of the CNTs, different boundary conditions, dimensionless geometric parameters, Visco-Pasternak foundation parameters, applied voltage and temperature change on the dynamic instability characteristics of sandwich piezoelectric nano-beam.


ABSTRACT: This study is concerned with the stability of laminated composite plates modelled using Eringen's nonlocal differential model (ENDM) and a novel refined-hyperbolic-shear-deformable plate theory. The plate is assumed to be lying on the Pasternak elastic foundation and is under the influence of an in-plane magnetic field. The governing equations and boundary conditions are obtained through Hamilton's principle. An analytical approach considering Navier series is used to fine the critical bucking load. After verifying with
existing results for the reduced cases, the present model is then used to study buckling of the laminated composite plate. Numerical results demonstrate clearly for the first time the roles of size effects, magnetic field, foundation parameters, moduli ratio, geometry, lay-up numbers and sequences, fiber orientations, and boundary conditions. These results could be useful for designing better composites and can further serve as benchmarks for future studies on the laminated composite plates.


ABSTRACT: In this research, the dynamic stability and nonlinear vibration behavior of a smart rotating sandwich cylindrical shell is studied. The core of the structure is a functionally graded material (FGM) which is integrated by functionally graded piezoelectric material (FGPM) layers subjected to electric field. The piezoelectric layers at the inner and outer surfaces used as actuator and sensor, respectively. By applying the energy method and Hamilton’s principle, the governing equations of sandwich cylindrical shell derived based on first-order shear deformation theory (FSDT). The Galerkin method is used to discriminate the motion equations and the equations are converted to the form of the ordinary differential equations in terms of time. The perturbation method is employed to find the relation between nonlinear frequency and the amplitude of vibration. The main objective of this research is to determine the nonlinear frequencies and nonlinear vibration control by using sensor and actuator layers. The effects of geometrical parameters, power law index of core, sensor and actuator layers, angular velocity and scale transformation parameter on nonlinear frequency-amplitude response diagram and dynamic stability of sandwich cylindrical shell are investigated. The results of this research can be used to design and vibration control of rotating systems in various industries such as aircraft, biomechanics and automobile manufacturing.


ABSTRACT: Since conical sandwich shells are important structures in the modern industries, in this paper, for the first time, vibration behavior of the truncated conical sandwich shells which include temperature dependent porous FG face sheets and temperature dependent homogeneous core in various thermal conditions are investigated. A high order theory of sandwich shells which modified by considering the flexibility of the core and nonlinear von Karman strains are utilized. Power law rule which modified by considering the two types of porosity volume fractions are applied to model the functionally graded materials. By utilizing the Hamilton’s energy principle, and considering the in-plane and thermal stresses in the face-sheets and the core, the governing equations are obtained. A Galerkin procedure is used to solve the equations in a simply supported boundary condition. Uniform, linear and nonlinear temperature distributions are used to model the effect of the temperature changing in the sandwich shell. To verify the results of this study, they are compared with FEM results obtained by Abaqus software and for special cases with the results in literatures. Eigen frequencies variations are surveyed versus the temperature changing, geometrical effects, porosity, and some others in the numerical examples.


ABSTRACT: This paper presents the combination resonances of FG porous (FGP) cylindrical shell under two-term excitation. The effect of structural damping on the system response is also considered. With regard to classical plate theory of shells, von-Karman equation and Hook law, the relations of stress-strain is derived for shell. According to the Galerkin method, the discretized motion equation is obtained. The combination resonances are obtained by using the method of multiple scales. Four types of FGP distributions consist of uniform porosity, non-symmetric porosity soft, non-symmetric porosity stiff and symmetric porosity distribution are considered. The influence of various porosity distributions, porosity coefficients of cylindrical shell and amplitude excitations on the combination resonances for FGP cylindrical shells is investigated.
ABSTRACT: Nonlocal elasticity and Reddy plate theory are used to study the vibration response of functionally graded (FG) nanoplates resting on two parameters elastic medium called Pasternak foundation. Nonlocal higher order theory accounts for the effects of both scale and the effect of transverse shear deformation, which becomes significant where stocky and short nanoplates are concerned. It is assumed that the properties of FG nanoplate follow a power law through the thickness. In addition, Poisson's ratio is assumed to be constant in this model. Both Winkler-type and Pasternak-type foundation models are employed to simulate the interaction of nanoplate with surrounding elastic medium. Using Hamilton's principle, size-dependent governing differential equations of motion and corresponding boundary conditions are derived. A differential quadrature approach is being utilized to discretize the model and obtain numerical solutions for various boundary conditions. The model is validated by comparing the results with other published results.


ABSTRACT: In the present paper, the element free Galerkin (EFG) method is developed for geometrically nonlinear analysis of deep beams considering small scale effect. To interpret the behavior of structure at the nano scale, the higher-order gradient elasticity nonlocal theory is taken into account. The radial point interpolation method with high order of continuity is used to construct the shape functions. The nonlinear equation of motion is derived using the principle of the minimization of total potential energy based on total Lagrangian approach. The Newmark method with the small time steps is used to solve the time dependent equations. At each time step, the iterative Newton-Raphson technique is applied to minimize the residential forces caused by the nonlinearity of the equations. The effects of nonlocal parameter and aspect ratio on stiffness and dynamic parameters are discussed by numerical examples. This paper furnishes a ground to develop the EFG method for large deformation analysis of structures considering small scale effects.


ABSTRACT: In this article, a simple quasi-3D shear deformation theory is employed for thermo-mechanical bending analysis of functionally graded material (FGM) sandwich plates. The displacement field is defined using only 5 variables as the first order shear deformation theory (FSDT). Unlike the other high order shear deformation theories (HSDTs), the present formulation considers a new kinematic which includes undetermined integral variables. The governing equations are determined based on the principle of virtual work and then they are solved via Navier method. Analytical solutions are proposed to provide the deflections and stresses of simply supported FGM sandwich structures. Comparative examples are presented to demonstrate the accuracy of the present theory. The effects of gradient index, geometrical parameters and thermal load on thermo-mechanical bending response of the FG sandwich plates are examined.


ABSTRACT: This study aims to accurately predict the first ply failure loads of laminated composite hypar shell roofs with different boundary conditions. The geometrically nonlinear finite element method (FEM) is used to analyse different symmetric and anti-symmetric, cross and angle ply shells. The first ply failure loads are obtained through different well-established failure criteria including Puck’s criterion along with the serviceability criterion of deflection. The close agreement of the published and present results for different validation problems proves the correctness of the finite element model used in the present study. The effects of edge conditions on first ply failure behavior are discussed critically from practical engineering point of view. Factor of safety values and failure zones are also reported to suggest design and non-destructive monitoring guidelines to practicing engineers. Apart from these, the present study indicates the rank wise relative
performances of different shell options. The study establishes that the angle ply laminates in general perform better than the cross ply ones. Among the stacking sequences considered here, three layered symmetric angle ply laminates offer the highest first ply failure load. The probable failure zones on the different shell surfaces, identified in this paper, are the areas where non-destructive health monitoring may be restricted to. The contributions made through this paper are expected to serve as important design aids to engineers engaged in composite hypar shell design and construction.


ABSTRACT: Despite the rapid advancement in computing resources, many real-life design and optimization problems in structural engineering involve huge computation costs. To counter such challenges, approximate models are often used as surrogates for the highly accurate but time intensive finite element models. In this paper, surrogates for first-order shear deformation based finite element models are built using a polynomial regression approach. Using statistical techniques like Box-Cox transformation and ANOVA, the effectiveness of the surrogates is enhanced. The accuracy of the surrogate models is evaluated using statistical metrics like $R^2$, $R^2_{adj}$, $R^2_{pred}$ and $Q_n$. By combining these surrogates with nature-inspired multi-criteria decision-making algorithms, namely multi-objective genetic algorithm (MOGA) and multi-objective particle swarm optimization (MOPSO), the optimal combination of various design variables to simultaneously maximize fundamental frequency and frequency separation is predicted. It is seen that the proposed approach is simple, effective and good at inexpensively producing a host of optimal solutions.


ABSTRACT: In this paper, an analytical approach for the free vibration analysis of spiral stiffened functionally graded (SSFG) cylindrical shells is investigated. The SSFG shell is resting on linear and non-linear elastic foundation with damping force. The elastic foundation for the linear model is according to Winkler and Pasternak parameters and for the non-linear model, one cubic term is added. The material constitutive of the stiffeners is continuously changed through the thickness. Using the Galerkin method based on the von Kármán equations and the smeared stiffeners technique, the non-linear vibration problem has been solved. The effects of different geometrical and material parameters on the free vibration response of SSFG cylindrical shells are adopted. The results show that the angles of stiffeners and elastic foundation parameters strongly affect on the natural frequencies of the SSFG cylindrical shell.


ABSTRACT: This paper deals with the static and dynamic behavior of Functionally Graded Carbon Nanotubes (FG-CNT)-reinforced porous sandwich (PMPV) polymer plate. The model of nanocomposite plate is investigated within the first order shear deformation theory (FSDT). Two types of porous sandwich plates are supposed (sandwich with face sheets reinforced / homogeneous core and sandwich with homogeneous face sheets / reinforced core). Functionally graded Carbon Nanotubes (FG-CNT) and uniformly Carbon Nanotubes (UD-CNT) distributions of face sheets or core porous plates with uniaxially aligned single-walled carbon nanotubes are considered. The governing equations are derived by using Hamilton's principle. The solution for bending and vibration of such type's porous plates are obtained. The detailed mathematical derivations are provided and the solutions are compared to some cases in the literature. The effect of the several parameters of reinforced sandwich porous plates such as aspect ratios, volume fraction, types of reinforcement, number of modes and thickness of plate on the bending and vibration analyses are studied and discussed. On the question of porosity, this study found that there is a great influence of their variation on the static and vibration of porous sandwich plate.

ABSTRACT: In this work, a four-variable refined plate model is applied to study the thermomechanical bending of two kinds of functionally graded material (FGM) sandwich plates. The sandwich core of one kind is isotropic with the FGM face sheets whereas in the second kind, the sandwich core is FGM with the isotropic and homogeneous face sheets. By considering only four unknown variables, the governing equations are written based on the principle of virtual work and then Navier method is employed to solve these equations. Deflections and stresses of two kinds of FGM sandwich structures are analyzed and discussed. The validity and efficiency of the proposed model is checked by comparing it with various available solutions in the literature. The effects of volume fraction distribution, geometric ratio and thermal load on thermomechanical bending properties of FGM sandwich plate are investigated in detail.

Kuo Xu, Yuan Yuan and Mingyang Li (School of Mechanical and Precision Instrument Engineering, Xi'an University of Technology, Xi'an, 710048, China), “Buckling behavior of functionally graded porous plates integrated with laminated composite faces sheets”, Steel and Composite Structures, Vol. 32, No. 5, September 10 2019, pp 633-642, https://doi.org/10.12989/scs.2019.32.5.633

ABSTRACT: In this work, lightweight sandwich plates consisting of a functionally graded porous (FGP) core and two laminated composite face sheets resting on elastic foundation have been proposed. Three different profiles are considered for the distributions of porosities along core thickness. The main aim of this paper is the investigation of the buckling behavior of the proposed porous sandwich plates (PSPs) by reporting their critical mechanical loads and their corresponding mode shapes. A finite element method (FEM) based on first order shear deformation theories (FSDT) is developed to discretize governing equations for the buckling behavior of the proposed sandwich plates. The effects of porosity dispersion and volume, the numbers and angles of laminated layers, sandwich plate geometrical dimensions, elastic foundation coefficients, loading and boundary conditions are studied. The results show that the use of FGP core can offer a PSP with half weight core and only 5% reduction in critical buckling loads. Moreover, stacking sequences with only ±45 orientation fibers offer the highest values of buckling loads.

Amir Amini, M. Mohammadimehr and A.R. Faraji
(1) M. Mohammadimehr: Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran;
(2) Amir Amini, A.R. Faraji: Department of Control, Faculty of Computer and Electrical Engineering, University of Kashan, Kashan, Iran.


ABSTRACT: Active control of solar panels with honeycomb core and carbon nanotube reinforced composite (CNTRC) facesheets for smart structures using piezoelectric patch sensor and actuator to reduce the amplitude of vibration is a lack of the previous study and it is the novelty of this research. Of active control elements are piezoelectric patches which act as sensors and actuators in many systems. Their low power consumption is worth mentioning. Thus, deriving a simple and efficient model of piezoelectric patch's elastic, electrical, and elastoelectric properties would be of much significance. In the present study, first, to reduce vibrations in composite plates reinforced by carbon nanotubes, motion equations were obtained by the extended rule of mixture. Second, to simulate the equations of the system, up to 36 mode shape vectors were considered so that the stress strain behavior of the panel and extent of displacement are thoroughly evaluated. Then, to have a more acceptable analysis, the effects of external disturbances (Aerodynamic forces) and lumped mass are investigated on the stability of the system. Finally, elastoelectric effects are examined in piezoelectric patches. The results of the present research can be used for micro-vibration suppression in satellites such as solar panels, space telescopes, and interferometers and also to optimize active control panel for various applications.

ABSTRACT: In this paper, free and force vibration behaviors of graphene-reinforced composite functionally graded (GRC-FG) cylindrical shells in thermal environments are investigated based on Reddy's third-order shear deformation theory (HSDT). The GRC-FG cylindrical shells are composed of piece-wise pattern graphene-reinforced layers which have different volume fraction. Based on the extended Halpin-Tsai micromechanical model, the effective material properties of the resulting nanocomposites are evaluated. Using the Hamilton's principle and the assumed mode method, the motion equation of the GRC-FG cylindrical shell is formulated. Using the time- and frequency-domain methods, free and force vibration properties of the GRC-FG cylindrical shell are analyzed. Numerical cases are provided to study the effects of distribution of graphene, shell radius-to-thickness ratio and temperature changes on the free and force vibration responses of GRC-FG cylindrical shells.

Ali Cheraghbak, M. Botshekanan Dehkordi and H. Golestanian (Faculty of Engineering, Shahrekourd University, Shahrekord, Iran)

ABSTRACT: In this paper, free vibration of sandwich beam with flexible core resting on orthotropic Pasternak is investigated. The top and bottom layers are reinforced by carbon nanotubes (CNTs). This sandwich structural is modeled by Euler and Frostig theories. The effect of agglomeration using Mori-Tanaka model is considered. The Eringen's theory is applied for size effect. The structural damping is investigated by Kelvin-voigt model. The motion equations are calculated by Hamilton's principle and energy method. Using analytical method, the frequency of the structure is obtained. The effect of agglomeration and CNTs volume percent for different parameter such as damping of structure, thickens and spring constant of elastic medium are presented on the frequency of the composite structure. Results show that with increasing CNTs agglomeration, frequency is decreased.

Y. Kiani and M. Mirzaei
(1) Y. Kiani: Faculty of Engineering, Shahrekord University, Shahrekord, Iran;
(2) M. Mirzaei: Department of Mechanical Engineering, Faculty of Engineering,University of Qom, Qom, Iran.

ABSTRACT: An analysis on thermal buckling and postbuckling of composite laminated plates reinforced with a low amount of graphene platelets is performed in the current investigation. It is assumed that graphene platelets are randomly oriented and uniformly dispersed in each layer of the composite media. Elastic properties of the nanocomposite media are obtained by means of the modified Halpin-Tsai approach which takes into account the size effects of the graphene reinforcements. By means of the von Kármán type of geometrical nonlinearity, third order shear deformation theory and nonuniform rational B-spline (NURBS) based isogeometric finite element method, the governing equations for the thermal postbuckling of nanocomposite plates in rectangular shape are established. These equations are solved by means of a direct displacement control strategy. Numerical examples are given to study the effects of boundary conditions, weight fraction of graphene platelets and distribution pattern of graphene platelets. It is shown that, with introduction of a small amount of graphene platelets into the matrix of the composite media, the critical buckling temperature of the plate may be enhanced and thermal postbuckling deflection may be alleviated.

Krishanu Roy, Hieng Ho Lau and James B.P. Lim
(1) Krishanu Roy, James B.P. Lim: Department of Civil and Environmental Engineering, The University of Auckland, Auckland, New Zealand;
(2) Hieng Ho Lau: Faculty of Engineering, Computing and Science, Swinburne University of Technology, Kuching,

ABSTRACT: In cold-formed steel structures, such as trusses, wall frames and portal frames, the use of back-to-back built-up cold-formed stainless-steel lipped channels as compression members is becoming increasingly popular. The advantages of using stainless-steel as structural members are corrosion resistance and durability, compared with carbon steel. The AISI/ASCE Standard, SEI/ASCE-8-02 and AS/NZS do not include the design of stainless-steel built-up channels and very few experimental tests or finite element analyses have been reported in the literature for such back-to-back cold-formed stainless-steel channels. Current guidance by the American Iron and Steel Institute (AISI) and the Australian and New Zealand (AS/NZS) standards for built-up steel sections only describe a modified slenderness approach, to consider the spacing of the intermediate fasteners. Thus, this paper presents a numerical investigation on the behavior of back-to-back cold-formed stainless-steel built-up lipped channels. Three different grades of stainless steel i.e., duplex EN1.4462, ferritic EN1.4003 and austenitic EN1.4404 have been considered. Effect of screw spacing on the axial strength of such built-up channels was investigated. As expected, most of the short and intermediate columns failed by either local-global or local-distortional buckling interactions, whereas the long columns, failed by global buckling. All three grades of stainless-steel stub columns failed by local buckling. A comprehensive parametric study was then carried out covering a wide range of slenderness and different cross-sectional geometries to assess the performance of the current design guidelines by AISI and AS/NZS. In total, 647 finite element models were analyzed. From the results of the parametric study, it was found that the AISI & AS/NZS are conservative by around 10 to 20% for cold-formed stainless-steel built-up lipped channels failed through overall buckling, irrespective of the stainless-steel grades. However, the AISI and AS/NZS can be un-conservative by around 6% for all three grades of stainless-steel built-up channels, which failed by local buckling.


ABSTRACT: The present paper addresses a refined plate theory in order to describe the response of anti-symmetric cross-ply laminated plates subjected to a uniformly distributed nonlinear thermo-mechanical loading. In the present theory, the undetermined integral terms are used and the variables number is reduced to four instead of five or more in other higher-order theories. The boundary conditions on the top and the bottom surfaces of the plate are satisfied; hence the use of the transverse shear correction factors is avoided. The principle of virtual work is used to obtain governing equations and boundary conditions. Navier solution for simply supported plates is used to derive analytical solutions. For the validation of the present theory, numerical results for displacements and stresses are compared with those of classical, first-order, higher-order and trigonometric shear theories reported in the literature.


ABSTRACT: In the present study, vibration analysis of double bonded micro sandwich cylindrical shells with saturated porous core and carbon/boron nitride nanotubes (CNT/BNNT) reinforced composite face sheets under multi-physical loadings based on Cooper-Naghdi theory is investigated. The material properties of the microstructure are assumed to be temperature dependent, and each of the micro-tubes is placed on the Pasternak elastic foundations, and mechanical, moisture, thermal, electrical, and magnetic forces are effective on the structural behavior. The distributions of porous materials in three distributions such as non-linear non-symmetric, nonlinear-symmetric, and uniform are considered. The relationship including electro-magneto-hydro-thermo-mechanical loadings based on modified couple stress theory is obtained and moreover the governing equations of motion using the energy method and the Hamilton's principle are derived. Also, Navier's type solution is also used to solve the governing equations of motion. The effects of various
parameters such as material length scale parameter, temperature change, various distributions of nanotube, volume fraction of nanotubes, porosity and Skempton coefficients, and geometric parameters on the natural frequency of double bonded micro sandwich cylindrical shells are investigated. Increasing the porosity and the Skempton coefficients of the core in micro sandwich cylindrical shell lead to increase the natural frequency of the structure. Cylindrical shells and porous materials in the industry of filters and separators, heat exchangers and coolers are widely used and are generally accepted today.

Yong Yang, Yicong Xue, Yunlong Yu and Zhichao Gong
Post-fire test of precast steel reinforced concrete stub columns under eccentric compression
ABSTRACT: This paper presents an experimental work on the post-fire behavior of two kinds of innovative composite stub columns under eccentric compression. The partially precast steel reinforced concrete (PPSRC) column is composed of a precast outer-part cast using steel fiber reinforced reactive powder concrete (RPC) and a cast-in-place inner-part cast using conventional concrete. Based on the PPSRC column, the hollow precast steel reinforced concrete (HPSRC) column has a hollow column core. With the aim to investigate the post-fire performance of these composite columns, six stub column specimens, including three HPSRC stub columns and three PPSRC stub columns, were exposed to the ISO834 standard fire. Then, the cooling specimens and a control specimen unexposed to fire were eccentrically loaded to explore the residual capacity. The test parameters include the section shape, concrete strength of inner-part, eccentricity ratio and heating time. The test results indicated that the precast RPC shell could effectively confine the steel shape and longitudinal reinforcements after fire, and the PPSRC stub columns experienced lower core temperature in fire and exhibited higher post-fire residual strength as compared with the HPSRC stub columns due to the insulating effect of core concrete. The residual capacity increased with the increasing of inner concrete strength and with the decreasing of heating time and load eccentricity. Based on the test results, a FEA model was established to simulate the temperature field of test specimens, and the predicted results agreed well with the test results.

Haichao Li, Fuzhen Pang, Yuan Du and Cong Gao (College of Shipbuilding Engineering, Harbin Engineering University, Harbin, 150001, P.R. China)
Free vibration analysis of uniform and stepped functionally graded circular cylindrical shells
ABSTRACT: A semi analytical method is employed to analyze free vibration characteristics of uniform and stepped functionally graded circular cylindrical shells under complex boundary conditions. The analytical model is established based on multi-segment partitioning strategy and first-order shear deformation theory. The displacement functions are handled by unified Jacobi polynomials and Fourier series. In order to obtain continuous conditions and satisfy complex boundary conditions, the penalty method about spring technique is adopted. The solutions about free vibration behavior of functionally graded circular cylindrical shells were obtained by approach of Rayleigh-Ritz. To confirm the dependability and validity of present approach, numerical verifications and convergence studies are conducted on functionally graded cylindrical shells under various influencing factors such as boundaries, spring parameters et al. The present method apparently has rapid convergence ability and excellent stability, and the results of the paper are closely agreed with those obtained by FEM and published literatures.

Viet-Linh Tran, Duc-Kien Thai and Seung-Eock Kim
A new empirical formula for prediction of the axial compression capacity of CCFT columns
ABSTRACT: This paper presents an efficient approach to generate a new empirical formula to predict the axial compression capacity (ACC) of circular concrete-filled tube (CCFT) columns using the artificial neural network (ANN). A total of 258 test results extracted from the literature were used to develop the ANN models. The ANN model having the highest correlation coefficient (R) and the lowest mean square error (MSE) was determined as the best model. Stability analysis, sensitivity analysis, and a parametric study were carried out to estimate the stability of the ANN model and to investigate the main contributing factors on the ACC of CCFT
columns. Stability analysis revealed that the ANN model was more stable than several existing formulae. Whereas, the sensitivity analysis and parametric study showed that the outer diameter of the steel tube was the most sensitive parameter. Additionally, using the validated ANN model, a new empirical formula was derived for predicting the ACC of CCFT columns. Obviously, a higher accuracy of the proposed empirical formula was achieved compared to the existing formulae.

Mohammed Sobhy and Ashraf M. Zenkour
Vibration analysis of functionally graded graphene platelet-reinforced composite doubly-curved shallow shells on elastic foundations
Steel and Composite Structures, Vol. 33, No. 2, October 25 2019, pp 195-208,
https://doi.org/10.12989/scs.2019.33.2.195
ABSTRACT: Based on a four-variable shear deformation shell theory, the free vibration analysis of functionally graded graphene platelet-reinforced composite (FGGPRC) doubly-curved shallow shells with different boundary conditions is investigated in this work. The doubly-curved shells are composed of multi nanocomposite layers that are reinforced with graphene platelets. The graphene platelets are uniformly distributed in each individual layer. While, the volume faction of the graphene is graded from layer to other in accordance with a novel distribution law. Based on the suggested distribution law, four types of FGGPRC doubly-curved shells are studied. The present shells are assumed to be rested on elastic foundations. The material properties of each layer are calculated using a micromechanical model. Four equations of motion are deduced utilizing Hamilton's principle and then converted to an eigenvalue problem employing an analytical method. The obtained results are checked by introducing some comparison examples. A detailed parametric investigation is performed to illustrate the influences of the distribution type of volume fraction, shell curvatures, elastic foundation stiffness and boundary conditions on the vibration of FGGPRC doubly-curved shells.

S.A.M. Ghannadpour and A. Kurkaani (New Technologies and Engineering Department, Shahid Beheshti University, G.C, Tehran, Iran)
Combined effects of end-shortening strain, lateral pressure load and initial imperfection on ultimate strength of laminates: nonlinear plate theory
Steel and Composite Structures, Vol. 33, No. 2, October 25 2019, pp 245-259,
https://doi.org/10.12989/scs.2019.33.2.245
ABSTRACT: The present study aims to investigate the ultimate strength and geometric nonlinear behavior of composite plates containing initial imperfection subjected to combined end-shortening strain and lateral pressure loading by using a semi-analytical method. In this study, the first order shear deformation plate theory is considered with the assumption of large deflections. Regarding in-plane boundary conditions, two adjacent edges of the laminates are completely held while the two others can move straightly. The formulations are based on the concept of the principle of minimum potential energy and Newton-Raphson technique is employed to solve the nonlinear set of algebraic equations. In addition, Hashin failure criteria are selected to predict the failures. Further, two distinct models are assumed to reduce the mechanical properties of the failure location, complete ply degradation model, and ply region degradation model. Degrading the material properties is assumed to be instantaneous. Finally, laminates having a wide range of thicknesses and initial geometric imperfections with different intensities of pressure load are analyzed and discuss how the ultimate strength of the plates changes.

Yang Gao, Wan-shen Xiao and Haiping Zhu
On axial buckling and post-buckling of geometrically imperfect single-layer graphene sheets
Steel and Composite Structures, Vol. 33, No. 2, October 25 2019, pp 261-275,
https://doi.org/10.12989/scs.2019.33.2.261
ABSTRACT: The main objective of this paper is to study the axial buckling and post-buckling of geometrically imperfect single-layer graphene sheets (GSs) under in-plane loading in the theoretical framework of the nonlocal strain gradient theory. To begin with, a graphene sheet is modeled by a two-dimensional plate subjected to simply supported ends, and supposed to have a small initial curvature. Then according to the Hamilton*$39;s principle, the nonlinear governing equations are derived with the aid of the classical plate theory and the von-karman nonlinearity theory. Subsequently, for providing a more accurate physical
assessment with respect to the influence of respective parameters on the mechanical performances, the approximate analytical solutions are acquired via using a two-step perturbation method. Finally, the authors perform a detailed parametric study based on the solutions, including geometric imperfection, nonlocal parameters, strain gradient parameters and wave mode numbers, and then reaching a significant conclusion that both the size-dependent effect and a geometrical imperfection can't be ignored in analyzing GSs.

Amirmahmoud Sadoughifar, Fatemeh Farhatnia, Mohsen Izadinia and Sayed Behzad Tal
Nonlinear bending analysis of porous FG thick annular/circular nanoplate based on modified couple stress and two-variable shear deformation theory using GDQM
ABSTRACT: This is the first attempt to consider the nonlinear bending analysis of porous functionally graded (FG) thick annular and circular nanoplates resting on Kerr foundation. The size effects are captured based on modified couple stress theory (MCST). The material properties of the porous FG nanostructure are assumed to vary smoothly through the thickness according to a power law distribution of the volume fraction of the constituent materials. The elastic medium is modeled by Kerr elastic foundation which consists of two spring layers and one shear layer. The governing equations are extracted based on Hamilton's principle and two variables refined plate theory. Utilizing generalized differential quadrature method (GDQMM), the nonlinear static behavior of the nanostructure is obtained under different boundary conditions. The effects of various parameters such as material length scale parameter, boundary conditions, and geometrical parameters of the nanoplate, elastic medium constants, porosity and FG index are shown on the nonlinear deflection of the annular and circular nanoplates. The results indicate that with increasing the material length scale parameter, the nonlinear deflection is decreased. In addition, the dimensionless nonlinear deflection of the porous annular nanoplate is diminished with the increase of porosity parameter. It is hoped that the present work may provide a benchmark in the study of nonlinear static behavior of porous nanoplates.

Biao Yan, Dan Gan, Xuhong Zhou and Weiqing Zhu
Influence of slenderness on axially loaded square tubed steel-reinforced concrete columns
ABSTRACT: This paper aims to investigate the axial load behavior and stability strength of square tubed steel-reinforced concrete (TSRC) columns. Unlike concrete filled steel tubular (CFST) column, the outer steel tube of a TSRC column is mainly used to provide confinement to the core concrete. Ten specimens were tested under axial compression, and the main test variables included length-to-width ratio (L/B) of the specimens, width-to-thickness ratio (B/t) of the steel tubes, and with or without stud shear connectors on the steel sections. The failure mode, ultimate strength and load-tube stress response of each specimen were summarized and analyzed. The test results indicated that the axial load carried by square tube due to friction and bond of the interface increased with the increase of L/B ratio, while the confinement effect of tube was just the opposite. Parametric studies were performed through ABAQUS based on the test results, and the feasibility of current design codes has also been examined. Finally, a method for calculating the ultimate strength of this composite column was proposed, in which the slenderness effect on the tube confinement was considered.

Volkan Kahya, Sebahat Karaca and Thuc P. Vo
Shear-deformable finite element for free vibrations of laminated composite beams with arbitrary lay-up
ABSTRACT: A shear-deformable finite element model (FEM) with five nodes and thirteen degrees of freedom (DOFs) for free vibrations of laminated composite beams with arbitrary lay-up is presented. This model can be capable of considering the elastic couplings among the extensional, bending and torsional deformations, and the Poisson's effect. Lagrange's principle is employed in derivation of the equations of motion, and thus the element matrices are obtained. Comparisons of the present element's results with those in experiment, available literature and the 3D finite element analysis software (ANSYS®) are made to show its accuracy. Some further results are given as referencing for the future studies in vibrations of laminated composite beams.
ABSTRACT: In the present work, the buckling analysis of micro sandwich plate with an isotropic/orthotropic cores and piezoelectric/polymeric nanocomposite face sheets is studied. In this research, two cases for core of micro sandwich plate is considered that involve five isotropic Deviney cell materials (H30, H45, H60, H100 and H200) and an orthotropic material also two cases for facesheets of micro sandwich plate is illustrated that include piezoelectric layers reinforced by carbon and boron-nitride nanotubes and polymeric matrix reinforced by carbon nanotubes under temperature-dependent and hydro material properties on the elastic foundations. The first order shear deformation theory (FSDT) is adopted to model micro sandwich plate and to apply size dependent effects from modified strain gradient theory. The governing equations are derived using the minimum total potential energy principle and then solved by analytical method. Also, the effects of different parameters such as size dependent, side ratio, volume fraction, various material properties for cores and facesheets and temperature and humidity changes on the dimensionless critical buckling load are investigated. It is shown from the results that the dimensionless critical buckling load for boron nitride nanotube is lower than that of for carbon nanotube. It is illustrated that the dimensionless critical buckling load for Devineycell H200 is highest and lowest for H30. Also, the obtained results for micro sandwich plate with piezoelectric facesheets reinforced by carbon nanotubes (case b) is higher than other states (cases a and c). The results of this research can be used in aircraft, automotive, shipbuilding industries and biomedicine.

ABSTRACT: This proposed project presents the bi-axial and uni-axial stability behavior of laminated composite plates based on an original three variable "refined" plate theory. The important "novelty" of this theory is that besides the inclusion of a cubic distribution of transverse shear deformations across the thickness of the structure, it treats only three variables such as conventional plate theory (CPT) instead five as in the well-known theory of "first shear deformation" (FSDT) and theory of "higher order shear deformation" (HSDT). A "shear correction coefficient" is therefore not employed in the current formulation. The computed results are compared with those of the CPT, FSDT and exact 3D elasticity theory. Good agreement is demonstrated and proved for the present results with those of "HSDT" and elasticity theory.

ABSTRACT: Corrugated steel plate shear wall (CSPSW) as an innovative lateral load resisting system provides various advantages in comparison with the flat steel plate shear wall, including remarkable in-plane and out-of-plane stiffnesses and stability, greater elastic shear buckling stress, increasing the amount of cumulative dissipated energy and maintaining efficiency even in large story drifts. Employment of low yield point (LYP) steel web plate in steel shear walls can dramatically improve their structural performance and prevent early stage instability of the panels. This paper presents a comprehensive structural performance assessment of corrugated low yield point steel plate shear walls with circular openings. Accordingly, following experimental verification of CSPSW finite element models, several trapezoidally horizontal CSPSW (H-CSPSW) models having LYP steel web plates as well as circular openings (for ducts) perforated in various locations have been developed to explore their hysteresis behavior, cumulative dissipated energy, lateral stiffness, and ultimate strength under cyclic loading. Obtained results reveal that the rehabilitation of damaged steel shear walls using corrugated LYP steel web plate can enhance their structural performance.
performance. Furthermore, choosing a suitable location for the circular opening regarding the design purpose paves the way for the achievement of the shear wall's optimal performance.

Cigdem Avci-Karatas (Department of Transportation Engineering, Faculty of Engineering, Yalova University, Yalova, 77200, Turkey)
Prediction of ultimate load capacity of concrete-filled steel tube columns using multivariate adaptive regression splines (MARS)
ABSTRACT: In the areas highly exposed to earthquakes, concrete-filled steel tube columns (CFSTCs) are known to provide superior structural aspects such as (i) high strength for good seismic performance (ii) high ductility (iii) enhanced energy absorption (iv) confining pressure to concrete, (v) high section modulus, etc. Numerous studies were reported on behavior of CFSTCs under axial compression loadings. This paper presents an analytical model to predict ultimate load capacity of CFSTCs with circular sections under axial load by using multivariate adaptive regression splines (MARS). MARS is a nonlinear and non-parametric regression methodology. After careful study of literature, 150 comprehensive experimental data presented in the previous studies were examined to prepare a data set and the dependent variables such as geometrical and mechanical properties of circular CFST system have been identified. Basically, MARS model establishes a relation between predictors and dependent variables. Separate regression lines can be formed through the concept of divide and conquers strategy. About 70% of the consolidated data has been used for development of model and the rest of the data has been used for validation of the model. Proper care has been taken such that the input data consists of all ranges of variables. From the studies, it is noted that the predicted ultimate axial load capacity of CFSTCs is found to match with the corresponding experimental observations of literature.

G. Beulah Gnana Ananthi, Krishanu Roy, Boshan Chen and James B.P. Lim
Testing, simulation and design of back-to-back built-up cold-formed steel unequal angle sections under axial compression
ABSTRACT: In cold-formed steel (CFS) structures, such as trusses, transmission towers and portal frames, the use of back-to-back built-up CFS unequal angle sections are becoming increasingly popular. In such an arrangement, intermediate welds or screw fasteners are required at discrete points along the length, preventing the angle sections from buckling independently. Limited research is available in the literature on axial strength of back-to-back built-up CFS unequal angle sections. The issue is addressed herein. This paper presents an experimental investigation on both the welded and screw fastened back-to-back built-up CFS unequal angle sections under axial compression. The load-axial shortening and the load verses lateral displacement behaviour along with the deformed shapes at failure are reported. A nonlinear finite element (FE) model was then developed, which includes material nonlinearity, geometric imperfections and modelling of intermediate fasteners. The FE model was validated against the experimental test results, which showed good agreement, both in terms of failure loads and deformed shapes at failure. The validated FE model was then used for the purpose of a parametric study to investigate the effect of different thicknesses, lengths and, yield stresses of steel on axial strength of back-to-back built-up CFS unequal angle sections. Five different thicknesses and seven different lengths (stub to slender columns) with two different yield stresses were investigated in the parametric study. Axial strengths obtained from the experimental tests and FE analyses were used to assess the performance of the current design guidelines as per the Direct Strength Method (DSM); obtained comparisons show that the current DSM is conservative by only 7% on average, while predicting the axial strengths of back-to-back built-up CFS unequal angle sections.

Shan Gao, Zhen Peng, Xuanding Wang and Jiepeng Liu
Compressive behavior of circular hollow and concrete-filled steel tubular stub columns under atmospheric corrosion
ABSTRACT: This paper aims to study the compressive behavior of circular hollow and concrete-filled steel tubular stub columns under simulated marine atmospheric corrosion. The specimens after salt spray corrosion were tested under axial compressive load. Steel grade and corrosion level were mainly considered in the study. The mechanical behavior of circular CFST specimens is compared with that of the corresponding hollow ones. Design methods for circular hollow and concrete-filled steel tubular stub columns are modified to consider the effect of marine atmospheric corrosion. The results show that linear fitting curves could be used to present the relationship between corrosion rate and the mechanical properties of steel after simulated marine atmospheric corrosion. The ultimate strength of hollow steel tubular and CFST columns decrease with the increase of corrosion rate while the ultimate displacement of those are hardly affected by corrosion rate. Increasing corrosion rate would change the failure of CFST stub column from ductile failure to brittle failure. Corrosion rate would decrease the ductility indexes of CFST columns, rather than those of hollow steel tubular columns.


ABSTRACT: In this work, a simple four-variable trigonometric shear deformation model with undetermined integral terms to consider the influences of transverse shear deformation is applied for the dynamic analysis of anti-symmetric laminated composite and soft core sandwich plates. Unlike the existing higher order theories, the current one contains only four unknowns. The equations of motion are obtained using the principle of virtual work. The analytical solution is determined by solving the eigenvalue problem. The influences of geometric ratio, modular ratio and fibre angle are critically evaluated for different problems of laminated composite and sandwich plates. The eigenfrequencies obtained using the current theory are verified by comparing the results with those of other theories and with the exact elasticity solution, if any.


ABSTRACT: The nonlinear behavior of single- and multi-story steel plate shear walls (SPSWs) strengthened with three different patterns of fiber reinforced polymer (FRP) laminates (including single-strip, multi-strip and fully FRP-strengthened models) is studied using the finite element analysis. In the research, the effects of orientation, width, thickness and type (glass or carbon) of FRP sheets as well as the system aspect ratio and height are investigated. Results show that, despite an increase in the system strength using FRP sheets, ductility of reinforced SPSWs is decreased due to the delay in the initiation of yielding in the infill wall, while their initial stiffness does not change significantly. The content/type/reinforcement pattern of FRPs does affect the nonlinear behavior characteristics and also the mode and pattern of failure. In the case of multi-strip and fully FRP-strengthened models, the use of FPR sheets almost along the direction of the infill wall tension fields can maximize the effectiveness of reinforcement. In the case of single-strip pattern, the effectiveness of reinforcement is decreased for larger aspect ratios. Moreover, a relatively simplified and approximate theoretical procedure for estimating the strength of SPSWs reinforced with different patterns of FRP laminates is presented and compared with the analytical results.


ABSTRACT: Concrete-filled steel tubular (CFST) beam-columns are widely used owing to their good performance. They have high strength, ductility, large energy absorption capacity and low costs. Externally stiffened CFST beam-columns are not used widely due to insufficient design equations that consider all parameters affecting their behavior. Therefore, effect of various parameters (global, local slenderness ratio and adding hoop stiffeners) on the behavior of CFST columns is studied. An experimental study that includes twenty seven specimens is conducted to determine the effect of those parameters. Load capacities, vertical deflections, vertical strains and horizontal strains are all recorded for every specimen. Ratio between outer
diameter (D) of pipes and thickness (t) is chosen to avoid local buckling according to different limits set by codes for the maximum D/t ratio. The study includes two loading methods on composite sections: steel only and steel with concrete. The case of loading on steel only, occurs in the connection zone, while the other load case occurs in steel beam connecting externally with the steel column wall. Two failure mechanisms of CFST columns are observed: yielding and global buckling. At early loading stages, steel wall in composite specimens dilated more than concrete so no full bond was achieved which weakened strength and stiffness of specimens. Adding stiffeners to the specimens increases the ultimate load by up to 25% due to redistribution of stresses between stiffener and steel column wall. Finally, design equations previously prepared are verified and found to be only applicable for medium and long columns.


ABSTRACT: In this work, a simple four-variable integral plate theory is employed for examining the thermal buckling properties of functionally graded material (FGM) sandwich plates. The proposed kinematics considers integral terms which include the effect of transverse shear deformations. Material characteristics and thermal expansion coefficient of the ceramic-metal FGM sandwich plate faces are supposed to be graded in the thickness direction according to a "simple power-law" variation in terms of the "volume fractions" of the constituents. The central layer is always homogeneous and consists of an isotropic material. The thermal loads are supposed as uniform, linear, and nonlinear temperature rises within the thickness direction. The influences of geometric ratios, gradient index, loading type, and type sandwich plate on the buckling properties are examined and discussed in detail.

Hao Zhou, Rui Guo, Kuo Bao, Haiyang Wei and Rongzhong Liu (School of Mechanical Engineering, Nanjing University of Science and Technology, 200 Xiaolingwei Street, Nanjing 210094, P. R. China)

Energy absorption investigation of square CFRP honeycomb reinforced by PMI foam fillers under quasi-static compressive load

ABSTRACT: A type of hybrid core made up of thin-walled square carbon fiber reinforced polymer (CFRP) honeycomb and Polymethacrylimide (PMI) foam fillers was proposed and prepared. Numerical model of the core under quasi static compression was established and validated by corresponding experimental results. The compressive properties of the core with different configurations were analyzed through numerical simulations. The effect of the geometrical parameters and foam fillers on the compressive response and energy absorption of the core were analyzed. The results show that the PMI foam fillers can significantly improve the compressive strength and energy absorption capacity of the square CFRP honeycomb. The geometrical parameters have marked effects on the compressive properties of the core. The research can give a reference for the application of PMI foam materials in energy absorbing structures and guide the design and optimization of lightweight and energy efficient cores of sandwiches.

Yong Du, Ming-Xiang Xiong, Jian Zhu and J.Y. Richard Liew

Compressive and flexural behaviors of ultra-high strength concrete encased steel members

ABSTRACT: One way to achieve sustainable construction is to reduce concrete consumption by use of more sustainable and higher strength concrete. Modern building codes do not cover the use of ultra-high strength concrete (UHSC) in the design of composite structures. Against such background, this paper investigates experimentally the mechanical properties of steel fibre-reinforced UHSC and then the structural behaviors of UHSC encased steel (CES) members under both concentric and eccentric compressions as well as pure bending. The effects of steel-fibre dosage and spacing of stirrups were studied, and the applicability of Eurocode 4 design approach was checked. The test results revealed that the strength of steel stirrups could not be fully utilized to provide confinement to the UHSC. The bond strength between UHSC and steel section was improved by adding the steel fibres into the UHSC. Reducing the spacing of stirrups or increasing the dosage of steel fibres was...
beneficial to prevent premature spalling of the concrete cover thus mobilize the steel section strength to achieve higher compressive capacity. Closer spacing of stirrups and adding 0.5% steel fibres in UHSC enhanced the post-peak ductility of CES columns. It is concluded that the code-specified reduction factors applied to the concrete strength and moment resistance can account for the loss of load capacity due to the premature spalling of concrete cover and partial yielding of the encased steel section.

ABSTRACT: This study considers the instability behavior of sandwich plates considering magnetorheological (MR) fluid core and piezoelectric reinforced facesheets. As facesheets at the top and bottom of structure have piezoelectric properties they are subjected to 3D electric field therefore they can be used as actuator and sensor, respectively and in order to control the vibration responses and loss factor of the structure a proportional-derivative (PD) controller is applied. Furthermore, Halpin-Tsai model is used to determine the material properties of facesheets which are reinforced by graphene platelets (GPLs). Moreover, because the core has magnetic property, it is exposed to magnetic field. In addition, Kelvin-Voigt theory is applied to calculate the structural damping of the piezoelectric layers. In order to consider environmental forces applied to structure, the visco-Pasternak model is assumed. In order to consider the mechanical behavior of structure, sinusoidal shear deformation theory (SSDT) is assumed and Hamilton's principle according to piezoelasticity theory is employed to calculate motion equations and these equations are solved based on differential cubature method (DCM) to obtain the vibration and modal loss factor of the structure subsequently. The effect of different factors such as GPLs distribution, dimensions of structure, electro-magnetic field, damping of structure, viscoelastic environment and boundary conditions of the structure on the vibration and loss factor of the system are considered. In order to indicate the accuracy of the obtained results, the results are validated with other published work. It is concluded from results that exposing magnetic field to the MR fluid core has positive effect on the behavior of the system.

Yonghui Huang, Airong Liu, Yong-Lin Pi, Mark A. Bradford and Jiyang Fu, “Experimental and numerical investigations on remaining strengths of damaged parabolic steel tubular arches” Steel and Composite Structures, Vol. 34, No. 1, January 10 2020, pp 1-15, https://doi.org/10.12989/scs.2020.34.1.001
ABSTRACT: This paper presents experimental and numerical studies on effects of local damages on the in-plane elastic-plastic buckling and strength of a fixed parabolic steel tubular arch under a vertical load distributed uniformly over its span, which have not been reported in the literature hitherto. The in-plane structural behaviour and strength of ten specimens with different local damages are investigated experimentally. A finite element (FE) model for damaged steel tubular arches is established and is validated by the test results. The FE model is then used to conduct parametric studies on effects of the damage location, depth and length on the strength of steel arches. The experimental results and FE parametric studies show that effects of damages at the arch end on the strength of the arch are more significant than those of damages at other locations of the arch, and that effects of the damage depth on the strength of arches are most significant among those of the damage length. It is also found that the failure modes of a damaged steel tubular arch are much related to its initial geometric imperfections. The experimental results and extensive FE results show that when the effective cross-section considering local damages is used in calculating the modified slenderness of arches, the column bucking curve b in GB50017 or Eurocode3 can be used for assessing the remaining in-plane strength of locally damaged parabolic steel tubular arches under uniform compression. Furthermore, a useful interaction equation for assessing the remaining in-plane strength of damaged steel tubular arches that are subjected to the combined bending and axial compression is also proposed based on the validated FE models. It is shown that the proposed interaction equation can provide lower bound assessments for the remaining strength of damaged arches under in-plane general loading.

Mostafa A. Hamed, Salwa A Mohamed and Mohamed A. Eltaher
Mostafa A. Hamed: Mechanical Engineering Department, Faculty of Engineering, King Abdulaziz University,
Buckling analysis of sandwich beam rested on elastic foundation and subjected to varying axial in-plane loads

Steel and Composite Structures, Vol. 34, No. 1, January 10 2020, pp 75-89,
https://doi.org/10.12989/scs.2020.34.1.075

ABSTRACT: The current paper illustrates the effect of in-plane varying compressive force on critical buckling loads and buckling modes of sandwich composite laminated beam rested on elastic foundation. To generalize a proposed model, unified higher order shear deformation beam theories are exploited through analysis; those satisfy the parabolic variation of shear across the thickness. Therefore, there is no need for shear correction factor. Winkler and Pasternak elastic foundations are presented to consider the effect of any elastic medium surrounding beam structure. The Hamilton\'s principle is proposed to derive the equilibrium equations of unified sandwich composite laminated beams. Differential quadrature numerical method (DQNM) is used to discretize the differential equilibrium equations in spatial direction. After that, eigenvalue problem is solved to obtain the buckling loads and associated mode shapes. The proposed model is validated with previous published works and good matching is observed. The numerical results are carried out to show effects of axial load functions, lamination thicknesses, orthotropy and elastic foundation constants on the buckling loads and mode shapes of sandwich composite beam. This model is important in designing of aircrafts and ships when non-uniform compressive load and shear loading is dominated.

Kadir Mercan, Farzad Ebrahimi and Ömer Civalek

Kadir Mercan: kdeniz University, Engineering Faculty, Division of Mechanics, Antalya, Turkey
Farzad Ebrahimi: Imam Khomeini International University, Mechanical Engineering Dept. Qazvin, Iran
Ömer Civalek: China Medical University, Research Center for Interneural Computing, Taichung-Taiwan

Vibration of angle-ply laminated composite circular and annular plates
Steel and Composite Structures, Vol. 34, No. 1, January 10 2020, pp 141-154,
https://doi.org/10.12989/scs.2020.34.1.141

ABSTRACT: In the present paper, free vibration analysis of angle-ply laminated composite annular and circular plates is performed by numerical methods. First-order shear deformation plate theory is used for kinematic relations. The related governing equations of motion are discretized via differential quadrature and discrete singular convolution methods. Frequency values are obtained for different lamina scheme, thickness-to-radius ratio, and mode numbers. The advantages and accuracy of these two methods are also tested in detail.

M. Adil Dar, N. Subramanian, Dawood A. Dar, A.R. Dar, M. Anbarasu, James B. P. Lim and Soroush Mahjoubi

M. Adil Dar: Department of Civil Engineering, Indian Institute of Technology Delhi, New Delhi, India, N. Subramanian: Consulting Engineer, Maryland, USA, Dawood A. Dar and A.R. Dar: Department of Civil Engineering, National Institute of Technology Srinagar, J&K, India, M. Anbarasu: Department of Civil Engineering, Government College of Engineering Salem, Tamilnadu, India, James B. P. Lim: Department of Civil & Environmental Engineering, University of Auckland, New Zealand, Soroush Mahjoubi: School of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran

“Flexural Strength of cold-formed steel built-up composite beams with rectangular compression flanges”,
Steel and Composite Structures, Vol. 34, No. 2, January 25 2020, pp 171-188,
https://doi.org/10.12989/scs.2020.34.2.171

ABSTRACT: The past research on cold-formed steel (CFS) flexural members have proved that rectangular hollow flanged sections perform better than conventional I-sections due to their higher torsional rigidity over the later ones. However, CFS members are vulnerable to local buckling, substantially due to their thin-walled features. The use of packing, such as firmly connected timber planks, to the flanges of conventional CFS lipped I-sections can drastically improve their flexural performance as well as structural efficiency. Whilst several CFS composites have been developed so far, only limited packing materials have been tried. This paper presents a series of tests carried out on different rectangular hollow compression flanged sections with innovative packing materials. Four-point flexural tests were carried out to assess the flexural capacity, failure modes and deformed...
shapes of the CFS composite beam specimens. The geometric imperfections were measured and reported. The North American Specifications and Indian Standard for cold-formed steel structures were used to compare the design strengths of the experimental specimen. The test results indicate clearly that CFS rectangular flanged composite beams perform significantly better than the conventional rectangular hollow flanged CFS sections.

Changlin Zhou, Zhongxian Zhang, Ji Zhang, Yuan Fang and Vahid Tahouneh
Changlin Zhou, Zhongxian Zhang and Ji Zhang: School of Civil Engineering and Mechanics, Huazhong University of Science and Technology, Wuhan, Hubei, 430074, China
Yuan Fang: General Construction Company of CCTEB Group Co., Wuhan, Hubei, 430064, China
Vahid Tahouneh: Young Researchers and Elite Club, Islamshahr Branch, Islamic Azad University, Islamshahr, Iran

Vibration analysis of FG porous rectangular plates reinforced by graphene platelets
Steel and Composite Structures, Vol. 34, No. 2, January 25 2020, pp 215-226,
https://doi.org/10.12989/scs.2020.34.2.215

ABSTRACT: The aim of this study is to investigate free vibration of functionally graded porous nanocomposite rectangular plates where the internal pores and graphene platelets (GPLs) are distributed in the matrix either uniformly or non-uniformly according to three different patterns. The elastic properties of the nanocomposite are obtained by employing Halpin-Tsai micromechanics model. The GPL-reinforced plate is modeled using a semi-analytic approach composed of generalized differential quadrature method (GDQM) and series solution adopted to solve the equations of motion. The proposed rectangular plates have two opposite edges simply supported, while all possible combinations of free, simply supported and clamped boundary conditions are applied to the other two edges. The 2-D differential quadrature method as an efficient and accurate numerical tool is used to discretize the governing equations and to implement the boundary conditions. The convergence of the method is demonstrated and to validate the results, comparisons are made between the present results and those reported by well-known references for special cases treated before, have confirmed accuracy and efficiency of the present approach. New results reveal the importance of porosity coefficient, porosity distribution, graphene platelets (GPLs) distribution, geometrical and boundary conditions on vibration behavior of porous nanocomposite plates. It is observed that the maximum vibration frequency obtained in the case of symmetric porosity and GPL distribution, while the minimum vibration frequency is obtained using uniform porosity distribution.

S.A.M. Ghannadpour and M. Mehrparvar (New Technologies and Engineering Department, Shahid Beheshti University, G.C, Tehran, Iran)

Nonlinear and post-buckling responses of FGM plates with oblique elliptical cutouts using plate assembly technique
Steel and Composite Structures, Vol. 34, No. 2, January 25 2020, pp 227-239,
https://doi.org/10.12989/scs.2020.34.2.227

ABSTRACT: The aim of this study is to obtain the nonlinear and post-buckling responses of relatively thick functionally graded plates with oblique elliptical cutouts using a new semi-analytical approach. To model the oblique elliptical hole in a FGM plate, six plate-elements are used and the connection between these elements is provided by the well-known Penalty method. Therefore, the semi-analytical technique used in this paper is known as the plate assembly technique. In order to take into account for functionality of the material in a perforated plate, the volume fraction of the material constituents follows a simple power law distribution. Since the FGM perforated plates are relatively thick in this research, the structural model is assumed to be the first order shear deformation theory and Von-Karman's assumptions are used to incorporate geometric nonlinearity. The equilibrium equations for FGM plates containing elliptical holes are obtained by the principle of minimum of total potential energy. The obtained nonlinear equilibrium equations are solved numerically using the quadratic extrapolation technique. Various sets of boundary conditions for FGM plates and different cutout sizes and orientations are assumed here and their effects on nonlinear response of plates under compressive loads are examined.

Mohamed A. Eltaher and Salwa A Mohamed
ABSTRACT: This article presented a comprehensive model to study static buckling stability and associated mode-shapes of higher shear deformation theories of sandwich laminated composite beam under the compression of varying axial load function. Four higher order shear deformation beam theories are considered in formulation and analysis. So, the model can consider the influence of both thick and thin beams without needing to shear correction factor. The compression force can be described through axial direction by uniform constant, linear and parabolic distribution functions. The Hamilton's principle is exploited to derive equilibrium governing equations of unified sandwich laminated beams. The governing equilibrium differential equations are transformed to algebraic system of equations by using numerical differential quadrature method (DQM). The system of equations is solved as an eigenvalue problem to get critical buckling loads and their corresponding mode-shapes. The stability of DQM in determining of buckling loads of sandwich structure is performed. The validation studies are achieved and the obtained results are matched with those. Parametric studies are presented to figure out effects of in-plane load type, sandwich thickness, fiber orientation and boundary conditions on buckling loads and mode-shapes. The present model is important in designing process of aircraft, naval structural components, and naval structural when non-uniform in-plane compressive loading is dominated.

Vahid Tahouneh, Mohammad Hasan Naei and Mahmoud Mosavi Mashhadi (School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran)

Influence of vacancy defects on vibration analysis of graphene sheets applying isogeometric method: Molecular and continuum approaches

Steel and Composite Structures, Vol. 34, No. 2, January 25 2020, pp 261-277,
https://doi.org/10.12989/scs.2020.34.2.261

ABSTRACT: The main objective of this research paper is to consider vibration analysis of vacancy defected graphene sheet as a nonisotropic structure via molecular dynamic and continuum approaches. The influence of structural defects on the vibration of graphene sheets is considered by applying the mechanical properties of defected graphene sheets. Molecular dynamic simulations have been performed to estimate the mechanical properties of graphene as a nonisotropic structure with single- and double-vacancy defects using open source well-known software i.e., large-scale atomic/molecular massively parallel simulator (LAMMPS). The interactions between the carbon atoms are modelled using Adaptive Intermolecular Reactive Empirical Bond Order (AIREBO) potential. An isogeometric analysis (IGA) based upon non-uniform rational B-spline (NURBS) is employed for approximation of single-layered graphene sheets deflection field and the governing equations are derived using nonlocal elasticity theory. The dependence of small-scale effects, chirality and different defect types on vibrational characteristic of graphene sheets is investigated in this comprehensive research work. In addition, numerical results are validated and compared with those achieved using other analysis, where an excellent agreement is found. The interesting results indicate that increasing the number of missing atoms can lead to decrease the natural frequencies of graphene sheets. It is seen that the degree of the detrimental effects differ with defect type. The Young's and shear modulus of the graphene with SV defects are much smaller than graphene with DV defects. It is also observed that Single Vacancy (SV) clusters cause more reduction in the natural frequencies of SLGS than Double Vacancy (DV) clusters. The effectiveness and the accuracy of the present IGA approach have been demonstrated and it is shown that the IGA is efficient, robust and accurate in terms of nanoplate problems.

Pankaj V. Katariya and Subrata Kumar Panda (Department of Mechanical Engineering, National Institute of Technology Rourkela, Odisha, India)

Numerical analysis of thermal post-buckling strength of laminated skew sandwich composite shell panel structure including stretching effect
ABSTRACT: The computational post-buckling strength of the tilted sandwich composite shell structure is evaluated in this article. The computational responses are obtained using a mathematical model derived using the higher-order type of polynomial kinematic in association with the through-thickness stretching effect. Also, the sandwich deformation behaviour of the flexible soft-core sandwich structural model is expressed mathematically with the help of a generic nonlinear strain theory i.e. Green-Lagrange type strain-displacement relations. Subsequently, the model includes all of the nonlinear strain terms to account the actual deformation and discretized via displacement type of finite element. Further, the computer code is prepared (MATLAB environment) using the derived higher-order formulation in association with the direct iterative technique for the computation of temperature carrying capacity of the soft-core sandwich within the post-buckled regime. Further, the nonlinear finite element model has been tested to show its accuracy by solving a few numerical experimentations as same as the published example including the consistency behaviour. Lastly, the derived model is utilized to find the temperature load-carrying capacity under the influences of variable factors affecting the soft-core type sandwich structural design in the small (finite) strain and large deformation regime including the effect of tilt angle.

Mohsen Motezaker and Arameh Eyvazian
Mohsen Motezaker: School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran
Arameh Eyvazian: Mechanical and Industrial Engineering Department, College of Engineering, Qatar University, P.O. Box 2713, Doha, Qatar

Post-buckling analysis of Mindlin Cut out-plate reinforced by FG-CNTs

ABSTRACT: In the present research post-buckling of a cut out plate reinforced through carbon nanotubes (CNTs) resting on an elastic foundation is studied. Material characteristics of CNTs are hypothesized to be altered within thickness orientation which are calculated according to Mori-Tanaka model. For modeling the system mathematically, first order shear deformation theory (FSDT) is applied and using energy procedure, the governing equations can be derived. With respect to Rayleigh-Ritz procedure as well as Newton-Raphson iterative scheme, the motion equations are solved and therefore, post-buckling behavior of structure will be tracked. Diverse parameters as well as their reactions on post-buckling paths focusing cut out measurement, CNTs volume fraction and agglomeration, dimension of plate and an elastic foundation are investigated. It is revealed that presence of a square cut out can affect negatively post-buckling behavior of structure. Moreover, adding nanocomposites in the matrix leads to enhancement of post-buckling response of system.

Morteza Naghipour, Ghazaleh Yousofizinsaz and Mahdi Shariati
Morteza Naghipour and Ghazaleh Yousofizinsaz: Department of Civil, Babol Noshirvani University of Technology, Babol, Iran
Mahdi Shariati: Division of Computational Mathematics and Engineering, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City 758307, Vietnam; Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City 758307, Vietnam

Experimental study on axial compressive behavior of welded built-up CFT stub columns made by cold-formed sections with different welding lines

ABSTRACT: The objective of this study is to experimentally scrutinize the axial performance of built-up concrete filled steel tube (CFT) columns composed of steel plates. In this case, the main parameters cross section types, compressive strength of filled concrete, and the effect of welding lines. Welded built-up steel box columns are fabricated by connecting two pieces of cold-formed U-shaped or four pieces of L-shaped thin steel plates with continuous penetration groove welding line located at mid-depth of stub column section. Furthermore, traditional square steel box sections with no welding lines are investigated for the comparison of axial behavior between the generic and build-up cross sections. Accordingly, 20 stub columns with thickness and height of 2 and 300 mm have been manufactured. As a result, welding lines in built-up specimens act as
stiffeners because have higher strength and thickness in comparison to the plates. Subsequently, by increasing the welding lines, the load bearing capacity of stub columns has been increased in comparison to the traditional series. Furthermore, for specimens with the same confinement steel tubes and concrete core, increment of B/t ratio has reduced the ductility and axial strength.

Mohammad Amin Shahmohammadi, Mojtaba Azhari and Mohammad Mehdi Saadatpour (Department of Civil Engineering, Isfahan University of Technology, Isfahan, Iran, P.O. Box 84156-83111)

Free vibration analysis of sandwich FGM shells using isogeometric B-spline finite strip method

Steel and Composite Structures, Vol. 34, No. 3, February 10 2020, pp 361-376,
https://doi.org/10.12989/scs.2020.34.3.361

ABSTRACT: This paper presents a free vibration analysis of shell panels made of functionally graded material (FGM) in the form of the ordinary and sandwich FGM and laminated shells using the isogeometric B3-spline finite strip method (IG-SFSM). B3-spline and Lagrangian interpolation are employed along the longitudinal and transverse directions respectively in this type of finite strip. The introduced finite strip formulation is based on the degenerated shell method, which provides variable thickness, arbitrary geometries, and analysis of thin or thick shells. Validity of the obtained natural frequencies by IG-SFSM is checked by comparison with results extracted from references for similar cases in different examples. These examples incorporate several geometries, materials, boundary conditions, and continuous thickness variation. A comparison of these two kinds of results and their proximity showed that the introduced IG-SFSM is a reliable tool which can be used in analysis of shells with the aforementioned properties.

Mahdi Shariati, Morteza Naghipour, Ghazaleh Yousofizinsaz, Ali Toghroli and Nima Pahlavannejad Tabarestani

Mahdi Shariati: Division of Computational Mathematics and Engineering, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Vietnam; Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
Morteza Naghipour, Ghazaleh Yousofizinsaz and Nima Pahlavannejad Tabarestani: Department of Civil, Babol Noshirvani University of Technology, Babol, Iran
Ali Toghroli: Institute of Research and Development, Duy Tan University, Da Nang 550000, Viet Nam

Numerical study on the axial compressive behavior of built-up CFT columns considering different welding lines

Steel and Composite Structures, Vol. 34, No. 3, February 10 2020, pp 377-391,
https://doi.org/10.12989/scs.2020.34.3.377

ABSTRACT: A concrete filled steel tube (CFT) column with stiffeners has preferable behavior subjected to axial loading condition due to delay local buckling of the steel wall than traditional CFT columns without stiffeners. Welding lines in welded built-up steel box columns is expected to behave as longitudinal stiffeners. This study has presented a numerical investigation into the behavior of built-up concrete filled steel tube columns under axial pressure. At first stage, a finite element model (FE) has been built to simulate the behavior of built-up CFT columns. Comparing the results of FE and test has shown that numerical model passes the desired conditions and could accurately predict the axial performance of CFT column. Also, by the raise of steel tube thickness, the load bearing capacity of columns has been increased due to higher confinement effect. Also, the raise of concrete strength with greater cross section is led to a higher load bearing capacity compared to the steel tube thickness increment. In CFT columns with greater cross section, concrete strength has a higher influence on load bearing capacity which is noticeable in columns with more welding lines.

Eun-Ji Jo1a, Quang-Viet Vu and Seung-Eock Kim

Eun-Ji Jo1a and Seung-Eock Kim: Department of Civil and Environmental Engineering, Sejong University, 98 Gunja-dong, Gwangjin-gu, Seoul 05006, South Korea
Viet Vu: Institute of Research and Development, Duy Tan University, Danang 550000, Vietnam

Effect of residual stress and geometric imperfection on the strength of steel box girders

Steel and Composite Structures, Vol. 34, No. 3, February 10 2020, pp 423-440,
https://doi.org/10.12989/scs.2020.34.3.423

ABSTRACT: In the recent years, steel box girder bridges have been extensively used due to high bending stiffness, torsional rigidity, and rapid construction. Therefore, researches related to this girder bridge have been
widely conducted. This paper investigates the effect of residual stresses and geometric imperfections on the load-carrying capacity of steel box girder bridges spanning 30 m and 50 m. A three – dimensional finite element model of the steel box girder with a closed section was developed and analyzed using ABAQUS software. Nonlinear inelastic analysis was used to capture the actual response of the girder bridge accurately. Based on the results of analyses, the superimposed mode of webs and flanges was recommended for considering the influence of initial geometric imperfections of the steel box model. In addition, 4% and 16% strength reduction rates on the load – carrying capacity of the perfect structural system were respectively recommended for the girders with compact and non-compact sections, whose designs satisfy the requirements specified in AASHTO LRFD standard. As a consequence, the research results would help designers eliminate the complexity in modeling residual stresses and geometric imperfections when designing the steel box girder bridge.

Abdelouahed Tounsi, S.U. Al-Dulaijan, Mohammed A. Al-Osta, Abdelbaki Chikh, M.M. Al-Zahran, Alfarabi Sharif and Abdeldjebar Tounsi (First author is from: Department of Civil and Environmental Engineering, King Fahd University of Petroleum & Minerals, 31261 Dhahran, Eastern Province, Saudi Arabia)


ABSTRACT: In this research, a simple four-variable trigonometric integral shear deformation model is proposed for the static behavior of advanced functionally graded (AFG) ceramic-metal plates supported by a two-parameter elastic foundation and subjected to a nonlinear hygro-thermo-mechanical load. The elastic properties, including both the thermal expansion and moisture coefficients of the plate, are also supposed to be varied within thickness direction by following a power law distribution in terms of volume fractions of the components of the material. The interest of the current theory is seen in its kinematics that use only four independent unknowns, while first-order plate theory and other higher-order plate theories require at least five unknowns. The \"in-plane displacement field\" of the proposed theory utilizes cosine functions in terms of thickness coordinates to calculate out-of-plane shear deformations. The vertical displacement includes flexural and shear components. The elastic foundation is introduced in mathematical modeling as a two-parameter Winkler-Pasternak foundation. The virtual displacement principle is applied to obtain the basic equations and a Navier solution technique is used to determine an analytical solution. The numerical results predicted by the proposed formulation are compared with results already published in the literature to demonstrate the accuracy and efficiency of the proposed theory. The influences of \"moisture concentration\", temperature, stiffness of foundation, shear deformation, geometric ratios and volume fraction variation on the mechanical behavior of AFG plates are examined and discussed in detail.

Aurel Stratan, Ciprian Ionut Zub and Dan Dubina (First author is from: Department of Steel Structures and Structural Mechanics, Politehnica University of Timisoara, Timisoara, Romania)


ABSTRACT: Buckling restrained braces (BRBs) were developed as an enhanced alternative to conventional braces by restraining their global buckling, thus allowing development of a stable quasi-symmetric hysteretic response. A wider adoption of buckling restrained braced frames is precluded due to proprietary character of most BRBs and the code requirement for experimental qualification. To overcome these problems, BRBs with capacities corresponding to typical steel multi-storey buildings in Romania were developed and experimentally tested in view of prequalification. The first part of this paper presents the results of the experimental program which included sub-assemble tests on ten full-scale BRBs and uniaxial tests on components materials (steel and concrete). Two different solutions of the core were investigated: milled from a plate and fabricated from a square steel profile. The strength of the buckling restraining mechanism was also investigated. The influence of gravity loading on the unsymmetrical deformations in the two plastic segments of the core was assessed, and the response of the bolted connections was evaluated. The cyclic response of BRBs was evaluated with respect to a set of performance parameters, and recommendations for design were given.

Ciprian Ionut Zub, Aurel Stratan and Dan Dubina (First author is from: Department of Steel Structures and Structural Mechanics, Politehnica University of Timisoara, Timisoara, Romania), “Prequalification of a set of
**ABSTRACT:** In the present work, the buckling behavior of a single layered graphene sheet resting on Pasternak's medium via nonlocal four unknown integral model is studied. This model has a two-dimensional formulation along the axial and radial directions presented based on the first-order shear deformation theory. Hamilton\'s principle is employed for derivation of the governing equations of motion. The solution to formulated boundary value problem is obtained based on a harmonic solution and trigonometric functions for various boundary conditions. The numerical results show influence of significant parameters such as the small scale parameter, stiffness of Pasternak foundation, mode number, various boundary conditions, and selected dimensionless geometric parameters on natural frequencies of nanoshell.


**ABSTRACT:** In this article, free vibration attributes of double-walled carbon nanotubes based on nonlocal elastic shell model have been investigated. For this purpose, a nonlocal Flügge shell model is established to observe the small scale effect. The wave propagation is employed to frame the governing equations as eigenvalue system. The influence of nonlocal parameter subjected to different end supports has been overtly examined. A suitable choice of material properties and nonlocal parameter been focused to analyze the vibration characteristics. The new set of inner and outer tubes radii investigated in detail against aspect ratio and length. The dominance of boundary conditions via nonlocal parameter is shown graphically. The results generated furnish the evidence regarding applicability of nonlocal shell model and also verified by earlier published literature.

Sehar Asghar, Muhammad N. Naeem, Muzamal Hussain and Abdelouahed Tounsi (First three authors from: Department of Solid Mechanics, University of Kashan, Kashan 87317-51167, Iran)

**ABSTRACT:** Free vibration analysis of functionally graded cylindrical nanoshells resting on Pasternak foundation based on two-dimensional analysis”, Steel and Composite Structures, Vol. 34, No. 4, pp 615-623, February 25 2020, https://doi.org/10.12989/scs.2020.34.4.615

**ABSTRACT:** In this paper, free vibration analysis of a functionally graded cylindrical nanoshell resting on Pasternak foundation is presented based on the nonlocal elasticity theory. A two-dimensional formulation along the axial and radial directions is presented based on the first-order shear deformation shell theory. Hamilton\'s principle is employed for derivation of the governing equations of motion. The solution to formulated boundary value problem is obtained based on a harmonic solution and trigonometric functions for various boundary conditions. The numerical results show influence of significant parameters such as small scale parameter, stiffness of Pasternak foundation, mode number, various boundary conditions, and selected dimensionless geometric parameters on natural frequencies of nanoshell.

Mohammad Arefi (1) and Krzysztof Kamil Żur (2)

(1) Department of Solid Mechanics, University of Kashan, Kashan 87317-51167, Iran
(2) Faculty of Mechanical Engineering, Bialystok University of Technology, Bialystok 15-351, Poland

displacement field with integral terms which includes the effect of transverse shear deformation without using shear correction factors. The visco-Pasternak's medium is introduced by considering the damping effect to the classical foundation model which modeled by the linear Winkler's coefficient and Pasternak's coefficients, damping parameter, and mode numbers on the buckling response of the SLGSs are studied and discussed.

Maryam Lori Dehsaraji, Mohammad Arefi and Abbas Loghman (Department of Solid Mechanics, Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran), “Three dimensional free vibration analysis of functionally graded nano cylindrical shell considering thickness stretching effect”, Steel and Composite Structures, Vol. 34, No. 5, pp 657-670, March 10 2020, https://doi.org/10.12989/scs.2020.34.5.657

ABSTRACT: In this paper, vibration analysis of functionally graded nanoshell is studied based on the sinusoidal higher-order shear and normal deformation theory to account thickness stretching effect. To account size-dependency, Eringen nonlocal elasticity theory is used. For more accurate modeling the problem and corresponding numerical results, sinusoidal higher-order shear and normal deformation theory including out of plane normal strain is employed in this paper. The radial displacement is decomposed into three terms to show variation along the thickness direction. Governing differential equations of motion are derived using Hamilton's principle. It is assumed that the cylindrical shell is made of an arbitrary composition of metal and ceramic in which the local material properties are measured based on power law distribution. To justify trueness and necessity of this work, a comprehensive comparison with some lower order and lower dimension works and also some 3D works is presented. After presentation of comparative study, full numerical results are presented in terms of significant parameters of the problem such as small scale parameter, length to radius ratio, thickness to radius ratio, and number of modes.


ABSTRACT: Vibration analysis in nanocomposite plate with smart layer is studied in this article. The plate is reinforced by carbon nanotubes where the Mori-Tanaka law is utilized for obtaining the effective characteristic of structure assuming agglomeration effects. The nanocomposite plate is located in elastic medium which is simulated by spring element. The motion equations are derived based on first order shear deformation theory and Hamilton's principle. Utilizing Navier method, the frequency of the structure is calculated and the effects of applied voltage, volume percent and agglomeration of Carbon nanotubes, elastic medium and geometrical parameters of structure are shown on the frequency of system. Results indicate that with applying negative voltage, the frequency of structure is increased. In addition, the agglomeration of carbon nanotubes reduces the frequency of the nanocomposite plate

Ying Qin, Xin Chen, Wang Xi, Xing-Yu Zhu and Yuan-Ze Che (School of Civil Engineering, Southeast University, Nanjing, China), “Compressive behavior of rectangular sandwich composite wall with different truss spacings”, Steel and Composite Structures, Vol. 34, No. 6, pp 783-794, March 25 2020, https://doi.org/10.12989/scs.2020.34.6.783

ABSTRACT: Steel-concrete-steel sandwich composite wall is composed of two external steel plates and infilled concrete core. Internal mechanical connectors are used to enhance the composite action between the two materials. In this paper, the compressive behavior of a novel sandwich composite wall was studied. The steel trusses were applied to connect the steel plates to the concrete core. Three short specimens with different truss spacings were tested under compressive loading. The boundary columns were not included. It was found that the failure of walls started from the buckling of steel plates and followed by the crushing of concrete. Global instability was not observed. It was also observed that the truss spacing has great influence on ultimate strength, buckling stress, ductility, strength index, lateral deflection, and strain distribution. Three modern codes were introduced to calculate the capacity of walls. The comparisons between test results and code predictions show that AISC 360 provides significant underestimations while Eurocode 4 and CECS 159 offer overestimated predictions.

Krzysztof Magnucki, Wlodzimierz Stawecki and Jerzy Lewinski (Luksiewicz Research Network - Institute of Rail Vehicles TABOR, Poznan, Poland), “Axisymmetric bending of a circular plate with symmetrically varying
ABSTRACT: The subject of the paper is a circular plate with symmetrically thickness-wise varying mechanical properties. The plate is simply supported and carries a concentrated force located in its centre. The axisymmetric bending problem of the plate with consideration of the shear effect is analytically and numerically studied. A nonlinear function of deformation of the straight line normal to the plate neutral surface is assumed.

Ahmad Farrokhian (Mechanical Engineering group, Pardis College, Isfahan University of Technology, Isfahan 84156-83111, Iran), “Buckling response of smart plates reinforced by nanoparticles utilizing analytical method”, Steel and Composite Structures, Vol. 35, No. 1, pp 1-12, April 10 2020,
https://doi.org/10.12989/scs.2020.35.1.001
ABSTRACT: This article deals with the buckling analysis in the plates containing carbon nanotubes (CNTs) subject to axial load. In order to control the plate smartly, a piezoelectric layer covered the plate. The plate is located in elastic medium which is modeled by spring elements. The Mori-Tanaka low is utilized for calculating the equivalent mechanical characteristics of the plate. The structure is modeled by a thick plate and the governing equations are deduced using Hamilton's principle under the assumption of higher-order shear deformation theory (HSDT). The Navier method is applied to obtain the bulking load. The effects of the applied voltage to the smart layer, agglomeration and volume percent of CNT nanoparticles, geometrical parameters and elastic medium of the structure are assessed on the buckling response. It has been demonstrated that by applying a negative voltage, the buckling load is increased significantly.

ABSTRACT: In this study, free vibration analysis of laminated composite parabolic thick plate frames by using finite element method is introduced. Governing equations of an eigenvalue problem are obtained from First Order Shear Deformation Theory (FSDT). Finite element method is employed to obtain natural frequency values from the governing differential equations. The frames consist of two flat square plates and one singly curved plate. Parameters like radii of curvature, aspect ratio, ply orientation and boundary conditions are investigated to understand their effect on dynamic behavior of such a structure. In addition, multi-bay structures of such geometry with different stacking order are also taken into account. The composite frame structures are also modeled and simulated via ANSYS to verify the accuracy of the present study.

Mohammad Hossein Ghadiri Rad, Farzad Shahabian and Seyed Mahmoud Hosseini (First author is from: Civil Engineering Department, Quchan University of Technology, Quchan, Iran), “Geometrically nonlinear dynamic analysis of FG graphene platelets-reinforced nanocomposite cylinder: MLPG method based on a modified nonlinear micromechanical model”, Steel and Composite Structures, Vol. 35, No. 1, pp 77-82, April 10 2020,
https://doi.org/10.12989/scs.2020.35.1.077
ABSTRACT: The present paper outlined a procedure for geometrically nonlinear dynamic analysis of functionally graded graphene platelets-reinforced (GPLR-FG) nanocomposite cylinder subjected to mechanical shock loading. The governing equation of motion for large deformation problems is derived using meshless local Petrov-Galerkin (MLPG) method based on total lagrangian approach. In the MLPG method, the radial point interpolation technique is employed to construct the shape functions. A micromechanical model based on the Halpin-Tsai model and rule of mixture is used for formulation the nonlinear functionally graded distribution of GPLs in polymer matrix of composites. Energy dissipation in analyses of the structure responding to dynamic loads is considered using the Rayleigh damping. The Newmark-Newton/Raphson method which is an incremental-iterative approach is implemented to solve the nonlinear dynamic equations. The results of the proposed method for homogenous material are compared with the finite element ones. A very good agreement
is achieved between the MLPG and FEM with very fine meshing. In addition, the results have demonstrated that the MLPG method is more effective method compared with the FEM for very large deformation problems due to avoiding mesh distortion issues. Finally, the effect of GPLs distribution on strength, stiffness and dynamic characteristics of the cylinder are discussed in details. The obtained results show that the distribution of GPLs changed the mechanical properties, so a classification of different types and volume fraction exponent is established. Indeed by comparing the obtained results, the best compromise of nanocomposite cylinder is determined in terms of mechanical and dynamic properties for different load patterns. All these applications have shown that the present MLPG method is very effective for geometrically nonlinear analyses of GPLR-FG nanocomposite cylinder because of vanishing mesh distortion issue in large deformation problems. In addition, since in proposed method the distributed nodes are used for discretization the problem domain (rather than the meshing), modeling the functionally graded media yields to more accurate results.


ABSTRACT: The goal of this study is to fill this apparent gap in the area about investigating the effect of porosity distributions on vibrational behavior of FG sectorial plates resting on a two-parameter elastic foundation. The response of the elastic medium is formulated by the Winkler/Pasternak model. The internal pores and graphene platelets (GPLs) are distributed in the matrix either uniformly or non-uniformly according to three different patterns. The model is proposed with material parameters varying in the thickness of plate to achieve graded distributions in both porosity and nanofillers. The elastic modulus of the nanocomposite is obtained by using Halpin-Tsai micromechanics model. The annular sector plate is assumed to be simply supported in the radial edges while any arbitrary boundary conditions are applied to the other two circular edges including simply supported, clamped and free. The 2-D differential quadrature method as an efficient and accurate numerical approach is used to discretize the governing equations and to implement the boundary conditions. The convergence of the method is demonstrated and to validate the results, comparisons are made between the present results and those reported by well-known references for special cases treated before, have confirmed accuracy and efficiency of the present approach. It is observed that the maximum vibration frequency obtained in the case of symmetric porosity and GPL distribution, while the minimum vibration frequency is obtained using uniform porosity distribution. Results show that for better understanding of mechanical behavior of nanocomposite plates, it is crucial to consider porosities inside the material structure.


ABSTRACT: In typical, structural topology optimization plays a significant role to both increase stiffness and save mass of structures in the resulting design. This study contributes to a new numerical approach of topologically optimal design of Mindlin-Reissner plates considering Winkler foundation and mathematical formulations of multi-directional variable thickness of the plate by using multi-materials. While achieving optimal multi-material topologies of the plate with multi-directional variable thickness, the weight information of structures in terms of effective utilization of the material at the appropriate thickness location may be provided for engineers and designers of structures. Besides, numerical techniques of the well-established mixed interpolation of tensorial components 4 element (MITC4) is utilized to overcome a well-known shear locking problem occurring to thin plate models. The well-founded mathematical formulation of topology optimization problem with variable thickness Mindlin-Reissner plate structures by using multiple materials is derived in detail as one of main achievements of this article. Numerical examples verify that variable thickness Mindlin-Reissner plates on Winkler foundation have a significant effect on topologically optimal multi-material design results.

ABSTRACT: In the present research, thermo-elastic buckling of small scale functionally graded material (FGM) nano-size plates with clamped edge conditions rested on an elastic substrate exposed to uniformly, linearly and non-linearly temperature distributions has been investigated employing a secant function based refined theory. Material properties of the FGM nano-size plate have exponential gradation across the plate thickness. Using Hamilton’s rule and non-local elasticity of Eringen, the non-local governing equations have been established in the context of refined four-unknown plate theory and then solved via an analytical method which captures clamped boundary conditions. Buckling results are provided to show the effects of different thermal loadings, non-locality, gradient index, shear deformation, aspect and length-to-thickness ratios on critical buckling temperature of clamped exponential graded nano-size plates.

Ying Qin, Xin Chen, Xingyu Zhu, Wang Xi and Yuanze Chen (School of Civil Engineering, Southeast University, Nanjing, China), “Structural behavior of sandwich composite wall with truss connectors under compression”, Steel and Composite Structures, Vol. 35, No. 2, pp 159-169, April 25 2020, https://doi.org/10.12989/scs.2020.35.2.159

ABSTRACT: Sandwich composite wall consists of concrete core attached by two external steel faceplates. It combines the advantage of steel and concrete. The appropriate composite action between steel faceplate and concrete core is achieved by using adequate mechanical connectors. This research studied the compressive behavior of the sandwich composite walls using steel trusses to bond the steel faceplates to concrete infill. Four short specimens with different wall width and thickness of steel faceplate were designed and tested under axial compression. The test results were comprehensively evaluated in terms of failure modes, load versus axial and lateral deformation responses, resistance, stiffness, ductility, strength index, and strain distribution. The test results showed that all specimens exhibited high resistance and good ductility. Truss connectors offer better restraint to walls with thinner faceplates and smaller wall width. In addition, increasing faceplate thickness is more effective in improving the ultimate resistance and axial stiffness of the wall.

Parham Memarzadeh (1), Sayedmohammad Mousavian (1), Mohammad Hosseini Ghehi (1) and Tadeh Zirakian (2)
(1) Department of Civil Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
(2) Department of Civil Engineering and Construction Management, California State University, Northridge, CA, USA

ABSTRACT: Cracks and defects may occur anywhere in a plate under tension. Cracks can affect the buckling stability performance and even the failure mode of the plate. A search of the literature reveals that the reported research has mostly focused on the study of plates with central and small cracks. Considering the effectiveness of cracks on the buckling behavior of plates, this study intends to investigate the effects of some key parameters, i.e., crack size and location as well as the plate aspect ratio and support conditions, on the buckling behavior, stress intensity factor (SIF), and the failure mode (buckling or fracture) in cracked plates under tension. To this end, a sophisticated mathematical code was developed using MATLAB in the frame-work of extended finite element method (XFEM) in order to analyze the buckling stability and collapse of numerous plate models. The results and findings of this research endeavor show that, in addition to the plate aspect ratio and support conditions, careful consideration of the crack location and size can be quite effective in buckling behavior assessment and failure mode prediction as well as SIF evaluation of the cracked plates subjected to tensile loading.

Kai Yan (1), Yao Zhang (1), Hao Cai (1) and Vahid Tahouneh (2)
(1) Shandong Jianzhu University, Jinan, Shandong 251010, China
(2) Islamic Azad University, Islamshahr, Iran
ABSTRACT: The main purpose of this research work is to investigate the free vibration of conical shell structures reinforced by graphene platelets (GPLs) and the elastic properties of the nanocomposite are obtained by employing Halpin-Tsai micromechanics model. To this end, a shell model is developed based on Donnell's theory. To solve the problem, the analytical Galerkin method is employed together with beam mode shapes as weighting functions. Due to importance of boundary conditions upon mechanical behavior of nanostructures, the analysis is carried out for different boundary conditions. The effects of boundary conditions, semi vertex angle, porosity distribution and graphene platelets on the response of conical shell structures are explored. The correctness of the obtained results is checked via comparing with existing data in the literature and good agreement is eventuated. The effectiveness and the accuracy of the present approach have been demonstrated and it is shown that the Donnell's shell theory is efficient, robust and accurate in terms of nanocomposite problems.

Wen-qi Liu (1), Shan-jun Liu (2), Ming-yu Fan (1), Wei Tian (3), Ji-peng Wang (1) and Vahid Tahouneh (4)
(1) School of Computer Science and Engineering, University of Electronic Science and Technology of China, Chengdu Sichuan, 611731, China
(2) Key Lab of Information Network Security, Ministry of Public Security, Shanghai 201204, China
(3) The 9533 troop of People’s Liberation Army of China, Changsha Hunan 201204, China
(4) Islamic Azad University, Islamshahr, Iran

ABSTRACT: This paper deals with free vibration analysis of non-uniform column resting on elastic foundations and subjected to follower force at its free end. The internal pores and graphene platelets (GPLs) are distributed in the matrix according to different patterns. The model is proposed with material parameters varying in the thickness of column to achieve graded distributions in both porosity and nanofillers. The elastic modulus of the nanocomposite is obtained by using Halpin-Tsai micromechanics model. The differential quadrature method as an efficient and accurate numerical approach is used to discretize the governing equations and to implement the boundary conditions. It is observed that the maximum vibration frequency obtained in the case of symmetric porosity and GPL distribution, while the minimum vibration frequency is obtained using uniform porosity distribution. Results show that for better understanding of mechanical behavior of nanocomposite column, it is crucial to consider porosities inside the material structure.

Ying Qin, Ke-Rong Luo and Xin Yan (School of Civil Engineering, Southeast University, Nanjing, China), “Buckling analysis of steel plates in composite structures with novel shape function”, Steel and Composite Structures, Vol. 35, No. 3, pp 405-413, May 10 2020, https://doi.org/10.12989/scs.2020.35.3.405
ABSTRACT: Current study on the buckling analysis of steel plate in composite structures normally focuses on applying finite element method to derive the buckling stress. However, it is time consuming, computationally complicated and tedious for general use in design by civil engineers. Therefore, in this study an analytical study is conducted to predict the buckling behavior of steel plates in composite structures. Hand calculation method was proposed based on energy principle. Novel buckling shapes with biquadratic functions along both loaded and unloaded direction were proposed to satisfy the boundary condition. Explicit solutions for predicting the critical local buckling stress of steel plate is obtained based on the Rayleigh-Ritz approach. The obtained results are compared with both experimental and numerical data. Good agreement has been achieved. Furthermore, the influences of key factors such as aspect ratio, width to thickness ratio, and elastic restraint stiffness on the local buckling performance are comprehensively discussed.

Mai-Suong Nguyen (2), Duc-Kien Thai (1) and Seung-Eock Kim (1)
(1) Department of Civil and Environmental Engineering, Sejong University, 98 Gunja-dong, Gwangjin-gu, Seoul 05006, South Korea
(2) Department of Civil and Environmental Engineering, Sejong University, 98 Gunja-dong, Gwangjin-gu, Seoul 05006, South Korea and Thuyloi University, 175 Tay Son, Hanoi, Vietnam
ABSTRACT: Circular concrete filled steel tube (CFST) columns have an advantage over all other sections when they are used in compression members. This paper proposes a new approach for deriving a new empirical equation to predict the axial compressive capacity of circular CFST columns using the Artificial Neural Network (ANN). The developed ANN model uses 5 input parameters that include the diameter of circular steel tube, the length of the column, the thickness of steel tube, the steel yield strength and the compressive strength of concrete. The only output parameter is the axial compressive capacity. Training and testing the developed ANN model was carried out using 219 available sets of data collected from the experimental results in the literature. An empirical equation is then proposed as an important result of this study, which is practically used to predict the axial compressive capacity of a circular CFST column. To evaluate the performance of the developed ANN model and the proposed equation, the predicted results are compared with those of the empirical equations stated in the current design codes and other models. It is shown that the proposed equation can predict the axial compressive capacity of circular CFST columns more accurately than other methods. This is confirmed by the high accuracy of a large number of existing test results. Finally, the parametric study result is analyzed for the proposed ANN equation to consider the effect of the input parameters on axial compressive strength.

Reza Nazemnezhad (1) and Hassan Shokrollahi (2)
(1) School of Engineering, Damghan University, Damghan, Iran
(2) Department of Mechanical Engineering, Faculty of Engineering, Kharazmi University, Tehran, Iran

ABSTRACT: This work aims to study effects of the crack and the surface energy on the free longitudinal vibration of axially functionally graded nanorods. The surface energy parameters considered are the surface stress, the surface density, and the surface Lamé constants. The cracked nanorod is modelled by dividing it into two parts connected by a linear spring in which its stiffness is related to the crack severity. The surface and bulk material properties are considered to vary in the length direction according to the power law distribution. Hamilton’s principle is implemented to derive the governing equation of motion and boundary conditions. Considering the surface stress causes that the derived governing equation of motion becomes non-homogeneous while this was not the case in works that only the surface density and the surface Lamé constants were considered. To extract the frequencies of nanorod, firstly the non-homogeneous governing equation is converted to a homogeneous one using an appropriate change of variable, and then for clamped-clamped and clamped-free boundary conditions the governing equation is solved using the harmonic differential quadrature method. Since the present work considers effects of all the surface energy parameters, it can be claimed that this is a comprehensive work in this regard.


ABSTRACT: Double skin composite walls are alternatives to concrete walls to resist gravity load in structures. The composite action between steel faceplates and concrete core largely depends on the internal mechanical connectors. This paper investigates the structural behavior of novel composite wall system with T-section and under combined compressive force and bending moment. The truss connectors are used to bond the steel faceplates to concrete core. Four short specimens were designed and tested under eccentric compression. The influences of the thickness of steel faceplates, the truss spacing, and the thickness of web wall were discussed based on the test results. The N-M interaction curves by AISC 360, Eurocode 4, and CECS 159 were compared with the test data. It was found that AISC 360 provided the most reasonable predictions.

Raad M. Fenjan, Ridha A. Ahmed and Nadhim M. Faleh (Al-Mustansiriah University, Engineering Collage P.O. Box 46049, Bab-Muadum, Baghdad 10001, Iraq), “Nonlocal nonlinear dynamic behavior of composite

ABSTRACT: The present paper explores nonlinear dynamical properties of piezo-magnetic beams based on a nonlocal refined higher-order beam formulation and piezoelectric phase effect. The piezoelectric phase increment may lead to improved vibrational behaviors for the smart beams subjected to magnetic fields and external harmonic excitation. Nonlinear governing equations of a nonlocal intelligent beam have been achieved based upon the refined beam model and a numerical provided has been introduced to calculate nonlinear vibrational curves. The present study indicates that variation in the volume fraction of piezoelectric ingredient has a substantial impact on vibrational behaviors of intelligent nanobeam under electrical and magnetic fields. Also, it can be seen that nonlinear free/forced vibrational behaviors of intelligent nanobeam have dependency on the magnitudes of induced electrical voltages, magnetic potential, stiffening elastic substrate and shear deformation.

Khalid H. Almaitani (1), Alaa A. Abdelrahman (2) and Mohamed A. Eltaher (1,2)
(1) Department of Mechanical Engineering, Faculty of Engineering, King Abdulaziz University, P.O. Box 80204, Jeddah, Saudi Arabia
(2) Department of Mechanical Design & Production, Faculty of Engineering, Zagazig University, P.O. Box 44519, Zagazig, Egypt


ABSTRACT: This paper aims to present an analytical methodology to investigate influences of nanoscale and surface energy on buckling stability behavior of perforated nanobeam structural element, for the first time. The surface energy effect is exploited to consider the free energy on the surface of nanobeam by using Gurtin-Murdoch surface elasticity theory. Thin and thick beams are considered by using both classical beam of Euler and first order shear deformation of Timoshenko theories, respectively. Equivalent geometrical constant of regularly squared perforated beam are presented in simplified form. Problem formulation of nanostructure beam including surface energies is derived in detail. Explicit analytical solution for nanoscale beams are developed for both beam theories to evaluate the surface stress effects and size-dependent nanoscale on the critical buckling loads. The closed form solution is confirmed and proven by comparing the obtained results with previous works. Parametric studies are achieved to demonstrate impacts of beam filling ratio, the number of hole rows, surface material characteristics, beam slenderness ratio, boundary conditions as well as loading conditions on the non-classical buckling of perforated nanobeams in incidence of surface effects. It is found that, the surface residual stress has more significant effect on the critical buckling loads with the corresponding effect of the surface elasticity. The proposed model can be used as benchmarks in designing, analysis and manufacturing of perforated nanobeams.

Seyed Sajad Mirjavadi (1), Masoud Forsat (1), Mohammad Reza Barati (2) and A.M.S. Hamouda (1)
(1) Department of Mechanical and Industrial Engineering, Qatar University, P.O. Box 2713, Doha, Qatar
(2) Fidar project Qaem Company, Darvazeh Dolat, Tehran, Iran


ABSTRACT: Based on third-order shear deformation shell theory, the present paper investigates post-buckling properties of eccentrically stiffened metal foam curved shells/panels having initial geometric imperfection. Metal foam is considered as porous material with uniform and non-uniform models. The single-curve porous shell is subjected to in-plane compressive loads leading to post-critical stability in nonlinear regime. Via an analytical trend and employing Airy stress function, the nonlinear governing equations have been solved for calculating the post-buckling loads of stiffened geometrically imperfect metal foam curved shell. New findings display the emphasis of porosity distributions, geometrical imperfection, foundation factors, stiffeners and geometrical parameters on post-buckling properties of porous curved shells/panels.

Nie Biao, Xu Shanhua, Zhang Haijiang and Zhang Zongxing (School of Civil Engineering, Xi'an University of Architecture & Technology, No.13, middle section of Yanta Road, Beilin District, China), “Experimental and
ABSTRACT: Experimental investigation and finite element analysis of corroded cold-formed steel (CFS) columns are presented. 11 tensile coupon specimens and 6 stub columns of corroded CFS that had a channel section of C160x60x20 were subjected to monotonic tensile tests and axial compression tests, respectively. The degradation laws of the mechanical properties of the tensile coupon specimens and stub columns were analysed. An appropriate finite element model for the corroded CFS columns was proposed and the influence of local corrosion on the stability performance of the columns was studied by finite element analysis. Finally, the axial capacity of the experimental results was compared with the predictions obtained from the existing design specifications. The results indicated that with an increasing average thickness loss ratio, the ultimate strength, elastic modulus and yield strength decreased for the tensile coupon specimens. Local buckling deformation was not noticeable until the load reached about 90% of the ultimate load for the non-corroded columns, while local buckling deformation was observed when the load was only 40% of the ultimate load for the corroded columns. The maximum reduction of the ultimate load and critical buckling load was 57% and 81.7%, respectively, compared to those values for the non-corroded columns. The ultimate load of the columns with web thickness reduced by 2 mm was 53% lower than that of the non-corroded columns, which indicates that web corrosion most significantly affects the bearing capacity of the columns with localized corrosion. The results predicted using the design specifications of MOHURD were more accurate than those predicted using the design specifications of AISI.

Pouyan Talebizadehsardari (1), Arameh Eyvazian (2), Mojtaba Gorji Azandariani (3), Trong Nhan Tran (4), Dipen Kumar Rajak (5) and Roohollah Babaei Mahani (6)
(1) Metamaterials for Mechanical, Biomechanical and Multiphysical Applications Research Group, Ton Duc Thang University, Ho Chi Minh City, Vietnam
(2) Mechanical and Industrial Engineering Department, College of Engineering, Qatar University, P.O. Box 2713, Doha, Qatar
(3) Structural Engineering Division, Faculty of Civil Engineering, Semnan University, Semnan, Iran
(4) Faculty of Automobile Technology, Van Lang University, Ho Chi Minh City, Vietnam
(5) Department of Mechanical Engineering, Sandip Institute of Technology and Research Centre, Nashik 422213, MH-India
(6) Faculty of Civil Engineering, Duy Tan University, Da Nang 550000, Vietnam
ABSTRACT: The buckling analysis of the embedded sinusoidal piezoelectric beam is evaluated using numerical method. The smart beam is subjected to external voltage in the thickness direction. Elastic medium is simulated with two parameters of spring and shear. The structure is modelled by sinusoidal shear deformation theory (SSDT) and utilizing energy method, the final governing equations are derived on the basis of piezoelectricity theory. In order to obtaining the buckling load, the differential quadrature method (DQM) is used. The obtained results are validated with other published works. The effects of beam length and thickness, elastic medium, boundary condition and external voltage are shown on the buckling load of the structure. Numerical results show that with enhancing the beam length, the buckling load is decreased. In addition, applying negative voltage, improves the buckling load of the smart beam.

ABSTRACT: This paper proposes the use of a porous core between layers of laminated composite plates to examine its effect on the natural frequencies of the resulted porous laminated composite sandwich plate (PLCS) resting on a two-parameter elastic foundation. Moreover, it has been suggested that the dispersion of porosity has two different functionally graded (FG) patterns which are compared with a uniformly dispersed (UD) profile to find their best vibrational efficiency in the proposed PLCSPs. In FG patterns, two types of dispersions, including symmetric (FG-S) and asymmetric (FG-A) patterns have been considered. To derive the
governing Eigen value equation of such structures, the first order shear deformation theory (FSDT) of plates has been employed. Accordingly, a finite element method (FEM) is developed to solve the derived Eigen value equation. Using the mentioned theory and method, the effects of porosity parameters, fiber orientation of laminated composite, geometrical dimensions, boundary conditions and elastic foundation on the natural frequencies of the proposed PLCSPs have been studied. It is observed that embedding porosity in core layer leads to a significant improvement in the natural frequencies of PLCSPs. Moreover, the natural frequencies of PLCSPs with FG porous core are higher than those with UD porous core.

Ammar Melaibari (1), Ahmed B. Khoshaim (2), Salwa A. Mohamed (3) and Mohamed A. Eltaher (2,3)
(1) Mechanical Engineering Department, Faculty of Engineering, King Abdulaziz University, P.O. Box 80204, Jeddah, Saudi Arabia; Centre of Nanotechnology, King Abdulaziz University, Jeddah, Saudi Arabia
(2) Mechanical Engineering Department, Faculty of Engineering, King Abdulaziz University, P.O. Box 80204, Jeddah, Saudi Arabia
(3) Department of Engineering Mathematics, Faculty of Engineering, Zagazig University, P.O. Box 44519, Zagazig, Egypt


ABSTRACT: This manuscript presents impacts of gradation of material functions and axial load functions on critical buckling loads and mode shapes of functionally graded (FG) thin and thick beams by using higher order shear deformation theory, for the first time. Volume fractions of metal and ceramic materials are assumed to be distributed through a beam thickness by both sigmoid law and symmetric power functions. Ceramic–metal–ceramic (CMC) and metal–ceramic–metal (MCM) symmetric distributions are proposed relative to mid-plane of the beam structure. The axial compressive load is depicted by constant, linear, and parabolic continuous functions through the axial direction. The equilibrium governing equations are derived by using Hamilton's principles. Numerical differential quadrature method (DQM) is developed to discretize the spatial domain and covert the governing variable coefficients differential equations and boundary conditions to system of algebraic equations. Algebraic equations are formed as a generalized matrix eigenvalue problem, that will be solved to get eigenvalues (buckling loads) and eigenvectors (mode shapes). The proposed model is verified with respectable published work. Numerical results depict influences of gradation function, gradation parameter, axial load function, slenderness ratio and boundary conditions on critical buckling loads and mode-shapes of FG beam structure. It is found that gradation types have different effects on the critical buckling. The proposed model can be effective in analysis and design of structure beam element subject to distributed axial compressive load, such as, spacecraft, nuclear structure, and naval structure.


ABSTRACT: The homotopy perturbation method (HPM) to predict the pre- and post-buckling behaviour of simply supported steel beams with rectangular hollow section (RHS) is presented in this paper. The non-linear differential equations solved by HPM derive from a kinematics where large twist and cross-sections distortions are considered. The results (linear and non-linear paths) given by the present HPM are compared to those provided by the Newton–Raphson algorithm with arc length and by the commercial FEM code Abaqus. To investigate the effect of cross-sectional distortion of beams, some numerical examples are presented.


ABSTRACT: The goal of this study is to investigate dynamic responses of laminated composite beams under a moving load with thermal effects. The governing equations of problem are derived by using the Lagrange procedure. The transverse-shear strain and rotary inertia are considered within the Timoshenko beam theory. The material properties of lamina are considered as the temperature dependent physical property. The differential equations of the problem are solved by the Ritz method. The solution step of dynamic problem, the Newmark average acceleration method is used in the time history. A compassion study is performed for
accuracy of used formulations and method. In the numerical results, the effects of velocity of moving load, temperature values, the fiber orientation angles and the stacking sequence of laminas on the dynamic responses of the composite laminated beam are investigated.


ABSTRACT: In this article, the influence of fuzzified uncertain composite elastic properties on non-linear deformation behaviour of the composite structure is investigated under external mechanical loadings (uniform and sinusoidal distributed loading) including the different end boundaries. In this regard, the composite model has been derived considering the fuzzified elastic properties (through a triangular fuzzy function, a cut) and the large geometrical distortion (Green-Lagrange strain) in the framework of the higher-order mid-plane kinematics. The results are obtained using the fuzzified nonlinear finite element model via in-house developed computer code (MATLAB). Initially, the model accuracy has been established and explored later to show the dominating elastic parameter affect the deflection due to the inclusion of fuzzified properties by solving a set of new numerical examples.


ABSTRACT: In the context of classic conical shell formulation, nonlinear forced vibration analysis of truncated conical shells and annular plates made of multi-scale epoxy/CNT/fiberglass composites has been presented. The composite material is reinforced by carbon nanotube (CNT) and also fiberglass for which the material properties are defined according to a 3D Mori-Tanaka micromechanical scheme. By utilizing the Jacobi elliptic functions, the frequency-deflection curves of truncated conical shells and annular plates related to their forced vibrations have been derived. The main focus is to study the influences of CNT amount, fiberglass volume, open angle, fiber angle, truncated distance and force magnitude on forced vibrational behaviors of multi-scale truncated conical shells and annular plates.


ABSTRACT: The effect of Chitosan (CS), Carbon Nanotube (CNT) and hybrid (CS-CNT) fillers on the natural frequency of drilled composite plate is investigated by experimentally in this study. The numerical validation is also made with a program based on Finite Element Method (SolidWorks). Nine types filled and one neat composite plates are used in the study. The fillers ratios are 1% CS, 2% CS, 3% CS, 0.1% CNT, 0.2% CNT, 0.3% CNT, 1% CS+0.3% CNT, 2% CS+0.3% CNT, 3% CS+0.3% CNT. The specimens cut to certain sizes by water jet from the plates 400 mm x 400 mm in dimensions. Some of them are drilled in certain dimensions with drill. The natural frequency of each specimen is measured by the vibration test set up to determine the vibration characteristic. The vibration test set up includes an accelerometer, a current source power unit, a data acquisition card and a computer. A code is written in Matlab® program for the signal processing. The study are investigated and discussed in four main points to understand the effect of the fillers on the natural frequency of the composite plate. These are the effect of fillers contents and amounts, orientation angles of fibers, holes numbers and holes sizes. As results, the natural frequency of the plate with 1% CS and 0.1% CNT hybrid filler is lower than those of the plates with other fillers ratios for 45° orientation angle. Besides, in the composite plate with 0° orientation angle, the natural frequency increases with increasing the filler ratio. Moreover, the natural frequency increases until a certain hole number and then it decreases. Furthermore, the natural frequency is not affected until a certain hole diameter but then it decreases.
ABSTRACT: This paper presents the influence of carbon nanotubes (CNTs) waviness, aspect ratio, internal pores and graphene platelets (GPLs) on the vibrational behavior of functionally graded nanocomposite sandwich beams resting on two-parameter elastic foundations. The distributions of CNTs are considered functionally graded (FG) or uniform along the thickness of upper and bottom layers of the sandwich beam and their mechanical properties are estimated by an extended rule of mixture. In this study, the classical theory concerning the mechanical efficiency of a matrix embedding finite length fibers has been modified by introducing the tube-to-tube random contact, which explicitly accounts for the progressive reduction of the tubes\' effective aspect ratio as the filler content increases. The core of structure is porous and the internal pores and graphene platelets (GPLs) are distributed in the matrix of core either uniformly or non-uniformly according to three different patterns. The elastic properties of the nanocomposite are obtained by employing Halpin-Tsai micromechanics model. The equations of motion are derived based on Timoshenko beam theory and employing Hamilton\'s principle. The problem is modeled using a semi-analytical approach composed of generalized differential quadrature method (GDQM) and series solution adopted to solve the equations of motion. Detailed parametric studies are carried out to investigate carbon nanotubes (CNTs) waviness, CNT aspect ratio, porosity coefficient, porosity distribution, graphene platelets (GPLs) distribution, Winkler foundation modulus, shear elastic foundation modulus and geometrical conditions on the vibrational behavior of the sandwich structure.

ABSTRACT: In this study, free vibration behavior of trapezoidal sandwich plates with porous core and two graphene platelets (GPLs) reinforced nanocomposite outer layers are presented. The distribution of pores and GPLs are supposed to be functionally graded (FG) along the thickness of core and nanocomposite layers, respectively. The effective Young modulus of the GPL-reinforced (GPLR) nanocomposite layers is determined using the modified Halpin-Tsai micromechanics model, while the Poisson ratio and density are computed by the rule of mixtures. The FSDT plate theory is utilized to establish governing partial differential equations and boundary conditions (B.C.s) for trapezoidal plate. The governing equations together with related B.C.s are discretized using a mapping- generalized differential quadrature (GDQ) method in the spatial domain. Then natural frequencies of the trapezoidal sandwich plates are obtained by GDQ method. Validity of current study is evaluated by comparing its numerical results with those available in the literature. A special attention is drawn to the role of GPLs weight fraction, GPLs patterns of two faces through the thickness, porosity coefficient and distribution of porosity on natural frequencies characteristics. New results show the importance of this permeates on vibrational characteristics of porous/GPLR nanocomposite plates. Finally, the influences of B.C.s and dimension as well as the plate geometry such as face to core thickness ratio on the vibration behaviors of the trapezoidal plates are discussed.

ABSTRACT: The present research investigates post-buckling behavior of geometrically imperfect tapered curved micro-panels made of graphene oxide powder (GOP) reinforced composite. Micro-scale effects on the panel structure have been included based on strain gradient elasticity. Micro-panel is considered to be tapered based on thickness variation along longitudinal direction. Weight fractions of uniformly and linearly distributed GOPs are included in material properties based on Halpin-Tsai homogenization scheme considering. Post-buckling curves have been determined based on both perfect and imperfect micro-panel assumptions. It is found that post-buckling curves are varying with the changes of GOPs weight fraction, geometric imperfection, GOP distribution type, variable thickness parameters, panel curvature radius and strain gradient.

Seyed Sajad Mirjavadi, Masoud Forsat, Mohammad Reza Barati and A.M.S. Hamouda, “Investigating nonlinear forced vibration behavior of multi-phase nanocomposite annular sector plates using Jacobi elliptic
Compressive tests were conducted on three short specimens with different width experimentally investigated the effect of width thickness have been previously studied by the authors on short walls under uniform compression. This paper investigated by the authors. Furthermore, the influences of the truss spacings, the wall width, and the faceplate rectangular high walls under compression and T, bonded the steel plates to the concrete core to achieve good composite action. The structural behavior of capacity, large axial stiffne.

**ABSTRACT:** Double skin composite wall system owns several structural merits in terms of high load-carrying capacity, large axial stiffness, and favorable ductility. A recently proposed form of truss connector was used to bond the steel plates to the concrete core to achieve good composite action. The structural behavior of rectangular high walls under compression and T-shaped high walls under eccentric compression has been investigated by the authors. Furthermore, the influences of the truss spacings, the wall width, and the faceplate thickness have been previously studied by the authors on short walls under uniform compression. This paper experimentally investigated the effect of width-to-thickness ratio on the compressive behavior of short walls. Compressive tests were conducted on three short specimens with different width-to-thickness ratios. Based on


**ABSTRACT:** In this paper, wavy square absorbers were experimentally and numerically investigated. Numerical simulations were performed with LS-Dyna software on 36 wavy absorbers and their crushing properties were extracted and compared with the simple one. The effect of different parameters, including wave height, wave depth, and wave type; either internal or external on the crushing characteristics were also investigated. To experimentally create corrugation to validate the numerical results, a set of steel mandrel and matrix along with press machines were used. Since the initial specimens were brittle, they were subjected to heat treatment and annealing to gain the required ductility for forming with mandrel and matrix. The annealing of aluminum shells resulted in a 76% increase in ultimate strain and a 60% and 56% decrease in yield and ultimate stresses, respectively. The results showed that with increasing half-wave height in wavy square absorbers, the maximum force was first reduced and then increased. It was also found that in the specimen with constant diameter and half-wave depth, an increment in the half-wave height led to an initial increase in efficiency, followed by a decline. According to the conducted investigations, the lowest maximum force can be observed in the specimen with zero half-wave depth as compared to those having a depth of 1 cm.


**ABSTRACT:** In this paper, the forced resonance vibration of porous functionally graded (FG) curved nanobeam is examined. In order to capture the hardening and softening mechanisms of nanostructure, the nonlocal strain gradient theory is employed to build the size-dependent model. Using the Timoshenko beam theory together with the Hamilton principle, the equations of motion for the curved nanobeam are derived. Then, Navier series are used in order to obtain the dynamical deflections of the porous FG curved nanobeam with simply-supported ends. It is found that the resonance position of the nanobeam is very sensitive to the nonlocal and strain gradient parameters, material variation, porosity coefficient, as well as geometrical conditions. The results indicate that the resonance position is postponed by increasing the strain gradient parameter, while the nonlocal parameter has the opposite effect on the results. Furthermore, increasing the opening angle or length-to-thickness ratio will result in resonance position moves to lower-load frequency.


**ABSTRACT:** Double skin composite wall system owns several structural merits in terms of high load-carrying capacity, large axial stiffness, and favorable ductility. A recently proposed form of truss connector was used to bond the steel plates to the concrete core to achieve good composite action. The structural behavior of rectangular high walls under compression and T-shaped high walls under eccentric compression has been investigated by the authors. Furthermore, the influences of the truss spacings, the wall width, and the faceplate thickness have been previously studied by the authors on short walls under uniform compression. This paper experimentally investigated the effect of width-to-thickness ratio on the compressive behavior of short walls. Compressive tests were conducted on three short specimens with different width-to-thickness ratios. Based on
the test results, it is found that the composite wall shows high compressive resistance and good ductility. The walls fail by local buckling of steel plates and crushing of concrete core. It is also observed that width-to-thickness ratio has great influence on the compressive resistance, initial stiffness, and strain distribution across the section. Finally, the test results are compared with the predictions by modern codes.


ABSTRACT: This article presented a nanoscale modified continuum model to investigate the free vibration of functionally graded (FG) porous nanobeam by using finite element method. The main novelty of this manuscript is presenting effects of four different porosity models on vibration behaviors of nonlocal nanobeam structure including size effect, that not be discussed before. The proposed porosity models are, uniform porosity distribution, symmetric with mid-plane, bottom surface distribution and top surface distribution. The nano-scale effect is included in modified model by using the differential nonlocal continuum theory of Eringen that adding the length scale into the constitutive equations as a material parameter constant. The graded material is distributed through the beam thickness by a generalized power law function. The beam is simply supported, and it is assumed to be thin. Therefore, the kinematic assumptions of Euler-Bernoulli beam theory are held. The mathematical model is solved numerically using the finite element method. Results demonstrate effects of porosity type, material gradation, and nanoscale parameters on the free vibration of nanobeam. The proposed model is effective in vibration analysis of NEMS structure manufactured by porous functionally graded materials.


ABSTRACT: The current work, present dynamic analysis of the FG-sandwich plate seated on elastic foundation with various kinds of support using refined shear deformation theory. The present analytical model is simplified which the unknowns number are reduced. The zero-shear stresses at the free surfaces of the FG-sandwich plate are ensured without introducing any correction factors. The four equations of motion are determined via Hamilton’s principle and solved by Galerkin’s approach for FG-sandwich plate with three kinds of the support. The proposed analytical model is verified by comparing the results with those obtained by other theories existing in the literature. The parametric studies are presented to detect the various parameters influencing the fundamental frequencies of the symmetric and non-symmetric FG-sandwich plate with various boundary conditions.


ABSTRACT: Double skin composite walls are increasingly popular and have been applied to many safety-related facilities. They come from the concept of composite slabs. Conventional connectors such as shear studs and binding bars were used in previous studies to act as the internal mechanical connectors to lock the external steel faceplates to the concrete core. However, the restraint effects of these connectors were sometimes not strong enough. In this research, a recently proposed unique type of steel truss was employed along the wall height to enhance the composite action between the two materials. Concrete-filled tube columns were used as the boundary elements. Due to the existence of boundary columns, the restraints of steel faceplates to the concrete differ significantly for the walls with different widths. Therefore, there is a need to explore the effect of height-to-width ratio on the structural behavior of the wall. In the test program, three specimens were designed with the height of 3000 mm, the thickness of 150 mm, and different widths, to simulate the real walls in practice. Axial compression was applied by two actuators on the tested walls. The axial behavior of the walls was evaluated based on the analysis of test results. The influences of height-to-width ratio on structural performance were evaluated. Finally, discussion was made on code-based design.
ABSTRACT: This paper studies nonlinear stability behavior of a nanocrystalline silicon curved nanoshell considering strain gradient size-dependency. Nanocrystallines are composite materials with an interface phase and randomly distributed nano-size grains and pores. Imperfectionness of the curved nanoshell has been defined based on an initial deflection. The formulation of nanocrystalline nanoshell has been established by thin shell theory and an analytical approach has been used in order to solve the buckling problem. For accurately describing the size effects related to nano-grains or nano-pores, their surface energies have been included. Nonlinear stability curves of the nanoshell are affected by the size of nano-grain, curvature radius and nanopore volume fraction. It is found that increasing the nano-pore volume fraction results in lower buckling loads.


ABSTRACT: This article presents a comprehensive static analysis of simply supported cross-ply carbon nanotubes reinforced composite (CNTRC) laminated nanobeams under various loading profiles. The nonlocal strain gradient constitutive relation is exploited to present the size-dependence of nano-scale. New higher shear deformation beam theory with hyperbolic function is proposed to satisfy the zero-shear effect at boundaries and parabolic variation through the thickness. Carbon nanotubes (CNTs), as the reinforced elements, are distributed through the beam thickness with different distribution functions, which are, uniform distribution (UD-CNTRC), V- distribution (FG-V CNTRC), O- distribution (FG-O CNTRC) and X- distribution (FG-X CNTRC). The equilibrium equations are derived, and Fourier series function are used to solve the obtained differential equation and get the response of nanobeam under uniform, linear or sinusoidal mechanical loadings. Numerical results are obtained to present influences of CNTs reinforcement patterns, composite laminate structure, nonlocal parameter, length scale parameter, geometric parameters on center deflection ad stresses of CNTRC laminated nanobeams. The proposed model is effective in analysis and design of composite structure ranging from macro-scale to nano-scale.


ABSTRACT: The aim of this research is to analyze buckling and bending behavior of a sandwich Reddy beam with porous core and composite face sheets reinforced by boron nitride nanotubes (BNNTs) and shape memory alloy (SMA) wires resting on Vlasov's foundation. To this end, first, displacement field's equations are written based on the higher-order shear deformation theory (HSDT). And also, to model the SMA wire properties, constitutive equation of Brinson is used. Then, by utilizing the principle of minimum potential energy, the governing equations are derived and also, Naviert's analytical solution is applied to solve the governing equations of the sandwich beam. The effect of some important parameters such as SMA temperature, the volume fraction of SMA, the coefficient of porosity, different patterns of BNNTs and porous distributions on the behavior of buckling and bending of the sandwich beam are investigated. The obtained results show that when SMA wires are in martensite phase, the maximum deflection of the sandwich beam decreases and the critical buckling load increases significantly. Furthermore, the porosity coefficient plays an important role in the maximum deflection and the critical buckling load. It is concluded that increasing porosity coefficient, regardless of porous distribution, leads to an increase in the critical buckling load and a decrease in the maximum deflection of the sandwich beam.


ABSTRACT: The current study deals with the size-dependent free vibration analysis of graphene nanoplatelets (GNPs) reinforced polymer nanocomposite plates resting on Pasternak elastic foundation containing different boundary conditions. Based on a four variable refined shear deformation plate theory, which considers shear
deformation effect, in conjunction with the Eringen nonlocal elasticity theory, which contains size-dependency inside nanostructures, the equations of motion are established through Hamilton's principle. Moreover, the effective material properties are estimated via the Halpin-Tsai model as well as the rule of mixture. Galerkin's mathematical formulation is utilized to solve the equations of motion for the vibrational problem with different boundary conditions. Parametrical examples demonstrate the influences of nonlocal parameter, total number of layers, weight fraction and geometry of GNPs, elastic foundation parameter, and boundary conditions on the frequency characteristic of the GNPs reinforced nanoplates in detail.


ABSTRACT: In the present research, the free vibration analysis of functionally graded (FG) nanocomposite deep spherical shells reinforced by graphene platelets (GPLs) on elastic foundation is performed. The elastic foundation is assumed to be Winkler-Pasternak-type. It is also assumed that graphaene platelets are randomly oriented and uniformly dispersed in each layer of the nanocomposite shell. Volume fraction of the graphene platelets as nanofillers may be different in the layers. The modified HalpinTsai model is used to approximate the effective mechanical properties of the multilayer nanocomposite. With the aid of the first order shear deformation shell theory and implementing Hamilton's principle, motion equations are derived. Afterwards, the generalized differential quadrature method (GDQM) is utilized to study the free vibration characteristics of FG-GPLRC spherical shell. To assess the validity and accuracy of the presented method, the results are compared with the available researches. Finally, the natural frequencies and corresponding mode shapes are provided for different boundary conditions, GPLs volume fraction, types of functionally graded, elastic foundation coefficients, opening angles of shell, and thickness-to-radius ratio.


ABSTRACT: Composite beams with corrugated steel webs represent a new innovative system which has emerged in the past decade for medium span in the construction technology. The use of composite beams with corrugated steel webs results in a range of benefits, including flexible spaces and reduced foundation costs in the construction technology. The thin corrugated web affords a significant weight reduction of these beams, compared with hot-rolled or welded ones. In the current research, an optimal designed I-girder beam with corrugated web has been proposed to improve the structural performance of continuous composite girder under bending moment. The experimental program has been conducted for six simply supported composite beams with different loading conditions. The tested specimens are designed by using one of the stochastic techniques called hunting search algorithm. In the optimization process, besides the thickness of concrete slab and studs, corrugated web properties are considered as design variables. The design constraints are respectively implemented from Eurocode 3, BS-8110 and DIN 18-800 Teil-1. The last part of the study focuses on performing a numerical study on composite beams by utilizing finite element analysis and the bending behavior of steel girders with corrugated webs experimentally and numerically verified the results. A nonlinear analysis was carried out using the finite element software ANSYS on the composite beams which were modelled using the elements ten-node high order quadrilateral type.


ABSTRACT: This study examines the wave propagation of the functionally graded polymer composite (FG-PC) nanoplates reinforced with graphene nanoplatelets (GNPs) resting on elastic foundations in the framework of the nonlocal strain gradient theory incorporating both stiffness hardening and softening mechanisms of nanostructures. To this end, the material properties are based on the Halpin-Tsai model, and the expressions for the classical and higher-order stresses and strains are consistently derived employing the second-order shear deformation theory. The equations of motion are then consistently derived using Hamilton's principle of variation. These governing equations are solved with the help of Trial function method. Extensive numerical discussions are conducted for wave propagation of the nanoplates and the influences of different parameters,
such as the nonlocal parameter, strain gradient parameter, weight fraction of GNPs, uniform and non-uniform distributions of GNPs, elastic foundation parameters as well as wave number.


ABSTRACT: In this paper, free vibration finite element analysis of axially moving laminated composite beams subjected to axial tension is studied. It is assumed that the beam has a constant axial velocity and is subject to uniform axial tension. The analysis is based on higher-order theories that have been presented by Carrera Unified Formulation (CUF). In the CUF technique, the three dimensional (3D) displacement fields are expressed as the approximation of the arbitrary order of the displacement unknowns over the cross-section. This higher-order expansion is considered in equivalent single layer (ESL) model. The governing equations of motion are obtained via Hamilton’s principle. Finally, several numerical examples are presented and the effect of the ply-angle, travelling speed and axial tension on the natural frequencies and beam stability are demonstrated.


ABSTRACT: The present paper investigates the simultaneous resonance behavior of spiral stiffened multilayer functionally graded (SSMFG) cylindrical shells with internal and external functionally graded stiffeners under the two-term large amplitude excitations. The structure is embedded within a generalized nonlinear viscoelastic foundation which is composed of a two-parameter Winkler-Pasternak foundation augmented by a Kelvin-Voigt viscoelastic model with a nonlinear cubic stiffness. The cylindrical shell has three layers consist of ceramic, FGM, and metal. The exterior layer of the cylindrical shell is rich ceramic while the interior layer is rich metal and the functionally graded material layer is located between these layers. With regard to classical shells theory, von-Kármán equation, and Hook law, the relations of stress-strain are derived for shell and stiffeners. The spiral stiffeners of the cylindrical shell are modeled according to the smeared stiffener technique. According to the Galerkin method, the discretized motion equation is obtained. The simultaneous resonance is obtained using the multiple scales method. Finally, the influences of different material and geometrical parameters on the system resonances are investigated comprehensively.


ABSTRACT: Curved steel-concrete composite box girder has been widely adopted in urban overpasses and ramp bridges. In order to investigate its mechanical behavior under complicated and combined bending, shear and torsion load, two large-curvature composite box girders with interior angles of 25 and 45 were tested under static hogging moment. Based on the strain and deflection measurement on critical cross-sections during the static loading test, the failure mode, cracking behavior, load-displacement relationship, and strain distribution in the steel plate and rebar were investigated in detail. The test result showed the large-curvature composite box girders exhibited notable shear lag in the concrete slab and steel girder. Also, the constraint torsion and distortion effect caused the stress measured at the inner side of the composite beam to be notably higher than that of the outer side. The strain distribution in the steel web was approximately linear; therefore, the assumption that the plane section remains plane was approximately validated based on strain measurement at steel web. Furthermore, the full-process non-linear elaborate finite element (FE) models of the two specimens were developed based on commercial FE software MSC.MARC. The modeling scheme and constitutive model were illustrated in detail. Based on the comparison between the FE model and test results, the FE model effectively simulated the failure mode, the load-displacement curve, and the strain development of longitudinal rebar and steel girder with sufficient accuracy. The comparison between the FE model and the test result validated the accuracy of the developed FE model.

Mohamed A. Khadimallah, Muzamal Hussain, Khaled Mohamed Khedher, Muhammad Nawaz Naeem and Abdelouahed Tounsi, “Backward and forward rotating of FG ring support cylindrical shells”, Steel and
ABSTRACT: In this research work, the analytical rotating vibration for functionally graded shell with ring supports are restricted to some volume fraction laws based on Rayleigh-Ritz technique. The frequencies of functionally grade cylindrical shells have been investigated for the distribution of material composition of material with two kinds of material. Stability of a cylindrical shell depends highly on these aspects of material with ring supports. The frequency behavior is investigated with fraction laws versus circumferential wave number, length-to-radius and height-to-radius ratios. The frequencies are higher for higher values of circumferential wave number. The frequency first increases and gain maximum value with the increase of circumferential wave mode. Moreover, the effect of angular speed is also investigated. It is examined that the backward and forward frequencies increases and decreases on increasing the ratio of height- and length-to-radius ratios.


ABSTRACT: To explore the feasibility of eliminating the longitudinal rebars and stirrups by using ultra-high-performance fiber reinforcement concrete (UHPFRC) in concrete encased steel composite stub column, compressive behavior of UHPFRC encased steel stub column has been experimentally investigated. Effect of concrete types (normal strength concrete, high strength concrete and UHPFRC), fiber fractions, and transverse reinforcement ratio on failure mode, ductility behavior and axial compressive resistance of composite columns have been quantified through axial compression tests. The experimental results show that concrete encased composite columns with NSC and HSC exhibit concrete crushing and spalling failure, respectively, while composite columns using UHPFRC exhibit concrete spitting and no concrete spalling is observed after failure. The incorporation of steel fiber as micro reinforcement significantly improves the concrete toughness, restrains the crack propagation and thus avoids the concrete spalling. No evidence of local buckling of rebars or yielding of stirrups has been detected in composite columns using UHPFRC. Steel fibers improve the bond strength between the concrete and, rebars and core shaped steel which contribute to the improvement of confining pressure on concrete. Three prediction models in Eurocode 4, AISC 360 and JGJ 138 and a proposed toughness index (T.I.) are employed to evaluate the compressive resistance and post peak ductility of the composite columns. It is found that all these three models predict close the compressive resistance of UHPFRC encased composite columns with/without the transverse reinforcement. UHPFRC encased composite columns can achieve a comparable level of ductility with the reinforced concrete (RC) columns using normal strength concrete. In terms of compressive resistance behavior, the feasibility of UHPFRC encased steel composite stub columns with lesser longitudinal reinforcement and stirrups has been verified in this study.


ABSTRACT: In this paper, dynamic buckling of a smart sandwich nanotube is studied. The nanostructure is composed of a carbon-nanotube with inner and outer surfaces coated with ZnO piezoelectric layers, which play the role of sensor and actuator. Nanotube is under magnetic field and ZnO layers are under electric field. The nanostructure is located in a viscoelastic environment, which is assumed to obey Visco-Pasternak model. Non-local piezo-elasticity theory is used to consider the small-scale effect, and Kelvin model is used to describe the structural damping effects. Surface stresses are taken into account based on Gurtin-Murdoch theory. Hamilton principle in conjunction with zigzag shear-deformation theory is used to obtain the governing equations. The governing equations are then solved using the differential quadrature method, to determine dynamic stability region of the nanostructure. To validate the analysis, the results for simpler case studies are compared with others reported in the literature. Then, the effect of various parameters such as small-scale, surface stresses, Visco-Pasternak environment and electric and magnetic fields on the dynamic stability region is investigated. The results show that considering the surface stresses leads to an increase in the excitation frequency and the dynamic stability region happens at higher frequencies.

ABSTRACT: Vibration response in a sandwich plate with a nanocomposite core covered by magnetic layer is presented. The core is armed by functionaly graded-carbon nanotubes (FG-CNTs) where the Mori-Tanaka law is utilized assuming agglomeration effects. The structure plate is located on elastic medium simulated by Pasternak model. The governing equations are derived based on Mindlin theory and Hamilton's principle. Utilizing differential quadrature method (DQM), the frequency of the structure is calculated and the effects of magnetic layer, volume percent and agglomeration of CNTs, elastic medium and geometrical parameters of structure are shown on the frequency of system. Results indicate that with considering magnetic layer, the frequency of structure is increased.


ABSTRACT: Steel plate shear wall with self-centering energy dissipation braces (SPSW-SCEDB) is a lateral force-resistant system that exhibits flag-shaped hysteretic responses, which consists of two pre-pressed spring self-centering energy dissipation (PS-SCED) braces and a wall plate connected to horizontal boundary elements only. The present study conducted a series of cyclic tests to study the hysteretic performances of braces in SPSW-SCEDB and the effects of braces on the overall hysteretic characteristics of this system. The SPSW-SCEDB with PS-SCED braces only exhibits excellent self-centering capability and the energy loss caused by the large inclination angle of PS-SCED braces can be compensated by appropriately increasing the friction force. Under the combined effect of the two components, the SPSW-SCEDB exhibits a flag-shaped hysteretic response with large lateral resistance, good energy dissipation and self-centering capabilities. In addition, the wall plate is the primary energy dissipation component and the PS-SCED braces provide supplementary energy dissipation for system. The PS-SCED braces can provide up to 90% self-centering capability for the SPSW-SCEDB system. The compressive bearing capacity of the wall plate should be smaller than the horizontal remaining restoring force of the braces to achieve better self-centering effect of the system.


ABSTRACT: Eight cold-formed thin-walled steel beams were performed to investigate the effect of corrosion damage on the flexural behavior of steel beams. The relationships between failure modes or load-displacement curves and corrosion degree of steel beams were investigated. A series of parametric analysis with more than forty finite element models were also performed with different corrosion degrees, types and locations. The results showed that the reduction of cross-section thickness as well as corrosion pits on the surface would lead to a decline in the stiffness and flexural capacity of steel beams, and gradually intensified with the corrosion degree. The yield load, ultimate load and critical buckling load of the corroded specimen IV-B46-4 decreased by 22.2%, 26% and 45%, respectively. The failure modes of steel beams changed from strength failure to stability failure or brittle fracture with the corrosion degree increasing. In addition, thickness damage and corrosion pits at different locations caused the degradation of flexural capacity, the worst of which was the thickness damage of compression zone. Finally, the method for calculating flexural capacity of corroded cold-formed thin-walled steel beams was also proposed based on experimental investigation and numerical analysis results.


ABSTRACT: The application of double-skin composite wall should meet different layout plans. However, most available research focused on the rectangular section with uniform axial compression. In this research, the structural behavior of double-skin composite wall with L section was studied. Due to the unsymmetric geometric characteristics, the considered loading condition combined the axial compression and biaxial

ABSTRACT: Twenty-two corrosion-damaged columns were simulated through accelerated steel corrosion tests. Eight specimens were directly tested to failure under axial load, and the remaining specimens were tested after concrete-filled steel tube (CFST) strengthening. This study aimed to investigate the damage of RC columns after corrosion and their restoration and enhancement after strengthening. The research parameters included different corrosion degrees of RC columns, diameter-to-thickness ratio of steel tube and the strengthening concrete strength. Experimental results showed that CFST strengthening method could change the failure mode of corrosion-damaged RC columns from brittleness to ductility. In addition to the bearing capacity provided by the strengthening materials, it can also provide an extra 26.7% amplification because of the effective confinement provided by steel tubes. The influence of corrosion on reinforcement and concrete was quantitatively analyzed and considered in the design formula. The proposed formula accurately predicted the bearing capacity of the strengthened columns with a maximum error of only 7.68%.


ABSTRACT: A novel spiral confined angle-steel reinforced concrete (SCARC) column was developed in this study. A total of 16 specimens were prepared and tested (eight of them were tested under axial loading, the other eight were tested under eccentric loading). The failure processes and load-displacement relationships of specimens under axial and eccentric loads were examined, respectively. The load-carrying capacity and ductility were evaluated by parametric analysis. A calculation approach was developed to predict the axial and eccentric load-carrying capacity of these novel columns. Results showed that the spiral reinforcement provided enough confinement in SCARC columns under axial and low eccentric loads, but was not effective in that under high eccentric loads. The axial load-carrying capacity and ductility of SCARC columns were improved significantly due to the satisfactory confinement from spirals. The outer reinforcement and other construction measures were necessary for SCARC columns to prevent premature spalling of the concrete cover. The proposed calculation approach provided a reliable prediction of the load-carrying capacity of SCARC columns.


ABSTRACT: Recently, Concrete-filled double skin steel tubular (CFDST) columns have proven an exceptional structural resistance in terms of strength, stiffness, and ductility. However, the resistance of these column members can be severely affected by the type of loading in which bending stresses increase in direct proportion with axial load and eccentricity value. This paper presents a non-linear finite element based modeling approach that studies the behavior of slender CFDST columns under biaxial loading. Finite element models were calibrated based on the outcomes of experimental work done by other researchers. Results from simulations of slender CFDST columns under axial loading eccentric in one direction showed good agreement with the experimental response. The calibrated models are expanded to a total of thirty models that studies the behavior of slender CFDST columns under combined compression and biaxial bending. The influences of parameters that are usually found in practice are taken into consideration in this paper, namely, eccentricity-to-diameter (e/D) ratios, slenderness ratios, diameter-to-thickness (D/t) ratios, and steel contribution ratios. Finally, an analytical study based on current code provisions is conducted. It is concluded that South African national standards (2011) provided the most accurate results contrasted with the Eurocode 4 (2004) and American...
Institute of Steel Construction (2016) that are found to be conservative. Accordingly, correction factors are proposed to the current design guidelines to provide more satisfactory results.


ABSTRACT: This research deals with the study of vibrational behavior of armchair and zigzag single-walled carbon nanotubes invoking extended Love shell theory. The effects of different physical and material parameters on the fundamental frequencies are investigated. By using volume fraction for power law index, the fundamental natural frequency spectra for two forms of single-walled carbon nanotubes are calculated. The influence of frequencies against length-to-diameter ratios with varying power law index are investigated in detail for these tubes. To discretize the governing equation in eigen-value form, wave propagation approach is developed. Complex exponential functions have been used and the axial model depends on boundary condition that has been described at the edges of carbon nanotubes to calculate the axial modal dependence. Computer software MATLAB is utilized for the frequencies of single-walled carbon nanotubes and current results shows a good stability with comparison of other studies.


ABSTRACT: The buckling properties of a single-layered graphene sheet (SLGS) are examined using nonlocal integral first shear deformation theory (FSDT) by incorporating the influence of visco-Pasternaks medium. This model contains only four variables, which is even less than the conventional FSDT. The visco-Pasternak's medium is introduced by considering the damping influence to the conventional foundation model which modeled by the linear Winkler’s coefficient and Pasternak's (shear) foundation coefficient. The nanoplate under consideration is subjected to compressive in-plane edge loads per unit length. The impacts of many parameters such as scale parameter, aspect ratio, the visco-Pasternak's coefficients, damping parameter, and mode numbers on the stability investigation of the SLGSs are examined in detail. The obtained results are compared with the corresponding available in the literature.


ABSTRACT: This paper deals with free vibration of FG sandwich annular sector plates on Pasternak elastic foundation with different boundary conditions, based on the three-dimensional theory of elasticity. The plates with simply supported radial edges and arbitrary boundary conditions on their circular edges are considered. The influence of carbon nanotubes (CNTs) waviness, aspect ratio, internal pores and graphene platelets (GPLs) on the vibrational behavior of functionally graded nanocomposite sandwich plates is investigated in this research work. The distributions of CNTs are considered functionally graded (FG) or uniform along the thickness of upper and bottom layers of the sandwich sectorial plates and their mechanical properties are estimated by an extended rule of mixture. In this study, the classical theory concerning the mechanical efficiency of a matrix embedding finite length fibers has been modified by introducing the tube-to-tube random contact, which explicitly accounts for the progressive reduction of the tubes' effective aspect ratio as the filler content increases. The core of structure is porous and the internal pores and graphene platelets (GPLs) are distributed in the matrix of core either uniformly or non-uniformly according to three different patterns. The elastic properties of the nanocomposite are obtained by employing Halpin-Tsai micromechanics model. A semi-analytic approach composed of 2D-Generalized Differential Quadrature Method (2D-GDQM) and series solution is adopted to solve the equations of motion. The fast rate of convergence and accuracy of the method are investigated through the different solved examples. Some new results for the natural frequencies of the plate are prepared, which include the effects of elastic coefficients of foundation, boundary conditions, material and geometrical parameters. The new results can be used as benchmark solutions for future researches.

Google the string “Journal of Thermal Stresses, then click on the entry, “Journal of Thermal Stresses – Taylor & Francis Online”, and find the list of journal issues.


ABSTRACT: Thermoelastic damping of nanobeams by considering the size effects of nanostructure and heat conduction is studied herein. The size effect of nanostructure is investigated based on Euler–Bernoulli beam assumptions in the framework of nonlocal strain gradient elasticity, and the size dependence of heat conduction is taken into account by incorporating phase-lagging and nonlocal effects. Closed-form solutions of thermoelastic damping and quality factor characterized by thermoelastic coupling are derived. Graphene nanoribbon is chosen as a nanobeam. The effects of relaxation time, aspect ratio, elastic modulus, thermal expansion, and thermal conductivity on quality factor of graphene nanobeams are discussed in detail.


ABSTRACT: An analytical solution for accurately predicting the edge effects in elastic and hybrid multilayered panels integrated with piezoelectric actuator and sensor layers under thermal gradient loading is presented. The associated thermal problem is solved independently by performing a heat transfer analysis. The extended Reissner-type mixed variational principle is employed to develop the governing equations of the three dimensional (3D) piezothermoelasticity problem. Their solution is obtained using the mixed-field multitem extended Kantorovich method, developed recently by the author group. The mixed field solution exactly satisfies all the mechanical and electric boundary conditions pointwise, leading to an accurate solution. The formulation is general, and is applicable for composite, sandwich and hybrid panels with arbitrary lay-up and boundary conditions. The solution is validated against the exact 3D solution available for simply supported panels. The free edge stress field in sandwich and hybrid composite laminates is investigated under uniform as well as gradient thermal loading. The solution successfully captures the singularity in free edge interlaminar stresses. The significance of pyroelectric coupling on the free edge thermal stress field is investigated, and the feasibility of its control through electric field actuation is examined.

References listed at the end of the paper:

References listed at the end of the paper:


**ABSTRACT:** The thermo-mechanical vibration characteristics of doubly-curved nano-composite shells reinforced by graphene nanoplatelets are investigated by considering a uniform distribution of graphene and a first-order shear deformation theory. The mechanical properties of the nano-composite shells are estimated by using the modified Halpin–Tsi model. The governing equations are first derived by a variational formulation using Hamilton’s principle and are solved using the Galerkin technique. Numerical results are presented for various shell curvatures and compared with those available in the archival literature. Furthermore, parametric studies are offered to highlight the significant influence of graphene nanoplatelets’ weight fraction, dimensions of graphene nanoplatelets, and temperature variation, on the free vibration of the nano-composite shells.

**References listed at the end of the paper:**

reinforced with graphene nanoplatelets (GPLs)

organ/10.1007/s40997

·

distributed graphene platelets (GPLs)

·

graphene platelets

composite beams

·

thermal environments

·

on 3D elasticity

·

discrete singular convolution method

·

subjected to uniaxial and biaxial loading

review

shells

·

pp.

·

Z.

R.

R.

M.

D.

H. S.

H. S.

B.

G.

X. Y.

Y.

S.

F.

H. S.

G. M.

Pouresmaeeli

Pouresmaeeli

Moghaddam

Zhao

Kuilla

Gholami

Chen

J.

J.

S.

R. B.

and

K.

–

Y.

Feng

and

Kaner

–

M. H. G.

Emrick

and

S. A.

Dhand

K. Y.

Park

and

Marzocca,

and

K.-Y.

Wang

J.

J.

of

Materials science. Graphene

article polymer composites: where two small worlds meet

Fiedler

T. P.

Russell

and

Nanop

Berlin, Germany

Berlin, Germany


ABSTRACT: Wrinkling represents one of the failure modes in sandwich structures, although in practical designs the loss of strength and global buckling often occur at lower compressive loads. However, the properties of both polymeric matrix in the facings as well as the polymeric core degrade under an elevated temperature. As a consequence, wrinkling that does not present a problem at the room temperature may become a dominant mode of failure at elevated temperatures. In this article, we suggest that a reinforcement of the core material with stiff random nanoscale or microscale reinforcements may alleviate wrinkling. The solution accounts for the thermal loading history and the effect of temperature on the stiffness of the materials of the core and facings. While nano or microscale reinforcements increase the capacity of the structure to resist wrinkling, the strength of the core may be compromised due to the presence of such inclusions in the core material. Accordingly, the residual stresses in the reinforced core are evaluated using a finite element method and accounting for the effect of temperature on the properties and stresses. It is demonstrated that both wrinkling and the core strength analyses should account for the effect of temperature on the material properties. References listed at the end of the paper:


References listed at the end of the paper:

ABSTRACT: In the present study, a simple four-parameter exponential shear deformation theory is developed for the bending of functionally graded material (FGM) rectangular plates resting on two-parameter elastic foundation using four unknown plate theory. Journal of Thermal Stresses, Vol. 42, No. 2, pp. 213–232, 2019. https://doi.org/10.1080/01495739.2018.1469962

The present theory has four independent unknowns. The elastic properties, coefficient of thermal expansion, and coefficient of moisture expansion of the plate are assumed to be graded in the thickness direction according to a simple power-law distribution in terms of volume fractions of material constituents. Unlike first-order and other higher-order plate theories, the present theory has four independent unknowns. The in-plane displacement field of the present theory uses exponential functions in terms of thickness coordinate for calculating out-of-plane shearings. The transversal displacement includes bending and shear components. The principle of virtual displacement is employed to derive the governing equations and associated boundary conditions. A Navier solution technique is employed to obtain an analytical solutions. The elastic foundation is modelled as two-parameter Winkler–Pasternak foundation. The numerical results obtained are compared with previously published results wherever possible to prove the efficacy and accuracy of the present theory. The effects of stiffness and gradient index of the foundation on the hygrothermomechanical responses of the plates are discussed.

References listed at the end of the paper:


ABSTRACT: In this article, thermal buckling of laminated composite beams, based on hyperbolic refined shear deformation theory, presented for the first time, is formulated using the principle of minimum total potential energy. Navier’s analytical solution is derived to analytically solve the differential equations and the thermal critical buckling is presented in closed-form solution. The effects of temperature distribution, length to thickness ratio, modulus ratio, and thermal expansion coefficient ratio on thermal buckling of isotropic, orthotropic and laminated composite beams are investigated. The accuracy of the numerical model is verified by comparison with the available results in the literature.

References listed at the end of the paper:


ABSTRACT: In this article, a fully-coupled thermoelastic formulation is developed to deal with the free-vibration analysis of multilayered plate composite and sandwich structure. Some advanced theories are obtained by expanding the unknown displacement variables along the thickness direction and using equivalent-single-layer (ESL) models, layer-wise (LW) models, and variable-kinematic models. The variable-kinematic models permit to reduce the computational cost of the analyses grouping some layers of the multilayered structure with ESL models and keeping the LW models in other zones of the multilayer. This model is here extended for the free-vibration analysis of fully-coupled thermomechanical problems. The used refined models are grouped in the Carrera unified formulation (CUF), and they accurately describe the displacement field and the temperature distributions along the thickness of the multilayered plate. The governing equations are derived from the principle of virtual displacement, and the finite element method (FEM) is employed to solve them. Isotropic plates, cross-ply composite plates, and sandwich structures with composite skins and simply-supported edges are analyzed. Various aspect ratios are considered. The results, obtained with different theories within CUF context, are compared with the elasticity solutions, and other higher-order analytical and FEM solutions given in the literature. From the results, it is possible to conclude that the plate element based on the CUF is very efficient in the study of thermomechanical problems of composite structures. The variable-kinematic models combining the ESL with the LW models, permit to have a reduction of the computational costs, respect with the full LW models, preserving the accuracy of the results.

References listed at the end of the paper:


ABSTRACT: Large amplitude thermally induced vibrations of cylindrical shells made of a through-the-thickness functionally graded material (FGM) are investigated in the current research. All of the thermomechanical properties of the FGM shell are assumed to be functions of temperature and thickness coordinate. Shell is subjected to rapid surface heating on the ceramic-rich surface while the other surface of the shell is kept at reference temperature. One dimensional heat conduction equation is constructed and solved by means of a hybrid finite difference-Crank–Nicolson algorithm. The constructed heat conduction equation is nonlinear since the thermal conductivity is temperature dependent. With the aid of first-order shear deformation shell theory under the axisymmetric Donnell kinematic assumptions and von Kármán type of strain-displacement relations, the total energy of the shell is established. Implementing the conventional Ritz method, a set of nonlinear coupled algebraic equations are obtained which govern the dynamics of the shell under thermal shock. These equations are solved in time domain using the Newmark time marching scheme and the simple Picard successive method. Parametric studies are given to explore the dynamics of an FGM cylindrical shell under thermal shock.

References listed at the end of the paper:

ABSTRACT: This research deals with the nonlocal temperature-dependent dynamic buckling analysis of embedded laminated quadrilateral micro plates reinforced by functionally graded carbon nanotubes (FG-CNTs). The material properties of structure are assumed viscoelastic based on Kelvin–Voigt model. The effective material properties of structure are considered based on mixture rule. The elastic medium is simulated by orthotropic visco-Pasternak medium. The motion equations are derived applying Sinuosoidal shear deformation theory (SSDT) in which the size effects are considered using higher order nonlocal strain gradient theory. The transformed weighing (TW) and differential quadrature (DQ) method in conjunction with the Bolotin’s method are applied for calculating resonance frequency and dynamic instability region (DIR) of structure. The effects of different parameters such as volume percent of CNTs, distribution type of CNTs, temperature, nonlocal parameter and structural damping on the dynamic instability of visco-system are shown. The results are compared with other published works in the literature. Results indicate that the CNTs have an important role in dynamic stability of structure and FGX distribution type is the better choice.

References listed at the end of the paper:


ABSTRACT: In this work, the thermal effect on the buckling response of the axially functionally graded (AFG) nanobeams is studied based on the nonlocal thermoelasticity theory. Size effects of elastic deformation and heat conduction are considered simultaneously. Non-uniform distribution of temperature along the longitudinal direction of the AFG nanobeams is taken into account and determined by the nonlocal heat conductive law. Equations of motion and the corresponding boundary conditions are derived with the aid of the variational principle within the sinusoidal shear deformation theory and the nonlocal thermoelasticity theory. Ritz method is used to obtain the solutions for the thermal buckling response of the AFG nanobeams with various boundary conditions. Numerical results addressing the significance of the AFG index, the nonlocal parameters of elasticity and heat conduction, and the transverse shear deformation on the buckling behavior are displayed. It is found that, in addition to the nonlocal effect of elasticity, the nonlocal heat conduction plays an important role in analyzing the thermal–mechanical behaviors of the FG nanostructures.

References listed at the end of the paper:
I. Introduction

The present study, a new computational model which incorporates the effect of transverse shear and normal deformation is presented for the thermal analysis of laminated composite and sandwich plates. The present theory involves nine unknowns and uses a polynomial function in terms of thickness coordinates which is expanded up to fifth-order. In the present fifth-order shear and normal deformation theory (FOSNDT), the governing equations are variationally consistent and obtained by using the principle of virtual work. Plates are analyzed for simply supported boundary conditions using Navier’s solution technique. Numerical results obtained by using the present theory are compared with three-dimensional elasticity solution and other higher-order theories available in the literature. It is found that the present theory is accurately predicting the thermal response of laminated composite and sandwich plates compared to any other theory available in the literature.

II. Theory

The theory involves the following assumptions:

1. The material is linearly elastic.
2. The plate is thin.
3. The plate is isotropic.
4. The temperature distribution is known.
5. The plate is subjected to a thermal load.

The governing equations are derived using the principle of virtual work and are given by

\[ \delta V = 0 \]

where \( V \) is the virtual work done by the external forces and \( \delta \) is the virtual displacement.

The boundary conditions are given by

1. Simply supported boundary conditions.
2. Clamped boundary conditions.
3. Free boundary conditions.

III. Numerical Results

The numerical results are presented for various cases and compared with the results obtained using other theories. The results show that the present theory is accurately predicting the thermal response of laminated composite and sandwich plates.

IV. Conclusion

The present study shows that the new computational model is accurate and efficient for the thermal analysis of laminated composite and sandwich plates. The model is based on the FOSNDT and incorporates the effect of transverse shear and normal deformation.

V. References


ABSTRACT: In the present study, a new computational model which incorporates the effect of transverse shear and normal deformation is presented for the thermal analysis of laminated composite and sandwich plates. The present theory involves nine unknowns and uses a polynomial function in terms of thickness coordinates which is expanded up to fifth-order. In the present fifth-order shear and normal deformation theory (FOSNDT), the governing equations are variationally consistent and obtained by using the principle of virtual work. Plates are analyzed for simply supported boundary conditions using Navier’s solution technique. Numerical results obtained by using the present theory are compared with three-dimensional elasticity solution and other higher-order theories available in the literature. It is found that the present theory is accurately predicting the thermal response of laminated composite and sandwich plates compared to any other theory available in the literature.

ABSTRACT: Buckling and postbuckling behaviors of two models of sandwich plate reinforced by carbon nanotubes (CNTs) resting on elastic foundations and subjected to uniaxial compressive and thermomechanical loads are investigated in this paper. Material properties of all constituents are assumed to be temperature dependent and effective properties of CNT-reinforced composite layer are determined according to extended rule of mixture. Governing equations are established within the framework of first-order shear deformation theory taking into account von Kármán nonlinearity, initial geometrical imperfection, plate-foundation interaction and tangential elastic constraints of unloaded edges. Three types of loading are considered including uniaxial compression, preexisting thermal load combined with uniaxial compression and preexisting mechanical load combined with thermal load. Approximate analytical solutions are assumed to satisfy simply supported boundary conditions and the Galerkin method is used to derive nonlinear load-deflection relations from which buckling loads and postbuckling equilibrium paths are determined. The most important findings are that tangential constraints of unloaded edges significantly lowers buckling loads and postbuckling load capacity of sandwich plates and, in contrast, buckling loads and postbuckling strength are considerably enhanced as sandwich plate is constructed from CNT-reinforced composite core layer and homogeneous face sheets.

References listed at the end of the paper:


ABSTRACT: In this study, the thermo-hygro-mechanical bending and vibration of functionally graded material (FGM) microbeams with microporosity defect are investigated. The mathematical model of the system is developed by using the sinusoidal beam theory and the modified couple stress theory. Based on Hamilton’s principle, the governing equations and boundary conditions of imperfect FGM microbeams are derived. Then, Navier’s method is utilized to calculate the deflections and natural frequencies of the system. Analytical results are presented to illustrate the effects of the microporosity volume fraction, the microporosity distribution type, the power-law index, the temperature and the moisture on the static bending and free vibration of imperfect FGM microbeams.

References listed at the end of the paper:


ABSTRACT: In the context of a memory-dependent generalized thermoelasticity, the thermal-induced transient response in an infinite elastic body containing a spherical shell is investigated. A thermal shock is applied on the inner surface of the spherical shell. The infinite body and the spherical shell are assumed to be isotropic but two dissimilar materials. By using an analytical technique based on the Laplace transform along with its numerical inversion, the governing equations of the problem are solved and the non-dimensional physical quantities in the two materials, i.e., temperature, displacement and stress, are obtained and illustrated graphically respectively. In simulation, the accuracy of memory-dependent derivative (MDD) is verified by degrading the present model into L-S model to compare the results obtained from the cases with interfacial thermal resistance and without interfacial thermal resistance. In addition, the effects of the different kernel functions as well as the ratios of the two materials, including the ratios of the density, the thermal-conductivity and the time-delay, on the distributions of the considered variables are obtained and demonstrated graphically respectively.

References listed at the end of the paper:


that there is no maximum COP when the temperature difference across the TEC is zero. However, the effect of buckling on the cooling performance of TEC can be ignored if the TEC achieves the maximum COP. The peak value of COP is independent of the ratio of length-to-thickness of the TEC. An optimized value of the electric current corresponding to the maximum COP of the TEC is obtained.

References listed at the end of the paper:

References listed at the end of the paper:


**ABSTRACT:** Postbuckling and nonlinear bending of a geometrically perfect circular plate arisen by the temperature of one side of a axisymmetric circular plate made from a poroelastic solid whose matrix pores have been saturated by fluid have been numerically analyzed. The plate porosity varies continuously through the plate thickness according to some given specific functions. The postbuckling and nonlinear bending configurations of respectively clamped and simply-supported plates, as well as the critical postbuckling temperature, have been obtained under the influence of the plate one side surface temperature, thickness, type of pore distribution, porosity and compressibility of fluid confined by the pores. Equilibrium equations of the plate have been derived on the basis of the classical plate theory, Love–Kirchhoff hypothesis and the Sander’s nonlinear strain–displacement relationship. They have been discretized via differential quadrature method. The numerical results approximately coincide with the relevant literature, namely the results of saturated porous and mathematically equivalent plates made from functionally graded materials.

**References listed at the end of the paper:**

shock loads, which are both imposed on its upper and lower bounding surfaces. It is further assumed that responses of nanosandwich structure subjected to th

ABSTRACT: Nowadays, the nanosandwich structure stands as one of the most promising candidates for nanodevices and nanocomposites (e.g., nanogenerator, nano-energy harvester) due to its superior mechanical properties. The size-dependent response analysis of nanosandwich structure under extreme in-service environment is of great importance for its fabrication and exploitation. This motivates us to study the transient responses of nanosandwich structure subjected to the symmetrical transient thermal and chemical potential shock loads, which are both imposed on its upper and lower bounding surfaces. It is further assumed that


ABSTRACT: Nowadays, the nanosandwich structure stands as one of the most promising candidates for nanodevices and nanocomposites (e.g., nanogenerator, nano-energy harvester) due to its superior mechanical properties. The size-dependent response analysis of nanosandwich structure under extreme in-service environment is of great importance for its fabrication and exploitation. This motivates us to study the transient responses of nanosandwich structure subjected to the symmetrical transient thermal and chemical potential shock loads, which are both imposed on its upper and lower bounding surfaces. It is further assumed that
thermal contact resistance and diffusional contact impedance at the interface of each two adjacent layers are zero with ideal adhesion. For each isotropic homogeneous elastic layer, the governing equations are formulated in the context of size-dependent generalized thermoelastic diffusion theory and then are solved by using Laplace transformation techniques. The effects of elastic nonlocal parameter, fractional order parameters as well as material characteristic parameters on structural transient responses are also analyzed and discussed. The present study not only provides a comprehensive understanding of the size-dependent thermoelastic diffusion coupling of nanosandwich structure, but also offers basic guidelines for optimal design.

References listed at the end of the paper:


ABSTRACT: This article deals with the study of three-dimensional vibrations in stress free as well as rigidly fixed, thermally insulated (or isothermal), homogeneous transversely isotropic solid cylinder under the purview of three-phase lag model of generalized thermoelasticity. The displacement potential functions have been introduced in the equations of motion and heat conduction in order to decouple the purely shear and longitudinal motions. The matrix Frobenius method of extended power series is employed to obtain the solution of coupled ordinary differential equations along the radial coordinate. Circumferential wave propagation in cylindrical curved plate is discussed. To illustrate the analytic results, the numerical solution of various relations and equations have been carried out to compute the lowest frequency, inverse quality factor, and dissipation factor of vibrations and the computer-simulated results are presented graphically for different thermoelastic models.

References listed at the end of the paper:
Coupled thermoelasticity analysis of FGM plate integrated with piezoelectric layers under thermal shock


ABSTRACT: Based on theory of piezoelectricity and using generalized coupled thermoelasticity, transient response of a simply supported functionally graded material rectangular plate embedded in sensor and actuator piezoelectric layers under applied electric field and thermal shock is studied. Thermoelastic properties of the plate vary continuously along the thickness direction according to exponential functions and Poisson ratio is assumed to be constant. Applying Fourier series state space technique to the basic coupled thermoelastic differential equations results in the ordinary differential equations which are solved analytically by using Laplace transform. Validation of the present approach is assessed by comparing the numerical results with the available results in literature. In parametric study, effect of the relaxation time, applied voltage and temperature and time history of the thermoelastic response of FGM plate attached to piezoelectric layers are investigated. References listed at the end of the paper:


Subjected to thermal and mechanical shock loads of elasticity plates in thermal environment actuators and sensors in unsteady temperature field

The dynamic analysis of smart plates environment

Plates with integrated piezoelectric sensors and actuators


ABSTRACT: In this study, thermal buckling of moderately thick functionally graded rectangular plates with all edges simply supported is analyzed by means of an improved third order shear deformation theory (improved TSDT). The plate is assumed to be under two types of thermal loadings, namely; uniform temperature rise and nonlinear temperature change across the thickness. The equilibrium and stability equations are derived based on the von Kármán type of geometrical nonlinearity and the improved third-order theory. By solving the stability equations, the value of buckling temperature difference is obtained. To calculate the critical buckling temperature difference, this value is minimized with respect to the half-wave parameters. The results are compared with the known data in literatures. The results indicate that, the values of critical buckling temperature difference which are obtained based on the improved TSDT, are lower in comparison with those obtained based on TSDT. Also, the results show that incorporation of the von Kármán type of geometrical nonlinearity with the improved third-order theory, gives the lower values of the critical buckling temperature difference.

References listed at the end of the paper:


ABSTRACT: This article develops a nonlocal strain gradient plate model for buckling analysis of graphene sheets under hygrothermal environments. For more accurate analysis of graphene sheets, the proposed theory contains two scale parameters related to the nonlocal and strain gradient effects. Graphene sheet is modeled via a two-variable shear deformation plate theory needless of shear correction factors. Governing equations of a nonlocal strain gradient graphene sheet on elastic substrate are derived via Hamilton’s principle. Galerkin’s method is implemented to solve the governing equations for different boundary conditions. Effects of different factors such as moisture concentration rise, temperature rise, nonlocal parameter, length scale parameter, elastic foundation and geometrical parameters on buckling characteristics a graphene sheets are examined.

References listed at the end of the paper:

ABSTRACT: A nonuniform rational B-spline isogeometric finite element formulation is presented in this research to analyze the thermal buckling behavior of composite laminated skew plates reinforced by graphene platelets. Formulation is based on the first-order shear deformation plate theory. It is assumed that each layer of the composite laminated plate may have different volume fraction of graphene platelets leading to a through-the-thickness piecewise functionally graded medium. The equivalent properties of the plate are obtained by means of the Halpin–Tsai rule. The developed solution method may be used for arbitrary combinations of boundary conditions. The accuracy of the developed formulation is depicted via comparison studies with respect to the available data in the open literature. Novel numerical results are also given to show the effects of volume fraction of graphene platelets, distributed patterns of graphene platelets, and geometric characteristics of the skew plate.

References listed at the end of the paper:


ABSTRACT: A nonuniform rational B-spline isogeometric finite element formulation is presented in this research to analyze the thermal buckling behavior of composite laminated skew plates reinforced by graphene platelets. Formulation is based on the first-order shear deformation plate theory. It is assumed that each layer of the composite laminated plate may have different volume fraction of graphene platelets leading to a through-the-thickness piecewise functionally graded medium. The equivalent properties of the plate are obtained by means of the Halpin–Tsai rule. The developed solution method may be used for arbitrary combinations of boundary conditions. The accuracy of the developed formulation is depicted via comparison studies with respect to the available data in the open literature. Novel numerical results are also given to show the effects of volume fraction of graphene platelets, distributed patterns of graphene platelets, and geometric characteristics of the skew plate.

References listed at the end of the paper:

with graphene nanoplatelets

- Y. Y. Zhang, C. M. Wang, Y. Cheng, and Y. Xiang, “Mechanical properties of bilayer graphene sheets coupled by sp3 bonding,”


- X. Zhao, Q. Zhang, D. Chen, and P. Lu, “Enhanced mechanical properties of graphene-based poly(vinyl alcohol) composites,”


- A. Parashar and P. Martiny, “Representative volume element to estimate buckling behavior of graphene/polymer nanocomposite,”


- F. Lin, Y. Xiang, and H. S. Shen, “Temperature dependent mechanical properties of graphene reinforced polymer nanocomposites—a molecular dynamics simulation,”


- H. S. Shen, Y. Xiang, and F. Lin, “Nonlinear bending and thermal postbuckling of functionally graded graphene-reinforced composite laminated beams resting on elastic foundations,”


- H. S. Shen, Y. Xiang, and F. Lin, “Thermal buckling and postbuckling of functionally graded graphene-reinforced composite laminated plates resting on elastic foundations,”

- Y. Yu, H. S. Shen, H. Wang, and D. Hui, “Postbuckling of sandwich plates with graphene-reinforced composite face sheets in thermal environments,”


- Y. Kiani, “NURBS-based isogeometric thermal postbuckling analysis of temperature dependent graphene reinforced composite laminated plates,”

- H. S. Shen, Y. Xiang, and Y. Fan, “Postbuckling of functionally graded graphene-reinforced composite laminated cylindrical panels

- H. S. Shen and Y. Xiang, “Postbuckling behavior of functionally graded graphene-reinforced composite laminated cylindrical shells

- H. S. Shen and Y. Xiang, “Postbuckling of functionally graded graphene-reinforced composite laminated cylindrical shells subjected to external pressure in thermal environments,”

- H. S. Shen and Y. Xiang, “Thermal buckling and postbuckling behavior of FG-GRC laminated cylindrical shells with temperature-dependent material properties,”

- Y. Kiani, “Buckling of functionally graded graphene reinforced conical shells under external pressure in thermal environment,”

- J. Yang, H. Wu, and S. Kitipornchai, “Buckling and postbuckling of functionally graded multilayer graphene platelet-reinforced composite beams,”

- Z. Yang, J. Yang, A. Liu, and J. Fu, “Nonlinear in-plane stability of functionally graded multilayer graphene reinforced composite shallow arches,”

- S. Kitipornchai, D. Chen, and J. Yang, “Free vibration and elastic buckling of functionally graded porous beams reinforced by graphene platelets,”


- H. Wu, S. Kitipornchai, and J. Yang, “Thermal buckling and postbuckling of functionally graded graphene composite plates,”

- M. Song, J. Yang, and S. Kitipornchai, “Bending and buckling analyses of functionally graded polymer composite plates reinforced
Parametric studies of the perfect/imperfect FG porous beams for two types of immovable boundary conditions as clamped–rolling and clamped–clamped are analyzed. Thermo-mechanical non-homogeneous material properties of the FG porous beam are assumed to be temperature and position dependent. FG porous beams are subjected to different types of thermal loads as heat conduction and uniform temperature rise. Heat conduction equation is solved analytically using the polynomial series solution for the one-dimensional condition. The governing equilibrium equations are obtained by applying the virtual displacement principle. Assuming von Kármán type of geometrical nonlinearity, equilibrium equations are nonlinear and are solved using an analytical method. A two-step perturbation technique is used to obtain the thermal buckling and postbuckling responses of FG porous beams. The numerical results are compared with the case of perfect FG Timoshenko beams without porosity distribution based on the midplane formulation. Parametric studies of the perfect/imperfect FG porous beams for two types of thermal loading and boundary conditions are provided.

References listed at the end of the paper:


ABSTRACT: A quasi-3D tangential shear deformation theory is employed to analyze free vibration behavior of a three-layered FG porous micro plate which is located between two polymeric nano-composite layers. The structure is in a hygrothermal environment and Lorentz force is applied to it. Also, it rests on an elastic foundation which is modeled by Pasternak type. The properties of core and faces are changed following the given functions and also are temperature-dependent. Hamilton’s principle and Navier’s method are employed to extract and solve motion equations, respectively. Effect of the most prominent parameters is considered and discussed in detail.

References listed at the end of the paper:


Mathieu functions. A closed nonlinear free vibration equation of elliptic structure is developed with thermally insulated and is derived using the classical method. The strain energy due to bending of the middle face ABSTRACT: The present article investigates the thermoelastic free vibration of conical panels with elastically restrained against rotation edges in thermal environment.


ABSTRACT: The present article investigates the thermoelastic free vibration for a simply supported elliptic plate subjected to a thermal load. The realistic solution involving the Mathieu functions and also their derivatives for the heat conduction differential equation subjected to sinusoidal sectional heating on the upper face with the lower face and the curved inner surface is kept at zero temperature, and the outer curve is kept thermally insulated and is derived using the classical method. The strain energy due to bending of the middle surface of the plate undergoing large deflection was well-thought-out by neglecting the second strain invariant terms for the analysis of large amplitude (nonlinear)-free vibrations of a simply supported plate. Furthermore, nonlinear free vibration equation of elliptic structure is developed with the aid of Berger assumption and Hamilton’s principle and obtained its solution using a new integral transform involving Mathieu and modified Mathieu functions. A closed-form bending stress function obtained has been equated with those obtained by
Berger’s methodology. The thermal stress components are obtained in terms of resultant bending moments and resultant forces for numerical analysis. The free-vibration mode of the corresponding nonlinear problem, the Jacobi elliptic function, is obtained from the exact resolution of the natural frequency of the simply supported elliptic plate. For the particular case by applying limiting conditions, the elliptic region can degenerate into the problem of the circular zone, and some numerical results have also been plotted in a few instances.

References listed at the end of the paper:


Eduardo Saetta, Valeria Settini and Giuseppe Rega (Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy), “Minimal thermal modeling of two-way thermomechanically coupled plates

ABSTRACT: Minimal thermal modeling of two-way thermomechanically coupled plates is addressed in the framework of a unified formulation of the underlying continuum problem. Variably refined reduced-order models are considered, and some main features of the relevant transient and steady responses to a variety of active thermal sources are investigated, by properly reconstructing 3D temperature configurations and energy balances. In comparison with a richer reduced model and available analytical solutions, a model with assumed cubic temperature distribution along the thickness has the advantage of being the minimal one still allowing to consider a wide set of boundary and body thermal excitations, while showing a comprehensive capability to reliably describe the thermal response. This appears of particular interest also in view of further pursuing a systematic, yet computationally demanding, investigation of the nonlinear dynamics of the coupled plate, in the cheapest possible way from both the mechanical and thermal viewpoint.

References listed at the end of the paper:
by avoiding significant mode changes or occurrences of mode conver-
temperature variation make it possible for characterization the variations of vibrations and particularly the
calculations of both strain and kinetic energies for vibration mode identification or charact-
frequencies and vibration modes can be calculated as a function of temperature, then they can be used in the
well described b
functioning frequency of a quartz crystal resonator during the temperature variation and maintain its operations
Thermal Stresses, Vol. 43, No. 4, pp 456
mode shape variations of quartz crystal plates in a thermal field with strain and kinetic energies”
Engineering, Huzhou Vocational and Technical College, China), "'

Qi Huang, Rongxing Wu, Longtao Xie, Aibing Zhang, Bin Huang, Jianke Du & Ji Wang (First author is from
School of Mechanical Engineering and Mechanics, Ningbo University, China and Dept. of Architectural
Engineering, Huzhou Vocational and Technical College, China), “Examinations of vibration frequency and
mode shape variations of quartz crystal plates in a thermal field with strain and kinetic energies”, Journal of
ABSTRACT: The frequency-temperature behavior has long been analyzed to ensure the smoothness of
functioning frequency of a quartz crystal resonator during the temperature variation and maintain its operations
in a stable state. It has been proven that vibrations of quartz crystal plates in the thickness-shear mode can be
well described by the theory of incremental thermal field in conjunction with the Mindlin plate equations,
demonstrating the possibility that vibration frequencies and mode shapes can also be well predicted with the
temperature as a targeted variable. By studying the vibrations with temperature changes in a given range, the
frequencies and vibration modes can be calculated as a function of temperature, then they can be used in the
calculations of both strain and kinetic energies for vibration mode identification or characterization based on
energy proportion and changes. The trends of changes of vibration frequency, amplitudes, and energy with
temperature variation make it possible for characterization the variations of vibrations and particularly the
weakening or enhancement of the dominance of specific vibration modes. With such relations between
vibration properties and temperature known, possible analytical tools can be developed to aid the optimal design
by avoiding significant mode changes or occurrences of mode conversion.

ABSTRACT: Current investigation deals with the generalized thermoelastic response of a finite hollow disk made of a piezoelectric material. The constitutive equations of the piezoelectric media are reduced to a two dimensional plane-stress state. To capture the finite speed of temperature wave, the single relaxation time theory of Lord and Shulman is used. Three coupled differential equations in terms of radial displacement, electric potential, and temperature change are obtained. These equations are written in a dimensionless presentation. With the aid of the differential quadrature method (DQM) a time-dependent algebraic system of equations is extracted. The Newmark time marching scheme is applied to trace the temporal evolution of temperature change, electric potential, radial displacement, stresses, and electric displacement. Numerical results demonstrate that radial displacement and temperature waves propagate with finite speed while the electric potential propagates with infinite speed.


ABSTRACT: In engineering practice, it is difficult to guarantee that the foundation of a beam is homogeneous along the whole length. This paper presents an investigation on buckling and post-buckling behavior of beams on the elastic foundation under thermal loading. The virtual work method is employed to deduce the buckling governing equation and post-buckling differential equation of equilibrium. The Buckling load of beams on homogeneous foundation is investigated analytically and it is found that the first buckling mode is determined by nondimensional foundation stiffness. The beam will jump to another mode at a certain value of foundation stiffness. This paper investigates the buckling and post-buckling behavior of beams on elastic foundation under thermal loading. The buckling and post-buckling behaviors of beams on weakened foundation are analyzed by using a shooting technique. The results show that the weakening effect has a significant influence on buckling temperature and buckling mode, and post-buckling path is stable in the whole loading process under thermal effects. It is also observed that the weakening effect can give rise to local deformation of the beam, and the location of the weakening effect has an obvious influence on buckling mode and post-buckling deformation.

References listed at the end of the paper:

distribution and a non-typical types of multilayer FG cylindrical shells with an FG porosity core distribution consist of a uniform porosity distribution core are considered.


ABSTRACT: In this article, a semi-analytical and analytical method for the nonlinear static and dynamic thermal buckling behavior of imperfect multilayer FG cylindrical shells with an FG porous core in the thermal environment is investigated. The structure is embedded within a generalized nonlinear elastic foundation which is composed of a two-parameter Winkler-Pasternak foundation augmented by a nonlinear cubic stiffness. Two types of multilayer FG cylindrical shells with an FG porosity core distribution consist of a uniform porosity distribution and a non-uniform porosity distribution core are considered. Using the Galerkin method with regard
to the von Kármán equations, the discretized motion equation is obtained. The fourth-order Runge-Kutta method is utilized to obtain the nonlinear dynamic thermal buckling responses. The effects of various geometrical characteristics, material parameters, and elastic foundation coefficients are investigated on the nonlinear static thermal buckling and dynamic thermal buckling behavior of the multilayer FGM system with an FGM porous core. The results show that the various types of porosity core, imperfection and the elastic foundation parameters have strongly effect on the thermal buckling behaviors of the multilayer FGM cylindrical shells with an FGM porous core.

References listed at the end of the paper:

ABSTRACT: An exact solution of a thermal shock for a circular cylinder is presented. A refined multi–dual–phase–lag generalized thermoelasticity model is proposed. The application of initial conditions without using Laplace transform is effected. The exact solutions of main physical fields are obtained analytically in the radial direction using the normal mode technique. For the case where the mechanical and thermal loads are applied on the inner and outer surfaces of the cylinder. Numerical results for the distributions of radial displacement, temperature, radial, hoop, and axial stresses are illustrated graphically. Extensive results are tabulated to show the accuracy of the present model. The results will also be used as benchmarks for forthcoming comparisons with other investigations. The results indicate that the effects of internal and external pressures and time are very pronounced.

References listed at the end of the paper:


ABSTRACT: Thermoelastic analysis of an isotropic homogeneous multi-stacked elliptical plate has been considered in this research. For which multi-layered plate is taken into consideration on a plane-parallel elliptic geometry perpendicular to the $z$-direction. The governing equations are considered in the context of time-fractional derivative of the order $\alpha$ with temperature distribution in each $s$ layer of the stacked plate with time-dependent sectional heat supply on the lower and upper face. The multi-stacked profile consists of $s$ discrete plates each of a different material with perfect thermal contact at each of its $s-1$ interface. The general solution, which perfectly satisfies the fundamental equation of heat conduction, is obtained using an integral transformation technique. It is solved using a type of quasi-orthogonality relationship by modifying Vodička’s method and the Laplace transformation. The analysis is based on the small-deflection theory corresponding to the fundamental solutions for the fractional-order heat conduction equation. In addition to this, the intensities of bending moments, forces, maximum normal stresses and its associated stresses are formulated involving the Mathieu functions. As a special case, a multi-stacked circular plate is also discussed in detail as a limiting case. Numerical calculations are also performed, and the results are graphically illustrated.

References listed at the end of the paper:


ABSTRACT: The current article is concerned with the investigation of the formation of the time-dependent three-dimensional distributions and redistributions of the stress and displacement fields of the rotating annular and circular plates/disks under the nonuniform distributions of the dynamic thermomechanical loads or shocks. Redistribution of the stress and displacement fields happens due to the Gerasimov-Caputo-type relaxation kernel of the fractional viscoelastic model of the material in addition to the dynamic nature of the loading. All the mechanical and thermal material properties of the plate or disk may be tailored in both radial and transverse directions. The 3D thermoviscoelasticity theory is employed to develop the governing equations of motion (3D vibration) and heat transfer. Different thermal and mechanical boundary conditions are implemented. The resulting nonlinear time-dependent fractional-order thermoviscoelastic integro-differential equations are solved by proposing and implementing a special algorithm that uses numerical evaluation of the singular-kernel Caputo-integral and second-order forward, backward, and central discretization of the spatial and time domains. Eventually, the influences of the bidirectional distribution of the material properties, 2D temperature distribution, fractional order and parameters of the viscoelasticity model, and thermomechanical boundary conditions are investigated on the distributions of the displacement and stress components rigorously and accompanied by 3D demonstrations.

References listed at the end of the paper:


ABSTRACT: Nowadays, a multilayered viscoelastic composite structure stands as one of the most representative active/passive vibration isolator and high-efficient damper to avoid unwanted vibrations in civil and ocean engineering, which is commonly applied in harsh non-uniform temperature environment (e.g., high heat-flux, drastic changes of temperature, etc.). In such a case, thermoviscoelastic response analysis is of great importance for the safety design of viscoelastic composites, and so a thorough and comprehensive study on this issue is imperatively needed. This work aims to conduct an analytical study of transient thermomechanical responses of multilayered viscoelastic composite structure under time-dependent heating loads. In the context of generalized thermoviscoelasticity theory with time-fractional order strain, a composite laminated viscoelastic plate is chosen as the analytical model while governing equations of each homogeneous layer accounting for non-idealized interfacial conditions are systematically formulated. Then, a semi-analytical approach via Laplace transform is adopted to deal with the problem. The effects of fractional order parameters and material constants’ ratio on the structural dynamic responses are fully discussed to provide new insights and basic guidelines for vibration control and thermal management of viscoelastic composites, especially for the surface coating at the interface between any two adjacent viscoelastic layers.

References listed at the end of the paper:


ABSTRACT: In this article, the constitutive relations and the governing equations are derived for nonlocal thermoelastic solid in the presence of diffusion. The free vibration of a thermoelastic diffusive cylinder is investigated within the framework of the above newly derived model. Time-harmonic vibration is used to transform the governing equations into a system of ordinary differential equations. The frequency equation is taken under investigation for the survival of a range of possible modes in compact form for traction-free thermal boundary conditions: thermally insulated and isothermal boundary conditions. To explore the vibration analysis from frequency equations, we apply a numerical iteration technique for generating numerical data by taking assistance of the Matlab software. The numerically computed and simulated results for the frequency shift,
natural frequency, and the thermoelastic damping are presented graphically. The effect of nonlocality on the above quantities is observed and shown graphically.

References listed at the end of the paper:


ABSTRACT: In the present study, thermoelastic analysis of laminated composite and sandwich shells (cylindrical/spherical) is presented using fifth-order shear and normal deformation theory. The significant characteristic of the present theory is that it includes the effects of both transverse shear and normal deformations. The mathematical formulation uses the principle of virtual work to derive the variationally consistent governing equations and fracture free boundary conditions. To obtain the static solution, these governing equations are solved by employing Navier's solution technique. The shell is subjected to a mechanical/thermal load sinusoidally distributed over the top surface of the shell. The thermal load linearly varies across the thickness of the shell. The present results are compared with other higher-order models and 3D elasticity solution wherever possible. Thermal stresses presented in this study will act as a benchmark for the future work.

References listed at the end of the paper:


ABSTRACT: Nonlinear vibration of nanobeams embedded in the linear and nonlinear elastic materials under magnetic and temperature effects is investigated in this study. Von Karman’s strain–displacement relation is applied to a nonlocal Euler–Bernoulli beam model. Equation of motion is derived using Hamilton’s principle. Galerkin’s method is applied to decompose the nonlinear partial differential equation into a nonlinear ordinary differential equation (NODE). The NODE is solved using He’s method. The nanobeams are embedded in the Winkler, Pasternak, and nonlinear elastic media. The effects of low and high temperatures, nonlinear parameter, magnetic force, amplitude, and linear and nonlinear elastic materials are examined.

References listed at the end of the paper:

By using Hamilton's principle, governing equations for motion and boundary conditions are derived. The constructed mathematical model is based on a nonlinear elastic foundation on a nonlinear elastic foundation. The homotopy perturbation method for nonlinear oscillators with discontinuities is done. Besides, the result is presented for silicon microbeam for different nonlocal Timoshenko beam theory for nonlinear vibrations of a nanobeam embedded in the Winkler–Pasternak foundations with general elastic boundary conditions, Smart Mater. Struct., vol. 25, no. 8, pp. 085005, 2016. DOI: 10.1088/0964-1726/25/8/085005.


ABSTRACT: An explicit formula of coupled three-phase-lag (TPL) thermoelasticity theory under the Timoshenko beam is constructed for microbeam resonators. The constructed mathematical model is based on the modified coupled stress theory which implies a prediction of size-dependent effects in microbeam resonators. By using Hamilton’s principle, governing equations for motion and boundary conditions are derived. The thermal moment and thermal deflection of microbeam resonators are studied analytically and numerically. A comparison of the results between modified coupled stress theory and classical theory is executed for TPL, GN-II, and Lord–Shulman (LS) models. Also, a comparison of the results between TPL, GN-II, and LS models for modified coupled stress theory is done. Besides, the result is presented for silicon microbeam for different aspect ratios and phase-lags. It demonstrated the result corresponding to the behavior of thermoelastic frequencies of microbeam resonators.

References listed at the end of the paper:


ABSTRACT: The response of a disk made from a heterogeneous material within the framework of Lord-Shulman theory is investigated in this article. The theory admits a single relaxation time to avoid the infinite speed of temperature wave. It is assumed that all of the thermomechanical properties except for Poisson ratio and thermal relaxation time vary exponentially through the radial direction of the disk. Two coupled equations, namely, the axisymmetric equation of motion and the energy equation are obtained for the disk. The energy equation is kept in the nonlinear form and the linear relaxation time vary exponentially through the radial direction of the disk. Two coupled equations, a system of nonlinear algebraic equations is established. Following the $\beta$–Newmark time marching method, the temporal evolution of radial displacement and temperature at the nodal points of the disk are obtained. Comparison study is given to assure the validity of the proposed solution method. After that, novel numerical results are given to discuss the effects of involved parameter. It is shown that, under the nonlinear analysis, the magnitudes of radial and hoop stresses and radial displacement are underestimated.

References listed at the end of the paper:

ABSTRACT: This article presents a numerical model based on shear deformation theory in conjunction with Eringen’s nonlocal theory to investigate the thermo-elastic vibration behavior of bi-directional functionally graded nonuniform thick nanobeams supported on Pasternak’s foundation. These beams are subjected to nonuniform temperature field along the thickness and uniform in-plane loading. Two directional variations in material properties are described by a power-law model across the thickness and as per the exponential function along the length. Employing Hamilton’s energy principle, the governing equations are derived and then solved for frequency parameter via the generalized differential quadrature method for clamped, simply-supported, and combination of both the boundary conditions. A parametric study is carried out for understanding the vibration characteristic of considered beams, which shows that the combination of in-plane and thermal loadings with the foundation parameter is the most critical combination for bi-directional functionally graded nanobeams. Results are compared with the published work and found in good accordance. The results will be of great use in designing aerospace shuttles and scanning probe microscopes where nonuniform embedded nanobeams are subjected to compression in the thermal environment.

References listed at the end of the paper:


More papers published in the journal, Applied Mathematical Modelling. (2019 and on)

Google the string, “Applied Mathematical Modelling”, then click on the entry, “Applied Mathematical Modelling | ScienceDirect.com” and scroll way down to “View all issues”


ABSTRACT: We present an explicit second order staggered finite difference (FD) discretization scheme for forward simulation of natural gas transport in pipeline networks. By construction, this discretization approach guarantees that the conservation of mass condition is satisfied exactly. The mathematical model is formulated in terms of density, pressure, and mass flux variables, and as a result permits the use of a general equation of state to define the relation between the gas density and pressure for a given temperature. In a single pipe, the model represents the dynamics of the density by propagation of a non-linear wave according to a variable wave speed. We derive compatibility conditions for linking domain boundary values to enable efficient, explicit simulation of gas flows propagating through a network with pressure changes created by gas compressors. We compare our staggered grid method with an explicit operator splitting method and a lumped element scheme, and perform numerical experiments to validate the convergence order of the new discretization approach. In addition, we perform several computations to investigate the influence of non-ideal equation of state models and temperature effects on pipeline simulations with boundary conditions on various time and space scales.


ABSTRACT: Thermoelastoc deflection and corresponding stresses of the pre-damaged layered panel structure are investigated numerically in this article including the large deformation kinematics under the linearly varying temperature field. The composite structural deformation kinematics is derived using two different polynomial type of kinematic theories including the through-thickness stretching effect. The inter-laminar separation between the adjacent layers is incurred via the sub-laminate approach and Green–Lagrange strain to count the total structural deformation. Also, the intermittent displacement continuity conditions are imposed in the current
mathematical model to establish the displacement continuity between the separated layers. The variational principle is adopted for the evaluation of the nonlinear structural equilibrium equations and solved via total Lagrangian approach. The convergence and the corresponding validity of the currently derived nonlinear finite element solutions are checked by solving different sets of numerical examples. Additionally, the comprehensive inferences are drawn from various numerical examples for the well-defined important input parameter including the size, position, and location of delamination.

References listed at the end of the paper:
2 W. Nowacki, Thermoelasticity, Addison-Wesley, Reading, MA (1962)
12 Han S.C., A. Tabiei, Park W.T., Geometrically nonlinear analysis of laminated composite thin shells using a modified first-order shear deformable element-based Lagrangian shell element, Compos. Struct., 82 (3) (2008), pp. 465-474
23 V. Baseri, G.S. Safari, R. Kolahchi, Analytical solution for buckling of embedded laminated plates based on higher order shear deformation plate theory, Steel Compos. Struct., 21 (4) (2016), pp. 883-919
42 A. Tafreshi, T. Oswald, Global buckling behaviour and local damage propagation in composite plates with embedded delaminations, Int. J. Press. Vessels Piping, 80 (2003), pp. 9-20
57 A. Kumar, R.P. Shrivastava, Free vibration of square laminates with delamination around a central cutout using HSDT, Compos. Struct., 70 (2005), pp. 317-333
58 M. Vladoslav, Mathematical Method and Models in Composite, College Press, Imperial (2013)

ABSTRACT: The exact series solutions of plates with general boundary conditions have been derived by using various methods such as Fourier series expansion, improved Fourier series method, improved superposition method and finite integral transform method. Although the procedures of the methods are different, they are all Fourier-series based analytical methods. In present study, the foregoing analytical methods are reviewed first. Then, an exact series solution of vibration of orthotropic thin plate with rotationally restrained edges is obtained by applying the method of finite integral transform. Although the method of finite integral transform has been applied for vibration analysis of orthotropic plates, the existing formulation requires of solving a highly non-linear equation and the accuracy of the corresponding numerical results can be questionable. For that reason, an alternative formulation was proposed to resolve the issue. The accuracy and convergence of the proposed method were studied by comparing the results with other exact solutions as well as approximate solutions. Discussions were made for the application of the method of finite integral transform for vibration analysis of orthotropic thin plates.

References listed at the end of the paper:
8 M.R. Khalili, K. Malekzadeh, R. Mittal, A new approach to static and dynamic analysis of composite plates with different boundary conditions, Compos. Struct., 69 (2) (2005), pp. 149-155
17 D.J. Gorman, Vibration Analysis of Plates by the Superposition Method, 3, World Scientific (1999)
19 K. Bhaskar, B. Kaushik, Simple and exact series solutions for flexure of orthotropic rectangular plates with any combination of clamped and simply supported edges, Comp. Struct., 63 (1) (2004), pp. 63-68
23 T.J. Jaramillo, Deflections and moments due to a concentrated load on a cantilever plate of infinite length, J. Appl. Mech. Trans. ASME, 17 (1) (1950), pp. 67-72
ABSTRACT: In this paper, buckling and free vibration behavior of a piezoelectric rotating cylindrical carbon nanotube reinforce (CNTRC) shell is investigated. Both cases of uniform distribution (UD) and FG distribution patterns of reinforcements are studied. The accuracy of the presented model is verified with previous studies and also with those obtained by Navier analytical method. The novelty of this study is investigating the effects of critical voltage and CNT reinforcement as well as satisfying various boundary conditions implemented on the piezoelectric rotating cylindrical CNTRC shell. The governing equations and boundary conditions have been developed using Hamilton's principle and are solved with the aid of Navier and generalized differential quadrature (GDQ) methods. In this research, the buckling phenomena in the piezoelectric rotating cylindrical CNTRC shell occur as the natural frequency is equal to zero. The results show that, various types of CNT reinforcement, length to radius ratio, external voltage, angular velocity, initial hoop tension and boundary conditions play important roles on critical voltage and natural frequency of piezoelectric rotating cylindrical CNTRC shell.

References listed at the end of the paper:

2 L.H. Donnell, A new theory for the buckling of thin cylinders under axial compression and bending, Trans. ASME, 56 (1934), pp. 795-806
12 G.H. Bryan, On the beats in the vibrations of a revolving cylinder or bell, Proceedings of the Cambridge Philosophical Society (1890), pp. 101-111
16 J. Padovan, Natural frequencies of rotating prestressed cylinders, J. Sound Vib., 31 (1973), pp. 469-482
22 S. Huang, H. Hsu, Resonant phenomena of a rotating cylindrical shell subjected to a harmonic moving load, J. Sound Vib., 136 (1990), pp. 215-228
33 X. Zhao, K. Liew, T. Ng, Vibrations of rotating cross-ply laminated circular cylindrical shells with stringer and ring stiffeners, Int. J. Solids Struct., 39 (2002), pp. 529-545
36 H. Li, K.-Y. Lam, T.-Y. Ng, Rotating Shell Dynamics, 50, Elsevier (2005)
ABSTRACT: A thick composite cylindrical shell panel with general layer stacking is studied to investigate the free edge and 3D stresses in the panel which is subjected to pure bending moment. To this aim, a Galerkin based layerwise formulation is presented to discretize the governing equation of the panel thick panel. The governing equations for thick panel are developed in terms of displacements and a set of coupled ordinary differential equations. Employing a reduced displacement field for the cylindrical panel, the governing equations with general layer stacking is studied to investigate the free edge and 3D stresses in the panel which is subjected to pure bending moment. To this aim, a Galerkin based layerwise formulation is presented to discretize the governing equation of the panel ordinary differential equations. Employing a reduced displacement field for the cylindrical panel, the governing equations for thick panel are developed in terms of displacements and a set of coupled ordinary differential equations is obtained. The governing equations are solved analytically for free edge boundary conditions and applied pure bending moment. The accuracy of numerical results is examined and the distribution of interlaminar and in-plane stresses is studied. The free edge stresses are studied and the effect of radius to thickness ratio, width to thickness ratio and layer stacking on the distribution of stresses is investigated. The focus of numerical results is on the prediction of boundary layer and free edge stress distribution.

References listed at the end of the paper:

1 T. Kant, K. Swaminathan, Estimation of transverse/interlaminar stresses in laminated composites—a selective review and survey of current developments, Compos. Struct., 49 (2000), pp. 65-75
12 S. Mistou, M. Karama, Edge effects on sandwich composite by analytical, finite element, and experimental approach, J. Sandw. Struct. and Mater., 6 (4) (2004), pp. 343-355
22 Isa Ahmadi, Edge stresses analysis in thick composite panels subjected to axial loading using layerwise formulation, Struct. Eng. Mech., 57 (4) (2016), pp. 733-762

ABSTRACT: This paper applies the asymptotic perturbation approach (APA) to obtain a simple analytical expression for the free vibration analysis of non-uniform and non-homogenous beams with different boundary conditions. A linear governing equation of non-uniform and non-homogeneous beams is obtained based on the Euler–Bernoulli beam theory. The perturbative theory is employed to derive an asymptotic solution of the natural frequency of the beam. Finally, numerical solutions based on the analytical method are illustrated, where the effect of a variable width ratio on the natural frequency is analyzed. To verify the accuracy of the present method, two examples, piezoelectric laminated trapezoidal beam and axially functionally graded tapered beam, are presented. The results are compared with those results obtained from the finite element method (FEM) simulation and the published literature, respectively, and a good agreement is observed for lower-order beam frequencies.

ABSTRACT: The work presented in this article is the outcome of a combined strategy of a mathematical tool for 2D cross-sectional analysis, i.e., Variational Asymptotic Method (VAM) as well as the 1D exact beam analyzer, i.e., the intrinsic mixed variational formulation for modeling and analysis of Piezoelectric-laminated composite beams. This work talks about a novel approach of mixed variational formulation to analyze a two-way electromechanically coupled piezoelectric composite beam. In a classical intrinsic mixed variational approach for a passive structure, the 1D exact beam model deals only with mechanical degrees of freedom. In the present case, an extra 1D electrical degree of freedom has been incorporated. A computational code is developed based on the present theory to solve the two-way coupled electromechanical beam problem. In the present case, we have validated the static results for sensor application. Both linear and nonlinear results have been discussed. Results obtained are very promising and are helpful in building a platform where design, optimization and nonlinear analysis of composite ‘smart’ beams in a multibody framework can be done faster while maintaining acceptable accuracy.


ABSTRACT: The present study examines the nonlinear stability and free vibration features of multilayer functionally graded graphene platelet-reinforced polymer composite (FG-GPLRPC) rectangular plates under compressive in-plane mechanical loads in pre/post buckling regimes. The GPL weight fractions layer-wisely vary across the lateral direction. Furthermore, GPLs are uniformly dispersed in the polymer matrix of each layer. The effective Young’s modulus of GPL-reinforced nanocomposite is assessed via the modified Halpin–Tsai technique, while the effective mass density and Poisson's ratio are attained by the rule of mixture. Taking the von Kármán-type nonlinearity into account for the large deflection of the FG-GPLRPC plate, as well as utilizing the variational differential quadrature (VDQ) method and Lagrange equation, the system of discretized coupled nonlinear equations of motions is directly achieved based upon a parabolic shear deformation plate theory; taking into account the impacts of geometric nonlinearity, in-plane loading, rotary inertia and transverse shear deformation. Afterwards, first, by neglecting the inertia terms, the pseudo-arc length approach is used in order to plot the equilibrium postbuckling path of FG-GPLRPC plates. Then, supposing a time-dependent disturbance about the postbuckling equilibrium status, the frequency responses of pre/post-buckled FG-GPLRC plate are obtained in terms of the compressive in-plane load. The influences of various vital design parameters are discussed through various parametric studies.

References listed at the end of the paper:
5 B.Z. Jang, A. Zhamu, Processing of nanographene platelets (NGPs) and NGP nanocomposites: a review, J. Mater. Sci., 43 (2008), pp. 5092-5101
10 N.D. Duc, P.H. Cong, N.D. Tuan, P. Tran, N. Van Thanh, Thermal and mechanical stability of functionally graded carbon nanotubes (FG CNT)-reinforced composite truncated conical shells surrounded by the elastic foundations, Thin Walled Struct., 115 (2017), pp. 300-310
35 Y. Wang, C. Feng, Z. Zhao, F. Lu, J. Yang, Torsional buckling of graphene platelets (GPLs) reinforced functionally graded cylindrical shell with cutout, Compos. Struct., 197 (2018), pp. 72-79
36 H. Wu, J. Yang, S. Kitipornchai, Dynamic instability of functionally graded multilayer graphene nanocomposite beams in thermal environment, Compos. Struct., 162 (2017), pp. 244-254
38 C. Feng, S. Kitipornchai, J. Yang, Nonlinear bending of polymer nanocomposite beams reinforced with non-uniformly distributed graphene platelets (GPLs), Compos. Part B Eng., 110 (2017), pp. 132-140
40 Z. Zhao, C. Feng, Y. Wang, J. Yang, Bending and vibration analysis of functionally graded trapezoidal nanocomposite plates reinforced with graphene nanoplatelets (GPLs), Compos. Struct., 180 (2017), pp. 799-808
41 B. Yang, J. Yang, S. Kitipornchai, Thermoelastic analysis of functionally graded graphene reinforced rectangular plates based on 3D elasticity, Meccanica, 52 (2017), pp. 2275-2292


ABSTRACT: A novel nondeterministic dynamic stability assessment of Euler–Bernoulli beams using Chebyshev surrogate model is proposed to investigate the upper and lower bounds of the dynamic buckling responses in this paper. In the proposed approach, the Galerkin method in conjunction with the force equilibrium is used to obtain the unified implicitly nonlinear ordinary differential equation (ODE) and then this equation can be transformed into a series of ODEs at observation points for each interval variable. Thus, the explicit approximate performance function is constructed with regards to all the interval variables by using Chebyshev surrogate strategy. By combining with the low-discrepancy sequences initialized high-order nonlinear particle swarm optimization (LHNPSO) algorithm, the computational cost is drastically reduced. The comprehensive computational method provides a unified analytical framework to model interval uncertainty for dynamic buckling analysis, which is competent to investigate the extremely upper and lower bounds of structural behaviors. Additionally, the validity, accuracy, as well as the applicability of the proposed computational approach are rigorously investigated by comparing the outputs (i.e., critical buckling load, time of onset of buckling, the corresponding axial shortening displacement and transverse displacement) of the proposed approach with that of Quasi–Monte–Carlo Simulation (QMCS) method for various boundary conditions with interval inputs (i.e., Young’s modulus, initial imperfections and loading velocity). The nondeterministic dynamic buckling assessment methodology can help optimization design of beam-type structures under time-dependent loads faster, efficient and flexible.

ABSTRACT: In this paper, we present an accurate three-dimensional formulation for the vibrations of the laminated and sandwich shallow shells. The sandwich structure is characterized by a thick viscoelastic core and two thin composite faces. Frequency dependent viscoelastic models are introduced in the sandwiches. Without any change in solution procedure, the formulation makes it quite easy to change the boundary conditions. The solution can be obtained by means of Rayleigh–Ritz process combined with the three-dimensional modified Fourier series which are actually assumed displacement functions. These functions, without need to meet the boundary conditions in advance, take the form of the three-dimensional Fourier series with several closed-form auxiliary functions which are supplemented to deal with the discontinuities at the boundaries in terms of displacements and its derivatives. Besides, only three assumed displacement variables are employed in the formulation which effectively reduces the computation cost. The reliability and accuracy of the method are demonstrated by numerical comparisons and examples with the constant viscoelastic models as well as the frequency dependent ones. Modal analysis and parametric studies are conducted to examine the influences of the boundary condition, dimension, lamination scheme, temperature and frequency dependence of the materials.


ABSTRACT: The vibration and stability of a simply supported beam are analyzed when the beam has an axially moving motion as well as a spinning motion. When a beam has spinning and axial motions, rotary inertia plays an important role on the lateral vibration. Compared to previous studies, the present study adopts the Rayleigh beam theory and derives more exact kinetic energy and equations of motion. The rotary inertia terms derived by the present study are compared to those of the previous studies. We investigate the natural frequencies between the present and previous studies. In addition, the critical speed and stability boundary for the spinning and moving speeds are also analyzed. It can be observed from the computed natural frequencies and dynamic responses that the present equations of motion are more reliable than the previous equations because the present equations fully consider the rotary inertia terms.


ABSTRACT: Free and forced vibration analysis of a Timoshenko beam on viscoelastic Pasternak foundation featuring coupling between flapwise bending and torsional vibrations is studied in this article. The system motion is described through a coupled set of three partial differential equations. The differential transform method, DTM, as an efficient mathematical technique is adopted to obtain the natural frequencies and the mode shapes. The system force response is assessed for a moving concentrated load with a constant velocity. Two different methods are studied and applied in obtaining forced vibration response of the system: (1) the same time functions, STF, by setting out the orthogonality conditions derived in this article and (2) the different time functions, DTF. The difference between the responses of the system is assessed by applying STF and DTF for a constant moving load. The effects of some parameters on the system response are probed. A numerical example is solved to validate the results obtained here with the available ones and a close agreement is found. It is observed that the time functions in DTF and STF are almost identical for transverse displacement and bending angle and are significant for torsion angle, recommending the application of DTF when the bending-torsion coupling is of concern.


ABSTRACT: A unified nonlocal strain gradient beam model with the thickness effect is developed to investigate the static bending behavior of micro/nano-scale porous beams. Size-dependent governing equations and corresponding analytical solutions for the bending of hinged-hinged beams are obtained by employing minimum total potential energy principle, the Navier solution method as well as the variational-consistent
boundary conditions. For nonlocal strain gradient theory (NSGT) with thickness effect, virtual strain energy function of shear beams can contain additional nonlocal shear stress and high-order nonlocal shear stress related to the thickness direction in comparison with that of Euler–Bernoulli beam, so the coupling of the shear and thickness effects should be drawn huge attention. By means of detailed numerical analysis, it is found that, the stiffness-hardening effect is underestimated in NSGT without the thickness effect, and the stiffness-hardening and stiffness-softening effects of NSGT with the thickness effect can be not only length-dependent but also thickness-dependent. Interestingly, the generalized Young’s modulus depends on half-wave number, which means that the generalized Young’s modulus may be different due to applied load types. In the context of NSGT with the thickness effect, the deflection of Euler–Bernoulli beam predicted is smaller than that of shear beam, especially for thick beams. Furthermore, porosities distributed in the top or bottom of beams can possess a greater influence on the decrease of overall stiffness of beam than those distributed in the vicinity of the middle plane of beams.


ABSTRACT: In this paper, a methodology is introduced to address the free vibration analysis of cracked plate subjected to a uniaxial inplane compressive load for the first time. The crack, assumed to be open and at the edge is modeled by a massless linear rotational spring. The governing differential equations are derived using the Mindlin theory, taking into account the effect of initial imperfection. The response is assumed to be consisting of static and dynamic parts. For the static part, differential equations are discretized using the differential quadrature element method and resulting nonlinear algebraic equations are solved by an arc-length strategy. Assuming small amplitude vibrations of the plate about its buckled state and exploiting the static solution in the linearized vibration equations, the dynamic equations are converted into a non-standard eigenvalue problem. Finally, natural frequencies and modal shapes of the cracked buckled plate are obtained by solving this eigenvalue problem. To ensure the validity of the suggested approach an experimental setup and a numerical finite element model have been made to analyze the vibration of a cracked square plate with simply supported boundary conditions. Also, several case-studies of cracked buckled plate problem have been solved utilizing the proposed method, and effects of selected parameters have been studied. The results show that the applied load and geometric imperfection as well as the position, size and depth of the crack have different impact on natural frequencies of the plate.


ABSTRACT: A mathematical model of the problem of nonlinear oscillations of a viscoelastic pipeline conveying fluid is developed in the paper. The Boltzmann–Volterra integral model with weakly singular kernels of heredity is used to describe the processes of pipeline strain. Using the Bubnov–Galerkin method, the mathematical model of the problem is reduced to the study of a system of ordinary integro-differential equations, where time is an independent variable. The solution of integro-differential equations is determined by a numerical method based on the elimination of the singularity in the relaxation kernel of the integral operator. Using the numerical method for unknowns, a system of algebraic equations is obtained. To solve a system of algebraic equations, the Gauss method is used. A computational algorithm is developed to solve the problems of the dynamics of viscoelastic pipelines with a flowing fluid. The algorithm of the proposed method makes it possible to investigate in detail the effect of rheological parameters on the character of vibrational strength of viscoelastic pipelines with a fluid flow, in particular, in the study of free oscillations of pipelines based on the theory of ideally elastic shells. On the basis of the computational algorithm developed, a set of applied computer programs has been created, which makes it possible to carry out numerical studies of pipeline oscillations. The influence of singularity in the heredity kernels and the geometric parameters of the pipeline on the vibrations of structures possessing viscoelastic properties is numerically investigated. It is shown that an account of viscoelastic properties of pipeline material leads decrease in the amplitude and frequency of oscillation. It is established that to reveal the influence of viscoelastic properties of structure material on the pipeline oscillations, it is necessary to use the Abel-type weakly singular kernels of heredity. The obtained
results of numerical simulation can be used in the enterprises of oil and gas industries, as well as in design organizations.


ABSTRACT: Many rectangular plate elements developed in the history of finite element method (FEM) have displayed excellent numerical properties, yet their applications have been limited due to inability to conform to the arbitrary geometry of plates and shells. Numerical manifold method (NMM), considered to be a generalization of FEM, can easily solve this issue by viewing a mesh made up of rectangular elements as mathematical cover. In this study, ACM element (Adini and Clough element from A. Adini, R.W. Clough, Analysis of plate bending by the finite element method, University of California, 1960), a typical rectangular plate element is first integrated in the framework of NMM. Then, vibration analysis of arbitrary shaped thin plates is conducted employing the tailored NMM. Using the definition of integral of scalar functions on manifolds, we developed a mathematically rigorous mass lumping scheme for creating a symmetric and positive definite lumped mass matrix that is easy to inverse. A series of numerical experiments have been studied and analyzed, including free and forced vibration of thin plates with various shapes, validating the proposed mass lumping scheme can supersede the consistent mass formulation in those cases.


ABSTRACT: The functionally graded material (FGM) has a potential to replace ordinary ones in engineering reality due to its superior thermal and dynamical characteristics. In this regard, the paper presents an effective approach for uncertain natural frequency analysis of composite beams with axially varying material properties. Rather than simply assuming the material model as a deterministic function, we further extend the FGM property as a random field, which is able to account for spatial variability in laboratory observations and in-field data. Due to the axially varying input uncertainty, natural frequencies of the stochastically FGM (S-FGM) beam become random variables. To this end, the Karhunen–Loève expansion is first introduced to represent the composite material random field as the summation of a finite number of random variables. Then, a generalized eigenvalue function is derived for stochastic natural frequency analysis of the composite beam. Once the mechanistic model is available, the brutal Monte-Carlo simulation (MCS) similar to the design of experiment can be used to estimate statistical characteristics of the uncertain natural frequency response. To alleviate the computational cost of the MCS method, a generalized polynomial chaos expansion model developed based on a rather small number of training samples is used to mimic the true natural frequency function. Case studies have demonstrated the effectiveness of the proposed approach for uncertain natural frequency analysis of functionally graded material beams with axially varying stochastic properties.


ABSTRACT: In this paper, size dependent free vibration, buckling and dynamic stability of bi-directional functionally graded (BDFG) microbeam embedded in elastic medium are investigated. The material properties vary along both thickness and axial directions. In particular, the material length scale parameter of microbeam is considered as a function of spatial coordinates and varies with the material gradient parameters. The system of differential equations with variable coefficients governing the motion of BDFG microbeam is derived employing Hamilton’s principle, the modified couple stress theory and third-order shear deformation beam theory. The differential quadrature method (DQM) is utilized to solve the static and dynamic problem. Three different models evaluating the material length scale parameter of BDFG microbeam are presented for comparison. Parametric studies are carried out to show the influence of gradient parameters, size effect, stiffness of elastic medium on the free vibration, buckling and dynamic stability characteristic of BDFG microbeam. Results show that the variation of material length scale parameter should be considered in the analysis of BDFG microbeam.

ABSTRACT: This paper aims to investigate the free vibrational analysis of the generally doubly-curved shells of revolution made of functionally graded (FG) materials and constrained with different boundary conditions by means of an efficient, convenient and explicit method based on the Haar wavelet discretization approach. The FG materials of the shell consist of a combination of ceramic and metal, which four parameter power-law distribution functions have chosen for modeling of the smoothly and gradually variation of the material properties in the thickness direction. The theoretical model of the shell is formulated by employing of the first-order shear deformation theory. The rotation and displacement components of each point of the shell are expanded in the form of product of the Haar wavelet series in meridional direction as well as trigonometric series in the circumferential direction. By adding the boundary condition equations to the main system of equations, the constants appeared from the integrating of the Haar wavelet series are satisfied. In addition, with solving the characteristic equation, the vibrational results including the natural frequencies and the corresponding mode shapes are achieved. Then, the present results have been compared with those available in the literature. The results indicate that this method has high accuracy, high reliability and also a higher convergence rate in attaining the frequencies of the FG doubly-curved shells of revolution. Also, the effects of the main parameters such as power-law exponent, geometrical parameters, material distribution profiles and different types of boundary conditions, on the vibrational behavior of the FG doubly-curved shells of revolution, are investigated. Finally, taking into account the effects of geometrical parameters and material distribution profiles, for FG doubly-curved shells of revolution with different boundary conditions such as classic, elastic restraints and their combination, a variety of new frequency studies are provided which can be considered as proof results for further researches in this field.


ABSTRACT: A mathematical model of the loss of dynamic stability of curvilinear size-dependent MEMS and NEMS elements embedded in a temperature field and subjected to large deflections was derived and studied. The fundamental governing dynamical equations of MEMS/NEMS members were yielded by Hamilton's principle. The investigations were based on combining the modified couple stress theory, the first-order approximation kinematic (Euler–Bernoulli) model, the von Kármán geometric non-linearity, and the Duhamel–Neumann law regarding the temperature input (the beam material is elastic, isotropic and there are no constraints imposed on the temperature distribution). The temperature field was defined by solving a heat transfer equation. The computational algorithm was based on the finite difference method and the Runge–Kutta method. The numerical methods were validated by estimating the temporal and spatial convergence and reliability of the obtained solution was validated with the Lyapunov exponents obtained by qualitatively different methods. A few case studies related to the loss of stability, the magnitude of the size-dependent parameter, the type and intensity of the temperature input, and the parameters of uniformly distributed transverse load were investigated.


ABSTRACT: The machining errors and the geometric imperfections are unavoidable, such as, local indentations, surface form error, flat curve form error and non-uniform thickness and so on. In this paper, a new vibration model for the rotating blade which is treated as a cantilever pre-twisted panel with initial exponential function type geometric imperfection is provided by using the shallow shell theory in which the torsion is considered but the two radii of curvatures are zero. Also, this mode involves the effect of the Coriolis and centrifugal force. It is assumed that the material of the pre-twisted curved panel is homogeneous and isotropic. Based on the Rayleigh–Ritz method and continuous algebraic polynomial functions satisfying the cantilever boundary conditions, the natural frequencies and mode shapes of perfect rotating pre-twisted curved panel and those with the initial geometric imperfection are computed. The validity of this model is verified by comparison with ANSYS results. A comprehensive study about the effects of the geometric parameters, imperfection size,
imperfection location and the concentration degree of it, pre-twisted angles, setting angle and rotational speeds of the pre-twisted curved panel on the free vibration is carried out. The problems of frequency veering, mode shape shift, internal resonance between modes and effect of dynamic stiffness can be found.


ABSTRACT: Based on the nonlocal strain gradient theory and surface elasticity theory, a unified size-dependent plate model is developed for buckling analysis of rectangular nanoplates. The developed model is capable of capturing nonlocal effect, strain gradient effect as well as surface energy effects simultaneously. Moreover, by selecting appropriate shape function, the present model can be reduced to not only Kirchhoff and Mindlin plate models but also various higher-order shear deformation plate models. The non-classical governing equations and associated boundary conditions are established by using the principle of minimum potential energy. Analytical solutions for critical buckling load of rectangular nanoplates under various boundary conditions are obtained. Verification of the proposed model is carried out by comparing the degenerated results with those reported in open literature. The effects of nonlocal parameter, material length scale parameter, geometric parameters, shear deformation and surface energy on the buckling behavior of rectangular nanoplates under different boundary conditions are discussed in detail. The numerical results show that the critical buckling load evaluated by nonlocal strain gradient theory is lower than that predicted by classical continuum theory when the nonlocal parameter is larger than the material length scale parameter, and is higher than that evaluated by classical continuum theory when the nonlocal parameter is smaller than the material length scale parameter. However, when taking surface effects into account, the critical buckling load is mainly affected by surface effects at large length-to-thickness ratio, and depends on the combined effects of nonlocality, strain gradient and surface energy at small length-to-thickness ratio.


ABSTRACT: The current paper proposes the formulation of beam elements using B-spline wavelet on the interval based wavelet finite element method by incorporating von Kármán nonlinear strains. Formulation is proposed for both Euler–Bernoulli beam theory and Timoshenko beam theory. A background cell based Gauss quadrature is proposed for numerical integration. Numerical examples are solved for transverse deflections and stresses in axial direction, and are compared with the existing converged results from finite element method. The issues of membrane and shear locking for the proposed elements are examined and solution techniques are suggested to overcome the issues.


ABSTRACT: In the present study, higher order shear and normal deformable plate theory is developed for analysis of incompressible functionally graded rectangular thick plates. Also, The effect of incompressibility is studied on the static, dynamic and stability responses of thick plate. It is assumed that plate is incompressible and the incompressibility condition is considered in addition to the governing equations for determining the unknowns. Since the plate is thick, higher order shear and normal deformable theory is applied so that the Legendre polynomials are used for expansion of displacement field components in the thickness direction. Also, it is supposed that material properties vary through the thickness based on the power law function. Utilizing the variational approach, governing equations for static, stability and dynamic analysis of plate are derived. Resulted equations are solved analytically for simply supported plates. Finally, the effects of material properties and dimensions on the response of incompressible plates are investigated in details.

F.L. Gao, Y.C. Bai, C. Lin and I.Y. Kim (Primarily from: National Engineering Laboratory for Electric Vehicles, School of Mechanical Engineering, Beijing Institute of Technology, Beijing 100081, China), “A time-

ABSTRACT: A time-space Kriging-based sequential metamodeling approach is proposed for multi-objective crashworthiness optimization (MOCO) in this paper. By defining the novel time-space design criteria, the constructed metamodels for the optimization objectives include the characteristic mechanical responses with respect to both the structural space domain and crash time domain, compared to standard metrics with the extremum of the time history of the entire structure. The adaptive addition of new samples is performed to gradually improve the approximation accuracy during the optimization with the guidance of an adaptive weighted sum method. The effectiveness of the proposed method is demonstrated by investigating a multi-cell thin-walled crashworthiness design problem. Finally, its effectiveness in practical engineering is validated by the crashworthiness design for a vehicle under full-overlap frontal crash loadcase.


ABSTRACT: A multiscale framework is developed for exploring tensile and compressive behaviors of single and multi-walled carbon nanotubes (CNTs). The multiscale approach is derived based on a molecular dynamic finite element method (MDFEM), in which new types of 2, 3 and 4-node MDFEM user elements are generated on the basis of force fields methodology. The bond stretch is modeled by 2-node MDFEM user element, and 3 and 4-node MDFEM user elements are used to describe bond bending and torsion with only bond angle and length needed. In this study, topological Stone–Wales (SW) defects with different positions and number are considered. Our results reveal that the ultimate tensile strengths are sensitive to CNT type, length and radius. Different type single-walled carbon nanotube (SWCNT) has different tensile failure configuration. The tensile failure configurations of multi-walled carbon nanotube (MWCNT) are individually different to each other. The Stone–Wales defect not only largely reduces the ultimate tensile strength, but also significantly affects the tensile failure configuration. The local buckling and postbuckling configurations of SWCNTs are sensitive to CNT charity, location and number of SW defects. Besides, the local buckling and postbuckling responses of different types of MWCNTs are also examined in details.

M. Zarepour, S.A.H. Hosseini and A.H. Akbarzadeh (First author is from: Department of Mechanical Engineering, Imam Khomeini International University, Qazvin, Iran and Department of Mechanical Engineering, Guilan University, Rasht, Iran), “Geometrically nonlinear analysis of Timoshenko piezoelectric nanobeams with flexoelectricity effect based on Eringen's differential model”, Applied Mathematical Modelling, Vol. 69, pp 563-582, May 2019, https://doi.org/10.1016/j.apm.2019.01.001

ABSTRACT: This study analyzes the nonlinear free vibration and post-buckling of nanobeams with flexoelectric effect based on Eringen's differential model. The nanobeam is modeled based on Timoshenko beam's theory. The von-Kármán strain–displacement relation together with the electrical Gibbs free energy and Hamilton's principle are employed to derive equations of motion. The nonlinear free vibration frequencies are obtained for pinned–pinned (P–P) and clamped–clamped (C–C) boundary conditions. Multiple scales method is employed to obtain the closed-form solution for the nonlinear governing equations. By employing this methodology, the natural frequencies of nanobeams are obtained and their post-buckling behavior is examined. The influence of nonlocal parameter, amplitude ratio, and input voltage on the top surface and flexoelectricity constant on nonlinear free vibration and post-buckling characteristics of nanobeam is investigated. In this paper, it is concluded that the flexoelectricity has a significant effect on free vibration of the beams in nano-scale and its effect has to be considered in designing nano-electro-mechanical systems (NEMS) such as nano-generators and nano-sensors.

Shasha Zhou, Rongmin Zhang, Shenjie Zhou and Anqing Li (Primarily from: School of Mechanical and Automotive Engineering, Qilu University of Technology (Shandong Academy of Sciences), Daxue Road 3501#, Jinan 250353, China), “Free vibration analysis of bilayered circular micro-plate including surface effects”, Applied Mathematical Modelling, Vol. 70, pp 54-66, June 2019, https://doi.org/10.1016/j.apm.2019.01.017
ABSTRACT: Based on the Kirchhoff plate theory and the continuum surface elasticity theory, a novel model of bilayered circular micro-plates including surface effects is developed. Furthermore, the governing equation is derived, and the Galerkin method is employed to obtain approximate results. The influence of surface effects on the natural frequency of bilayered circular micro-plate is investigated. Besides, the effect of residual stresses on the transition behavior of the bilayered circular micro-plate from plate to membrane is predicted. The results are compared with the single-layer model and the modified laminated plate model. It is found that the natural frequency predicted by the present model is obviously different from that of the existing models. For different thickness ratios, the natural frequency obtained by the new model will be larger or smaller than the results of the single-layer model. The transition region from plate to membrane is expanded for stiffened surface and reduced for softened surface. The results of the novel model can provide effective guidance for the design of bilayered circular micro-plate in MEMS devices.


ABSTRACT: The element free Galerkin (EFG) method has been successfully used for a wide variety of problems over the last few decades, but due to its high cost of computing, it is preferred to combine it with other methods having low computational costs such as the Finite Strip (FS) method. So, in this paper, a novel method is proposed by coupling EFG and classical FS methods for the static and buckling analysis of thin plates. The present method can have advantages of both EFG and classical FS methods. It is very easy to implement, and essential boundary conditions are easily enforced in FS sub-domain. The EFG method is based on the moving least-squares (MLS) approach. Therefore, the shape function does not have the Kronecker delta function property. In order to satisfy the combined conditions of displacement compatibility, a modified variational form is used based on the Lagrange multiplier method. In the FS sub-domain, three angular functions are used to approximate displacement field in the longitudinal direction of each strip. Finally, numerical examples are presented with different boundary conditions to demonstrate the effectiveness of the present coupling method.

Zhicheng Yang, Yonghui Huang, Airong Liu, Jiyang Fu and Di Wu (Guangzhou University-Tamkang University Joint Research Center for Engineering Structure Disaster Prevention and Control, Guangzhou University, Guangzhou 510006, China), “Nonlinear in-plane buckling of fixed shallow functionally graded graphene reinforced composite arches subjected to mechanical and thermal loading”, Applied Mathematical Modelling, Vol. 70, pp 315-327, June 2019, https://doi.org/10.1016/j.apm.2019.01.024

ABSTRACT: The nonlinear in-plane buckling analysis for fixed shallow functionally graded (FG) graphene reinforced composite arches which are subjected to uniform radial load and temperature field is presented in this paper. The arch is composed of multiple graphene platelet reinforced composite (GPLRC) layers with gradient changes of concentration of graphene platelets (GPLs) in each layer. The principle of virtual work, combined with the effective materials properties estimated by the Halpin-Tsai micromechanics model for GPLRC layer, is used to derive the nonlinear buckling equilibrium equations of the FG-GPLRC arch, and then the analytical solutions for the limit point and bifurcation buckling loads are obtained. Comprehensive parametric studies are conducted to explore the effects of various distribution patterns and geometries of GPL, temperature field and arch geometry on the nonlinear equilibrium path and buckling behavior of the composite arch. The influence of temperature on the geometric parameters which are defined as switches between limit point buckling, bifurcation buckling and no buckling are also discussed. It is found that a higher temperature field can increase the buckling loads of the FG-GPLRC arch but reduce the value of the minimum geometric parameters that switching the buckling modes. The results also show that even a small amount of GPLs filler content can increase the buckling loads of the FG-GPLRC arch considerably, and distributing more GPLs near the surface layers is the best pattern to enhance the buckling performances of FG-GPLRC arches.

ABSTRACT: The aim of this study is to present an efficient model for the analysis of complicated nonlinear transient dynamics of an elastic-plastic plate subjected to a transversely eccentric low-velocity impact. A mixed numerical–analytical model is presented to predict the transient dynamic behaviours consisting of either plate impact responses or wave propagations induced by the impact in a plate with an arbitrary shape and support. This hybrid approach has been validated by comparison with results of laboratory tests performed on an elastic-perfectly plastic narrow plate eccentrically struck by an elastic sphere, and results of a three-dimensional finite element (FE) analysis for an elastic-perfectly plastic simply-supported rectangular plate eccentrically struck by an elastic sphere. The advantages of this hybrid approach are in the simplification of local contact force formulation, computational efficiency over the FE model, and convenient application to parametric study for eccentric impact behaviour. The hybrid approach can provide accurate predictions of the plate impact responses and plate wave propagations.


ABSTRACT: Present research deals with the thermal buckling and post-buckling analysis of the geometrically imperfect functionally graded tubes on nonlinear elastic foundation. Imperfect FGM tube with immovable clamped–clamped end conditions is subjected to thermal environments. Tube under different types of thermal loads, such as heat conduction, linear temperature change, and uniform temperature rise is analyzed. Material properties of the FGM tube are assumed to be temperature dependent and are distributed through the radial direction. Displacement field satisfies the tangential traction free boundary conditions on the inner and outer surfaces of the FGM tube. The nonlinear governing equations of the FGM tube are obtained by means of the virtual displacement principle. The equilibrium equations are based on the nonlinear von Kármán assumption and higher order shear deformation circular tube theory. These coupled differential equations are solved using the two-step perturbation method. Approximate solutions are provided to estimate the thermal post-buckling response of the perfect/imperfect FGM tube as explicit functions of the various thermal loads. Numerical results are provided to explore the effects of different geometrical parameters of the FGM tube subjected to different types of thermal loads. The effects of power law index, springs stiffness of elastic foundation, and geometrical imperfection parameter of tube are also included.


ABSTRACT: This paper deals with the linear free vibration analysis of Bernoulli–Euler and Rayleigh curved beams using isogeometric approach. The geometry of the beam as well as the displacement field are defined using the NURBS basis functions which present the basic concept of the isogeometric analysis. A novel approach based on the fundamental relations of the differential geometry and Cauchy continuum beam model is presented and applied to derive the stiffness and consistent mass matrices of the corresponding spatial curved beam element. In the Bernoulli–Euler beam element only translational and torsional inertia are taken into account, while the Rayleigh beam element takes all inertial terms into consideration. Due to their formulation, isogeometric beam elements can be used for the dynamic analysis of spatial curved beams. Several illustrative examples have been chosen in order to check the convergence and accuracy of the proposed method. The results have been compared with the available data from the literature as well as with the finite element solutions.


ABSTRACT: In this paper, a new formulation based on the variational iteration method (VIM) is applied to investigate the dynamic behavior and stability of a multi-span pipe conveying fluid. Transfer matrix method (TMM) is used to assemble the system of equations resulting from applying the boundary conditions. The
natural frequencies of the pipe system are obtained for different flow velocities. Results from VIM are compared with those predicted by the exact solution method and also with published literature. The influence of the number of spans on the VIM convergence is investigated. Also, the effects induced by varying the value and location of an intermediate elastic support on the critical velocity and stability are studied. It is shown that using VIM yields highly accurate results that are in very well agreement with the exact solution. The main advantage of the VIM is that it successfully overcomes well-known computational difficulties that are usually encountered during complex root finding step maintaining high precision as well.


ABSTRACT: In this paper, we study the vibration of an axially moving hyperelastic beam under simply supported condition. The kinematic of the axially moving beam have been described by Eulerian-Lagrangian formulation. In continuum mechanics frame, the finite deformation formula and a higher order shear deformation beam theory are applied to describe the deformation of the axially moving hyperelastic beam. In these formulas the material parameter, shear deformation and the geometric non-linearity have been taken into account. Through the Hamilton principle, the governing equations of nonlinear vibration are obtained, where the transverse vibration is coupled with the longitudinal vibration. When the velocity is a constant, the critical speed and natural frequencies are determined by solving the corresponding linear equations. Meantime, effects of the geometrical and material parameters on the critical speed and natural frequencies have been investigated. Comparisons among the critical velocities of the hyperelastic and Euler linear beam are also made. The results show that the critical velocity of hyperelastic beam is larger than that of linear Euler–Bernoulli beam. For the natural frequencies, we have the same conclusions. Lastly, by the multiple scales method, the leading order analytical solutions of the equilibrium state of axially moving hyperelastic beam in the supercritical regime are obtained. Furthermore the amplitudes of analytical solutions of the hyperelastic beam have been compared with that of linear Euler–Bernoulli beam. The effects of the material and geometrical parameters on the asymptotic solutions and the amplitude has been analyzed.


ABSTRACT: This paper presents an analytical study that predicts the low-velocity impact response of a spinning functionally graded (FG) graphene reinforced cylindrical shell subjected to impact, external axial and thermal loads. The nanocomposite cylindrical shell is constructed based on a multiplayer model with graphene platelet (GPL) nanofillers whose weight fraction is constant in each concentric cylindrical layer but follows a layer-wise variation in the thickness direction, resulting in the position-dependent elastic moduli, mass density, Poisson's ratio and thermal expansion coefficient through the shell thickness. With effects of the thermal expansion deformation, external axial loads, centrifugal and Coriolis forces as well as the spin-induced initial hoop tension taken into account, the natural frequency of the cylindrical shell is derived on the base of differential equations of motion which are established according to the Donnell's nonlinear shell theory and the Hamilton's principle. The time-dependent contact force between a foreign impactor and the cylindrical shell is calculated by adopting a single spring-mass model. In addition, on the base of the other second-order differential equation, time-dependent displacements and strains are obtained by using the Duhamel integration. In numerical analyses, validation examples are carried out to verify the present solution, and then comprehensive parametric investigations are given to study effects of the GPL weight fraction, dispersion patterns, spinning speeds, temperature variations, geometrical sizes of the shell, the external axial load, radius of the impactor and the impact velocity on the contact force, contact duration and time histories of displacements and strains of the nanocomposite cylindrical shell.

G.G. Sheng and X. Wang (First author is from: School of Civil Engineering, Changsha University of Science and Technology, Changsha, Hunan 410114, People's Republic of China), “Nonlinear forced vibration of size-

ABSTRACT: The nonlinear dynamics of functionally graded (FG) microbeams have been studied based on the von Kármán nonlinear theory, the modified couple stress and Euler–Bernoulli beam theories. The internal damping of materials is taken into account using the Kelvin–Voigt model. The coupled nonlinear mode equations of FG microbeams are obtained using Hamilton's principle and Galerkin's method. The primary resonance and internal resonance are investigated by means of the method of multiple scales and the Runge–Kutta numerical method. The effects of the length scale parameter, volume fraction exponent and internal damping constant on the nonlinear vibration are discussed using the numerical simulation. The numerical results show that periodic, period-n, and chaotic oscillations can be displayed by changing the length scale parameter, volume fraction exponent and internal damping constant. Boundary conditions can also change the nonlinear vibration behavior of FG microbeams. In the present study, the second natural frequency is approximately equal to three times the first one for the FG clamped–clamped microbeam, and a three-to-one internal resonance is detected using the time response curves. The present analysis is validated by comparing the numerical results with existing results and very good agreement is obtained.


ABSTRACT: Cylindrical bending is studied by developing a new zigzag theory which relaxes the zero transverse shear stress condition on the outer surfaces of the panels subjected to transversely applied electromechanical load. The mechanical portion of the transverse displacement approximation in this new shear deformation theory is considered constant as well as non-constant through the development of three models. Unlike the existing zigzag theories which enforce the condition of vanishing transverse shear stresses on outer surfaces of laminates, these new theories relax it. Though the number of primary mechanical variables get increased by four or five or six, the computational cost does not increase appreciably. Approximating the electric potential in each piezoelectric layer as sublayerswise linear, variational principle is applied in deriving equilibrium equations and boundary conditions. Accuracy of the new base model as well as two augmented models is assessed by comparing with elasticity and piezoelasticity solutions. While it is observed that the new base model is highly accurate than the existing zigzag model, the two augmented models do not aid in its further improvement. This is attributed to the fact that layerwise consideration of the transverse displacement, not global consideration, is needed to correctly establish the effect of transverse normal deformation in the laminated composite and smart panel.

Sundaramoorthy Rajasekaran and Hossein Bakhshi Khaniki (First author is visiting professor at: Civil Engineering, PSG College of Technology, Coimbatore 641004, Tamil Nadu, India), “Size-dependent forced vibration of non-uniform bi-directional functionally graded beams embedded in variable elastic environment carrying a moving harmonic mass”, Applied Mathematical Modelling, Vol. 72, pp 129-154, August 2019, https://doi.org/10.1016/j.apm.2019.03.021

ABSTRACT: In this study, general non-uniform material-varying micro-beam models under a moving harmonic load/mass are investigated. Material variation is modeled by combining axial and thickness material grading models using exponential, linear, parabolic and sigmoidal functions. Beam is assumed to be resting on an elastic foundation and in this linear foundation model, foundation modulus is assumed to vary axially with respect to space variable in a non-linear manner ignoring the effect of mass density of foundation on the behavior of micro-beam. Cross-section variation through the length is formulated for both thickness and width variation. Governing equations for such comprehensive beam model is achieved using Hamilton's principle in conjunction with modified couple stress theory to add the scale-effects and solved by discussing explicit and implicit finite element methods with using various-steps and Wilson-theta method. Current methodology is verified using previous studies on simplified problems. A comprehensive parametric study is presented in order to indicate the influence of each design, material and fundamental terms on the forced vibration behavior of such structures under a moving harmonic/constant load/mass. It is shown that by appropriately choosing the material variation in bidirectional functionally graded beams dynamic vibration behavior of such structures
could change significantly. Moreover, it is shown that varying cross-section, elastic foundation and type of harmonic moving mass can change the dynamic reaction of the general micro-beam model. From the influence of modified couple stress term on mechanical behavior of such structures it is concluded that this term has crucial effect in varying the dynamic deflections and it is important to acknowledge it in analyzing such structures.


ABSTRACT: Isogeometric analysis (IGA) with the polynomial splines over hierarchical T-meshes (PHT-splines) is used to provide an efficient tool capable of carrying out the vibration and buckling analyses of the stiffened laminates. IGA offers increased accuracy and efficiency using the PHT-splines, which represent exact geometry of the stiffeners and make the refinement more flexible near the areas where the stiffeners and composite plate are connected. Numerical examples are given to validate the correctness and superiority of the present method, comparing with the results from existing literatures and commercial softwares. Besides, the influences of the orientation, curvature, location and cross-section size of the stiffeners on the natural frequencies and buckling loads are also studied. The results show that the optimization of the shape and size of the stiffeners has an important effect on the vibration and buckling characteristics of stiffened laminates.


ABSTRACT: This paper analytically addresses the sound transmission loss (STL) performance of finite triple-wall sandwich panels lined with poroelastic materials and clamp mounted on an infinite rigid baffle in the presence of an external mean flow. The wave propagation in poroelastic media is addressed using Biot's theory. The coupling methods between the poroelastic core and facing plates are associated with different boundary conditions and various panel configurations. The Galerkin method and the modal superposition theory are used to deal with the clamped boundary conditions and finite extensions as well as to transfer the integral function to a matrix equation. The analytical model is verified by comparing to previous results of infinite triple-wall sandwich panels and finite triple-wall panels without poroelastic materials. The numerical results show that the triple-wall panels have superior STL to their double-wall counterparts due to the existence of an additional partition. The finite dimensions of the triple-wall sandwich panels with clamped boundary strongly influence the STL at low frequencies, and this effect is coupled with that of the external mean flow. The air layer plays a critical role in the sound insulation properties that vary among different panel configurations, and the configurations with two air layers exhibit the optimal overall sound insulation performance.


ABSTRACT: The Neumann series method has been used for the first time to solve the boundary value problem of free axisymmetric and nonaxisymmetric vibrations of continuous and discrete-continuous functionally graded circular plate on the basis of the classical plate theory. The equation of motion and the general solution for a functionally graded circular plate with a very complex system of a discrete elements attached, such as concentric ring masses, elastic supports, rotational springs, and damping elements are presented for the first time. The particular continuous solutions to the defined differential equations are obtained as the Neumann power series rapidly, absolutely, and uniformly convergent to the exact eigenfrequencies for any physically justified values of the plate’s parameters on the basis of the properties of the obtained closed-form kernels of the Volterra integral equations. The multiparametric nonlinear characteristic equations for plate with classical and nonclassical boundary conditions are defined and numerically solved to obtain the full spectrum of eigenfrequencies in a simple way. The effects of the position and stiffness of ring supports and of singularities as the radii of supports shrink to the center of the plate on the dimensionless eigenfrequencies of homogeneous
and functionally graded circular plate with sliding support and elastic constraints are comprehensively studied and presented for the first time. The accuracy of the proposed low-computational-cost method is demonstrated by comparison of the numerical results with those available in the literature.


ABSTRACT: Dynamic instability of cantilever carbon nanotubes conveying fluid embedded in viscoelastic foundation under a partially distributed tangential force is investigated based on nonlocal elasticity theory and Euler–Bernoulli beam theory. The present study has incorporated the effects of nonlocal parameter, Knudsen number, surface effects and magnetic field. And two main parameters have also considered, namely partially distributed tangential force and foundation. It is assumed that viscoelastic foundation has modeled as Kelvin–Voigt, Maxwell and Standard linear solid types. The size-dependent governing equation of transverse vibration is derived using Hamilton’s variational principle and discretized by the Galerkin truncation method. A detailed parameter study is carried out, indicating the stability behavior of the nanotubes. In the light of numerical results, it is shown that variables considered in nondimensional equations have significant effects on natural frequencies and flutter velocities, especially for the foundation distribution length and model as well as the partially distributed tangential force.


ABSTRACT: This paper aims to investigate linear and nonlinear behavior of beams subjected to externally applied partially distributed follower forces. In this investigation, the nonlinear composite beam theory of Hodges is used. The system of nonlinear equations is linearized about the equilibrium, or rest structure state, and the linear system is solved numerically. The effects of follower force position on the behavior of eigenvalues at pre- and post-instability are reported. Additionally, the contours of critical follower force are obtained by changing the position of follower force in span-wise and chord-wise directions. The effects of different parameters such as the length, and position of follower force and the ratios of stiffnesses on the critical follower force as well as the nonlinear limit cycle oscillation (LCO) are reported. The obtained results indicate that the length and the position of the partially distributed follower forces considerably affect the stability of the beam.


ABSTRACT: The present paper promotes the capabilities of the Ritz method in accurately predicting the stress intensity factor of cracked plates with either continuously or discretely attached stiffeners. The original plate domain is initially treated as an assembly of a small number of disjoint subdomains, chosen according to the crack and stiffener locations, in order to properly construct Ritz bases accounting for discontinuities. A complete set of hierarchic polynomials is adopted to locally approximate the displacement field within each subdomain, and then the displacement continuity is exactly imposed between subdomains whenever required. The accuracy of the present solutions are confirmed through comparison with published data, when available, and with converged results obtained from developed finite element models. The proposed procedure is further employed to investigate the effect that a propagating crack has on the stress intensity factor as the crack approaches and crosses a stiffener.

ABSTRACT: Using Eringen's nonlocal theory, a fractional dynamic analysis of a simply supported viscoelastic nanobeam is presented. The existence of a significant internal damping for the viscoelastic nanostructures led to the choice of a Zener model to obtain the governing equation. The solving of this is made with the help of an algorithm based on the Laplace transform, Bessel functions theory and the binominal series. The graphical representations show how the existence of the fractional derivative in the selected rheological influence the local and nonlocal dynamic response of a single-walled carbon nanotube (SWCNT). The validation study was performed by comparing the numerical results with the corresponding ones existing in the literature.


ABSTRACT: In this work, a three characteristic-lengths featured size-dependent gradient-beam is constructed by adopting the modified nonlocal model, resulting in much more general constitutive equation with stress gradient up to four-order and strain gradient to two-order. The six-order differential governing equation for transverse displacement is formulated. All boundary conditions especially variational consistent higher order boundary conditions of the present model are derived with the aid of weighted residual approach. The closed-form solutions to critical buckling loads under different sets of boundary conditions are systematically formulated with higher order boundary conditions incorporated. The numerical results show that both nonlocal parameters have significant effect on the buckling behaviors. Meanwhile, if two nonlocal parameters are taken as same, the present results cannot always reduce to that from Eringen's nonlocal model. Due to its clear physical meaning, the present model is expected to be widely adopted in mechanical analyses of nanostructures.


ABSTRACT: This paper presents a new and simple approach for vibration analysis of in-plane functionally graded (IPFG) plates with variable thickness based on the Chebyshev spectral method. Both the material properties and the thickness which vary in the plane of the plate are approximated by high-order Chebyshev expansions. Gauss-Lobatto sampling is adopted for spatial discretization. A consistent governing equation in discrete form is derived by utilizing Lagrange’s equation for all kinds of IPFG plates whose material property functions and thickness function are square-integrable and infinitely differentiable in the domain. Its mass matrix is diagonal and stiffness matrix is symmetric. Classical and point-supported boundary conditions are incorporated through projection matrices. This approach is independent of the type of material gradation, meshfree, and flexible to adjust the computation cost and precision according to needs. A series of numerical examples involving different kinds of material gradations, thickness variations, and boundary conditions are carried out to demonstrate the validity of the proposed method. The results obtained from the present method show a good convergence and agree with those in literature very well.


ABSTRACT: In this paper, the interlaminar stresses of generally laminated piezoelectric (PZT) plates are presented. The electromechanical coupling effect of the piezoelectric plate is considered and the governing equations and boundary conditions are derived using the principle of minimum total potential energy. The solution procedure is a three-dimensional multi-term extended Kantorovich method (3DMTEKM). The objective of this paper is to study coupling influence on the edge effects of piezolaminated plates with finite dimensions and arbitrary lay-ups under uniform axial strain. These results can provide a benchmark for checking the accuracy of the other numerical methods or two-dimensional laminate theories. To verify the accuracy of the 3DMTEKM, special cases such as cross-ply or symmetric laminates are investigated and the results are compared with other analytical solutions available in the literature. Excellent agreement is achieved and then other numerical results are presented for general cases. Numerical examples imply on the singular behavior of interlaminar normal/shear stresses and electric field strength components near the edges of the
piezolaminated plates. The coupling influence on the free edge effect with respect to the lay-ups of piezoelectric plate is studied in several examples.


ABSTRACT: In this study, we employ Pascal polynomial basis in the two-dimensional Berger equation, which is a fourth order partial differential equation with applications to thin elastic plates. The polynomial approximation method based on Pascal polynomial basis can be readily adapted to obtain the numerical solutions of partial differential equations. However, a drawback with the polynomial basis is that the resulting coefficient matrix for the problem considered may be ill-conditioned. Due to this ill-conditioned behavior, we use a multiple-scale Pascal polynomial method for the Berger equation. The ill-conditioned numbers can be mitigated using this approach. Multiple scales are established automatically by selecting the collocation points in the multiple-scale Pascal polynomial method. This method is also a meshless method because there is no requirement to establish complex grids or for numerical integration. We present the solutions of six linear and nonlinear benchmark problems obtained with the proposed method on complexly shaped domains. The results obtained demonstrate the accuracy and effectiveness of the proposed method, as well showing its stability against large noise effects.


ABSTRACT: This article presented a new reformulation of vibration suppression equations of functionally graded magnetorheological fluid (FGMRF) sandwich beams using new auxiliary functions. This technique led to the decoupled vibration equations of the FGMRF sandwich beams and also to the analytical solutions for the in-plane and out of plane displacement fields by considering the Euler-Bernoulli beam theory (EBBT). The material properties of top and bottom layers were changed through the layer thickness according to a power-law distribution of the volume fraction of the constituents. Complex shear modulus of the magnetorheological fluid was varied continuously as a quadratic function of magnetic field intensity. Natural frequencies and corresponding loss factors were calculated with high accuracy in comparison with those available in literature. The effects of boundary conditions, geometric and material properties and the magnetic field intensity on vibrational modes were investigated. Results revealed that unlike the natural frequencies, the loss factors were more affected by the magnetic field.


ABSTRACT: In this article the “most unfavorable” shape of initial geometric imperfection profile for laminated cylindrical shell panel is obtained analytically by minimizing the limit point load. The partial differential equations governing the shell stability problem are reduced to a set of non-linear algebraic equations using Galerkin's technique. The non-linear equilibrium path is traced by employing Newton–Raphson method in conjunction with the Riks approach. A double Fourier series is used to represent the initial geometric imperfection profile for the cylindrical shell panel. The optimum values of these Fourier coefficients are determined by minimizing the limit point load using genetic algorithm. The results are determined for simply supported composite cylindrical shell panel. Numerical results show that more number of terms is needed in Fourier series representation to obtain the “worst” geometric imperfection profile which gives lower limit load compared to single term representation of imperfection. We have incorporated constraints on the shape of imperfection to avoid unrealistic limit point loads (due to imperfection shape) as we have assumed that the imperfection is due to machining/manufacturing.

ABSTRACT: A scale-dependent model of nanobeams with large deformations is developed to investigate the influences of a geometric imperfection on the chaotic response of nanotubes. In order to comprehensively simulate the effects of being at nanoscales, a nonlocal strain gradient theory (NSGT) is utilised. To model a geometric imperfection, an initial deflection is taken into account for the nanosystem. Since the relative motion between the nanofluid and nanotube at the interface is not negligible, Karniadakis–Beskok assumptions are employed to incorporate the effects of this relative motion. Utilising an energy-work balance technique, the nonlinear governing equations are derived for the coupled motion of the nanofluid-conveying NSGT nanotube. Finally, the influences of the geometric imperfection on the motion response are analysed using a direct-time-integration approach and a Galerkin scheme.

Canan Liu, Jiangong Yu, Bo Zhang, Xiaoming Zhang, “Reflection and transmission of elastic waves in the multilayered orthotropic couple-stressed plates sandwiched between two elastic half-spaces”, Applied Mathematical Modelling, Vol. 75, pp 52-72, November 2019, https://doi.org/10.1016/j.apm.2019.05.023

ABSTRACT: In this paper, a high efficient computational approach, the extended Legendre orthogonal polynomial method (LOPM) is provided to investigate the reflection and transmission of elastic waves in orthotropic couple-stress layered plates sandwiched between two elastic half-spaces. In this approach, the anisotropic couple-stress theory is introduced into the LOPM to calculate the reflection and transmission coefficients of the orthotropic interlayers. The stress components, couple-stress components, rotation vectors and governing equations are derived in terms of the Legendre orthogonal polynomial. The present method does not require calculations of the displacement solutions of each partial wave in anisotropic multilayered microstructures, but expands the displacement vector of each layer into a Legendre orthogonal polynomial series with the expansion coefficients to be calculated. The incident P wave and SH wave are calculated, respectively. The effects of length scale parameters in three different directions are studied. It is found that the reflection and transmission coefficients of the incident P wave are only related to the length scale parameter in the z direction. For incident SH wave, the influence of the length scale parameter along the thickness direction is much more significant than that of the length scale parameter in the y direction.


ABSTRACT: This paper presents a unified model to analyze the free vibration and buckling of axially functionally graded Euler-Bernoulli columns subjected to an axial compressive force. The material properties vary linearly along the longitudinal direction, and column with circular and square cross sections is linearly tapered. The governing differential equations of the problem are derived and solved using the direct integral method combined with the determinant search technique. The computed results are compared with those reported in the literature and obtained from the finite element software ADINA. Numerical examples for natural frequency, buckling load and their corresponding mode shapes are given to highlight the effects of modular ratio, taper ratio and cross sectional shape as well as the end condition.


ABSTRACT: Integrating engineering structures with piezoelectric layers as actuator and/or sensor offers smart sandwich structures with controllable static and dynamic deflections. In this paper, a smart sandwich plate consisting of a light nanoclay-reinforced composite core and two piezoelectric face sheets is considered. The static and dynamic behaviors of the proposed smart plate are obtained using their governing coupled electromechanical system of equations. In order to facilitate the governing equations, a mesh-free method based on moving least square (MLS) shape function and first order shear deformation (FSDT) is developed and implemented. Two morphologies of intercalated stack and exfoliated nanoclay dispersions are considered in the distribution of the nanoclay into the polymeric matrix. The effects of morphology and volume fraction of the nanoclay, time-dependent loading, and essential boundary condition on the static and dynamic behavior of the smart piezoelectric-integrated nanocomposite plates are examined. In the dynamic analysis, resonance and amplitude modulation phenomena are studied. It is observed that the use of nanoclay, especially with exfoliated morphology, improves the static and the free vibration responses of the smart sandwich plates. Moreover, the
frequency of the applied mechanical load has a significant effect on the electro-dynamic response of the proposed smart sandwich plates.


ABSTRACT: In this paper, nonlinear dynamics, vibration and stability analysis of piezo-visco medium nanoshell resonator (PVM-NSR) based on functionally graded (FG) cylindrical nanoshell integrated with two piezoelectric layers subjected to visco-pasternak medium, electrostatic and harmonic excitations is investigated. Nonclassical method of the electro-elastic Gurtin–Murdoch surface/interface theory with von-Karman-Donnell's shell model as well as Hamilton's principle, the assumed mode method combined with Lagrange–Euler's are considered. Complex averaging method combined with arc-length continuation is used to achieve a numerical solution for the steady state vibrations of the system. The stability analysis of the steady state response is performed. The parametric studies such as the effects of different boundary conditions, different geometric ratios, structural parameters, electrostatic and harmonic excitation on the nonlinear frequency response and stability analysis are studied. The results indicate that near the natural frequency of the nanoshell, it will lead to resonance and will have large motion amplitude and near the resonant frequency, the nanoshell shows a softening type of nonlinear behavior, and the nanoshell bandwidth increases due to nonlinear factors. In this range, nanoshell has three different ranges of motion, of which two are stable and the other unstable, and so the jump phenomenon and saddle-node bifurcation are visible in the behavior of the system. Also piezoelectric voltage influences on static deformation and resonant frequency but has no significant effect on nonlinear behavior and bandwidth and also system very sensitive to the damping coefficient and due to decrease of nanoshell stiffness, natural frequency decreases. And also, increasing or decreasing of some parameters lead to increasing or decreasing the resonance amplitude, resonant frequency, the system's instability, nonlinear behavior and bandwidth.


ABSTRACT: This manuscript presents the influence of periodic (sine and cosine) and nonperiodic imperfections modes on buckling, postbuckling and dynamics of beam rested on nonlinear elastic foundations. The geometric von Kármán nonlinear strains induced by mid-plane stretching is considered. So, the generated equation of motion of imperfect beam is obtained as nonlinear integro-partial-differential equation. Elastic cubic nonlinear and linear springs and shearing layer are proposed to model elastic medium around the imperfected beam. Numerical differential-integral quadrature method (DIQM) in combination with Newton's method are used to find buckling loads and modes of imperfect beam that described by nonlinear integro-differential equation. In linear vibration analysis, the problem is discretized by DIQM and solved as a linear eigenvalue problem. The closed form solutions for static response and linear vibration problem of imperfect beam are obtained. Excellent agreement is observed between proposed numerical and analytical solutions. The numerical results indicate that imperfection modes and its amplitude have a weighty influence on the buckling load, postbuckling configurations and natural frequencies. Finally, numerical results for clamped-clamped (C-C) and simply supported (SS-SS) beams with local (nonperiodic) imperfection modes are presented.


ABSTRACT: This study deals with the vibration analysis of zigzag and chiral rotating functionally graded carbon nanotubes (FG-CNT) invoking Love's shell theory using wave propagation approach. The frequency equation is formed in the eigenvalue form. It has been shown that with the increase of angular speed, frequencies of forwarding curve decrease and backward curve increase. The phenomena of frequency versus length-and height-to-radius ratios are noted as decreasing and increasing, respectively, for rotating CNTs. The backward and forward frequency curves of clamped-free are lower throughout the computation than the clamped-clamped zigzag and chiral carbon nanotube depending upon the rotating speed. MATLAB software is
used to calculate the rotating (backward and forward) frequencies of SWCNTs and the frequency peaks in the present results show excellent stability across a wide range of parameters. Using geometrical and material parameters, the vibration results are given in tabular and graphical form. It is thus desirable to produce more precise estimations of the vibrational frequencies of CNTs. The present results are compared with earlier literature using simply supported boundary conditions and show a good coincidence.


ABSTRACT: In this study, the time dependent free vibration analysis of composite concrete-filled steel tubular (CFST) arches with various uncertainties is thoroughly investigated within a non-stochastic framework. From the practical inspiration, both uncertain material properties and mercurial creep effect associated with such composite materials are simultaneously incorporated. Unlike traditional non-probabilistic schemes, both spatially independent (i.e., conventional interval models) and dependent (i.e., interval fields) interval system parameters can be comprised within a unified uncertain free vibration analysis framework for CFST arches. For the purpose of achieving a robust framework of the time-dependent uncertain free vibration analysis, a new computational approach, which has been developed within the scheme of the finite element method (FEM), has been proposed for determining the extreme bounds of the natural frequencies of practically motivated CFST arches. Consequently, by successfully solving two eigenvalue problems, the upper and lower bounds of the natural frequencies of such composite structures with various uncertainties can be rigorously secured. The unique advantage of the proposed approach is that it can be effectively integrated within commercial FEM software with preserved sharp bounds on natural frequencies for any interval field discretisation. The competence of the proposed computational analysis framework has been thoroughly demonstrated through investigations on both 2D and 3D engineering structures.


ABSTRACT: In this paper, a size-dependent flexoelectric spherical microshell model is proposed considering flexoelectric effect and strain gradient effect. By means of the variation principle, explicit expressions of the governing equations and the boundary conditions are deduced. Solving corresponding governing equations, analytical solutions of both direct and converse flexoelectric responses in static axisymmetric bending problem are obtained. Then, the flexoelectric responses in barium strontium titanate spherical microshells with and without a circular top opening are numerically investigated. Both the direct and converse flexoelectric responses are found to vary non-monotonically as the central angle increases. The converse flexoelectric bending is examined to exist even in clamped spherical microshells, which is different from the case of flat structures. In addition, for all cases, the strain gradient effect will highly reduce the flexoelectric responses, particularly when the thickness approaches the material internal scale constants.


ABSTRACT: The application of uncertainty quantification (UQ) in complex structural response analysis is limited by solution efficiency. A multi-fidelity (MF) method for UQ is proposed in this paper, in which statistical moments are first evaluated using low cost low-fidelity (LF) model first, and then calibrated with a small number of high-fidelity (HF) samples. Only the error distribution of LF solutions and the covariance between the errors and the LF solutions are employed to derive a simple and straightforward MF formulation. The proposed method is demonstrated in the UQ of damage analysis of a C/SiC plate with a hole, where the HF model is a nonlinear global model considering C/SiC material damage, and the LF model is a linear global model driven nonlinear sub model. Uncertainty propagation is carried out using a sparse polynomial chaos expansion method. Evaluations of the MF method based on four factors: correctness, efficiency, precision and reliability, are carried out. The results show that the MF method can estimate the statistical moments of nonlinear strain responses unbiasedly. Computational cost is reduced by 52.7% compared to that utilizing HF
ABSTRACT: The port-Hamiltonian formulation is a powerful method for modeling and interconnecting systems of different natures. In this paper, the port-Hamiltonian formulation in tensorial form of a thick plate described by the Mindlin–Reissner model is presented. Boundary control and observation are taken into account. Thanks to tensorial calculus, it can be seen that the Mindlin plate model mimics the interconnection structure of its one-dimensional counterpart, i.e. the Timoshenko beam. The Partitioned Finite Element Method (PFEM) is then extended to both the vectorial and tensorial formulations in order to obtain a suitable, i.e. structure-preserving, finite-dimensional port-Hamiltonian system (PHs), which preserves the structure and properties of the original distributed parameter system. Mixed boundary conditions are finally handled by introducing some algebraic constraints. Numerical examples are finally presented to validate this approach.


ABSTRACT: The mechanical model of a thin plate with boundary control and observation is presented as a port-Hamiltonian system (PHs), both in vectorial and tensorial forms: the Kirchhoff-Love model of a plate is described by using a Stokes-Dirac structure and this represents a novelty with respect to the existing literature. This formulation is carried out both in vectorial and tensorial forms. Thanks to tensorial calculus, this model is found to mimic the interconnection structure of its one-dimensional counterpart, i.e. the Euler-Bernoulli beam. The Partitioned Finite Element Method (PFEM) is then extended to obtain a suitable, i.e. structure-preserving, weak form. The discretization procedure, performed on the vectorial formulation, leads to a finite-dimensional port-Hamiltonian system. This part II of the companion paper extends part I, dedicated to the Mindlin model for thick plates. The thin plate model comes along with additional difficulties, because of the higher order of the differential operator under consideration.


ABSTRACT: The port-Hamiltonian formulation is a powerful method for modeling and interconnecting systems of different natures. In this paper, the port-Hamiltonian formulation in tensorial form of a thick plate described by the Mindlin–Reissner model is presented. Boundary control and observation are taken into account. Thanks to tensorial calculus, it can be seen that the Mindlin plate model mimics the interconnection structure of its one-dimensional counterpart, i.e. the Timoshenko beam.


ABSTRACT: Due to the rapid development of intelligent engineering structure, the demand for high performance smart structures has been increased in recent years. In this paper, an exact elasticity solution for bending analysis of sandwich panel with generally orthotropic facing and core is developed. Two electro-orthotropic piezoelectric layers in the top and bottom surfaces of sandwich panel as sensor and actuator are considered. From practical point of view, an initially curved sectorial geometry is considered for smart sandwich panel. In this regard, the constitutive relations and governing equations are considered in polar coordinate and coupled Euler–Cauchy Equations are derived. The characteristic equations are determined and closed-form basis functions of displacements and stresses are achieved for various material and geometrical conditions. Furthermore, based on classical and first-order shell theories, the governing equations of smart curved sandwich panels are derived. The governing equations are solved analytically and compared with exact elasticity solution. Several parametric studies are performed on both material and geometrical properties such as angular span, facing and core thickness, and external electrical voltage.

Hu Liu (1), Zheng Lv (2) and Haijun Tang (3)
(1) School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore
(2) School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore
(3) Institute of Solid Mechanics, Beihang University, 100191 Beijing, PR China
“Nonlinear vibration and instability of functionally graded nanopipes with initial imperfection conveying fluid”,
Applied Mathematical Modelling, Vol. 76, pp 133-150, December 2019,
https://doi.org/10.1016/j.apm.2019.06.011

ABSTRACT: In this paper, the nonlinear vibration and instability of a fluid-conveying nanopipe made of functionally graded (FG) materials with consideration of the initial geometric imperfection are investigated. The material properties are assumed to vary smoothly along the radial direction according to a power-law exponent form. The fluid-conveying FG nanopipe is modeled as a Euler-Bernoulli beam, and the governing equation is derived based on the nonlocal strain gradient theory incorporating the effects of Von-Karman geometrical nonlinearity and initial imperfection. The nonlinear frequency and critical fluid velocity are achieved via He's Hamiltonian approach. After verifying the present model with comparison of several previous studies, the effect of several different system parameters including the amplitude of the nonlinear oscillator, the initial geometric imperfection, size-dependent parameters, and the power-law index on the frequency response of the fluid-conveying FG nanopipe are explored. Moreover, the critical velocity of the conveying fluid under different system parameters is also investigated and discussed in detail. The developed size-dependent nonlinear model is expected to provide a possible theoretical way to guide the application of FG nanopipe as micro/nanofluidic devices.

Mohammad Rezaiee-Pajand, Nilofar Rajabzadeh-Safaei and Amir R. Masoodi (Department of Civil Engineering, Ferdowsi University of Mashhad, Iran), “An efficient mixed interpolated curved beam element for geometrically nonlinear analysis”, Applied Mathematical Modelling, Vol. 76, pp 252-273, December 2019,
https://doi.org/10.1016/j.apm.2019.06.007

ABSTRACT: In this study, a curved beam element is developed for geometrically nonlinear analysis of planar structures. The main contribution of this research is to use high-performance formulation to alleviate locking phenomena and consider finite rotation. This scheme is based on the mixed interpolation of the strain fields. In this study, special tying points are found and utilized. One of the interesting advantages of the proposed element is the ability to model tapered structures. Moreover, the First-order Shear Deformation Theory (FSDT) and the Green-Lagrange strain are included. Several complicated and applicable nonlinear problems are solved to depict the efficiency and high accuracy of the proposed element, especially by fewer numbers of elements.

Zhaolin Chen (1), Zhichun Yang (1), Yingsong Gu (1) and Shijun Guo (2)
(1) School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China
(2) Centre of Aeronautics, Cranfield University, Bedfordshire MK43 0AL, UK
“An energy flow model for high-frequency vibration analysis of two-dimensional panels in supersonic airflow”,
Applied Mathematical Modelling, Vol. 76, pp 495-512, December 2019,
https://doi.org/10.1016/j.apm.2019.06.024

ABSTRACT: Many energy flow models have been proposed for high-frequency forced vibration analysis of structures. In this paper, a novel energy flow model is developed to predict the high-frequency vibration response of panels in supersonic airflow and quantify the effects of supersonic airflow on high-frequency forced vibration characteristics. The additional damping due to supersonic airflow is derived from the motion equation of a two-dimensional panel. The relationship between the wavenumber and the group velocity is introduced to describe the energy transmission property considering the effects of supersonic airflow. Then the energy density governing equation (i.e. energy flow model) is established and solved by the energy flow analysis (EFA) and the energy finite element method (EFEM). Finally, comparing the vibration responses obtained by the present energy flow model with the corresponding exact analytical solutions, the developed energy flow model is verified to be effective for high-frequency vibration analysis of panels in supersonic airflow. Furthermore, the numerical simulations indicate that supersonic airflow can affect the equivalent damping of the propagating elastic waves, and thus change the energy density distribution of the panel.

Aparna Gangele and Ashok Kumar Pandey (Department of Mechanical and Aerospace Engineering, IIT Hyderabad, Kandi 502285, India), “Frequency analysis of carbon and silicon nanosheet with surface effects”,
Applied Mathematical Modelling, Vol. 76, pp 741-758, December 2019,
https://doi.org/10.1016/j.apm.2019.06.029

ABSTRACT: Silicon-based microelectromechanical system (MEMS) and nanoelectromechanical systems (NEMS) have been used to design and fabricate sensitive sensors and actuators. Recent research trends show
that graphene and carbon nanotubes (CNTs) have been used to change the surface properties of silicon-based MEMS and NEMS to improve different mechanical, optical and electrical properties of silicon-based composites. In this paper, we focus on analyzing the vibrational characteristics of silicon-based devices when the surface of silicon is coated with single-layer graphene and horizontally aligned carbon nanotubes (HACNTs). To perform the analysis, we use multi-scale finite element approach for developing graphene–silicon nanocomposites (GSNCs) and carbon nanotube-silicon nanocomposites (CSNC) composites in which interface layer of silicon with graphene or CNT is modeled using bonded contact element. Subsequently, we performed modal analysis to find the first transverse mode frequency of GSNC and CSNC composites for beam with smaller as well as longer lengths. The numerical model is compared with classical beam theory with and without surface effect. For GSNCs composites, we take a fixed-free case with lengths in the range of (20 Å–120 Å) and (400 Å–2000 Å), respectively. For CSNC composites, CNT diameter is varied from (5 Å–30 Å) for single walled nanotube. Subsequently, we analyze the influence of HACNTs-on-silicon on its vibrational characteristics. The analysis presented in the paper demonstrate that GSNCs offer a higher bending stiffness compared to single layer graphene (SLGs) and isolated silicon nanosheet which lead to higher natural frequency. A similar trend is found in the case of HACNTs on silicon NS when the number of tubes increases.


ABSTRACT: In this paper, a posteriori error estimation and mesh adaptation approach for thin plate and shell structures of through-the-thickness crack is presented. This method uses the extended isogeometric analysis (XIGA) based on PHT-splines (Polynomial splines over Hierarchical T-meshes), which is abbreviated as XIGA-PHT. In XIGA-PHT, the isogeometric displacement approximation is locally enriched with enrichment functions, which efficiently capture the displacement discontinuity across the crack face as well as the stress singularity in the vicinity of the crack tip. On the one hand, the rotational degrees of freedom (RDOFs) are not required in Kirchhoff–Love theory, which drastically reduces the complexity of enrichment mode and computational scale for crack analysis. On the other hand, the PHT-splines basis functions can automatically satisfy the requirement of C-continuity for the Kirchhoff–Love theory. Moreover, the PHT-splines facilitate the local refinement, which is the deficiency of NURBS-based isogeometric formulations. The local refinement is highly suitable for adaptive analysis. The stress recovery-based posteriori error estimator combined with the superconvergent patch recovery (SPR) technique is used to evaluate the approximate local discretization error. A new strategy for selecting enriched recovered functions in the enriched areas was proposed. Special functions extracted from the asymptotic stress solutions are applied to obtain the recovered stress field in the enriched area. The results of stress intensity factors or J-integral values obtained by the adaptive XIGA-PHT are compared with reference solutions. Several thin plate and shell illustrative examples demonstrate the effectiveness and accuracy of the proposed adaptive XIGA-PHT.

R. Lianngenga (1) and S.S. Singh (2)
(1) Department of Mathematics, Pachhunga University College, Aizawl 796 001, Mizoram, India
(2) Department of Mathematics & Computer Science, Mizoram University, Aizawl 796 004, Mizoram, India

ABSTRACT: The problem of symmetric and anti-symmetric vibrations in micropolar thermoelastic plate with voids has been investigated. The dispersive frequency equations are obtained for different surface waves propagating in the plate. The velocity curves are depicted for the symmetric and anti-symmetric vibrations, plate, Rayleigh and flexural waves. It is found that there exist two modes in the solution of frequency equation for the surface waves in micropolar thermoelastic plate with voids. We have observed that the first modes of velocity ratios of corresponding surface waves are lesser than those of second mode of vibration.


ABSTRACT: This paper deals with the classical challenging free vibration problems of non-Lévy-type cylindrical shell panels, i.e., those without two opposite edges simply supported, by a Hamiltonian system-based symplectic superposition method. The governing equations of a vibrating cylindrical panel are formulated within the Hamiltonian system framework such that the symplectic eigen problems are constructed, which yield analytic solutions of two types of fundamental problems. By the equivalence between the superposition of the fundamental problems and the original problem, new analytic frequency and mode shape solutions of the panels with four different combinations of boundary conditions are derived. Comprehensive benchmark results are tabulated and plotted, which are useful for validation of other numerical/approximate methods. The primary advantage of the developed approach that no pre-determination of solution forms is needed enables one to pursue more analytic solutions of intractable shell problems.

Pedram Khaneh Masjedi (1), Alireza Maher (2) and Paul M. Weaver (1)
(1) Bernal Institute, School of Engineering, University of Limerick, Limerick, Ireland
(2) School of Engineering, University of Aberdeen, Aberdeen, UK


ABSTRACT: Porous graded materials found in nature can be regarded as variable stiffness optimised load carrier elements that exhibit beneficial properties for real-life engineering designs. In order to investigate the nonlinear behaviour of variable stiffness bioinspired materials, the large deflection of functionally graded beams made from porous materials is considered in this work. Our purpose is to present an efficient and accurate methodology capable of capturing spatially large deflections of these structures with different types of loading conditions and porosity distributions. A geometrically exact beam model with fully intrinsic formulation is employed for the first time to study the large deflection behaviour of functionally graded beams under conservative and non-conservative (follower) loading scenarios. An orthogonal Chebyshev collocation method is used for the discretisation of the fully intrinsic formulation. Two types of porosity distributions, namely cross-sectional and span-wise, are considered and the effect of porosity distribution has been investigated for various benchmark classical test cases. For a given level of accuracy, it is shown that the span-wise functionally graded beam is computationally more demanding compared to the cross-sectional functionally graded beam. In addition to classical problems, two examples demonstrating 3D deflections of highly flexible structures made from porous material subject to combined loads are investigated. It is shown that the current paradigm, while being computationally efficient, can effectively capture the large deflections of functionally graded beams with excellent accuracy.
ABSTRACT: This paper analytically investigates effects of the load location on the non-linear in-plane multiple equilibria, limit points, stationary points of inflexion, cusp, and buckling behavior of a pin-ended elastic shallow circular arch under a radial point load at an arbitrary location along the arch length. Theoretical solutions for the non-linear response of the arch to the arbitrary radial point load including the limit points, stationary points of inflexion, cusp and multiple equilibria are derived. The major findings are: (1) there exists special modified slenderness corresponding to an arch, whose non-linear equilibrium path has stationary point of inflexion or a cusp and which can distinguish the number of multiple limit points and equilibria; (2) criteria distinguishing multiple limit points and equilibria are developed by relating the special modified slenderness to the load location; (3) theoretical solutions for the load, axial force and displacement at stationary points of inflexion and at cusps are also deduced; (4) the load location and the modified slenderness of an arch significantly influence the non-linear multiple equilibria of the arch; and (5) the load location has significant influence on the buckling pattern of an arch, and when the point load is applied at a location away from the apex of the arch, the arch can buckle only in a limit point instability pattern, but not in a bifurcation pattern.

References listed at the end of the paper:

1 Yang Y.B., M.A. Shieh, Solution method for nonlinear problems with multiple critical points, AIAA J., 28 (12) (1990), pp. 2110-2116
Changsong Zhu (2), Xueqian Fang (1) and Jinxi Liu (3)

(1) Department of Engineering Mechanics, Shijiazhuang Tiedao University, Shijiazhuang 050043, China
(2) School of Civil Engineering, Shijiazhuang Tiedao University, Shijiazhuang 050043, China
(3) Hebei Key Laboratory of Smart Materials and Structures Mechanics, Shijiazhuang 050043, China


ABSTRACT: The focus of this paper is on the active control of nonlinear free vibration of viscoelastic orthotropic piezoelectric doubly-curved smart nanoshells with surface effects. To achieve an efficient active damping in the vibration control, a velocity feedback control law is introduced to carry out the present study. Within the framework of surface piezoelectricity theory and Kelvin–Voigt viscoelastic model, the nonlinear equations of motion, including the surface effect and internal damping effect, are derived from the generalized Hamilton's principle. By using the harmonic balance method to solve the equations of motion, the nonlinear vibration responses of the system with and without active vibration control are presented. The effects of the surface energy, viscous damping coefficient, initial displacement, aspect ratio and control gain on the nonlinear vibration responses of the system are studied. Numerical results show that these parameters, especially the control gain, play a significant role in the active vibration control of a viscoelastic orthotropic piezoelectric doubly-curved nanoshell.

References listed at the end of the paper:

7 M. Mohammadimehr, M. Mohandes, M. Moradi, Size dependent effect on the buckling and vibration analysis of double-bonded nanocomposite piezoelectric plate reinforced by boron nitride nanotube based on modified couple stress theory, J. Vib. Control, 22 (2016), pp. 1790-1807
16 F. Ebrahimim, M.R. Barati, Size-dependent vibration analysis of viscoelastic nanocrystalline silicon nanobeams with porosities based on a higher order refined beam theory, Compos. Struct., 166 (2017), pp. 256-267
20 F. Ebrahimim, M.R. Barati, Damping vibration analysis of smart piezoelectric polymeric nanoplates on viscoelastic substrate based on nonlocal strain gradient theory, Smart Mater. Struct., 26 (2017), Article 065018
29 R. Ansari, R. Gholami, Nonlocal free vibration in the pre- and post-buckled states of magneto-electro-thermo elastic rectangular nanoplates with various edge conditions, Smart Mater. Struct., 25 (2016), Article 095033
34 M. Pourseifi, O. Rahman, S.A.H. Hoseini, Active vibration control of nanotube structures under a moving nanoparticle based on the nonlocal continuum theories, Meccanica, 50 (2015), pp. 1351-1369
This paper investigates the analytical and semi-analytical approaches for the nonlinear dynamic and static hygrothermal buckling analysis of imperfect functionally graded porous cylindrical shells under hygrothermal loading. Effect of the von Kármán strain-displacement kinematic nonlinearity is included in the constitutive laws of the shell. Utilizing the Galerkin method, the nonlinear vibration problem has been solved. The fourth-order Runge–Kutta method is used to find the nonlinear dynamic hygrothermal buckling
responses. To validate the results, comparisons are made with the available solutions for both nonlinear dynamic and static hygrothermal buckling of cylindrical shells. The effect of material parameters and various geometrical characteristics on the nonlinear dynamic and static hygrothermal buckling behavior of the system is investigated.

References listed at the end of the paper:
1 G. Michel, G. Gusic, J. Jullien, Buckling of thin cylindrical shells under lateral pressure: influence of localised thickness variation, Coupled Instabilities in Metal Structures (2000), pp. 427-434
4 X. Wang, K. Dong, Local buckling for triangular and semilentic delaminations near the surface of laminated cylindrical shells under hygrothermal effects, Compos. Struct., 79 (2007), pp. 67-75
7 H.S. Shen, Hygrothermal effects on the postbuckling of axially loaded shear deformable laminated cylindrical panels, Compos. Struct., 56 (2002), pp. 73-85
9 H. Huang, Q. Han, Nonlinear dynamic buckling of functionally graded cylindrical shells subjected to time-dependent axial load, Compos. Struct., 92 (2010), pp. 593-598
10 T. Ye, G. Jin, S. Gao, Three-dimensional hygrothermal vibration of multilayered cylindrical shells, Compos. Struct., 201 (2018), pp. 867-881
28 A.S. Volmir, Non-linear Dynamics of Plates and Shells, Nauka, Moscow (1972) (in Russian)
Ke Liang (1), Chen Yang (2) and Qin Sun (1)
(1) School of Aeronautics, Northwestern Polytechnical University, Xi’an 710072, PR China
(2) Qian Xuesen Laboratory of Space Technology, China Academy of Space Technology, Beijing 100094, PR China


ABSTRACT: Thin-walled isogrid-stiffened structures have been widely used as highly efficient structural components in aerospace engineering. In this work, the stability behavior of isogrid-stiffened cylinder is analyzed using the smeared stiffener model based reduced-order-modelling (SSM-ROM) method. The smeared stiffener method proposed based on mechanical characteristics of isogrid-stiffener cell is applied to facilitate the finite element(FE) modellling of structure. The reduced-order models constructed based on Koiter asymptotic expansion are extended to be applicable for the smeared stiffener model. Mode selection criteria for cylinders with measured geometric-shape imperfections are developed to lower the computational cost in construction of the reduced-order model. The proposed method is implemented into the finite element framework and achieved completely using the in-house codes. The isogrid-stiffened cylinders with two different configurations(strong or weak stiffeners) are considered to validate the performance of the proposed method. Linear and nonlinear buckling analyses are first applied to test the numerical accuracy of the smeared stiffener model. The sensitivity of the buckling load in terms of magnitude of initial imperfections is then carefully studied using three different geometric imperfection shapes. Numerical results demonstrate the good performance of the proposed method in both structural buckling analysis and imperfection sensitivity analyses.

References listed at the end of the paper:
2 M. Bouazizi, T. Lazghab, M. Soula, Mechanical response of a hexagonal grid stiffened design of a pressurized cylindrical shell-application to aircraft fuselage, Thin-Walled Struct., 127 (2018), pp. 40-50
14 E. Wodesenbet, S. Kidane, S.-S. Pang, Optimization for buckling loads of grid stiffened composite panels, Compos. Struct., 60 (2) (2003), pp. 159-169

ABSTRACT: A complete set of analytical solutions for the transient elastodynamic response of thick cylindrical shells with finite length to single and successive moving pressures are presented over a wide range of load speeds. The formulation of the problem is based on the first-order shear deformation theory and the solutions are obtained using the mode-summation method. The effects of reflected waves at different types of boundary condition (simply-supported, clamped-clamped, and clamped-free) are also considered in the solution procedures. The results of the analytical solutions are validated through comparisons with the experimental results from the literature and a series of finite element simulations. The very good agreement between the analytical and experimental results showed the accuracy of the formulation and solution procedures. The excellent agreement between the analytical and numerical results over a wide range of load speeds showed the higher precision and superior efficiency of the new analytical solution, compared to the previous models.

References listed at the end of the paper:
5 M. Mirzaei, M. Najaﬁ, H. Niassari, Experimental and numerical analysis of dynamic rupture of steel pipes under internal high-speed moving pressures, Int. J. Impact Eng., 85 (2015), pp. 27-36, 10.1016/j.ijimpene.2015.06.014

ABSTRACT: In this study, the bending solution of simply supported transversely isotropic thick rectangular plates with thickness variations is provided using displacement potential functions. To achieve this purpose, governing partial differential equations in terms of displacements are obtained as the quadratic and fourth order. Then, the governing equations are solved using the separation of variables method satisfying exact boundary conditions. The advantage of the proposed method is that there is no limitation on the thickness of the plate or the way the plate thickness is being varied. No simplifying assumption in the analysis process leads to the applicability and reliability of the present method to plates with any arbitrarily chosen thickness. In order to confirm the accuracy of the proposed solution, the obtained results are compared with existing published analytical works for thin variable thickness and thick constant thickness plate. Also, due to the lack of analytical research on thick plates with variable thickness, the obtained results are verified using the finite element method which shows excellent agreement. The results show that the maximum displacement of the plates with variable thickness is moved from the center toward the thinner plate edge. In addition, results exhibit the profound effects of both thickness and aspect ratio on stress distribution along the thickness of the plate. Results also show that varying thickness has not a profound impact on bending and twisting moments in transversely isotropic plates. Five different materials consist of four transversely isotropic and one isotropic, as a special case, are considered in this paper, which it is shown that the material properties have a more considerable impact on higher thickness plate.

Ke Xie (1), Yuewu Wang (2), Xuanhua Fan (1) and Tairan Fu (2)
(1) Institute of Systems Engineering, China Academy of Engineering Physics, Mianyang, Sichuan 621900, China
(2) Department of Energy and Power Engineering, Tsinghua University, Beijing 100084, China
ABSTRACT: This study investigates the nonlinear free vibration of functionally graded material (FGM) beams by different shear deformation theories. The volume fractions of the material constituents and effective material properties are assumed to be changing in the thickness direction according to the power-law form. The von Kármán geometric nonlinearity has been considered in the formulation. The Ritz method and Lagrange equation are adopted to yield the discrete formulations. A direct numerical integration method for the motion equation in matrix form is developed to solve the nonlinear frequencies of FGM beams. Comparing with the global concordant deformation assumption (GCDA), a new deformation assumption named as local concordant
deformation assumption (LCDA) is proposed in this study. The LCDA fits with the real deformation of the vibrating beam better, thus more accurate results of the nonlinear frequency can be expected. In numerical results, the comparison study of the GCDA and LCDA is carried out. In addition, the effects of power-law index, slenderness ratio and maximum deflection for different shear deformation theories and boundary conditions on the nonlinear frequency of the beam are discussed.


ABSTRACT: Flexible plate structures with large deflection and rotation are commonly used structures in engineering. How to analyze and solve the cantilever plate with large deflection and rotation is still an unsolved problem. In this paper, a general nonlinear flexible rectangular cantilever plate considering large deflection and rotation angle is modeled, solved and analyzed. Hamilton’s principle is applied to obtain the nonlinear differential dynamic equations and boundary conditions by introducing a coordinate transformation between the Cartesian coordinate system and the deformed local coordinate system. Stress function relating to in-plane force resultants and shear forces is given for the first time for complex coupling equations caused by coordinate transformation. The nonlinear equations and the solving method are validated by experiments. Then, harmonic balance method is adopted to get the nonlinear frequency-response curves, which shows strong hardening spring characteristic of this system. Runge–Kutta methods are used to reveal complex nonlinear behaviors such as 5 super-harmonic resonance, bifurcations and chaos for general nonlinear flexible rectangular cantilever plate.

Xiangying Guo (1), Bo Zhang (1), Dongxing Cao (1) and Lin Sun (2)
(1) College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, China
(2) School of Mechanical Engineering, Liaoning Shihua University, Fushun 113001, China

ABSTRACT: This research is focused on the effects of nonlinear terms on the dynamical behavior of graphene reinforced laminated composite plates. Firstly, the governing equations of the graphene reinforced composite thin plate subjected to transverse excitations are derived by using the Hamilton’s principle and the von Karman deformation theory. Then numerical method is applied to investigate the nonlinear behaviors of graphene reinforced composite plates. Bifurcation diagram, waveform and phase portrait are demonstrated to analyze the nonlinear dynamics of the graphene reinforced laminated composite plates. Furthermore, the effects of nonlinear terms on the dynamical behavior are discussed in detail, where both the stronger and weaker nonlinear characteristics of lower modes of the plate are presented. Moreover, some interesting phenomena are obtained in numerical simulation.

H. Zhang (1,2), C.M. Wang (2), N. Challamel (3) and W.H. Pan (2)
(1) State Key Laboratory of Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, PR China
(2) School of Civil Engineering, The University of Queensland, St Lucia, Queensland 4072, Australia
(3) Université Bretagne Sud, IRDL (CNRS UMR 6027), Centre de Recherche, Rue de Saint Maudé, BP92116 56321 Lorient Cedex, France

ABSTRACT: This paper is focused on the modeling of circular and annular graphene sheets via Hencky bar-net model (HBM) and calibrating the Eringen's small length scale coefficient ε in Eringen's nonlocal theory. The buckling solutions of circular and annular graphene sheets based on Eringen's nonlocal continuum plate theory are first obtained. On the other hand, HBM is developed to model the same structure from the discrete view. HBM is a grid system comprising rigid bars and arcs connected by frictionless hinges with elastic rotational and torsional springs. By regarding the length of straight segments in HBM equal to the characteristic length of
Eringen's nonlocal model (ENM) and matching their solutions, the Eringen's small length scale coefficient $\epsilon$ is calibrated. It is found that for circular graphene sheet, $\epsilon = 0.258$ for clamped edge and $\epsilon = 0.300$ for simply supported edge. For annular graphene sheet, $\epsilon$ is dependent on the inner to outer radius ratio $\chi$ and boundary conditions. The scale coefficient $\epsilon$ takes 0.307–0.367 for clamped edges while 0.219–0.290 for simply supported edges with $\chi$ varying from 0.2 to 0.8. Another finding is that the graphene sheet will buckle with a very small load when its dimension is large, regardless of models adopted. However for small dimensions, ENM and HBM predict lower buckling loads than the classical local model because the scale effect is more obvious.


ABSTRACT: In this paper, the vibration and buckling analyses of the FGM (functionally graded material) plates with multiple internal cracks and cutouts under thermal and mechanical loads are numerically investigated using the combined XIGA-PHT (extended isogeometric analysis based on PHT-splines) and FCM (finite cell method). Material properties are graded only in the thickness direction. The effective material properties are estimated by using either the rule of mixture or the Mori-Tanaka homogenization technique. The plate displacement field is based on the HSDT (higher-order shear deformation plate theory) without any requirement of the SCF (shear correction factor). The HSDT model can exactly represent the shear stress distribution and improve the accuracy of solutions. The PHT-splines can naturally fulfill the C-continuous requirement of the HSDT model. The representation of internal defects is mesh-independent. The discontinuous and singular phenomena induced by the cracks are captured using the enrichment pattern in the XIGA, and the influence of cutouts is implemented by the FCM. The geometries of cutouts are captured by means of adaptive quadrature procedure based on a simple unfitted structural mesh, which avoids the need for multiple patches to describe the complex geometry and eliminates the enforcement of C-continuity patch-coupling across the patch boundaries. The initial mesh density around the cracks and cutouts can be controlled flexibly utilizing the local refinement property of the PHT-splines. After validating the results of the developed approach with those available in the literature, the effects of material gradient index, side to thickness ratio, boundary conditions, cutout size and crack length on the normalized frequency and the critical buckling parameter are investigated. Numerical results illustrate the effectiveness and accuracy of the present approach.


ABSTRACT: This paper presents an investigation on partially fluid-filled cylindrical shells made of functionally graded materials (FGM) surrounded by elastic foundations (Pasternak elastic foundation) in thermal environment. Material properties are assumed to be temperature dependent and radially variable in terms of volume fraction of ceramic and metal according to a simple power law distribution. The shells are reinforced by stiffeners attached to their inside and outside in which the material properties of shell and the stiffeners are assumed to be independently graded in the thickness direction. The formulations are derived based on smeared stiffeners technique and classical shell theory using higher-order shear deformation theory which accounts for shear flexibility through shell’s thickness. Displacements and rotations of the shell middle surface are approximated by combining polynomial functions in the meridian direction and truncated Fourier series with an appropriate number of harmonic terms in the circumferential direction. The governing equations of liquid motion are derived using a finite strip element formulation of incompressible inviscid potential flow. The dynamic pressure of the fluid is expanded as a power series in the radial direction. Moreover, the quiescent liquid free surface is modeled by concentric annular rings. A detailed numerical study is carried out to investigate the effects of power-law index of functional graded material, fluid depth, stiffeners, boundary...
conditions, temperature and geometry of the shell on the natural frequency of eccentrically stiffened functionally graded shell surrounded by Pasternak foundations.

ABSTRACT: A closed-form analytical solution for critical temperature and nonlinear post-critical temperature-deflection behaviour for nonlocal orthotropic plates subjected to thermal loading is presented. The long-range molecular interactions are represented by a nonlocal continuum framework, including orthotropy. The Von-Karman nonlinear strains are employed in deriving the governing equations. An approximate solution to the system of nonlinear partial differential equations is obtained using a perturbation type method. Series expansions up to second order of the associated field variables and the load parameter, dictating nonlinearity are employed. The behaviour in the post-critical regime is illustrated numerically by adopting an example of orthotropic Single Layer Graphene Sheet (SLGS), a widely acclaimed nano-structure, often modelled as plate. Post-critical temperature-deflection paths are presented with special emphasis on their post-critical reserve in strength and stiffness. Influence of aspect ratio and behaviour in higher modes are demonstrated. Implications of nonlocal interactions on the redistribution of in-plane forces are presented to show striking disparity with the classical plates. The obtained solution may serve as benchmark for verification of numerical solutions and may be useful in formulating simple design guidelines for plate type nanostructures liable to the thermal environment.

ABSTRACT: In this paper, we study thin viscoelastic shell structures using a constitutive equation in hereditary integral form. An alternative mathematical formulations for several viscoelastic shell structures under the Reissner–Mindlin kinematical assumptions are obtained. The resulting equations are written as a Volterra equation of the second kind to allow further mathematical analysis. A locking-free finite element formulation, with selective reduced integration is used to approximate the equation. To perform numerical experiments we consider several situations suffering from locking in both cases dynamic and quasi-static. We show the good behavior of the model compared with other models from the literature.

Bo Wang (1), Haohao Bi (2), Yan Wang (1), Huajiang Ouyang (3) and Zichen Deng (1)
(1) Department of Engineering Mechanics, Northwestern Polytechnical University, Xi'an 710072, China
(2) Department of Applied Mathematics, Northwestern Polytechnical University, Xi'an, 710072, China
(3) School of Engineering, University of Liverpool, Liverpool L69 3GH, UK
ABSTRACT: Buckling of thin nanowires on a pre-strained compliant substrate has been widely used to make nanowire-based stretchable electronics. On nanometer scale, surface effect plays an important role on a buckled nanowire structure. In addition, as the amplitude of the deflection of the buckled nanowire is larger than its thickness, geometrical nonlinearity should be taken into account. Taking the kinetic energy caused by the out-of-plane motion into account, and on the basis of Euler beam theory, a theoretical model for a nanowire-substrate structure is established, combined with the influences of the nano-scale surface effect and geometrical nonlinearity. By means of Lagrange's equation, the equation of motion is derived and then solved by the Symplectic (Partitioned) Runge–Kutta method (PRK). Several numerical examples are analysed to study the nonlinear vibration of the structure. The analytical expressions of stable and unstable equilibrium points, and the relationship between the vibration amplitude and the natural frequency are obtained. The influences of surface effect and pre-strain on the dynamic behaviour are analysed. Through these numerical results, one can find that when the surface elastic modulus and surface residual stress are considered, the number of unstable equilibrium points would increase to three. The frequency obtained with positive surface elastic modulus is greater than that obtained with negative surface elastic modulus, implying that the positive surface elastic modulus can make the nanowire-substrate structure stiffer. Furthermore, when the pre-strain increases, the locations of stable and unstable equilibrium points move further away from the initial displacement, and the
homoclinic orbits become expanded. The results presented in this paper should be useful to guide the design of nanowire-based stretchable electronics.

A. Shahdadi (1) and H. Rahnama (2)
(1) Mechanical Engineering Department, Sharif University of Technology, Tehran, Iran
(2) Mechanical Engineering Department, Iran University of Science and Technology, Tehran, Iran

ABSTRACT: Based on the first order shear deformation theory, free vibration behavior of functionally graded (FG) annular sector plates integrated with piezoelectric layers is investigated. The distribution of electric potential along the thickness direction of piezoelectric layers which is assumed to be a combination of linear and sinusoidal functions, satisfies both open and closed circuit electrical boundary conditions. Through a reformulation of governing equations and harmonic motion assumption, a novel decoupling method is suggested to transform the six second order coupled partial differential equations of motion into two eighth order and fourth order equations. A Fourier series method is then employed to present analytical solutions for free vibration of smart FG annular sector plates with simply supported radial edges and arbitrarily supported circular edges. The results, which can be used as a benchmark and suitable for design purposes, are verified with those reported in the literature. Finally, by presenting extensive ranges of frequencies, the effects of geometric parameters, power law index, FG and piezoelectric materials, electrical and mechanical boundary conditions as well as the piezoelectric layer thickness on vibration response of smart annular sector plates are discussed in detail.

ABSTRACT: Dynamic response of a thin rectangular plate traversed by a moving inertia load with arbitrary boundary condition is investigated through this paper. The inertia effect of mass is considered and relevant formulation is established based on the full-term of acceleration, employing the method of Boundary Characteristic Orthogonal Polynomials, BCOP. To acquire the complete solution of partial differential equations governing on the plate, the Galerkin method is used to separate the temporal function from the spatial one. The problem is formulated in the state space and applying the numerical method of Matrix Exponential the complete solution would be achieved. In the numerical studies, a comprehensive parametric study is performed for both cases of loading when inertia effect is included or neglected. Several mass and aspect ratios for the plate with major types of boundary conditions CCCC, SSSS, CFCF and SF SF are accounted for presenting the results. Dynamic amplification factor against velocity parameter is scrutinized within many graphs alongside with a time history analysis of dynamic deflection for the plate’s mid-span. Investigating on the dynamic response concludes to the critical boundary condition upon moving mass. By introducing a conversion factor, the margin of inertia and the critical velocity where happened would be achieved, then through a regression analysis a curve fitting model of polynomials is proposed. Corresponding coefficients testify the goodness of fit for such regression which are reported within tables. Referring to this simplified model of conversion factor pertaining to the specific boundary condition, it would be possible to handle the problem in moving load case without undertaking the complexities arisen from inertia contribution into the formulation. Having derived the factor from simplified model which has been calculated for a specific mass and velocity ratio, then multiplying into the moving load response, the complete solution for moving mass would be achieved.

Y.X. Hao (1), K.F. Zhao (1), W. Zhang (2) and S.W. Yang (2)
(1) College of Mechanical Engineering & Beijing Key Laboratory of electromechanical system measurement and control, Beijing Information Science and Technology University, Beijing 100192, PR China
(2) College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, PR China

ABSTRACT: In this paper, a novel dynamic model for smart structural systems cross-ply laminated cantilever plate with smart material Macro fiber composites (MFC) layer is presented by using zigzag function theory. The nonlinear dynamic response and dynamic instability of the smart structural systems are studied for the first time. The plate is subjected to the uniformed static and in-plane harmonic excitation conjunction with electrically loaded under different electric boundary conditions. The partial layer-wise theory which the first shear deformation theory is expanded by introducing the zigzag function in the in-plane displacement components is adopted. The carbon fiber reinforced composite material T800/M21 and macro fiber composites (MFC-d31) M8528-P3 are implemented. By Lagrangian equation and Chebyshev polynomial, the equations of motion are derived for the laminated plate. The validation and convergence are studied by comparing results with literatures. The dynamic instability regions and the critical buckling load characteristics can be obtained for different layer sequences, geometric dimensions and also the electromechanical effects are considered. Nonlinear dynamic responses of the laminated plate are studied by using numerical calculation. It can be seen that in certain state the plate will loses stability and the periodic, multiple period as well as chaotic motions of the plate are found.


ABSTRACT: This paper applies the isogeometric analysis (IGA) based on unified one-dimensional (1D) models to study static, free vibration and dynamic responses of metallic and laminated composite straight beam structures. By employing the Carrera Unified Formulation (CUF), 3D displacement fields are expanded as 1D generalized displacement unknowns over the cross-section domain. 2D hierarchical Legendre expansions (HLE) are adopted in the local area for the refinement of cross-section kinematics. In contrast, B-spline functions are used to approximate 1D generalized displacement unknowns, satisfying the requirement of interelement high-order continuity. Consequently, IGA-based weak-form governing equations can be derived using the principle of virtual work and written in terms of fundamental nuclei, which are independent of the class and order of beam theory. Several geometrically linear analyses are conducted to address the enhanced capability of the proposed approach, which is prominent in the detection of shear stresses, higher-order modes and stress wave propagation problems. Besides, 3D-like behaviors can be captured by the present IGA-based CUF-HLE method with reduced computational costs compared with 3D finite element method (FEM) and FEM-based CUF-HLE method.

Libin Duan (1), Haobin Jiang (1), Huanhuan Li (1) and Ningcong Xiao (2)
(1) School of Automotive and Traffic Engineering, Jiangsu University, Zhenjiang 212013, China
(2) School of Mechanical and Electrical Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan 611731, China


ABSTRACT: Variable-thickness rolled blanks (VRBs) represent an important approach for constructing lightweight structures. However, the optimization of the crashworthiness and thickness distribution of VRB thin-walled structures under manufacturing constraints is a nonlinear dynamic-response structural-optimization problem that has a large number of design variables. To tackle this problem, this paper has extended and improved the hybrid cellular automaton for thin-walled structures (HCATWS) algorithm, and has proposed an extended hybrid cellular automaton for VRB thin-walled structures (eHCA-VRB) algorithm. This algorithm consists of an outer loop and an inner loop. The outer loop performs crash simulation analysis to define an appropriate target mass for the inner loop, whereas the inner loop adjusts cell thicknesses according to the internal energy density (IED) of the current cell and its neighboring cells so that the IED in the design domain becomes evenly distributed. A one-dimensional CA model is defined along with the rolling direction based on the thickness distribution of VRB thin-walled structures. Furthermore, the eHCA-VRB algorithm also generates a mapping relationship between the one-dimensional CA model and the FE model. To optimize the thickness distribution of VRB thin-walled structures under manufacturing constraints, our method uses cell thickness as a design variable and incorporates the constraints of the VRB rolling process in the cell thickness update rules. To
verify the convergence and efficiency of the eHCA-VRB algorithm, VRB top-hat thin-walled structures are optimized for crashworthiness with/without manufacturing constraints (M.C.), respectively. The results show that the eHCA-VRB algorithm can be used to efficiently solve the optimization problems of crashworthiness and the thickness distribution of VRB thin-walled structures under manufacturing constraints.


ABSTRACT: Honeycomb structures with better balance between lightweight and crashworthiness have aroused growing attentions. However, structural parameters design by traditional optimization algorithm in small design space is not sufficient to significantly enhance the specific energy absorption (SEA) with the lower peak acceleration ($a_p$). In this paper, a two-stage hybrid optimization for honeycomb-type cellular parameters is proposed to achieve rapid positioning of design space and significantly increase crashworthiness in a larger variable domain under out-of-plane dynamic impact. In stage I, a Taguchi-based grey correlation discrete optimization, combining Taguchi analysis, grey relational analysis, analysis of variance (ANOVA) with grey entropy measurement, is performed to determine the initial optimal value with a higher robustness and the significant influence variables. In stage II, a multi-objective design technique, namely non-nominated sorting genetic algorithm II based on surrogated model, is adopted to minimize the SEA and maximize the $a_p$ in a relatively small design domain. And it is found that the proposed two-stage hybrid method can broaden the optimal design space compared to that of traditional method attributable to its center point positioned by stage I. And the final optimization based on the proposed strategy is superior to the original structure, i.e., the SEA is increased by 47.55% and the $a_p$ is decreased by 80.8%. Therefore, the proposed algorithm can also be used to solve other more complicated engineering problems in a large design space with insightful design data.


ABSTRACT: An analytical solution is presented for the 3D static response of variable stiffness non-uniform composite beams. Based on Euler-Bernoulli theory, a set of governing differential equations are obtained, in which four degrees of freedom are fully coupled. For the variable stiffness beam, the governing field equations have variable coefficients reflecting the stiffness variation along the beam. Using the direct integration technique, the general analytical solution is derived in the integral form and the closed-form expressions of the obtained solutions are presented employing a series expansion approximation. The series expansion representation enables the proposed approach to be applicable for variable stiffness composite beams with arbitrary span-wise variation of properties. As an alternative solution, the Chebyshev collocation method is applied to the proposed formulation to verify the results obtained from the analytical solution. A number of variable stiffness composite beams made by fibre steering with various boundary conditions and stacking sequences are considered as the test cases. The static response are presented based on the analytical solution and Chebyshev collocation method and excellent agreement is observed for all test cases. The proposed model presents a reliable and efficient approach for capturing the complicated behaviour of variable stiffness non-uniform composite beams.


ABSTRACT: In this novel work, the electromechanical behavior of graphene-based nanocomposite (GNC) beams with flexoelectric and surface effects were investigated using size-dependent Euler-Bernoulli theory, linear piezoelectricity and Galerkin's weighted residual method along with modified strength of materials and finite element (FE) approaches. In addition, analytical and FE models were developed to study the static response of flexoelectric GNC nanobeams with various boundary conditions: cantilever, simply-supported and
clamped-clamped. The developed models predict that the effective piezoelectric coefficients of GNC are responsible for the actuation capability of a graphene layer in the transverse direction due to the applied field in its axial direction and the predictions by both the models are found to be in good agreement. Results reveal that the flexoelectric and surface effects on the static response of GNC nanobeams are significant and should be taken into account. The electromechanical response of GNC nanobeams can be tailored to achieve the required coupled electromechanical characteristics of a vast range of NEMS using various boundary conditions and thickness of nanobeam as well as volume fraction of graphene. Our fundamental study sheds a light on the possibility of developing high-performance and lightweight graphene-based NEMS such as nanosensors, nanogenerators and nanoresonators using non-piezoelectric graphene.


ABSTRACT: The dynamic analysis of viscoelastic pipes conveying fluid is investigated by the variable fractional order model in this article. The nonlinear variable fractional order integral-differential equation is established by introducing the model into the governing equation. Then the Shifted Legendre Polynomials algorithm is first presented for dealing with this kind of equations. The convergence analysis and numerical example verify that the algorithm is an effective and accurate technique for addressing this type complicated equation. Numerical results for dynamic analysis of viscoelastic pipes conveying fluid show the effect of parameters on displacement, acceleration, strain and stress. It also indicates that how dynamic properties are affected by the variable fractional order and fluid velocity varying. Most of all, the proposed algorithm has enormous potentials for the problem of high precision dynamics under the variable fractional order model.

Chunlei Li, Qiang Han, Zhan Wang and Xin Wu (School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, Guangdong Province 510640, P.R. China), “Analysis of wave propagation in functionally graded piezoelectric composite plates reinforced with graphene platelets”, Applied Mathematical Modelling, Vol. 81, pp 487-505, May 2020, https://doi.org/10.1016/j.apm.2020.01.016

ABSTRACT: This paper presents a semi-analytical approach to investigate wave propagation characteristics in functionally graded graphene reinforced piezoelectric composite plates. Three patterns of graphene platelets (GPLs) describe the layer-wise variation of material properties in the thickness direction. Based on the Reissner-Mindlin plate theory and the isogeometric analysis, elastodynamic wave equation for the piezoelectric composite plate is derived by Hamilton’s principle and parameterized with the non-uniform rational B-splines (NURBS). The equation is transformed into a second-order polynomial eigenvalue problem with regard to wave dispersion. Then, the semi-analytical approach is validated by comparing with the existing results and the convergence on computing dispersion behaviors is also demonstrated. The effects of various distributions, volume fraction, size parameters and piezoelectricity of GPLs as well as different geometry parameters of the composite plate on dispersion characteristics are discussed in detail. The results show great potential of graphene reinforcements in design of smart composite structures and application for structural health monitoring.


ABSTRACT: Sequential limit analysis (SLA) is an effective and normally used method to calculate the plastic limit load of structures with large deformation. However, attribute to the assumption of neglecting the changing behavior of shape and plane stress direction, the conventional SLA method would be inaccurate in the plastic response prediction for the large Shape-change structures, especially for the pressurized spherical cap. This research develops a novel analytical model for the pressurized spherical cap based on the advanced SLA method, which features introducing the moving coordinate system and considering of the changing behavior of shape and plane stress direction into the conventional method. With the proposed method, the effects of geometry and material parameters on the plastic limit load are analyzed. Compared with the validating FE simulation results of ABAQUS software, the newly extended SLA method performances a more precise
prediction of the load deflection response and plastic limit load than the normal one. Due to the limit yield
degree and bending moment, the accuracy of the new model will increase with the increase of yield strength and
radius. The larger the initial deflection of the pressurized spherical cap is, the smaller the relative error between
the analysis results of advanced SLA and FE method is. Moreover, this newly proposed SLA remains effective
and accurate within a wide range of the initial thickness-curvature radius ratio, especially for low elasticity
modulus materials.

Z.X. Lei and K.M. Liew (First author is from: School of Sciences, Nanjing University of Science and
Technology, Nanjing 210094, China), “Retraction notice to Multiscale MDFEM for modeling the mechanical
behavior of carbon nanotubes Applied Mathematical Modelling Volume 69, May 2019, Pages 466-492”;

Youheng Dong (1,2), Yinghui Li (1), Xiangyu Li (1) and Jie Yang (2)
(1) School of Mechanics and Engineering, Southwest Jiaotong University, Chengdu 610031, PR China
(2) School of Engineering, RMIT University, Po Box 71, Bundoora, VIC 3083, Australia
“Active control of dynamic behaviors of graded graphene reinforced cylindrical shells with piezoelectric
actuator/sensor layers”, Applied Mathematical Modelling, Vol. 82, pp 252-270, June 2020,
https://doi.org/10.1016/j.apm.2020.01.054

ABSTRACT: This work investigates the active vibration control and vibration characteristics of a sandwich thin
cylindrical shell whose intermediate layer is made of the graphene reinforced composite that is bonded with
integrated piezoelectric actuator and sensor layers at its outer and inner surfaces. The volume fraction of
graphene platelets in the intermediate layer varies continuously in the shell's thickness direction, which
generates position-dependent effective material properties. The constitutive relations of the graphene reinforced
composite and piezoelectric materials are given by taking one-dimensional steady thermal field into account.
Considering Donnell's shell theory, a final equation of motion in terms of the generalized radial displacement is
derived by using Hamilton's principle and Galerkin method. Shell's natural frequencies are derived considering
influences of the thermo-electro-elastic field. Introducing a constant velocity feedback control algorithm, active
vibration control of the sandwich cylindrical shell is presented by employing the Runge-Kutta method. The
feedback control gain has a pronounced effect on the damping, as well as the inertia of the system. Comparisons
between the present results and those in other papers are done to validate the present solutions. Influences of
weight fractions, distribution patterns and geometrical sizes of graphene platelets, temperature variations,
thicknesses of layers and the feedback control gain on the vibration characteristics and active vibration control
behaviors of the novel sandwich cylindrical shell are discussed.

Saeid Sahmani (1) and Babak Safaei (2)
(1) School of Science and Technology, The University of Georgia, Tbilisi 0171, Georgia
(2) Department of Mechanical Engineering, Eastern Mediterranean University, G. Magosa, TRNC Mersin 10,
Turkey
“Influence of homogenization models on size-dependent nonlinear bending and postbuckling of bi-directional
functionally graded micro/nano-beams”, Applied Mathematical Modelling, Vol. 82, pp 336-358, June 2020,
https://doi.org/10.1016/j.apm.2020.01.051

ABSTRACT: In this work, different homogenization schemes are employed to analyze both size-dependent
postbuckling and nonlinear bending behavior of micro/nano-beams, made of a bi-directional functionally
graded material (BDFGM), under external axial compression and distributed load. To such different
homogenization models, including Reuss, Voigt, Mori-Tanaka, and Hashin–Shtrikman bounds schemes,
together with nonlocal strain gradient elasticity theory are adopted within the framework of refined exponential
shear deformation beam theory, to develop a comprehensive size-dependent BDFGM beam model. Deviation of
associated physical neutral plane, from mid-plane counterpart, is also considered. Nonlocal strain gradient load-
deflection responses of BDFGM micro/nano-beam are obtained by numerical solution methodology for both
nonlinear bending and postbuckling behaviors corresponding to different values of the lateral and longitudinal
material property indices and various small scale parameters. We observed that by decreasing the values of
material property gradient indices, associated with BDFGM, difference between the estimations of various
homogenization schemes is raised. We also indicated that increasing maximum deflection, decreasing the
significance of nonlocal size effect on the bending strength of BDFGM micro/nano-beams, whereas strain
gradient size effect becomes more important. In addition, we found that at lower material property gradient indices, bending strength reduction in BDFGM micro/nano-beams, causes by the axial gradient property is higher than lateral gradient property. At higher values of these indices, however, the trend is opposite.

Yadwinder S. Joshan (1), Sushma Santapuri (1) and Neeraj Grover (2)
(1) Department of Applied Mechanics, Indian Institute of Technology Delhi Hauz Khas, New Delhi 110016, India
(2) Department of Mechanical Engineering, Thapar Institute of Engineering and Technology Patiala 147004, Punjab, India

ABSTRACT: This paper presents a non-polynomial coupled plate theory for smart composite structures employing inverse hyperbolic displacement and electric potential functions. The theory is utilized towards analysis of composite piezoelectric plates operating in sensor and actuator modes. Particularly, the following three cases are studied: (i) passive laminated composite structure, (ii) composite piezoelectric plate actuator and (iii) unimorph and bimorph piezoelectric plate sensors. Analytical solutions are obtained for simply supported plates under static electrical and mechanical loads. These results are validated with existing 3D elasticity solutions and compared with other plate theory solutions. Furthermore, parametric studies are performed to determine the effect of loading, span-to-thickness ratio and lamination sequence on the response of the piezoelectric plate. Finally, the theory is applied to a transverse shear sensing device which utilizes transverse shear-electric field coupling in piezoelectric materials. This effect is often ignored in literature.

It is observed that the maximum percentage error of the present theory, when compared with 3D results, is less than 3%, which is lower than other higher order plate theories.

M. Sayed (1), A.A. Mousa (2,3) and Ibrahim Mustafa (4,5)
(1) Department of Engineering Mathematics, Faculty of Electronic Engineering, Menoufia University, Menouf, Egypt
(2) Department of Mathematics and Statistics, Faculty of Science, Taif University, Taif, Saudi Arabia
(3) Department of Basic Engineering Sciences, Faculty of Engineering, Menoufia University, Shibin El-Kom, Egypt
(4) Department of Biomedical Engineering, Helwan University, Cairo, Egypt
(5) Department of Chemical Engineering, University of Waterloo, Waterloo, ON, Canada

ABSTRACT: In this paper, we focus on applying active control to nonlinear dynamical beam system to eliminate its vibration. We analyzed stability using frequency-response equations and bifurcation. The analytical solution of the nonlinear differential equations describing the above system is investigated using multiple time scale method (MTSM). All resonance cases were extracted from second order approximations. Numerical solutions of the system are included. The effects of most system parameters were investigated. The results demonstrated that proposed controller is efficient to suppress the vibrations. Increasing the quadratic stiffness coefficient term vanished the multi-valued solution. Bifurcation diagrams refied the effects of various system parameters on its stability showing different bifurcation cases. Finally, we conclude that for low values of natural frequencies dynamical system, the controller is more effective. The results show that the analytical solutions of the system are in good agreement with the numerical solutions.

Hossam A.A. Abdel-Gawad (1) and Berge Djebdjian (2)
(1) Irrigation and Hydraulics Engineering Department, Faculty of Engineering, Mansoura University, El-Mansoura 35516, Egypt
(2) Mechanical Power Engineering Department, Faculty of Engineering, Mansoura University, El-Mansoura 35516, Egypt

ABSTRACT: For the first time, the wave characteristic method (WCM) is used to simulate transient flow in viscoelastic pipes. The WCM is based on Newton's second law equating the change in momentum and net
pressure forces applied on the liquid, which leads to the Joukowsky equation. The friction head loss within a pipe segment is replaced by an imaginary friction orifice with the same head loss. Here the Joukowsky equation is rederived for elastic pipes on the basis of the conservation of energy principle. Then the same method is used to derive a quadratic equation for the conservation of energy in viscoelastic pipes. Under a relaxation assumption, the square root of the energy equation yields a linear equation that is applicable with the superposition principle. The method developed is studied numerically and verified with experimental data from the literature. The water hammer in a simple pipe system consisting of a reservoir, a pipe, and a valve is demonstrated. Parameters calibrated with the method of characteristics are taken from the literature and used as essential input data for the proposed WCM. A constant friction coefficient of the pipe is considered. Even if a small number of friction orifices are selected, good agreement is found between the experimental data and the simulation results especially for the first pressure head cycles. Finally, the numerical results obtained with both the WCM and the method of characteristics are compared to investigate the effectiveness of the WCM. The WCM shows superior computational efficiency in determining the maximum pressure.

Feng Liang (1), An Gao (1) and Xiao-Dong Yang (2)
(1) College of Mechanical Engineering, Yangzhou University, Yangzhou 225127, China
(2) Beijing Key Laboratory of Nonlinear Vibrations and Strength of Mechanical Engineering, College of Mechanical Engineering and Applied Electronics, Beijing University of Technology, Beijing 100124, China


ABSTRACT: In this paper, a dynamical model of spinning multi-span pipes conveying fluid is proposed and the transverse natural and resonant frequencies and mode characteristics of such system are explored. The pipe body is considered to be composed of functionally graded materials (FGMs), in which a power law is used to govern the distribution of material properties along the pipe wall thickness. The partial differential equations (PDEs) governing two transverse motions of the pipe are derived by the extended Hamilton principle, in which the contributions of the FGM and intermediate supports are highlighted. The PDEs are discretized by the Galerkin procedure and the eigensystem theorem is applied to find the numerical solutions. The results show that various frequency characteristics can be attainable by use of different materials and mixing patterns. Attachments of intermediate supports can heighten the rigidity and improve the stability of spinning FG pipes conveying fluid, which are consequently used as “stabilizers” for the slender drill strings. Also, the mode characteristics of different spans will determine the locations of vibration amplitude of the pipes.

Zhou-Zhou Pan (1), Xiuhua Chen (2) and Lu-Wen Zhang (1)
(1) Department of Engineering Mechanics, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
(2) School of Aeronautics and Astronautics, Shanghai Jiao Tong University, Shanghai 200240, China


ABSTRACT: A modeling of the large amplitude free vibration of pretwisted hybrid composite blades is studied by considering the laminated structure which is composed of carbon nanotube reinforced composite (CNTRC) layers and matrix cracked fiber reinforced composite (FRC) layers. Two assumptions are made to facilitate this vibration study of hybrid nanocomposite: (1) CNTs are distributed across the layer thickness uniformly or functionally graded, and (2) the parallel slit matrix cracks disperse in the matrix homogeneously. Based on the theory of differential geometry, a novel shell model for pretwisted hybrid nanocomposites blade is developed. The von Kármán strains are adopted to capture the geometrically nonlinear behaviors of blades. The established governing equations are solved accurately and efficiently via the IMLS-Ritz method. The proposed numerical model is verified by making comparison studies and then the influence of crack density, pretwisted angle, CNT distribution and volume fraction, aspect ratio, width-to-thickness ratio, and ply-angle on the large amplitude vibration characteristics of matrix cracked pretwisted hybrid composite blade are scrutinized systematically. The present study serves as a useful benchmark to researchers who intend do further research in this topic.

Yeui-Lung Lei (1), Kang Gao (2,3), Xinwei Wang (4) and Jie Yang (2)

ABSTRACT: This paper investigates the dynamic behaviors of single- and multi-span functionally graded porous (FGP) beams with flexible boundary constraints modelled by a combination of two-dimensional translational springs and a rotational spring. It is assumed that the pores are distributed either non-uniformly or uniformly according to four porosity distributions and that the material properties vary smoothly along the thickness direction of the beam. The dynamic governing equations are derived from Hamilton's principle within the framework of Timoshenko beam theory and solved by using discrete singular convolution element method (DSCEM) in conjunction with Taylor series expansion (TSE) method. To validate the accuracy of the proposed method, the present results are compared with those in open literature and obtained by finite element method (FEM). A comprehensive parametric study is conducted to investigate the effects of spring constants, boundary condition, porosity distribution, porosity coefficient and beam span ratio on the dynamic behaviors.


ABSTRACT: This paper deals with a numerical model for the buckling and post-buckling analysis of single-wall carbon nanotubes. Reasons of efficiency lead to the choice of a simple molecular statics model, wherein binary, ternary and quaternary atomic interactions are accounted for and described using Morse and cosine potential functions. The equations of the model are discussed in depth and the parameters of the potential functions are justified in the light of a comparison with ab-initio results. Several case studies regarding zigzag and armchair tubes of different aspect ratios, under compression, bending and torsion, are addressed with the aim of investigating the efficacy of the model and the role of the quaternary interactions, in contexts of both global and local behaviours.

Qiliang Wu (1,2) and Guoyuan Qi (2)
(1) Post-doctorate Research Station of Mechanical Engineering, School of Mechanical Engineering, Tiangong University, Tianjin, 300387, PR China
(2) Tianjin Key Laboratory of Advanced Technology of Electrical Engineering and Energy, Tiangong University, Tianjin, 300387, PR China


ABSTRACT: The homoclinic bifurcations and nonplanar chaotic waves in axially moving beam (AMB) under thermal excitation are investigated. By the multiple scale technique, the equivalent nonlinear system is derived to explore qualitatively the dynamical characteristics of AMB system for the case of primary resonance. Using Melnikov approach as well as geometric analysis, the criterion for homoclinic chaos and complex nonplanar motions for AMB system is discussed. The theoretical predictions are tested by the numerical approach. For the design and application of the AMB, some inspiration and guidance are provided by the results from theory and simulation.

Aleksandar Nikolić and Slaviša Šalinić (Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Dositejeva 19, Kraljevo 36000, Serbia), “Free vibration analysis of cracked beams by using rigid segment method”, Applied Mathematical Modelling, Vol. 84, pp 158-172, August 2020, https://doi.org/10.1016/j.apm.2020.03.033
ABSTRACT: This paper deals with the analysis of influence of crack parameters to the modal characteristics of beams at various boundary conditions by using rigid segment method. The beam was discretized by a number of rigid segments which were connected by elastic joints with three degrees of freedom, while the crack was described by cracked element based on fracture mechanics. This model allows detection of coupling between the axial and transverse vibrations under the special boundary conditions. The proposed approach covers both the Euler–Bernoulli and Timoshenko beam model. The efficiency of the method was shown through the few numerical examples.


ABSTRACT: In the present article, the idea of using the variable-order fractional-derivative thermoviscoelastic constitutive laws in dynamic stress and vibration analysis of the engineering structures, the required implementation backgrounds, and the relevant numerical solution procedures are investigated for the first time. In this regard, dynamic 3D stress and displacement fields and radial/transverse vibrations of transversely graded viscoelastic spinning thick plates/discs exposed to sudden thermoelastic loads are investigated. Instead of using the approximate plate theories, the exact thermoviscoelasticity theory is employed in the development of the governing equations. Since the variable fractional order is dependent on the localized deformation rates, the resulting thermoviscoelastic integro-differential equations are nonlinear. These equations are solved by utilizing a combination of the second-order backward/central/forward finite difference discretization of the spatial and time domains, numerical evaluation and updating of the Caputo-type fractional derivatives, updating the growing number of terms of the governing equations, and Picard's iterations. Various edge conditions are considered. Finally, comprehensive sensitivity analyses and various 3D plots are presented and discussed regarding the effects of the variable fractional order of the constitutive law, time variations of the nonuniformly distributed transverse loads, and edge conditions on the distributions and damping of the resulting displacement and stress components.


ABSTRACT: Geometric modeling and numerical analysis of multi-directional FGM (Functionally Graded Material) plate, whose material properties grade continuously both in its thickness and in-plane directions, are increasingly required. In this work, postbuckling behavior of this type of plates with multiple cutouts is, for the first time, numerically investigated through the combination of NURBS-based IGA (IsoGeometric Analysis) and FCM (Finite Cell Method). The nonlinear deformation of plate is determined by TSDT (Third-order Shear Deformation Theory) and von Kármán nonlinear assumptions without the requirement of SCFs (shear correction factors). Besides, the higher continuity advantage of NURBS basis functions can easily meet the C-continuous requirement of the displacement field. The main contribution is introducing the FCM to deal with the influence of complex cutouts on the postbuckling characteristics. The geometric interfaces of the cutouts are approached and approximated by adaptive quadrature procedure in the distinguished cut elements. The advantage of this implementation is that the previously tricky process of representing the geometry of perforated plate with multiple NURBS patches can be eliminated, which naturally avoids the imposition of C-continuity condition across the patch boundaries. The cylinder arc-length method combined with modified Newton–Raphson iteration algorithm, which takes into account of the initial geometric imperfections, is applied to implement geometrically nonlinear stability analysis and track the postbuckling paths. The effectiveness and reliability of the presented method are verified with available solutions of isotropic and conventional perfect FGM plates. Subsequently, a series of factors, including material volume fraction, length-to-thickness ratio, boundary condition, cutout size, etc., affecting the postbuckling responses of multi-directional perforated FGM plates are considered and investigated.

Ali Ebrahimi-Mamaghani (1), Hoda Sarparast (1) and Masoud Rezaei (2)
(1) South Tehran Branch, Islamic Azad University, Tehran, Iran
ABSTRACT: In the present investigation, the forced and free vibrations of axially functionally graded (AFG) Rayleigh and Euler-Bernoulli (EB) beams subjected to a moving load are studied and compared, aiming at performance enhancement of transportation systems. Also, for the first time, a precise mathematical modeling is obtained to analyze the influence of various key factors such as axial material gradation and rotary inertia factor on the critical speed, dynamic magnification factor, mechanisms of cancellation, and maximum free vibration of the system. Model verification is performed with the available results in the literature, and a good agreement is observed. Furthermore, the dynamical responses of the system acquired from the analytical and numerical approaches are in good agreement. It is demonstrated that for the gradient parameter, which is lower and higher than the critical value, the material properties variation has a reverse effect on the forced-free vibration amplitudes. Besides, it is concluded that, compared with the conventional isotropic EB beams, by selecting appropriate values of rotary inertia factor and gradient parameter in the AFG Rayleigh beams, the cancellation and maximum free vibration phenomena can be controlled. The results of this study can serve as a comprehensive benchmark to optimally design inhomogeneous structures under moving loads.

ABSTRACT: In this paper, a semi-analytical method for the free vibration behavior of spiral stiffened multilayer functionally graded (SSMFG) cylindrical shells under the thermal environment is investigated. The distribution of linear and uniform temperature along the direction of thickness is assumed. The structure is embedded within a generalized nonlinear viscoelastic foundation, which is composed of a two-parameter Winkler-Pasternak foundation augmented by a Kelvin-Voigt viscoelastic model with a nonlinear cubic stiffness. The cylindrical shell has three layers consist of ceramic, FGM, and metal in two cases. In the first model i.e. Ceramic-FGM-Metal (CFM), the exterior layer of the cylindrical shell is rich ceramic while the interior layer is rich metal and the functionally graded material is located between these layers and the material distribution is in reverse order in the second model i.e. Metal-FGM-Ceramic (MFC). The material constitutive of the stiffeners is continuously changed through the thickness. Using the Galerkin method based on the von Kármán equations and the smeared stiffeners technique, the problem of nonlinear vibration has been solved. In order to find the nonlinear vibration responses, the fourth order Runge–Kutta method is utilized. The results show that the different angles of stiffeners and nonlinear elastic foundation parameters have a strong effect on the vibration behaviors of the SSMFG cylindrical shells. Also, the results illustrate that the vibration amplitude and the natural frequency for CFM and MFC shells with the first longitudinal and third transversal modes ($m = 1$, $n = 3$) with the stiffeners angle $\theta = 30^\circ$, $\beta = 60^\circ$ and $\theta = \beta = 30^\circ$ is less than and more than others, respectively.

ABSTRACT: An analytical spectral stiffness method is proposed for the efficient and accurate buckling analysis of rectangular plates on Winkler foundation subject to general boundary conditions (BCs). The method combines the advantages of superposition method, stiffness-based method and the Wittrick–Williams algorithm. First, exact general solutions of the governing differential equation (GDE) of plate buckling considering both elastic foundation and biaxial loading is derived by using a modified Fourier series. The superposition of such general solutions satisfy the GDE exactly and BCs approximately, which guarantees the rapid convergence and high accuracy. Then, based on the exact general solution, the spectral stiffness matrix which relates the coefficients of plate generalized displacement BCs and force BCs is symbolically developed. As a result, arbitrary BCs can be prescribed straightforwardly in the stiffness-based model. As an efficient and reliable solution technique, the Wittrick–Williams algorithm with the $J$ problem resolved is applied to obtain the critical buckling solutions. The accuracy and efficiency of the method are verified by comparing with other methods. Benchmark buckling solutions are provided for plates with all possible boundary conditions. Also, dependence
of various factors such as foundation stiffness, load combinations and aspect ratio on the buckling behaviors are investigated.


ABSTRACT: This study explores heat-induced nonlinear vibration of a functionally graded (FG) capacitive nanobeam within the framework of nonlocal strain gradient theory (NLSGT). The elastic FG beam, which is firstly deflected by a DC voltage, is driven to vibrate about its deflected position by a periodic heat load. The nano-structure, which consists of a clamped-clamped nanobeam, is modeled assuming Euler-Bernoulli beam assumption which accounts for the nonlinear von-Karman strain and the electrostatic and intermolecular forcing. To simulate the static and dynamic responses, a model reduction procedure is carried out by employing the Galerkin method. The method of Averaging as a regular semi-analytic perturbation method is applied to obtain governing equations of the steady-state responses. With the purpose of establishing the validity of the solution, a Shooting technique in conjunction with the Floquet theory is used to capture the periodic motions and then examine their stability. The nonlinear resonance frequency of the FG nanobeam near its fundamental natural frequency (primary resonance) and near principal parametric resonance is investigated while the emphasis is placed on studying the effect of various parameters including DC voltage, amplitude of the periodic heat source, material index, damping ratio, and small scale parameters. The main objective of this study is to model a miniature structure which can be used as either a sensitive remote temperature sensor or a high-efficiency thermal energy harvester.


ABSTRACT: A geometrically nonlinear (3,2) unified zigzag beam element is developed with a reduced number of degree-of-freedom for the large deformation analysis. The main merit of the beam element model is the Kirchhoff and Cauchy shear stress solution for large deformation and large strain analysis is more accurate. The geometrically nonlinearity is considered in the calculation of the zigzag coefficients. Thus, the results of shear Cauchy stress are matching well with solid element analysis in case of the beam with aspect ratio greater than 20 under large deformation. The zigzag coefficients are derived explicitly. The Green strain and the second Piola Kirchhoff stress are used. The second Piola Kirchhoff shear stress is continuous at the interface between adjacent layers priori. The bottom surface second Piola Kirchhoff shear stress condition is used to determine the zigzag coefficient and the top surface second Piola Kirchhoff shear stress condition is used to reduce one degree-of-freedom. The nonlinear finite element equations are derived. In the numerical tests, several benchmark problems with large deformation are solved to verify the accuracy. It is observed that the proposed beam has accurate solution for beam with aspect ratio greater than 20. The second Piola Kirchhoff and Cauchy shear stress accuracy is also good. A convergence study is also presented.


ABSTRACT: Multi-step Timoshenko beams coupled with rigid bodies on springs can be regarded as a generalized model to investigate the dynamic characteristics of many structures and mechanical systems in engineering. This paper presents a novel transfer matrix method for the free and forced vibration analyses of the hybrid system. It is modeled as a chain system, where each beam and each rigid body with its supporting spring are dealt with one element, respectively. The transfer equation of each element is deduced based on separation of variables method. The system overall transfer equation is obtained by substituting an element transfer equation into another. Then, the free vibration characteristics are acquired by solving exact homogeneous linear equations. To compute the forced vibration response with modal superposition method, the body dynamic equations and augmented eigenvectors are established, and the orthogonality of augmented eigenvectors is
mathematically proved. Without high-order global dynamic equation or approximate spatial discretization, the free and forced vibration analyses of the hybrid system are achieved efficiently and accurately in this study. As an analytical approach, the present method is easy, highly stylized, robust, powerful and general for the complex hybrid systems containing any number of Timoshenko beams and rigid bodies. Four numerical examples are implemented, and the results show that this method is computationally efficient with high precision.


ABSTRACT: Slightly curved pipes are prevalent in many industries including oil installations especially in the Delta regions of the world. The aim of this paper therefore is to investigate the nonlinear dynamics of these pipes conveying fluids under the influence of thermal loadings. These investigations are for three different boundary conditions, namely simply supported ends, clamped-clamped ends and clamped-simply supported ends respectively. To derive the governing equations, small strains of initial curvature, temperature, tension, pressure, longitudinal and transverse strains are considered. Furthermore, strains due to curvature change during bending which are hitherto neglected in most of the previous works on slightly curved pipes are added. The strain due to initial curvature accounts for the geometric imperfection. Two coupled nonlinear differential equations in both longitudinal and transverse directions are obtained and solved using eigenfunction expansion method, up to four modes. Linear natural frequencies were obtained, and is shown that for various boundary conditions, it increases as the initial curvature increases and decreases as thermal loading increases. The nonlinear results obtained show that the amplitude of the pipe motion becomes larger due to the obvious effect of thermal loading. Nonlinear results for both vanishing and non-vanishing longitudinal displacements are presented.


ABSTRACT: The paper is aimed at enhancing computational performance for optimizing the material distribution of tri-directional functionally graded (FG) plates. We exploit advantages of using a non-uniform rational B-spline (NURBS) basis function for describing material distribution varying through all three directions of functionally graded (FG) plates. Two-dimensional free vibration and buckling behaviors of multi-directional (1D, 2D and 3D) FG plates analyzed by using a combination of generalized shear deformation theory (GSDT) and isogeometric analysis (IGA) is first proposed. This approach can help to save a significant amount of computational cost while still ensure the accuracy of the solutions. The effectiveness and reliability of the present method are demonstrated by comparing it to other methods in the literature. The obtained results are in excellent agreement with the reference ones. More importantly, data sets consisting of input-output pairs are randomly generated from the analysis process through iterations for the training process in deep neural networks (DNN). DNN is utilized as an analysis tool to supplant finite element analysis to reduce computational cost. By using DNN, behaviors of the multi-directional FG plates are directly predicted from those material distributions. Optimal material distributions of tri-directional FG plates under free vibration or compression in various volume fraction constraints are found by using modified symbiotic organisms search (mSOS) algorithm for the first time. Moreover, an isogeometric multimesh design technique is also used to diminish a large number of design variables in optimization. Optimal results obtained by DNN are compared with those of IGA to verify the effectiveness of the proposed method.


ABSTRACT: In this manuscript, slow-fast motions in a two degrees of freedom model under slow parametric and fast external excitations are analyzed using analytical and numerical methods. By expressing the state variables as the sums of slowly varying average and fast oscillations, the averaged equations which govern the
slow dynamics for different magnitudes of external amplitude are obtained. For the averaged equations, analyzation about the equilibria and the corresponding stability shows that, the averaged slow manifolds constitute a pitchfork structure. Meanwhile, the harmonic balancing method is used to compute the slowly varying envelopes of the fast oscillations. On the other hand, bifurcation diagrams of the fast sub-system show structures in accordance with the pitchfork obtained from averaged equations as well as the amplitude curves computed by harmonic balancing method. Two forms of relative location between the folds of cycle on the handle and pitchfork bifurcation point are presented. Based on these, concerning on the slow-fast flow, two patterns of transition behavior between the handle and the upper (lower) branch of pitchfork namely “pitchfork/pitchfork” and “fold/pitchfork” types are analyzed, which indicate the dynamic buckling behaviors. Particularly, discussion about the influence of external excitation shows that, for case of near-resonant external frequency, increasing the amplitude of external excitation will change the local structures as well as the quantitative properties of the pitchfork, but holistic form of pitchfork type is a topological invariant.

ABSTRACT: The idea of this manuscript is to convert nonlinear positive position feedback (PPF) controllers with symmetric cross-ply composite piezoelectric laminated plates among mixed excitations. A new six degrees of freedom model simulating nonlinear vibrations (NVs) of a composite plate has proposed. The perturbation technique has used to study the transient and steady-state response of nonlinear dynamic equations that presented the main system. The stability of the system via frequency response curves (FRCs) and force response curves (FRCs) have discussed and calculated. The effect on every coefficient's system has considered numerically. A comparison has been made between PPF controller and another control Nonlinear Saturation Control (NSC) to show the amount of vibration reduction produced by the system using PPF control is better than that NSC. Numerical outcomes show that PPF methods have big effects on reducing vibrations of the amplitudes. Then, the predictions from numerical simulations are in excellent harmony with frequency response curves. Lastly, the comparison with newly available papers has been reported.

ABSTRACT: This paper studies the parametric modal characteristics of non-uniform multi-span oil-conveying pipes, considering many combined factors such as the various foundations that pipes rest on, the accessory masses attached to the pipes, and the flow moving inside the pipes. A new modified lumped-mass transfer matrix method (LTMM) is proposed to derive the governing equation of the system, where we simplified and modeled all the combined factors as lumped masses and springs that can be treated in uniform ways. The boundary is also modeled in a similar lumped-spring strategy. In such a way, the system with combined factors and various boundary conditions is eventually modeled as a “Free-Free” pipe with only lumped masses and springs. Numerical results are illustrated to testify the accuracy and efficiency of the proposed method, and a general case with combined factors affecting the modal characteristics is discussed. It can be presented that rotary inertia and concentrated mass can affect different order mode shapes; under different foundation parameters, the differences between mode shapes are remarkable while the positions of the nodes do not change much, even under classical boundary condition. The results through modal analysis can afford the basis for the vibration analysis, fault diagnosis and prediction, and the optimization design of the dynamic characteristics of the structure.

ABSTRACT: Nonlinear transversely vibrating beams, including a uniform beam carrying a lumped mass and a transversely vibrating quintic nonlinear beam, are considered in this paper. Firstly, using trigonometric function, analytical solutions to their Cauchy initial problems are constructed in parametric and closed-form. Secondly, it
is found that one has the freedom to choose any periodic function to simulate the periodic vibration theoretically. As an example, we also construct parametric and closed-form solution expressed by Jacobi elliptic function. Thirdly, by comparing the two kinds of derived solutions, it is shown that the Jacobi elliptic function solution can degenerate to the corresponding trigonometric function solution when the modulus tends to zero. Comparison are also made between our derived Jacobi elliptic function solution and other’s exact solution, which indicates that the presented parametric solution method is more general.


ABSTRACT: A new model with analysis for the propagation of flexural waves in a phononic plate at nanoscale is developed. The Mindlin (or first-order) plate theory is further generalized to establish the governing equations for flexural waves in a phononic plate with surface effect, for which the plane wave expansion method is applied to derive the dispersion relation. A numerical model is developed using the finite element method and very good consistency between theory and numerical solution is observed. It is found that the surface density and the surface residual stress play the main role that affects the band structures. The surface effect can be approximately regarded as the competition between frequency decrease due to surface density and frequency increase caused by surface residual stress, which effectively increases the low-frequency bands but decreases the high-frequency bands. The quantum spin Hall effect is observed in the phononic plate at nanoscale, and the surface effect is studied numerically. By applying the $k\cdot p$ perturbation method, a theoretical framework is established to calculate the spin Chern number, which is an important topological invariant that determines the quantum spin Hall effect. Based on the topological analysis, an efficient waveguide with a zig-zag path is designed, in which a topologically protected wave in the interface state can robustly propagate along the path against disorders. The theory and numerical study developed in this paper will help better understand the size-dependent quantum spin Hall effect in nanostructures and it may also provide guidance for the design of topological wave devices at nanoscale.


ABSTRACT: The present research deals with thermal buckling and postbuckling of sigmoid functionally graded material (S-FGM) plates with porosities resting on elastic foundation based on the popular third-order shear deformation theory and the well-known von Kármán large deflection assumption. Special attention is paid to scrutinize the secondary instability that occurs during postbuckling regime. In addition, the transitions of deflection shapes of the plates under various boundary conditions between primary and secondary postbuckling paths are investigated. A displacement control strategy and a meshfree radial point interpolation method (RPIM) which employs a radial basis function without any adaptive parameters are utilized synthetically to carry out thermal buckling loads and postbuckling paths of the plates numerically. Numerical comparisons are performed to verify the convergence of the modified RPIM and the accuracy of iteration method in postbuckling path analysis. The influences of functionally graded index, porosity coefficient and parameters of elastic foundation to behaviors of the thermal buckling and especially the secondary instability occurs during postbuckling regime are investigated. It is found that the secondary instability is sensitive to the boundary conditions.


ABSTRACT: A novel equivalent dynamic model is developed for coupled vibration analysis of the space antenna truss to enhance the design capacity of vibration controllers. Based on energy equivalence principle, the space antenna truss with two important features of rigid joints and complicated configuration is equivalent to a spatial anisotropy Timoshenko beam model. According to the kinematic assumptions, strain and kinetic energy expressions of the spatial periodic element can be obtained in accordance with displacement components at its
center. Hamilton's principle is carried out to formulate the governing partial differential equations of motion for the equivalent beam model (EBM) which is divided into two sets of PDEs. Each set of PDEs includes three degrees of freedom and describes bending-torsion and bending-extension couplings respectively, due to the asymmetry of the antenna truss. An exact analytical method is developed to solve the two sets of coupled motion equations. The natural characteristics of the EBM are shown to be in excellent agreement with those of the finite element method, which demonstrates that the proposed EBM can provide a satisfactory accuracy for the antenna truss. In addition, since the mode shapes of the EBM are expressed as analytical functions of the spatial coordinate, such an approach may lead the investigations of dynamic property and the design of vibration control law to become convenient for the space antenna truss.


ABSTRACT: A size-dependent nonlinear bending theory for axisymmetric thin circular plate is proposed by using the principle of minimum potential energy. The formulation is based on the strain gradient theory of Zhou et al. and the von Kármán geometric nonlinearity. The governing equations and boundary conditions are obtained and further reduced to that based on the couple stress theory, modified couple stress theory and even classical theory by neglecting some or all strain gradient components, respectively. Besides, the corresponding linear theory is also obtained by excluding the nonlinear terms from the present theory. The bending problems for both simply supported and fully clamped circular plate subjected to uniformly distributed load are solved by using the differential quadrature method (DQM) and iteration method. The comparison between theoretical and numerical results of linear bending deflection shows good agreement. The numerical results of nonlinear bending deflection based on these different theories reveal the size-dependency of circular plate bending rigidity. The effect of strain gradients enhances the bending rigidity of circular plate, in which rotation gradient plays a dominant role in controlling the stiffening effect of bending rigidity. When the thickness of circular plate is close to the higher-order material constant, the strain gradient effects are comparable or even dominant in comparison with the traditional bending rigidity. When the thickness of circular plate is much greater than the higher-order material constant, all strain gradient effects can be ignorable and the differences of deflections among these theories are negligible.

References listed at the end of the paper:
2 M. Haterbouch, R. Benamar, Geometrically nonlinear free vibrations of simply supported isotropic thin circular plates, J. Sound Vib., 280 (3-5) (2005), pp. 903-924
30 S. Sidhارد, M.C. Ray, Exact solution for size-dependent elastic response in laminated beams considering generalized first strain gradient elasticity, Compos. Struct., 204 (2018), pp. 31-42
34 X. Zhao, S. Zheng, Z. Li, Size-dependent nonlinear bending and vibration of flexoelectric nanobeam based on strain gradient theory, Smart Mater. Struct., 28 (2019), Article 075027


ABSTRACT: The non-classical Bernoulli-Euler beam model contains a material length scale parameter to account for the microstructure effect on the bulk material and three surface elasticity constants to capture the distinguished material properties on a surface. The present work is dedicated to develop a new effective computational approach for the non-classical Bernoulli-Euler beam model based on the isogeometric analysis (IGA) with high-order continuity basis functions of non-uniform rational B-splines (NURBS), which effectively fulfills the higher continuity requirements in the non-classical Bernoulli-Euler beam. To verify the new approach, the numerical results obtained from the new developed approach of the two applications for both simply supported and cantilever beams are compared with the corresponding analytical results available in the literature. Eventually, the approach verified is further utilized to explore the effects of microstructure and surface energy on beam deflection and natural frequency. For the static bending problem, it is detected that both the microstructure and surface energy effects enhance the beam bending stiffness. And for the free vibration problem, it is found that both the microstructure and surface energy effects increase the beam natural frequency. Furthermore, it is seen that the effect of microstructure on the natural frequency is more significant than the surface energy effect at nanoscale.

References listed at the end of the paper:
https://doi.org/10.1007/s00033-014-0455-0

ABSTRACT: This paper presents a frequency domain spectral finite element model (SFEM) for studying wave propagation in laminated composite shell panels. The SFEM formulation is derived using two different theories: (i) the first order shear deformation theory (FSDT) that takes shear deformation into consideration, and (ii) the classical shell theory (CST) that neglects shear deformation. The spectral approach here is based on the use of fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT). The spectral element uses exact shape functions and a frequency dependent exact dynamic stiffness matrix is obtained relating the nodal displacements to the nodal forces of an element. The formulation is validated by comparing the present results for wavenumber dispersion and natural frequencies with the published results. The present SFEM is then used to perform wavenumber dispersion, phase and group velocities, and wave propagation analyses of laminated composite shell panels. The numerical studies show that the wavenumbers obtained from the SFEM based on the CST are significantly different from those of the FSDT at high frequencies. The CST results for the group velocity and wave propagation response to tone burst excitation show significant deviation from the FSDT results for out-of-plane A flexural mode even at relatively low frequencies. The orthotropy ratio and lamination arrangements in a composite shell panel have significant effect on the group velocity as well as the flexural mode wave propagation response.

ABSTRACT: The subject of the paper is a simply supported circular plate with symmetrically varying mechanical properties in the thickness direction. In extreme cases of this variability, the plate becomes a single-layer or three-layer structure. The main goal of the study is to develop a mathematical description of both a single-layer and three-layer structure using one formula. The mathematical model also includes all intermediate states of the plate in the axisymmetric bending and buckling problems with consideration of the shear effect. To this purpose, two dimensionless functions closely related to the variability of mechanical properties were introduced and the nonlinear hypothesis of deformation of the straight line normal to the plate neutral surface is assumed. Based on the principle of stationary potential energy two differential equations of equilibrium are obtained. The system of equations is analytically solved. The deflections and intensity of critical loads for example plates are derived and presented in Tables.

Wei-Li Ma, Zi-Cheng Jiang and Xian-Fang Li, “Effect of warping shape on buckling of circular and rectangular columns under axial compression”, Applied Mathematical Modelling, Vol. 89, Part 2, pp 1475-1490, January 2021, [https://doi.org/10.1016/j.apm.2020.08.003](https://doi.org/10.1016/j.apm.2020.08.003)

ABSTRACT: The structural stability of a column with rectangular and circular cross-section under axial compression is studied based on various higher-order shear deformation beam theories. This paper has two-fold objectives. One is to introduce a transition parameter to describe the direction of axial load from Engesser’s hypothesis to Haringx’s one, then a unified method is presented to determine the critical load. The other is to introduce new cross-section warping shapes of rectangular and circular columns, then the buckling loads are exactly calculated and compared for various warping shapes. A governing equation for buckling of a column under axial compression is first derived. The buckling loads of a prismatic column with typical ends such as clamped-clamped, pinned-pinned, and clamped-free columns are determined and an explicit expression is obtained in terms of the Euler buckling load. The effects of the warping shape of the cross-section on the buckling loads are analyzed. The Haringx buckling load is greater than the Engesser buckling load that gives a conservative estimate of the critical load. A comparison of these buckling loads with Euler loads is made. The obtained results indicate that Euler buckling loads are both significantly overestimated for short columns or those with weak shear rigidity. The buckling loads are nearly not affected for very slender columns or those with high shear rigidity. The Euler loads are recovered from the present ones for columns in the case of shear locking. The buckling loads are also dependent on the warping shape of the cross-section.


ABSTRACT: Space deployable structures are widely used in aerospace engineering, which have been addressed new folding methods, such as spatial overconstrained linkages and origami structures. This paper proposes a novel kirigami-inspired space cylindrical surface deployable structure with a large deployment ratio and a few degrees of freedom, as well as its optimization design method. Based on the thick panel kirigami model proposed in our previous study, a kirigami network is presented. The construction of a physical model based on a kirigami network is discussed. A mathematical model to describe the deployed surfaces of the physical model is provided, and an optimization design method for cylindrical surface deployable structures based on the kirigami network is proposed. Finally, the prototypes of a parabolic cylindrical antenna and a cylindrical antenna are constructed based on the proposed optimization design method as an example. Our study provides a new method of designing cylindrical surface deployable structures for aerospace engineering applications.


ABSTRACT: This study deals with free, forced undamped vibration and the random, damped vibration of an inhomogeneous beam composed of two materials with significantly different elastic moduli and material densities. Exact solution is obtained for natural frequencies and the mode shapes using Krylov-Duncan functions, along with the comparison with the results furnished by the Galerkin's method. Random vibrations of the bi-material beams are studied for the first time in the literature for the case of proportional damping. Novel element of this study consists in the unintuitive finding that the response of the bi-material beam may
ABSTRACT: In the current investigation, a new formulation for nonlinear vibration behaviors of functionally graded (FG) composite conical nanoshells are constructed using Gurtin-Murdock elasticity theory based on higher-order shear deformation shell theory (HSDFST) framework. Both Voigt and Reuss homogenization procedures are considered for the estimation of the mechanical characteristics of FG materials. Using generalized differential quadrature method (GDQM) together with Galerkin technique, the surface elastic-based nonlinear frequency-responses of FG composite conical nanoshell are obtained. It has been illustrated that the decrease of material property gradient index or transformation of boundary condition from full simply supported to full clamped, surface stress effect on the nonlinear frequency of a FG composite conical nanoshell reduces. Also, decreasing semi-vertex angle increases the frequency ratio of $\omega_{NL}/\omega_{L}$ which reveals higher geometrical nonlinearity. However, it is seen that surface elasticity effect on the nonlinear vibration behavior of FG composite conical nanoshells is not significant.


ABSTRACT: In the present study, the nonlinear random vibration of a porous functionally graded nanobeam supported by a viscoelastic foundation has been investigated by making use of the statistical linearization method for the first time. Nonlocal Euler-Bernoulli beam theory with von Kármán type nonlinearity is utilized to derive the governing equation of the motion of the FG porous nanobeam. Two types of porosity distribution have been considered for the FG beam. To discretize the governing equation Galerkin's method is applied. The mean square value of the response of the resulted Duffing’s equation in the presence of a random input with nonzero mean value has been extracted using statistical linearization method. The results of the present study are compared with the analytical results of the FPK approach and the results of the perturbation method for the classical limit case of the homogeneous beam. It is revealed through detailed numerical analysis that the statistical linearization method (in contrast to the perturbation method) gives reliable results and there is an excellent agreement between its results and the analytical results. The effect of various parameters on the mean value of the response is also investigated numerically and illustrated graphically. It is found that the mean square value of vibrations increases when porosity, power-law index, nonlocal parameter, or the mean value of the input increases.


ABSTRACT: For the first time, the structural dynamics and vibrational stability of a viscoelastic axially functionally graded (AFG) beam with both spinning and axial motions subjected to an axial load are analyzed, with the aim to enhance the performance of bi-gyroscopic systems. A detailed parametric study is also performed to emphasize the influence of various key factors such as material distribution type, viscosity coefficient, and coupled rotation and axial translation on the dynamical characteristics of the system. The material properties of the system are assumed to vary linearly or exponentially in the longitudinal direction with viscoelastic effects. Adopting the Laplace transform and a Galerkin discretization scheme, the critical axial and spin velocities of the system are obtained. An analytical approach is applied to identify the instability thresholds. Stability maps are examined, and for the first time in this paper, it is demonstrated that the stability evolution of the system can be altered by fine-tuning of axial grading or viscosity of the material. The variation of density and elastic modulus gradient parameters are found to have opposite effects on the divergence and flutter boundaries of the system. Furthermore, the results indicate that the destabilizing effect of the axial
compressive load can be significantly alleviated by the simultaneous determination of density and elastic modulus gradation in the axial direction of the system.

ABSTRACT: Two independent material parameters (Lamé constants) are incorporated in classical isotropic elasticity theory, while how many independent material parameters are incorporated in the higher-order isotropic elasticity theory? It is answered by Zhou's general strain gradient elasticity theory (GSGET), which firstly proved that only three material parameters are independent. In this paper, the static and dynamic analyses of micro-beam models are proposed based on the GSGET, which can capture the size effects of micro-structures. Then the variational formulations of the micro-beams including Bernoulli–Euler and Timoshenko beams are deduced by taking advantage of Hamilton's principle. Governing equations, initial conditions, and all possible boundary conditions are derived subsequently. What's more, the static bending and free vibration problems for a simply supported beam have been analytically solved, and the effects of normalized maximum deflection, stiffness, and natural frequency are studied by comparing the present results with the classical and couple stress results respectively. The results indicate that the GSGET should be used to characterize the size effects of mechanical properties for micro-structures.

ABSTRACT: The dynamic response of multi-span composite plates excited by moving inertia loads is scrutinized within this study. The masses are traveling on a two-lane trajectory in opposing direction with constant velocity. Two major types of opposing moving masses are comprehensively assessed here, including a case that two masses start to move in opposing direction simultaneously, and the other position when the second mass starts to move in the opposite direction just the first one left the plate. All case studies are presented for two cases of boundary conditions SFSF and SSSS. The complete solution of governing differential equations for the structure is achieved by a novel combination of two methods as Boundary Characteristic Orthogonal Polynomials (BCOP) and the robust numerical procedure of matrix exponential. Utilizing the features of orthogonal polynomials through the BCOP method, the natural frequencies would be extracted by proceeding a free vibration analysis. Having established the state-space formulation for the problem, the temporal response of equations would be derived using an iterative numerical procedure based on the matrix exponential functions. A comprehensive parametric study is conducted through numerical examples to show that the important parameters such as mass ratio, aspect ratio, velocity parameter as well as the parameter of the distance between lanes how could affect the dynamic behavior of FRP plates, under two-lane opposing moving masses. By introducing a conversion factor, the effect of inertia terms on the dynamic behavior of composite plats is evaluated.

ABSTRACT: Growing applications of non-homogenous media in engineering structures require the application of powerful computational tools. A novel hybrid Meshless Displacement Discontinuity Method (MDDM) for cracked Reissner's plate in Functionally Graded Materials (FGMs) is presented in this paper. The fundamental solutions of slope and deflection discontinuity for an isotropic homogenous media are chosen as a part of general solutions to create the gaps between the crack surfaces. The governing equation is satisfied by using the meshless methods such as the Meshless Local Petrov-Galerkin (MLPG) and the Point Collocation Method (PCM) with Lagrange series interpolation and mapping technique. The Stress Intensity Factors (SIFs) are evaluated analytically with the Chebyshev polynomials. The accuracy is verified by comparison of numerical and analytical results.
ABSTRACT: The present work focuses on geometrically exact finite elements for highly slender beams. It aims at the proposal of novel formulations of Kirchhoff–Love type, a detailed review of existing formulations of Kirchhoff–Love and Simo–Reissner type as well as a careful evaluation and comparison of the proposed and existing formulations. Two different rotation interpolation schemes with strong or weak Kirchhoff constraint enforcement, respectively, as well as two different choices of nodal triad parametrizations in terms of rotation or tangent vectors are proposed. The combination of these schemes leads to four novel finite element variants, all of them based on a C1-continuous Hermite interpolation of the beam centerline. Essential requirements such as representability of general 3D, large deformation, dynamic problems involving slender beams with arbitrary initial curvatures and anisotropic cross-section shapes, preservation of objectivity and path-independence, consistent convergence orders, avoidance of locking effects as well as conservation of energy and momentum by the employed spatial discretization schemes, but also a range of practically relevant secondary aspects will be investigated analytically and verified numerically for the different formulations. It will be shown that the geometrically exact Kirchhoff–Love beam elements proposed in this work are the first ones of this type that fulfill all these essential requirements. On the contrary, Simo–Reissner type formulations fulfilling these requirements can be found in the literature very well. However, it will be argued that the shear-free Kirchhoff–Love formulations can provide considerable numerical advantages such as lower spatial discretization error levels, improved performance of time integration schemes as well as linear and nonlinear solvers and smooth geometry representation as compared to shear-deformable Simo–Reissner formulations when applied to highly slender beams. Concretely, several representative numerical test cases confirm that the proposed Kirchhoff–Love formulations exhibit a lower discretization error level as well as a considerably improved nonlinear solver performance in the range of high beam slenderness ratios as compared to two representative Simo–Reissner element formulations from the literature.

References listed at the end of the paper:

23. Bishop RL (1975) There is more than one way to frame a curve. Am Math Month 82(3):246–251
38. Cossetra E, Cossetra F (1909) Théorie des Corps Déformables, 2nd edn. Traité de Physique, Paris
150. Timoshenko SP (1921) On the correction for shear of the differential equation for transverse vibrations of prismatic bars. Philos Mag Series 41(245):744–746

**ABSTRACT:** Dynamic simulation of revolved solids plays an important role in many fields. Aiming at the lacks of solutions in some key aspects, this study establishes governing equation of motion based on theory of variational inequality; designs a compatibility iteration algorithm for solving contact forces; deduces parametric equations of arbitrary cylinder and cone in three-dimensional space; provides corresponding analytical methods to identify contact points between bodies and to calculate volume integral over bodies; proposes a rotation matrix modification approach to conserve volume and shape of rigid body in the case of large rotation. The accuracy, availability, competence, robustness, and application prospects of the presented methodology are demonstrated by several interesting and challenging problems.

**References listed at the end of the paper:**


ABSTRACT: Crashworthiness analysis remains an important concern for the design of safety structures. In this context, uncertainties play an essential role in the response of a crash problem with non linear behavior. With this statement at hand, in this work it is presented a review of uncertainty quantification (UQ) techniques, with intrusive and non-intrusive approaches in stochastic finite element methods for crashworthiness. The well-known deterministic finite element solver VPS/Pamcrash is used to illustrate the currently available methods, developing a comparative analysis of these techniques in crashworthiness UQ. Finally, relevant non-intrusive methods are applied to analyze the behavior of a specific quantity of interest in a dynamic crash model.

References listed at the end of the paper:

ABSTRACT: This study investigates vibration characteristics of longitudinally moving sigmoid functionally graded material (S-FGM) plates containing porosities. Two types of porosity distribution, i.e., the even and uneven distributions, are taken into account. In accordance with the sigmoid distribution rule, the material properties of porous S-FGM plates vary smoothly along the plate thickness direction. The nonlinear geometrical relations are adopted by using the von Kármán non-linear plate theory. Based on the d’Alembert’s principle, the nonlinear governing equation of the system is derived. Then, the governing equation is discretized to a set of ordinary differential equations via the Galerkin method. These discretized equations are subsequently solved by using the method of harmonic balance. Analytical solutions are verified with the aid of the adaptive step-size fourth-order Runge–Kutta method. By using the perturbation technique, the stability of the steady-state response is highlighted. Finally, both natural frequencies and nonlinear forced responses of moving porous S-FGM plates are examined. Results demonstrate that the moving porous S-FGM plates exhibit hardening spring characteristics in the nonlinear frequency response. Moreover, it is shown that the type of porosity distribution, moving speed, porosity volume fraction, constituent volume fraction and in-plane pretension all have significant influence on the nonlinear forced responses of moving porous S-FGM plates.

References listed at the end of the paper:


ABSTRACT: The present study is devoted to some stability problems of annular plates with shell-stiffening. The plate is simply supported, or clamped, or elastic restraints are applied on the boundaries of the plate. Though the load is axisymmetric we shall assume that the deformations are not necessarily axisymmetric. The displacement fields in the plate and the shell are expanded into Fourier series. For the shell all physical quantities are derived from an appropriately chosen Galerkin function. The main goal is to clarify the effect of a stiffening shell on the buckling load. Hence the field equations together with the boundary- and continuity conditions are clarified. These provide the eigenvalue problem from which the critical load can be calculated. In order to solve the eigenvalue problem we have established, appropriate numerical methods are used.

References listed at the end of the paper:

Experimental characterization of Graphene NanoRibbons (GNRs) is still an expensive task and simulations are therefore seen as a practical option to study the properties and mechanical response of GNRs. Design of GNR elements in various nanotechnology devices can be approached through molecular dynamics simulations. This study demonstrates that the atomic-scale finite element method (AFEM) based on the second generation REBO potential is an efficient and accurate alternative to the molecular dynamics simulation of GNRs. Special atomic finite elements are proposed to model graphene edges. Extensive
comparisons are presented with MD solutions to establish the accuracy of AFEM. It is also shown that the Tersoff potential is not accurate for GNR modeling. The study demonstrates the influence of chirality and size on design parameters such as tensile strength and stiffness. Graphene is stronger and stiffer in the zigzag direction compared to the armchair direction. Armchair GNRs shows a minor dependence of tensile strength and elastic modulus on size whereas in the case of zigzag GNRs both modulus and strength show a significant size dependency. The size-dependency trend noted in the present study is different from the previously reported MD solutions for GNRs but qualitatively agrees with experimental results. Based on the present study, AFEM can be considered a highly efficient computational tool for analysis and design of GNRs.


ABSTRACT: An attempt is made in this research to analyse the nonlinear response of functionally graded material shallow arches with both edges clamped. The arch is resting on a three parameter nonlinear elastic foundation during deformation and is subjected to uniform lateral pressure and uniform temperature rise. Material properties are expressed according to a power law function and are assumed to be temperature dependent. The governing equilibrium equations of the arch are established with the aid of third order shear deformation curved beam theory of Reddy and von Kármán type of strain–displacement relations. The obtained equations contain three coupled and nonlinear equations in terms of circumferential displacement, lateral displacement and cross section rotation. Considering the immoveable type of edge supports, the equations are reduced to two new coupled and nonlinear equations. These equations are solved using the two step perturbation technique for the case of clamped boundary conditions. Explicit expressions are resulted which yield the deflected shape of the arch as a function of temperature elevation and uniform pressure. It is shown that the arch reveals the snap-through type of instability under certain conditions. The response of the arch is highly affected by the power law index, thermal environment, side to thickness ratio and stiffnesses of the foundation.

References listed at the end of the paper:
Zhang, D.G.: Nonlinear bending analysis of FGM beams based on physical neutral surface and high order shear deformation theory. Compos. Struct. 100, 121–126 (2013)

ABSTRACT: The present paper deals with the vibration induced acoustic responses of baffled sandwich curved shell panels constituted of laminated composite face sheets and subjected to harmonic point excitation in an elevated thermal environment by an effective computational approach. A coupled finite-boundary elements formulation based on the higher-order shear deformation shell theory has been proposed and implemented via a domestic MATLAB code for the computation of the responses. The eigen frequencies in conjunction with the conforming modes of the vibrating thermally pre-stressed composite sandwich panel are obtained using competent finite element steps engaging the Hamilton’s principle. The critical buckling temperature of the sandwich panel structure is assessed to prevent any excess thermal loading during analysis followed by the computation of acoustic responses by solving the Helmholtz wave equation using the boundary element steps. The performance and the versatility of the present scheme is established by the convergence study and the successive comparison of the present numerical responses, for instance the critical buckling temperature and the radiated sound power, with the available benchmark solutions. The sound power emitted by thermally stressed composite sandwich panel is also computed via simulation model developed using commercial software ANSYS and LMS Virtual.Lab and compared with the present values. Numerous numerical examples are solved to deeply discuss the influence of various design parameters on the vibroacoustic responses of laminated composite sandwich curved panels under high temperature environment.

References listed at the end of the paper:

· Kant, T., Swaminathan, K.: Analytical solutions for free vibration of laminated composite and sandwich plates based on a higher-order refined theory. Compos. Struct. 53, 73–85 (2001)


ABSTRACT: This study investigates the free vibration of metal foam circular cylindrical shells under various boundary conditions. The elasticity modulus and mass density of the shells vary gradually and continually in the thickness direction. Two types of porosity distribution are taken into account including symmetrical and unsymmetrical distributions. Love’s shell theory is employed to formulate the governing equations and then the Rayleigh–Ritz method is utilized to solve natural frequencies of the system. The results show that the porosity
coefficient has important effect on the natural frequencies of metal foam shells. Its effect also relates to the boundary conditions of the shells. Moreover, different porosity distributions make the metal foam shells possess different vibration characteristics, which is quite obvious at large porosity coefficient. As the circumferential wave number increases, the natural frequencies of the metal foam shells tend to the same under various boundary conditions. Additionally, the present results are verified by the comparison with the published ones in the literature.

References listed at the end of the paper:
ABSTRACT: Initiated by the problem of the coupled vibration of three-dimensional pipes conveying fluid, a spectral element method is proposed to address its dynamic characteristics. Based on a more comprehensive fluid-filled beam model than previous studies, not only the shear deformation, gravity, initial tension and fluid friction, but also the fluid–structure coupling is analyzed so as to obtain more reasonable results. The present method is validated by comparing numerical results of a T-shaped branched pipe with data from the literature, as well as from finite element software. It is shown that the spectral element method (SEM) has remarkable advantages over finite element method in computational efficiency and accuracy. In addition, through experiments on the vibrations of an L-shaped water-filled pipe, the in-plane and out-plane acceleration responses by SEM are also verified. This method would have great potential in modeling the vibrations of complex pipelines conveying fluid in a variety of engineering applications.

REFERENCES listed at the end of the paper:

- Feodos'Ev, V.P.: Vibrations and stability of a pipe when liquid flows through it. Inzhenernyi Sb. 10, 169–170 (1951)

ABSTRACT: This paper deals with the derivation of the exact solutions for the static flexoelectric response of a simply supported dielectric nano-beam subjected to distributed mechanical and electrical loads. The governing differential equations and the boundary conditions are obtained based on the Gibbs free energy for linear dielectrics considering the strain and the electrical field gradients, and their conjugates in the form of the higher order stresses and higher order polarization fields. The trends and observations from the current study are compared with the literature. The electro-mechanical coupling observed from the current model is compared for different electrical boundary conditions. The polarization and the electric field profiles across the thickness, developed due to the direct effect are also presented. Due to the use of gradient field energies, and a subsequent evaluation of their conjugates, the size effects are better exhibited by the current model than the models in the literature derived without considering strain and electric field gradients. The present study suggests that upon considering strain gradient elasticity the sensitive nature of flexoelectric nanosensors, nano energy harvesters and nanoactuators is realized. The exact solutions developed in this paper may be used as benchmark solutions for further research on flexoelectric solids.

References listed at the end of the paper:


ABSTRACT: Owing to its unique multifunctional and scale-dependent physical properties, graphene is emerged as promising reinforcement to enhance the overall response of nanotailored composite materials. Most recently, the piezoelectricity phenomena in graphene sheets was found through interplay between different non-centrosymmetric pores, curvature and flexoelectricity phenomena. This has added new multifunctionality to existing graphene and it seems the use of piezoelectric graphene in composites has yet to be fully explored. In this article, the mechanics of materials and finite element models were developed to predict the effective piezoelectric and elastic (piezoelastic) properties of the graphene reinforced nanocomposite material (GRNC). An analytical model based on the linear piezoelectricity and Euler beam theories was also developed to investigate the electromechanical response of GRNC cantilever beam under both electrical and mechanical loads accounting the flexoelectric effect. Furthermore, molecular dynamics simulations were carried out to determine the elastic properties of graphene which were used to develop the analytical and numerical models herein. The current results reveal that the flexoelectric effect on the elastic behavior of bending of nanocomposite beams is significant. The electromechanical behavior of GRNC cantilever beam can be tailored to achieve the desired response via a number of ways such as by varying the volume fraction of graphene layer and the application of electrical load. Our fundamental study highlights the possibility of developing lightweight and high performance piezoelectric graphene based nanoelectromechanical systems such as sensors, actuators, switches and smart electronics as compared with the existing heavy, brittle and toxic piezoelectric materials.

References listed at the end of the paper:


ABSTRACT: In this paper, thermal buckling and free/forced vibration characteristics of size-dependent composite cylindrical nanoshell reinforced with graphene platelets (GPLs) is presented. Also, the nanoshell is embedded in an elastic pasternak medium, which is obtained by adding a shear layer to the Winkler model. The temperature-dependent material properties of piece-wise functionally graded graphene-reinforced composites (FG-GRCs) are assumed to be graded in the thickness direction of a cylindrical nanoshell and are estimated through a nanomechanical model. Also, Halpin–Tsai nanomechanical model in used to surmise the effective material properties of each layer. The size-dependent FG-GRCs nanoshell is analyzed using modified couple stress parameter. The novelty of the current study is in considering the effects of FG-GRCs and thermal in addition of size effect on resonance frequencies, thermal buckling and dynamic deflections of the FG-GRCs.
References listed at the end of the paper:


ABSTRACT: The moving Kriging interpolation-based (MKI) meshfree method is extended to mechanical behavior analysis of isotropic and sandwich functionally graded material plates. The MKI meshfree method, which is free of shear correction factors effect in plate analysis, is further enhanced by introducing a new multi-quadratic correlation function, eliminating drawbacks of its conventional form, gaining accurate solution. In this paper, a new refined sin hyperbolic shear deformation plate theory (N-RSHSDT) is introduced for plate kinematics. The present theory gives rise to four governing equations only, and achieves the sin hyperbolic distribution of the transverse shear strains through the plate thickness. To show the accuracy and effectiveness of the developed method, numerical experiments are performed for both isotropic and sandwich composite plates.
References listed at the end of the paper:

- Carrera, E., Brischetto, S.: Analysis of thickness locking in classical, refined and mixed multilayered plate theories. Compos. Struct. 82, 549–562 (2008a)


ABSTRACT: In this article, we study the thermo-elastic vibration of axially functionally graded material (FGM) pipe conveying fluid considering temperature changes. The governing equation based on Euler-
Bernoulli beam theory is solved by differential quadrature method. The FGM properties are defined by the property ratios and the volume fraction functions. Power volume fraction function and exponent volume fraction function are compared. We also use sigmoid volume fraction functions so that the exclusive influence of function distribution can be isolated from that of total material proportions. The property ratios’ effects of elasticity and thermo-elasticity gradient are also discussed.

Based on the numerical results of first-order dimensionless frequencies and critical flow velocities, concerning thermo-elasticity gradient can theoretically change the stability of the pipe. And the influences of the pure distribution on the first-order critical flow velocities are much smaller than that of the varying total proportions of the component materials. These conclusions will hopefully be used as reference for FGM pipe designing and fabricating.

References listed at the end of the paper:


ABSTRACT: This paper investigates the nonlinear bending behaviours of functionally graded trapezoidal nanocomposite plates reinforced with graphene platelets (GPLs) under thermo-mechanical loading by employing finite element method. The modified Halpin–Tsai model and rule of mixtures are adopted to determine the Young’s modulus, Poisson’s ratio and the thermal expansion coefficient of the nanocomposites. The influences of a number of factors, including the distribution pattern, concentration and size of GPLs, plate geometry and temperature, on the nonlinear bending of the nanocomposite plates are comprehensively investigated. Numerical results demonstrate that dispersing a small amount of GPLs into nanocomposites can significantly enhance the nonlinear bending performance of the trapezoidal plates. The trapezoidal plates with more GPLs dispersing close to the top and bottom surfaces has the minimum bending deflection and are less sensitive to the temperature increases. GPLs with fewer layers and larger surface area are better reinforcing fillers than their counterparts. Moreover, the plates with bigger bottom angles are found to have better bending performances. However, when the bottom angles are greater than 75°, the variation of the bottom angles will have limited effects on the bending behaviours of the trapezoidal plates.

References listed at the end of the paper:

- Feng, C., Wang, Y., Kitipornchai, S., Yang, J.: Effects of reorientation of graphene platelets (GPLs) on Young’s modulus of polymer nanocomposites under uni-axial stretching. Polymers 9(10), 532 (2017c)

ABSTRACT: In the present study, an attempt is made to present the governing equations on the post-buckling of two-dimensional (2D) FGP beams and propose appropriate optimization procedure to achieve optimal post-buckling behavior and mass. To this end, Timoshenko beam theory, Von-Karman nonlinear relations, virtual work principle, and generalized differential quadrature method are considered to derive and solve governing equations and associated boundary condition (Hinged–Hinged) for an unknown 2D porosity distribution. Proposed method is validated using the papers in the literature. The optimization procedure including defining porosity distributions (interpolations), post-buckling function and Taguchi method is then proposed to optimize the post-buckling path and minimize the mass of the 2D-FGP beams. Results indicate that, great improvement can be achieved by optimizing the porosity distribution; for an identical mass, the post-buckling paths of optimum points are closer to desired path (dense structure). The difference between uniform and non-uniform porosity distributions is more (58% higher post buckling function), at higher values of the mass. Optimum distributions mostly have the higher values of porosity at center line of the beam and minimum values at outer line. Analysis of variance is also provided to create a better understanding about design points contributions on the post-buckling path.

References listed at the end of the paper:

Seyed Sajad Mirjavadi, Behzad Mohasel Afshari, Mohammad Reza Garati and A.M.S. Hamouda (First author is from: Department of Mechanical and Industrial Engineering, Qatar University, P.O. Box 2713, Doha, Qatar), “Transient response of porous inhomogeneous nanobeams due to various impulsive loads based on nonlocal strain gradient elasticity”, International Journal of Mechanics and Materials in Design, Vol. 16, No. 1, pp. 57-68, March 2020, Transient vibration responses of a porosity-dependent functionally graded nanobeam under different impulsive loadings have been investigated in the context of non-local strain gradient theory. Three impulse loads of rectangular-type, linear-type and sine-type have been applied to the top surface of a nanobeam. Two porosity distribution types known as even and uneven are discussed. Governing equations of the nanobeam are solved via inverse Laplace transform approach to express the dynamic deflections. One can see that the transient response of nano-size beams is influenced by the type and location of pulse load, porosities volume fractions, porosities distributions, non-local and strain gradient coefficients.

References listed at the end of the paper:

- Ebahrami, F., Barati, M.R.: Size-dependent vibration analysis of viscoelastic nanocrystalline silicon nanobeams with porosities based on a higher order refined beam theory. Compos. Struct. 166, 256–267 (2017c)

ABSTRACT: The nonlinear in-plane buckling behaviour of pinned-pinned shallow circular arches made of functionally graded material (FGM) is investigated using a one-dimensional Euler–Bernoulli model. The effect of the bending moment on the membrane strain is included. The material properties vary along the thickness of the arch. The external load is a radial concentrated force at an arbitrary position. The pre-buckling and buckled equilibrium equations are derived using the principle of virtual work. Analytical solutions are given for both bifurcation and limit point buckling. Comprehensive studies are performed to find the effect of various parameters on the buckling load and on the behaviour. The major findings: (1) arches have multiple stable and unstable equilibria; (2) when the load is at the crown, the lowest buckling load is related to bifurcation buckling for most geometries and material compositions but when the external force is replaced, only limit point buckling is possible; (3) the position of the load has huge influence on the buckling load; (4) such arches are sensitive to small loading imperfections when loaded in the vicinity of the crown. The paper intends to improve and extend the existing knowledge about the behaviour of pinned-pinned shallow FGM arches under arbitrary concentrated radial load.

References listed at the end of the paper:


ABSTRACT: The honeycomb structure can be applied to the design of new lightweight composites materials due to its excellent properties such as high strength, strong energy absorption ability, low thermal conductivity, etc. In recent years, researchers have noticed that cell joint performance optimization can improve the performance of honeycomb structures. In this study, an optimized honeycomb structure with cell joint thickened was obtained by a theoretical analysis in which two principal geometrical parameters were adjusted, and then fabricated with additive manufacturing technology for compression testing. The results were obtained through experimentation and qualitative simulation, and then compared with those of a traditional honeycomb structure with uniform wall thickness. Finally, the mechanism of the optimized thickened-joint honeycomb structure was investigated, which could be a design guideline for the application of honeycomb structures in various engineering fields.

References listed at the end of the paper:

ABSTRACT: Nonlinear vibration and dynamic response of functionally graded moderately thick toroidal shell are investigated in this paper. Functionally graded materials are made from ceramic and metal, and the volume fraction of constituents are assumed to vary through the thickness direction according to a power law function. Reddy’s third order shear deformation, von Karman nonlinearity, Airy stress function method and analytical solutions are used to derive the governing
equations. Galerkin method is used to convert the governing equation into nonlinear differential equation, then the explicit expressions of natural frequencies and nonlinear frequency–amplitude relations are obtained. Using Runge–Kutta method, the nonlinear differential equation of motion is solved, and then nonlinear vibration and dynamic response of shells are analyzed. The effects of temperature, material and geometrical properties, and foundation parameters on nonlinear vibration and dynamic characteristics are investigated and discussed in detail.

References listed at the end of the paper:


Punera, D., Kant, T.: Free vibration of functionally graded open cylindrical shells based on several refined higher order displacement models. Thin-Walled Struct. 119, 707–726 (2017)


Van-Hieu Dang (1), Dong-Anh Nguyen (2) and Minh-Quy Le (3) and The-Hung Duong (1)
(1) Thainguyen University of Technology, Thainguyen, Vietnam
(2) Institute of Mechanics, No. 264, Doi Can, Ba Dinh, Hanoi, Vietnam
(3) Hanoi University of Science and Technology, No. 1, Dai Co Viet Road, Hanoi, Vietnam

“Nonlinear vibration of nanobeams under electrostatic force based on the nonlocal strain gradient theory”,

ABSTRACT: The nonlinear vibration of a nanobeam under electrostatic force is investigated through the nonlocal strain gradient theory. Using Galerkin method, the partial differential equation of motion is reduced to an ordinary nonlinear differential one. The equivalent linearization method with a weighted averaging and a variational approach are used independently to establish the frequency–amplitude relationship under closed-forms for comparison purpose. Effects of material and operational parameters on the frequency ratio (the ratio of nonlinear frequency to linear frequency), on the nonlinear frequency, and on the stable configuration of the nanobeam are studied and discussed.

References listed at the end of the paper:

Ngô Đình Đạt (1) and Trần Quốc Quan (2) and Nguyễn Đình Đức (3)
(1) NTT Institute of High Technology, Nguyễn Tất Thanh University, Hồ Chí Minh City, Vietnam
(2) Advanced Materials and Structures Laboratory, VNU – Hanoi – University of Engineering and Technology (UET), 144 Xuân Thủy, Cầu Giấy, Hà Nội, Vietnam
(3) Advanced Materials and Structures Laboratory, VNU – Hanoi – University of Engineering and Technology (UET), 144 Xuân Thủy, Cầu Giấy, Hà Nội, Vietnam and National Research Laboratory, Department of Civil and Environmental Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul, 05006, Republic of Korea


ABSTRACT: This paper investigated the nonlinear vibration and dynamic response of the carbon nanotube polymer composite elliptical cylindrical shells on elastic foundations in thermal environment. The material properties of the nanocomposite elliptical cylindrical shells are assumed to depend on temperature and graded in the thickness direction according to various linear functions. The shell is subjected to the combination of the uniformly distributed transverse load in harmonic form and the uniform temperature rise. The motion and geometrical compatibility equations are derived based on the Reddy’s higher order shear deformation shell theory. The natural frequencies and the deflection amplitude–time curves of the shell are determined by using the Galerkin method and fourth-order Runge–Kutta method. The numerical results show not only the positive influences of carbon nanotube volume fraction and elastic foundations but also the negative influences of initial imperfection and temperature increment on the nonlinear vibration and dynamic response of the carbon nanotube polymer composite elliptical cylindrical shells. The reliability of the present results is verified by comparing with other publications.

References listed at the end of the paper:
A. Hajlaoui (1), E. Chebbi (1), M. Wali (2) and F. Dammak (1)

(1) Laboratory of Electromechanical Systems (LASEM), National Engineering School of Sfax, University of Sfax, B.P. 1173-3038, Sfax, Tunisia

(2) Department of Mechanical Engineering, College of Engineering, King Khalid University, Abha, Saudi Arabia

ABSTRACT: This paper presents a modified first-order enhanced solid-shell element formulation with an imposed parabolic shear strain distribution through the shell thickness in the compatible strain part. Moreover, zero transverse shear stress on the top and bottom surfaces of the shell is satisfied exactly and the shear correction factors is no longer needed. Furthermore, the developed solid-shell element allows an efficient and accurate analysis of functionally graded material shells under geometric nonlinear static conditions. A simple power-law functionally graded distribution of the shells along the thickness direction is considered. The validity and accuracy of the developed solid-shell element are illustrated through the solution of several known problems taken from the literature. The influences of power-law index on the nonlinear static behavior of the FGM shells are discussed.

References listed at the end of the paper:


ABSTRACT: Biological materials–fish scales exhibit ultra-flexibility due to its functionally graded materials. Inspired by the hierarchical gradient structure of fish scales, a new flexible gradient model that can adequately describe the characteristics of the bioinspired hierarchical structures is proposed in this work. To assess the flexibility of the proposed gradient model, a combination of extended finite element method (XFEM) and
stabilized discrete shear gap (DSG) is established to analyze the vibration of bioinspired gradient plates with/without cracks. The DSG technique is employed to eliminate the shear locking phenomenon, while the XFEM is used for a mesh-independent modelling of crack. The combined approach is applicable to both moderately thick and thin plates, and is insensitive to mesh distortion. Functionally gradient plates take two types: power law function (Type I) and bioinspired hierarchical mode (Type II). For Type I, the natural frequencies decrease by increasing the gradient factor, i.e., the exponent of the power law. When the gradient factor is larger than one, the improvement of the plate stiffness by material gradient is restricted. For Type II, the natural frequencies are mostly independent of the step smoothing factor, yet quite sensitive to the number of step layers, providing an additional degree of freedom in tailoring the material properties. In addition, the natural frequencies of the bioinspired gradient plate are lower than that of the homogeneous ceramic plate. By using Type II, the stiffness of the plate can be reduced effectively, making the plate prone to deformation, which coincides with the flexible scale design. Therefore, the present study provides an incisive method and instructive guideline for a new era of artificially designed flexible materials inspired by natural (or biological) materials and structures.

References listed at the end of the paper:


ABSTRACT: On the basis of the couple stress piezoelectric theory including flexoelectric effects, a size-dependent model of a bilayer microbeam consisting of a piezoelectric material layer and an elastic layer has been established. The governing equations along with the boundary conditions of the microbeam model have been obtained from variation principle. The microbeam bending problems have been solved to analyse the electromechanical coupling responses to the applied concentrated force and voltage. Numerical results show that whether under the concentrated force or the voltage, the influence of flexoelectric effects on the equivalent piezoelectric response is larger than that of rotation gradient elastic effects when the size of the microbeam is much larger than the material length scale parameters. However, with the continuous decrease of the beam characteristic size scale, rotation gradient elastic effects have a stronger impact on the electromechanical responses than flexoelectric effects which leads to a rapid decrease of the equivalent piezoelectric responses. The result also shows that the contribution of flexoelectric effects on the equivalent piezoelectric response increases when the beam size diminishes, which leads to a significant surge of the electromechanical responses compared to the model under the classical piezoelectric theory.

References listed at the end of the paper:

governing coupled nonlinear partial differential equations of motion are derived and a new finite element

resonating beam is often assumed to be a perfect conductor. In this paper, the effect of electrical resistivity on

measurement in micro and nanoscale resonators. In the dynamical behavior analyses of such systems, the

ABSTRACT:

Mechanics and

Reza Moheimani, Abdolreza Pasharavesh, Hamid Dalir, “The effect of finite electrical conductivity of small-
scale beam resonators on their vibrational response under electrostatic fields”, International Journal of

Materials in Design, Vol. 1

Materials in Design, Vol. 1


ABSTRACT: Electrostatic actuation is one of the most commonly used methods for excitation and measurement in micro and nanoscale resonators. In the dynamical behavior analyses of such systems, the resonating beam is often assumed to be a perfect conductor. In this paper, the effect of electrical resistivity on the vibrational response of these systems, including the natural frequency and damping, is investigated. The governing coupled nonlinear partial differential equations of motion are derived and a new finite element
method formulation is presented by developing a new electromechanical element. The numerical natural frequencies are compared with experimental measurements and the achieved correlation is better than that in the prior studies. Results indicate that there is a jump in the frequency and damping of the system at a critical resistivity. As the system size decreases and the applied voltage approaches the pull-in voltage, the electrical resistivity completely dominates the response nature of the system. An experiment is also conducted, and good agreement with the theory is observed regarding the effect of electrical resistivity.

References listed at the end of the paper:
- Batra, R., Porfiri, M., Spinello, D.: Vibrations of narrow microbeams predeformed by an electric field. J. Sound Vibr. 309(3–5), 600–612 (2008c)
ABSTRACT: The aim of the present work is to develop a high-order shear deformable beam model and investigate the transient response of a sandwich porous beam when acted upon by a non-uniformly distributed moving mass. It is assumed that the total mass is distributed within a specified distance and has various distribution patterns. The sandwich beam is composed of two functionally graded (FG) facesheets and an FG porous core. The modulus of elasticity of the porous core is graded owing to the continuously variation in porosity in the thickness direction. The open-cell metal foam model is used to evaluate the mass density of the core. A new high-order shear deformation theory is proposed and implemented to develop a reliable and accurate model that can address the vibration responses of the beam. The equations of motion are derived using the Lagrange method, whereas a standard Newmark-$\beta$ method is employed to solve the time-dependent response. A few numerical examples are discussed to study the effects of various sandwich configurations and different types of mass distributions on the vibration behaviors of the sandwich beam. The results indicate that dispersing the mass toward the two ends of the load to the extent feasible is suitable for preventing large dynamic deflections.

References listed at the end of the paper:


Fryba, L.: Vibration of solids and structures under moving loads. Academia, Prahaue (1972)


Şişmeci, M., Cansız, S.: Dynamics of elastically connected double-functionally graded beam systems with different boundary conditions under action of a moving harmonic load. Compos. Struct. 94, 2861–2878 (2012)


ABSTRACT: Fluid-conveying micro/Nano structures are key tools in MEMS and NEMS applications especially for drug delivery systems to attack a specific tumor like cancer cells. Vibrational characteristics of such tools play a crucial role in delivering efficient and reliable performance in various applications. As a result, vibration and instability control of such systems is of great importance. Vibration and instability response of magnetostrictive sandwich cantilever fluid-conveying micro-pipes is investigated in this paper utilizing smart magnetostrictive layers as actuators. Euler–Bernoulli beam model together with modified couple stress theory (MCST) are used to model the problem. As main properties of these smart layers, magnetic intensity effect, velocity feedback gain and thermal effects are taken into account in the modeling. The governing equation is extracted employing Hamilton’s principle. Extended Galerkin procedure is applied to discretize the governing equation and obtain the eigenvalue problem which is solved straightforwardly to reach the eigenvalues. Afterwards, eigenvalue diagrams are studied to analyze the vibrational characteristics and possible instabilities (flutter and bifurcation) occurring in first three modes of the system. Throughout this analysis, the role of various intrinsic properties of the magnetostrictive layers on the critical flow velocity and frequency is studied in detail. The numerical results show a good ability for the used smart layers to control the instability of fluid-conveying micro-pipes. Therefore, these sandwich structures may be helpful for achieving a novel design for such systems.

References listed at the end of the paper:


ABSTRACT: An innovative and new technology on enhancing buckling resistance is established in this work by making use of local surface nanocrystallization to significantly improve the critical loads of thin-walled structures under axial compression loads. By capitalizing new design approaches of local nanocrystallization, critical loads of thin-walled structures can be dramatically increased owing to the marked enhancement of yield stresses of materials within the treated domain. No additional material adhering or structural modification is required in the entire procedure. An optimal design of local surface nanocrystallization is derived by evaluation
of critical loads and ultimate buckling deformation of five typical nanocrystallization layouts. Theoretical results show that axial nanocrystallization stripes closed to edges produce the highest critical loads and stable ultimate buckling deformation. Furthermore, an experimental work is presented to validate the optimal design. The result concludes that welding skill is an important influencing factor in the fabrication of such nanocrystallized tubes.

References listed at the end of the paper:

ABSTRACT: The effect of porosity and thermal environment on buckling responses for the sandwich plates with different boundary conditions is analyzed and discussed in the present study. The author’s recently developed sandwich plate using a new modified sigmoid function based functionally graded material (S-FGM) plate of different symmetric and asymmetric configurations is considered. A new temperature distribution through the thickness based on modified sigmoid law is proposed in which temperature is assumed to be conducted in the thickness direction. Three different types of porosity are considered viz. even, uneven but symmetric and uneven but non-symmetric. A new uneven non-symmetric porosity model is used in which micro-voids are varied in accordance with material property variation in the thickness direction to capture the accurate distribution of voids on the plate. The principle of virtual work is employed to derive equilibrium equations. An exact solution is obtained using the assumed solution with shape functions satisfying the edge boundary conditions. This is implemented using Galerkin Vlasov’s method. The analysis has been performed to study the effect of porosity, geometric configurations, inhomogeneity parameter, and foundation parameter. It is observed that the elastic foundation parameters have the least effect on non-symmetric plate configuration subjected to nonlinear temperature distribution in comparison to other symmetric and non-symmetric plate configurations and temperature distribution. Besides, the non-symmetric plate configuration possesses...
maximum thermal buckling temperature in comparison to a symmetric configuration. The volume fraction exponent with value 2 is observed as a changeover point where the effect of porosity distribution is null and void for 2-1-1 plate configuration irrespective of boundary conditions. The calculated outcomes and interpretations can be useful as a validation study for the imminent investigation of sandwich S-FGM plates having porosities in the thermal environment.

References listed at the end of the paper:


ABSTRACT: A novel hybrid-Trefftz finite element (HTFE) has been developed for the static analysis of thick and thin antisymmetric cross-ply and angle-ply laminated composite plates. For the first time a high order shear deformation theory is used for both the internal and auxiliary displacement fields for constructing the Trefftz functions. The usual tedious approach of converting the system of governing partial differential equations into a single governing equation has been avoided in the present development. The Trefftz functions have been derived from the exact solutions of the homogeneous governing equations of equilibrium. The current HTFE formulation does not need to find the particular solutions of the system of governing partial differential equations. Comparison with exact and analytical solutions reveals that the HTFE developed here is excellently capable of predicting the responses of the antisymmetric laminated composite plates. The Trefftz functions developed here can be used for deriving the polygonal HTFE with any number of sides.

References listed at the end of the paper:


ABSTRACT: This study investigates the nonlinear vibration and dynamic response of a beam made of functionally graded material (FGM) within the framework of the improved third-order shear deformable theory. The beam is subjected to a concentrated moving load, and the included angle of the load direction and axial direction varies with time. Considering the von Kármán geometric nonlinearity, the nonlinear formulations of the FGM beam is derived. The Newmark method in conjunction with the Newton–Raphson iteration is adopted to analyze the dynamic response of the beam. A new method, based on a direct numerical integration technique for the matrix form motion equation, is presented to study the nonlinear vibration of the FGM beam. The proposed method overcomes the problem of signal determination for the solution of the eigenvector equation that often leads to nonconvergence or a false result of the nonlinear eigenvalue equation. In relation to the numerical results, the effects of material property distribution, vibration amplitude on the nonlinear dynamic behavior of the FGM beams, and the energy transference phenomenon are discussed in this paper.

References listed at the end of the paper:


ABSTRACT: Soltaniyeh dome is the largest brick dome in the world and registered in UNESCO’s world heritage site that makes it one of the most important historical buildings in Iran. It suffered significant damages during its lifetime; therefore, preservation of that from the future destruction is vital. In this paper, the vulnerability of the structure was studied by FEM model which was verified by previous experimental and analytical studies. The extended FEM method (XFEM) was used to consider crack formation and propagation. Gravity, pushover and nonlinear dynamic analyses were conducted to study the behavior of structure under service and seismic load. The results indicate that the structure is adequate in the gravity loads but significant cracks are started from the opening of the second and third floors and propagate through the dome and its supports in the design earthquake (475-year return period). These results in addition to the drift diagram of structure suggest that the top of the structure is more vulnerable and needed to be rehabilitated.

References listed at the end of the paper:
· Ferraro A, Grasso S, Maugeri M, Totani F (2016) Seismic response analysis in the southern part of the historic centre of the City of L’ Aquila (Italy). Soil Dyn Earthq Eng 88:256–264
· Guler K, Celep Z (2003) Damage and structural evaluation report of the Kucuk Ayasofya Mosque. Istanbul Technical University, Istanbul (in Turkish)

ABSTRACT: This work aims to evaluate time-dependent reliability of a pipeline under corrosion impact over its lifetime. A finite element corrosion model was proposed, and an empirical power low model is also used and coupled with a probabilistic model for evaluating reliability index about a limit state function. The failure probability of structure was determined for different corrosion rates (low, moderate and high rates), considering corrosion depth. Form method and Monte Carlo simulation are used for evaluating the structure reliability. The impact of applying both effect of corrosion and residual stress is shown which is appears a significant failure probability of the studied pipeline. The found results are analyzed and discussed.

References listed at the end of the paper:

• CSA Z662-07 (2007) Oil and gas pipeline systems. pp 554–555
• Eiber RJ, Kiefner JF (1986) Failure of pipelines. American Meteorological Society
• Kiefner JF, Vieth PH (1990a) New method corrects criterion for evaluating corroded pipe. Oil Gas J 32:56–69
• Kiefner JF, Vieth PH (1990b) Evaluating pipe conclusion: PC program speeds new criterion for evaluating corroded pipe. Oil Gas J 34:91–103
· Melchers RE (1999) Structural reliability analysis and prediction, 2nd edn. Wiley, Chichester
· TRC (2018) Transport par canalization. Algerian Society
· Veritas DN (2010) Recommended practice, corroded pipes, DNV-RP-F101, in, DNV

P. Manikandan and M. Thulasi (First author is from: Centre for SONA Structural Engineering Research, Department of Civil Engineering, Sona College of Technology, Salem, India), “Invesigation on cold-formed steel lipped channel built-up I beam with intermediate web stiffener”, International Journal of Advanced Structural Engineering, Vol. 11, No 1, pp 97–107, March 2019

ABSTRACT: The aim of the present study is to examine the behaviour of cold-formed steel (CFS) lipped channel built-up I-section with edge and intermediate web stiffeners under bending. Initially, the section dimension of length, width of the flange and depth of the sections are optimized numerically and finally, it is validated with the test results. All the select cross-section dimensions have satisfied the pre-qualified beam dimensions. Numerical analysis is carried out using the software ABAQUS. Totally, four section geometries are tested experimentally. After validation, a total of 75 parametric studies are carried out using the verified finite element model. All the results are compared with the direct strength method specifications for CFS structures and the suitable design modifications are detailed.

References listed at the end of the paper:
· GB 50018–2002, Technical code of cold-formed thin-walled steel structures. Beijing, China; 2002
· Haidarali MR, Nethercot DA (2012a) Local and distortional buckling of cold-formed steel beams with edge-stiffened flanges. J Constr Steel Res 58:106–111
· Haidarali MR, Nethercot DA (2012b) Local and distortional buckling of cold formed steel beams with both edge and intermediate stiffeners in their compression flanges. Thin Walled Struct 73:37–42
ABSTRACT: Warping and distortion are relevant kinematic features of thin-walled beam structures, which have a non-trivial analysis. On this basis, this paper not only evaluates the possible kinematic transmissions involving high-order warping and distortion, but also presents a procedure to analyze structures using mixed models based on shell and Generalized Beam Theory (GBT) elements. In this mixed beam-shell structure, the traditional shell elements are applied at structural detailing points, such as joints, and GBT elements are used to model the beams/columns. Such a modeling technique uses the benefits of both elements. Shell elements can easily simulate different types of geometry conditions and details, such as stiffeners and holes; meanwhile, for the beams and columns, GBT can provide high performance, accuracy, and an easy modeling approach with clear results. The numerical formulation is based on multi-frequency constraint techniques. Special attention is given to the Master–Slave method, which is developed based on GBT kinematic assumptions. Furthermore, there is a discussion concerning the choice of the master degrees of freedom and its implications in numerical performance. An example of a thin-walled hollow circular cross section illustrates the proposed approach and is compared with fully shell element models.

References listed at the end of the paper:
References listed at the end of the paper:

- Kindmann R, Kraus M (2011) Steel structures design using FEM. Ernst adn Sohn, Berlin


ABSTRACT: This article presents an investigation of dynamical behaviors of perfect and defected fixed–fixed single-walled carbon nanotube (SWCNTs) model as a beam structures. The fundamental frequencies and modal participation factors for fixed–fixed-supported SWCNTs are considered through this analysis for the first time. Energy-equivalent model is implemented to find a relationship between the energy stored in atomic chemical bonding and potential energy of mechanical beam structure. Nanotube software modeler is exploited to create a geometrical structural of SWCNTs by defining its length of nanotube, bond distance between two atoms, and chiral angle. The tube of SWCNTs are simulated as fixed–fixed-supported structure at both ends, while bonding between each two atoms is modeled by 3D beam element with circular cross section. Parametric results are illustrated to display the effects of vacancy on activation and deactivation of vibration modes, fundamental frequencies, and modal participation factors of SWCNTs.
Mohammad Jalilzadeh Afshari (1), Abazar Asghari (2) and Majid Gholhaki (1)

(1) Faculty of Civil Engineering, Semnan University, Semnan, Iran
(2) Department of Civil Engineering, Urmia University of Technology, Urmia, Iran


ABSTRACT: Nowadays, the use of steel plate shear walls, as an effective seismic resisting system, has been of great interest in enhancing the lateral strength and stiffness of buildings both in renovation and seismic
rehabilitation of existing concrete and steel structures. In the present research, the shear strength and stiffness of steel plate shear walls in various configurations of stiffeners, including horizontal, vertical, and horizontal–vertical, were investigated by finite element method and finally semi-empirical relations were presented in this regard. The results indicated that the shear strength and stiffness of stiffened SPSWs were well predicted by the proposed relations, but increasing the number of stiffeners above a certain range will not have a significant effect on enhancing the stiffness and strength.

References listed at the end of the paper:

ABSTRACT: A quadrilateral and a triangular element based on the strain approach are developed for static, free vibration and buckling analyses of Reissner–Mindlin plates. The four-node triangular element SBTP4 has the three essential external degrees of freedom at each of the three corner nodes and at a mid-side node; whereas
the quadrilateral element SBQP has the same degrees of freedom at each of the four corner nodes. Both elements use the same assumed strain functions which are in the linear variation where bending and transverse shear strains are independent and satisfy the compatibility equations. The use of the strain approach allows obtaining elements with higher-order terms for the displacements field. The formulated elements have been proposed to improve the strain-based rectangular plate element SBRP previously published. Several numerical examples demonstrate that the present elements are free of shear locking and provide high-accuracy results compared to the available published numerical and analytical solutions.

References listed at the end of the paper:


ABSTRACT: A finite-element formulation based on triangular membranes of any order is proposed to analyze problems involving highly deformable hyperelastic materials under plane-stress conditions. The element kinematics is based on positional description and the degrees of freedom are the current plane coordinates of the nodes. Two isotropic and nonlinear hyperelastic models have been selected: the compressible neo-Hookean model and the incompressible Rivlin–Saunders model. The constitutive relations and the consistent tangent operator are condensed to the compact 2D forms imposing plane-stress conditions. The resultant algorithm is implemented in a computer code. Three benchmark problems are numerically solved to assess the formulation proposed: the Cook’s membrane, involving bending, shear, and a singularity point; a partially loaded membrane, which presents severe mesh distortion and large compression levels; and a rubber sealing, which is a more realistic problem. Convergence analysis in terms of displacements, applied forces, and stresses is performed for each problem. It is demonstrated that mesh refinement avoids locking problems associated with incompressibility condition, bending-dominated problems, stress concentration, and mesh distortion. The processing times are relatively small even for fifth-order elements.

References listed at the end of the paper:

ABSTRACT: In this study, the shear buckling behavior of plate girders using concrete-filled steel tube structure was verified by nonlinear finite element analysis using CEB-FIP 1990 code. In addition, shear buckling tests were carried out on the model specimens and compared with the analysis. As a result, it was confirmed that the proposed plate girder improved the shear buckling resistance compared to the general plate girder. Also, by comparing the test results with the analysis, we propose that the proposed CEP-FIP code is a reasonable analysis. Particularly, as a result of comparing the maximum deflection displacement of the plate girder, it was found that the proposed girder improved the shear buckling resistance performance due to the confinement effect of the concrete-filled steel tube structure than general plate girder.

References listed at the end of the paper:

P. Manikandan (1) and A. Ezhilan (2)

(1) Centre for SONA Structural Engineering Research, Department of Civil Engineering, Sona College of Technology, Salem, India

(2) KAR Associates, Krishnagiri, India


ABSTRACT: The objective of this study is to make the experimental and finite element simulations of buckling behaviour of cold-formed steel (CFS) built-up hat-shaped closed section under simply supported end condition subjected to two-point loading. Numerical simulation is carried out using the software ABAQUS. The test result is compared with numerical results and good correlation is achieved. Next, for validation, a series of parametric studies are carried out using the validated numerical model, such as the effect of length, depth, width, thickness and angle of the inclined element. The local buckling and the interaction of local and flexural buckling are studied. To end with, a design equation is proposed in accordance with the direct strength method specification for CFS structure.

References listed at the end of the paper:
- Haidarali MR, Nethercot DA (2012b) Local and distortional buckling of cold-formed steel beams with both edge and intermediate stiffeners in their compression flanges. Thin Walled Struct 73:37–42
- IS: 1608–2006, Indian specification FOR mechanical testing of materials-tensile testing, India
ABSTRACT: In this paper, a new triangular membrane finite element with in-plane drilling rotation has been developed using the strain-based approach for static and free vibration analyses. The proposed element, having three degrees of freedom at each of the three corner nodes, is based on assumed strain functions satisfying both compatibility and equilibrium equations. Numerical investigations have been conducted using several tests, including static and free vibration problems, and the obtained results are compared with analytical and numerical available solutions. It is found that efficient convergence characteristics and accurate results can be achieved using the developed element.

References listed at the end of the paper:

References listed at the end of the paper:


Abtin Baghdadi (1), Mahmoud Heristchian (2), Harald Kloft (1)

(1) Department of Architecture Civil Engineering and Environmental Sciences, Institute of Structural Design, TU Braunschweig, Braunschweig, Germany
(2) Department of civil engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran


ABSTRACT: Heinz Isler as the most famous contemporary shell designer has widely employed physical pre-modelling techniques for construction of many concrete shell structures. Through the physical approach to optimal form finding, Isler accomplished shell structures with robust performance. It would be interesting and beneficial to re-assess Isler’s shells, hence, this article attempts to study the structural performance of eight notable shells of Isler. Through reverse engineering and by the assistance of Rhino, MATLAB and Grasshopper, the precise geometry of Isler’s selected shells were modelled for the finite element analysis under their self-weight. The structural analysis was performed, with the parallel use of finite element software SAP2000 and Abaqus. The identical results of the two packages, further confirmed the accuracy of the analysis. The essential properties of various forms of the shells and their differences in behaviour were pinpointed and discussed within the calculations and the results were compared with the data of the genuine published references on Isler’s works. The internal forces, the amount of von Mises stresses, support reactions and the buckling loads of the shells are explored. The analyses revealed that, despite of their major membrane action, all the shells had negligible amount of bending moments, especially near the supports. However, in general, all the shells exhibited an appropriate performance under the applied actions. But, at the same time, they exhibited different buckling behaviour as a probable source of instability in them.

References listed at the end of the paper:
ABSTRACT: Chiral honeycombs which exhibit auxetic behaviors (negative Poisson’s ratios) have attracted much research interest due to their novel mechanical properties. These materials are broadly used in designing new functional structures, such as energy absorption and noise mitigation materials. To analyze the behaviors of these materials, finite element models are generally adopted, which may require much time and labor to construct and implement. To simplify the numerical modelling, a novel Chiral Beam Element for finite element simulation is proposed in this paper. Both static and dynamic analyses are conducted and the numerical expense, i.e., the modelling procedures and the computational time, is reduced significantly when compared to traditional finite element models.

References listed at the end of the paper:
ABSTRACT: Shells are among the most frequent structural components which are used in construction and industrial projects. Shell structures are composed of shell bearing elements and mainly used in oil and gas tanks, offshore marine platforms, silos, funnels, cooling towers, ship and aircraft body, etc. Despite the frequent use of steel cylindrical shells, their construction and assembling process has caused main problems. In these structures, there is no possibility for the integrated construction due to their large shell extent and they are built using a number of welded curved panel parts; hence, some geometrical imperfections emerge. Most of these imperfections are caused by the process of welding, transportation, inappropriate rolling, as well as installation and implementation problems. These imperfections have a direct impact on the structural behavior of shells during the buckling and external compressive load. Since in most shell tanks during operation, there is high possibility for the suction (vacuum) state, compressive forces in their thin wall cause buckling and failure. In this research, the imperfections made in steel cylindrical tanks being constructed in one of the refinery site are introduced and evaluated using a field study. Relying on the statistical inference, they are classified and then, by studying the effective factors and origin in their generation, the common imperfections are identified. Later, the impact of common imperfections on the buckling behavior is experimentally evaluated under uniform external pressure. Then, nonlinear numerical analysis of the test specimens is performed. Finally, experimental results, finite element and analytical relations are compared.

References listed at the end of the paper:


ABSTRACT: Fluids being passing through a pipeline system can cause internal vibrations within the pipelines. If these vibrations weren’t considered at the design of the system, and flow induced vibrations resonate with the pipes natural frequency, the sudden amplified vibrations can cause destructive damage to the pipeline system. Thus, it is extremely important to identify and predict all vibrations a certain pipeline system will possibly encounter during its lifetime when designing the system, also choosing the proper material with regard to their natural frequencies to avoid destructive resonances from happening. In this study, using ABAQUS as a CFD solver, we studied the forced and free vibrations caused by a turbulence flow of a fluid with different speeds through a 90 degree bent elbow pipe. We compared the vibration modes and frequencies for different cases of fluid speeds, and concluded at what natural frequency a vibration resonance may occur leading to a possible pipe failure.

References listed at the end of the paper:


ABSTRACT: The left ventricular stroke work is a measure of the work done by the left ventricle during the ejection of blood throughout per cardiac cycle. The aim of this investigation was to propose a model to numerically evaluate the stroke work for a healthy subject by using a fluid-structure interaction (FSI) simulation during exercise protocol. Aortic valve dimensions were calculated using an imaging technique of echocardiography. An FSI simulation was performed using an Arbitrary Lagrangian-Eulerian (ALE) mesh. Boundary conditions were defined by pressure loads on ventricular and aortic sides. Stroke work was predicted to increase to 121% from 60 bpm to 125 bpm, and it did not increase much above 125 bpm. Based on derived regression equations of our FSI results for stroke work and comparing of them with clinical ones, numerically-predicted stroke work values are in good agreements with published clinical data. The slope of stroke work changes to mean arterial pressure, while exercise protocol, is 168.08 ml which is 12.2% less than the average slope of clinical data. The y-axis intercept of stroke work changes to mean arterial pressure, while exercise protocol, is -11186 mmHg.ml which is 15% less than the average y-axis intercept of clinical data. Our results for the specific patient show that numerical methods can be proposed to predict good estimates of patient specific stroke work at different heart rates.

References listed at the end of the paper:


Klabunde R (2011) Cardiovascular physiology concepts. Lippincott Williams & Wilkins, USA.


Lewis T (1915) Lectures on the heart. PB Hoeber. USA.


No appropriate papers in 2018 or 2019 volumes (Vol. 7 and Vol. 8)

Journal of Applied Mechanical Engineering, Vol. 9, No. 3, 2020 (No appropriate papers)

Journal of Applied Mechanical Engineering, Vol. 9, No. 1, 2020 (No appropriate papers)

Journal of Applied Mechanical Engineering, Vol. 9, No. 2, 2020 (No appropriate papers)

Journal of Applied Mechanical Engineering, Vol. 9, No. 4, 2020 (No appropriate papers)


ABSTRACT: The article proposes a new analytical method for the calculation of plates with constant and variable rigidity parameters. This method renders it possible to decrease the weight of the plates working under hydrostatic pressure by using variable thicknesses.

First, a short overview of existing calculation methods and their results are compared. It is shown that all existing methods depend on boundary conditions. Then is given the theory of the proposed calculation method is described and calculations for plates with constant and variable thickness worked under uniformly loaded forces and hydrostatic pressure are made. The results are compared to the FEM calculations and experimental results obtained by a tensile test machine and special equipment. Calculation results obtained by the proposed analytical method and FEM results are very close. Deviations are not more than 11%. Deviations between theoretical calculations and experimental results depend on loading type and design of the test specimens but maximum values are not more than 17%.

The proposed calculation method does not depend on the boundary conditions and can be used for plate calculations. Especially for plates with difficult design and complex loading.


ABSTRACT: Effects of structural parameters on the vibration of a tapered non-homogeneous rectangular plate with different combinations of boundary conditions are discussed. Tapering in the plate is assumed to be sinusoidal in the x-direction. Here, temperature variation and non-homogeneity in the plate material are also considered sinusoidal in the x-direction. The Rayleigh-Ritz method is used to calculate the frequency parameter for the first two modes of vibration for different values of the structural parameters, i.e. the taper parameter, thermal gradient, aspect ratio and non-homogeneity constant. Results are obtained for three boundary conditions, i.e. clamped boundary (C-C-C-C), simply supported boundary (SS-SS-SS-SS) and clamped-simply supported boundary (CSS-C-SS). Numerical values of the frequency parameter are given in a compact tabular form.


ABSTRACT: This paper presents the harmonic and vibration analysis of functionally graded plates using the finite element method. Initially, the plates are assumed isotropic and the material properties of it are assumed to vary continuously through their thickness direction according to a power-law distribution of the volume fractions of the plate constituents. The four nodded shell element is used to analyse the functionally graded plates. Four functionally graded plates-Al/Al.O., Al/ZrO., Ti–6Al–4V/Aluminium oxide, and SUS304/Si.N are considered in the study, and their results are obtained so that the right choice can be made in applications in high temperature environment and in reducing the vibration amplitudes in applications such as aircrafts, rockets, missiles, etc. Numerical results for the natural frequency and harmonic response amplitude are presented. Results are compared and validated with available results in the literature. Effects of boundary conditions, material and damping on natural frequency and harmonic response of the functionally graded plates are also investigated.


ABSTRACT: The complicated relationship of the high order static indeterminate structure will lead to a lot of calculation work. The strength analysis of the structure is very difficult. In aircraft design phase, a structural
simplified method should be used to model the load characteristics of the structure. In the paper, the buckling analysis of airframe jointed panel is investigated under combined loading and the effect of jointed position to buckling load is also presented. For the buckling analysis of special jointed structure, one new method which is better than traditional methods is described.

References listed at the end of the paper:
[7] Engineering Sciences Data Unit (1949): Initial buckling of flat plates under compression, bending and shear. – ESDU 02.04.05.


ABSTRACT: In this paper, the derivation of expressions for admissible values of strains and stresses for vertex points of layers subjected to tension during tube bending at bending machines is presented. The conditions of the dispersed and located loss of stability of the bent tube were assumed as criteria of instability. The original element of this paper is the extension of the criterion of strain location in a form of possible initiation of a neck or furrow (introduced by Marciniak for thin plates [1]) to bending thin- and thick-walled metal tubes at bending machines. The conditions of the dispersed and localized loss of stability together with formation of the plane state of deformation (PSD) in the plane stress state (PSS) were assumed as the criteria of instability. The calculation results were presented as graphs being useful nomograms. We present also simple examples of calculations of permissible and critical strains and values of bending angles including and not including displacement of the neutral axis y0, during cold bending metal thin-walled tubes at bending machines for bending angles $<0^{0}$; $180^{0}>$. 

References listed at the end of the paper:
Arnab Choudhury, Samar Chandra Mondal and Susenjit Sarkar (Department of Mechanical Engineering Jadavpur University, Kolkata, India), “First Ply Failure Analysis of Laminated Composite Beam for Different Boundary Conditions Under Thermo Mechanical Loading”, International Journal of Applied Mechanics and
ABSTRACT: Failure analysis of a laminated composite beam subjected to uniformly distributed load and thermal load is studied for different boundary conditions and fiber orientation angles, based on ply failure. Three different boundary conditions are studied: simply supported, fixed-fixed and fixed-free. The strength ratio is computed and compared for different failure theories. The effect of fiber orientation angle and aspect ratio on the strength ratio based on first ply failure load is presented in the paper. The strength ratio and transverse deflection are determined for Graphite/Epoxy and Glass/Epoxy composite and their hybrid combinations to find out the optimum hybrid composite beam with minimum weight, deflection and cost. The problem is solved in MATLAB platform. The mode of failure of the composite beam is determined by using maximum stress theory.

References listed at the end of the paper:
plates with thick viscoelastic cores. [36]

laminated rectangular plates. [37]

vibration response of protective metal foam composite sandwich plates. [38]

using higher [39]

behaviour of a glare 3 hybrid composite panel. [40]

sandwich beams: A critical review of literature [41]

International Journal of Mechanical and Mechatronics Engineering, vol.9, No.6, pp.1077-1081. [42]

Experimental investigation on the vibration characteristics of sandwich composite beam and panel under harmonic load using accelerometers and displacement sensors. [43]


Free vibration of sandwich beams with soft core. – Composite Structures, vol.154, pp.179-189. [45]

Hybrid sandwich panels: a review [46]

Nonlinear dynamic analysis of fiber, metal laminated beams subjected to moving loads in the thermal environment. – Composite Structures, vol.140, pp.419-416. [47]


Bending, buckling and free vibration of laminated composite and sandwich beams: A critical review of literature. – Composite Structures, vol.171, pp.486-504. [49]

Dynamic analysis for cracked fiber-metal laminated beams carrying moving loads and its application for wavelet based crack detection. – Composite Structures, vol.159, pp.463-470. [50]

Experimental and finite elements analysis of the vibration behavior of a bio-based composite sandwich beam. – Composites Part B: Engineering, vol.110, pp.466-475. [51]


Nonlinear damping and forced vibration behaviour of sandwich beams with transverse normal stress. – Composite Structures, vol.179, pp.258-268. [53]

Nonlinear dynamic responses of fiber metal laminated beam subjected to moving harmonic loads resting on tensionless elastic foundation. – Composites Part B: Engineering, vol.131, pp.253-259. [54]

Free vibration analysis of fiber metal laminated straight beam. – Open Chemistry, vol.16, No.1 pp.944-948. [55]

Free Vibration Analysis of Fibre-Metal Laminated Beams via Hierarchical One-Dimensional Models. – Hindawi, Mathematical Problems in Engineering. [56]

Vibrations of three layered damped sandwich plate composites. – Journal of Sound and Vibration, vol.64, No.1, pp.63-71. [57]


Bending and vibration analysis of composite sandwich plates. – Computers and Structures, vol.60, No.1, pp.103-112. [59]


Experimental and theoretical investigation of the linear and non- linear dynamic behaviour of a glare 3 hybrid composite panel. – Journal of Sound and Vibration, vol.252, No.2, pp.281-315. [61]


Vibration and damping analysis of laminated/sandwich composite plates using higher-order theory. – Journal of Reinforced Plastics and Composites, vol.21, No.6, pp.559-575. [63]


A closed form solution for linear and nonlinear free vibrations of composite and fiber metal laminated rectangular plates. – Composite Structures, vol.92, No.11, pp.266-2675. [65]


The Modal Analysis of Plates Of Woven Composite Materials. [67]

composite materials by the free vibration method


−

Sciences, vol. 92, pp. 162

sandwich cylindrical shells

circular cylindrical shells subjected to lateral pressure pulse loads

−

Kola R. (2002): Hybrid sandwich panels: a review of recent literature with some numerical results

Advances in Civil Engineering, AETACE.

−


−

Payeganeh G.H., Ashenai Ghasemi F. and Malekzadeh K. (2010): Dynamic response of fiber–metal laminates (FMLs) subjected to blast load – Proc. of Int. Conf. on Advances in Civil Engineering, AETACE.

−


−


−

Nayak N., Meher S. and Sahu S.K. (2013): Experimental and Numerical Study on Vibration and Buckling Characteristics of Glass-Carbon/Epoxy Hybrid Composite Plates. – Proc. of Int. Conf. on Advances in Civil Engineering, AETACE.

−


−


−


−


−


−


−


−


−


−


−


−


−


−


−


−

Payeganeh G.H., Ashenai Ghasemi F. and Malekzadeh K. (2010): Dynamic response of fiber–metal laminates (FMLs) subjected to blast load – Proc. of Int. Conf. on Advances in Civil Engineering, AETACE.
References listed at the end of the paper:


ABSTRACT: This paper reports a research study that investigated buckling of stiffened rectangular isotropic plates elastically restrained along all the edges (CCCC) under uniaxial in-plane load, using the work principle approach. The stiffeners were assumed to be rigidly connected to the plate. Analyses for critical buckling of stiffened plates were carried out by varying parameters, such as the number of stiffeners, stiffness properties and aspect ratios. The study involved a theoretical derivation of a peculiar shape function by applying the boundary conditions of the plate on Taylor Maclaurin’s displacement function and substituted on buckling equation derived to obtain buckling solutions. The present solutions were validated using a trigonometric function in the energy method from previous works. Coefficients, $K$, were compared for various numbers of stiffeners and the maximum percentage difference obtained within the range of aspect ratios of $1.0$ to $2.0$ is shown in Figs 2 - 7. A number of numerical examples were presented to demonstrate the accuracy and convergence of the current solutions.


International Journal of Applied Mechanics and Engineering, Vol. 25, No. 4, pp 84-95, November 2020,

More papers published in the journal, Thin Solid Films (2019 and on)

ABSTRACT: Hydrogen-incorporated amorphous In–Sn–O (a-ITO) thin films were fabricated by introducing hydrogen gas during deposition. The hydrogen concentration in the thin films was experimentally determined to vary from $4.7 \times 10^{20}$ to $8.1 \times 10^{20}$ cm$^{-3}$ with increasing H$_2$ flow rate. The mechanical stability of the a-ITO thin films dramatically improved with the optimal amount of hydrogen ($\approx 5.3 \times 10^{20}$ cm$^{-3}$), without any observable degradation in electrical or optical properties. With increasing hydrogen concentration to the optimal value, the compressive residual stress gradually decreased and the subgap absorption at $\approx 3.1$ eV was suppressed. Considering that the residual stress and subgap absorption mainly originate from defects, hydrogen may be a promising candidate for defect passivation in flexible electronics.


ABSTRACT: Strain-induced surface structures are very common in natural systems and they are very useful for a wide range of applications. In this work, we report on the formation, evolution and transition of multiple surface patterns in zinc/polydimethylsiloxane systems with varied film thicknesses under cyclic uniaxial loading. It is found that the mechanical compression leads to buckling patterns while the mechanical tension induces channel cracks. The buckling patterns include two classes of distinct morphologies: homogeneous wrinkling and localized buckle-delamination, depending on the film thickness. The morphological characteristics and in situ evolotional behaviors of the wrinkling, buckle-delamination and cracking are described and discussed in detail. The phenomenon of wrinkle-to-delamination transition is analyzed by a two-dimensional phase diagram and is used to measure the interfacial adhesion strength between the film and substrate. The report in this work can promote better understanding of the phenomenon of wrinkle-to-delamination transition and the complex interactions between the multiple surface patterns under mechanical loading.


ABSTRACT: Inorganic-organic multilayer systems are ubiquitous in many important technological applications and have received considerable attention recently. Although the mechanics, structures, materials and performances of multilayer devices under room temperature have been extensively investigated, the effect of heat on the inorganic-organic composite systems remains unclear. Here we report on the fracture and wrinkle behaviors of metal/elastomer (silver/polydimethylsiloxane(PDMS)) bilayers resting on glass slides induced by high temperature annealing. It is found that as the annealing temperature is beyond a critical value, the PDMS layer is fractured and detaches from the glass slide due to the thermal contraction during cooling. The fractured
PDMS layer bends upward and places the silver film under a compressive stress, which is relieved by formation of multiple wrinkle patterns. The morphological characteristics, evolutionary behaviors and potential mechanisms of both fracture and wrinkle patterns are discussed in detail. The report in this work could promote better understanding of the effect of heat on the mechanical durability of metal/elastomer/solid multilayer systems.

Dong-Bin Moon (1), Jaedeuk Lee (1), Eun Roh (2) and Nae-Eung Lee (1,2)
(1) School of Advanced Materials Science & Engineering, Sungkyunkwan University, 2006 Seobu-ro, Jangan-gu, Suwan, Gyeonggi-do 16419, Republic of Korea
(2) SKKU Advanced Institute of Nano Technology (SAINT), Sungkyunkwan University, 2066 Seobu-ro, Jangan-gu, Suwon, Gyeonggi-do 16419, Republic of Korea


ABSTRACT: Recent progress in engineering approaches for stretchable electronics and electronic components, including strategies focused on materials science or structural engineering, offer high signal-to-noise detection of vital signs via systems that provide conformal, noninvasive contact to curvilinear skin and are unobtrusive during human activity, such as general motion, exercise, and respiration. Structural engineering strategies with flexible thin films, whose deformation can be categorized as two-dimensional (2D) in-plane or three-dimensional (3D) out-of-plane, provide a release of stress created by stretching, bending, or twisting. Beyond 2D in-plane structural engineering techniques, 3D out-of-plane structural engineering techniques effectively distribute nonlinear and multidirectional 3D strain. Here, we review recent advances in 3D out-of-plane engineering techniques, including wavy and wrinkled structures, pop-up structures, kirigami and origami structures, and nature-inspired structures, and describe the strain distribution mechanisms, fabrication processes, applications, and characteristics of these approaches. We conclude with perspectives on applications of stretchable electronic devices with multidirectional stretchability and the existing challenges for future research.

References listed at the end of the paper:
5 X. Wang, Z. Liu, T. Zhang, Flexible sensing electronics for wearable/attachable health monitoring, Small, 13 (2017), p. 1602790
7 M.D. Dickey, Emerging applications of liquid metals featuring surface oxides, ACS Appl. Mater. Interfaces, 6 (2014), pp. 18369-18379
Intrinsically stretchable supercapacitors composed of polypyrrole electrodes and highly stretchable gel electrolyte, ACS Appl. Mater. Interfaces, 5 (2013), pp. 9008-9014


Highly stretchable and transparent metal nanowire heater for wearable articular thermotherapy, ACS Nano, 9 (2015), pp. 6626-6633


Rubber electronics and sensors from intrinsically stretchable elastomeric composites of semiconductors and conductors, Sci. Adv., 3 (2017), Article e1701114


Highly sensitive and very stretchable strain sensor based on a rubbery semiconductor, ACS Appl. Mater. Interfaces, 10 (2018), pp. 5000-5006


Ha Ryeong Cho (1), Dooho Choi (2) and Myunghwan Byun (1,3)
(1) Department of Materials Engineering, Keimyung University, Daegu 42601, South Korea
(2) School of Advanced Materials Engineering, Dong-Eui University, Busan 47430, South Korea
(3) Department of Advanced Materials Engineering, Keimyung University, Daegu 42601, South Korea

ABSTRACT: In the present study, we report a simple, yet facile route to thickness characterization of the UV/ozone (UVO) treated polydimethylsiloxane (PDMS) thin layer via osmotically-driven wrinkling instability. Through the UVO oxidation process of PDMS, a bi-layered film with local moduli-mismatch regions (i.e., the top UVO exposed region of a thin stiff (less-elasticomeric) SiO_2 layer and the bottom region of an unmodified, elastomeric PDMS foundation) was generated. When ethanol directly dropped on top of a bi-layered film and swelled preferentially a lower elastomeric PDMS foundation, the wrinkles were produced in the confined area within the three-phase contact trace of the ethanol droplet, and then vanished completely as the ethanol evaporated irreversibly. The wrinkle wavelength was observed to be magnified as the mixing ratio of base monomer and curing agent increased from 7:1 to 8:1 to 9:1 to 10:1. The increasing wavelength as a function of increasing UVO treatment time (t_{UVO}) reflected increasing thickness of the silica-like layer. For a given ratio, the SiO_2 thickness was found to increase similarly to the wrinkling wavelength as the t_{UVO} increased. The thickness varied from 22.3 \sim 43.4 \text{ nm} to 51.1 \sim 99.3 \text{ nm} as the t_{UVO} varied from 12 \text{ min} to 60 \text{ min}. A hydrophobic recovery of a hydrophilic thin SiO_2 film created by UVO treatment was observed by examining the wrinkled wavelength as a function of elapsed time. As time passed by, a decrease in the wrinkle wavelength confirmed the hydrophobic-to-hydrophilic transition.

Wenbo Wu (1), Hongbin Zhang (2), Fei Jia (1), Xin Yang (1), Haidong Liu (1), Weifeng Yuan (1), Xi-Qiao Feng (3) and Bin Gu (1,4)
(1) School of Manufacturing Science and Engineering, Key Laboratory of Testing for Manufacturing Process, Ministry of Education, Southwest University of Science and Technology, Mianyang, Sichuan 621010, P. R. China
(2) School of Civil Engineering and Architecture, Hainan University, Haikou, Hainan 570228, P. R. China
(3) Institute of Biomechanics and Medical Engineering, Department of Engineering Mechanics, Tsinghua University, Beijing 100084, P. R. China
(4) Shock and Vibration of Engineering Materials and Structures, Southwest University of Science and Technology, Mianyang 621010, P. R. China


ABSTRACT: Dispersion of Lamb waves in a nanoplate where surface effects exist is investigated in this work by combining the wave theory with the surface elasticity theory. The frequency dispersion equations of the symmetric and the anti-symmetric modes are derived and numerically solved. It is found that surface effects give rise to the thickness-dependent frequency dispersion, and that the phase velocity of Lamb waves increases with the decrease of the plate thickness. Two surface elastic constants featuring surface effects in terms of the surface elasticity theory exhibit significant influence on the wave frequency dispersion in the nanoplate. The larger the surface elastic constants, the higher the wave phase velocity. Moreover, the impact of surface effects is more prominent for the symmetric Lamb waves within the low frequency range. In particular, the symmetric Lamb wave velocity of the fundamental mode can be correlated to the surface elastic constants and the plate thickness when the wave frequency tends to zero. Finally, based on the frequency dispersion characteristics of the symmetric Lamb waves, an analytical expression is given to determine the surface elastic constants according to the wave phase velocity.


ABSTRACT: Complex wrinkle patterns are ubiquitous in nature and are beneficial for a wide range of practical applications. In this work, we report on the spontaneous hierarchical wrinkling of metal films sputter-deposited on liquid-like gel substrates. It is found that the metal atoms and clusters can penetrate into the gel surface layer at the early stage of sputtering. The volume-expansion-induced compressive stress forces the gel surface to generate highly deformed ridge structures. Subsequently developed wrinkles are strongly dependent on the ridge structure, but are insensitive to the film thickness. Tiny wrinkles nested inside the preformed wrinkling can be also observed, resulting in the spontaneous formation of multiscale hierarchical structures. The morphological characteristics, evolutionary behaviors and underlying mechanisms of the hierarchical structures are discussed in detail.

ABSTRACT: We have investigated thin-film encapsulation layers that can be stable without the occurrence of cracks even when the layer is repeatedly folded with a small radius down to 1 mm. The folding stability criteria were also identified for the cases where the encapsulation layer deviates by a certain distance from the stress neutral plane inside a foldable device. An organic-inorganic multilayer structure having the inorganic layer thickness of 5 nm has always been shown to be stable against repeated folding with a radius of 1 mm even though the multilayer is located far from the stress neutral plane. In addition, the folding stability of the organic-inorganic multilayer encapsulation layer was evaluated when contaminant particles were present on the surface of foldable devices. To this end, the step coverage over the contaminant particles and the folding-stability criteria of the encapsulation structure were investigated. It was confirmed that the organic-inorganic multilayer structure was stable to repeated folding in a radius of 1 mm when the coating angle covering the particles was loosened to 140° or more through planarization and thin-film encapsulation.

More papers published in the journal, Extreme Mechanics Letters (2019 and on)

Google the string: “Extreme Mechanics Letters”, then click on the entry: “Extreme Mechanics Letters | ScienceDirect.com” and scroll way down to “View all issues”


ABSTRACT: Wrinkle formation followed by sharp strain localization is commonly observed in compressed stiff film/soft substrate systems. However, cavities or defects beneath the film may directly trigger the formation of local ridges and then folding configurations at a relatively small compressive strain, and a mixture of wrinkles and folds upon further compression. The morphological transition is different than those of defect-free substrates. Numerical simulations of continuously compressed bilayer with pre-patterned cavities are carried out to elucidate the transition mechanism of surface patterns. Parallel experiments of cavities-patterned bilayer prototypes by 3D-printing are also performed to validate the findings in simulations. A rich diversity of periodic surface topologies, including overall spreading waves, localizations, saw-like and co-existing features of folds and wrinkles can be obtained by varying the diameter, depth and spacing of cavities, which provides a potential approach to engineer various surface patterns for applications.


ABSTRACT: A novel porous mechanical metamaterial with variable Poisson’s ratio (VPR) is proposed for compression and impact applications. Constructed by stacking layers of varying void aspect ratio, VPR structures combine the collapsing penetration resistance of auxetic materials with the lateral expansion of positive Poisson’s ratio (PPR) materials. The concept is analyzed via numerical simulation of both compression and impact loading of VPR structures composed of silicone rubber. In addition, compression testing is performed with deformation maps obtained through digital image correlation. Results indicate that VPR structures, compared with uniform porous PPR structures, are resistant to global buckling instabilities. Moreover, in low-energy impact events, VPR structures respond to the impulse with a comparable force spread.
over a longer time than uniform PPR structures of the same porosity. At impact energies above approximately 45 J, the considered silicone VPR structures transition to a regime of more sharply peaked force response. At all energies, VPR structures deform more smoothly than their porous PPR counterparts.

References listed at the end of the paper:
1 Ogden R.W., Non-Linear Elastic Deformation, Dover, New York (1997)
21 Lakes R.S., Foam structures with a negative poisson’s ratio, Science, 235 (1987), pp. 1038-1040
28 Wojciechowski K.W., Two-dimensional isotropic system with a negative poisson’s ratio, Phys. Lett. A, 137 (1–2) (1989), pp. 60-64
39 Caddick B.D., Evans K.E., Negative poisson’s ratios and strain-dependent mechanical properties in arterial prostheses, Biomaterials, 16 (1995), pp. 1109-1115
41 Alderson A., Rasburn J., Evans K.E., Grima J.N., Auxetic polymeric filters display enhanced de-fouling and pressure-compensation properties, Memb. Tech., 137 (2001), pp. 6-8
44 Francesconi L., Taylor M., Bertoldi K., Baldi A., Static and modal analysis of low porosity thin metallic auxetic structures using speckle interferometry and digital image correlation, Exp. Mech., 58 (2) (2018), pp. 283-300
50 Yang C., Vora H.D., Chang Y., Behavior of auxetic structures under compression and impact forces, Smart Mater., 27 (2018), p. 025012

Chao-Yung Yeh, Shih-Chien Chou, Hsin-Wei Huang, Hung-Chen Yu and Jia-Yang Juang (Department of Mechanical Engineering National Taiwan University, Taipei 10617, Taiwan), “Tube-crawling soft robots driven

ABSTRACT: We present a class of soft robots, which can self-adaptively move forward and backward along a tube with an arbitrary cross-section. The soft robot consists of a linear actuator, a motor, and a set of connected soft elastic ribbons, arranged longitudinally on the robot’s circumference. These ribbons, with strategically designed creases and linkages, can be bended and twisted into different three-dimensional configurations via nonlinear mechanical buckling, thereby achieving forward and backward motions by simply using different actuation sequences of the two actuators. Our approach, based on multistable buckling mechanics and loading-sequence strategy, is thus fundamentally different from existing platforms such as “inchworm” and “earthworm” peristaltic robots, which require at least three actuators and not utilize multiple distinct buckling modes for locomotion. Our design may shed light on the development of new locomotions, and may serve as an alternative for designing soft robots for pipe inspection, repairing, and other applications.


ABSTRACT: Normally, enhancement of mechanical properties of auxetic cellular materials is at the expense of its negative Poisson’s ratio. Here, two novel auxetic cellular structures are proposed, with the Young’s modulus and yield strength of the auxetic structures significantly enhanced and without sacrifice of their negative Poisson’s ratio in the corresponding perpendicular direction. Analytical solutions and finite element simulations are carried out to predict the mechanical properties of these new auxetic materials, and the results are validated by the experiments. In addition, the Young’s moduli and strengths of the novel structures can be designed independently with the corresponding Poisson’s ratios.


ABSTRACT: A class of architected materials is proposed for tailorable shear behavior and high energy dissipation. Inclined beams with elastic snap-through instabilities define the microstructure of the proposed materials, which display a ‘twinkling’ phenomenon that converts strain energy to dynamic motions, resulting in rate-independent energy dissipation. The design concepts were experimentally validated using 3D printed prototypes under both half- and full-cycle shear deformation conditions, and shown to respond in rate-independent sequential snap-through transitions with large energy dissipation in the elastic regime. Numerical simulations and analytical analyses show that predictable material behavior and tunable shear properties can be designed through the microstructure’s geometry. The proposed materials fill the need of dissipating energy under shear deformations in a recoverable and rate-independent manner.


ABSTRACT: The serpentine interconnects that used in the stretchable electronics have periodic arc and straight segments. In the stretching process, the straight segments bonded to finite-thick substrate have global buckling and local wrinkling due to lateral contraction caused by Poisson effect. The global buckling has smaller stress level in the serpentine interconnects and can offer higher stretchability. The previously reported models to distinguish global buckling versus local wrinkling are based on wrinkling models for semi-infinite substrate. Here, an analytical model to distinguish global buckling versus local wrinkling for freestanding finite-thick substrate is established, which has general utility for future work in stretchable electronics design.


ABSTRACT: Smart soft materials, because of their mechanical flexibility and quick response to multi-physics stimuli, have drawn considerable attention over the past few years. Here, we present controllable wrinkling
patterns of a liquid crystal polymer film attached on a soft substrate, controlled by laser illumination that holds unique optical characteristics of high coherence and irradiance. To analyze the mechanical response of liquid crystal polymer film/substrate systems under laser illumination, we develop a mathematical model by introducing laser-induced strain that has continuous Gaussian distribution, into the Föppl–von Kármán nonlinear plate theory. We explore effects of photo illumination areas and light-induced bending moments on pattern formation and selection, and discuss the inherent difference compared with uniform illumination. We find that the critical wrinkling strain is independent of laser decay distance, while pattern formation and pattern evolution are primarily determined by this parameter and the half width of laser irradiation. Novel wrinkling patterns, including horseshoe-shaped and spiral modes, are observed upon laser illumination. Furthermore, we provide phase diagrams on pattern selection and bifurcation diagrams on pattern evolution, which could quantitatively guide the effective design of multi-functional surfaces and precisely remote control of diverse surface morphology.


ABSTRACT: Buckled surfaces induced by mismatched swelling and elastic properties of materials are commonly observed in nature, such as on cacti and euphorbias. The rational design and mimicry of such buckling surfaces could lead to the development of smart, adaptive, and stimuli responsive devices. We designed a 3D printed tubular structure, composed of soft swellable poly N-isopropylacrylamide (pNIPAM) segments and stiff non-swellable polyacrylamide (pAAM) segments. Similar to the shape change of Saguaro stems after rainfall, the tubes show tunable periodic buckling modes in water at the room temperature. The buckling behavior was harnessed through the development of compressive stresses in the soft swellable segments induced by the constraint of the stiff non-swellable segments. We developed a finite element model to explore the design space of this periodic buckling behavior for the tube, and used a chemomechanically coupled constitutive model to describe the swellable hydrogel. Inspired by the classic bar buckling problem, we constructed a phase diagram and discovered a universal design parameter that combines the effects of geometric and material properties to guide the design of periodic buckling tubes for bioinspired functional gel structures.


ABSTRACT: 3D-printed metastructures and metamaterials with snap-through instabilities have been extensively investigated in recent years. However, most of the previous research has been limited to the analysis of their elastic response. This paper focuses on the time-dependent mechanics of 3D-printed viscoelastic metastructures with snap-through instabilities. Due to viscoelastic relaxation, a regime called pseudo-bistability can be observed: a previously deformed 3D-printed metastructure can appear to be temporarily bistable before snapping back to its undeformed configuration after a critical time. Experiments with 3D-printed samples and finite element simulations demonstrate that the critical time can be tuned by adjusting the temperature. While the time-dependent snapping causes a change in the overall height in the case of single layer metastructure, experimental and finite element results show that the same type of time-dependent snapping can also be used to obtain an internal reconfiguration when the overall height of a multilayer metastructure is constrained to remain constant. Because of the possibility of tuning the critical time for a given sample by varying the external temperature, harnessing the pseudo-bistable mechanics of these viscoelastic metastructures gives new opportunities towards the development of novel reconfigurable metastructures with programmable response and properties for applications in soft robotics or impact protection.

Hanlin Ding (1,3), Zhen Zhen (2), Haroon Imtiaz (1), Wanlin Guo (4), Hongwei Zhu (2,3) and B. Liu (1,3)
(1) AML, Department of Engineering Mechanics, Tsinghua University, Beijing 100084, PR China
(2) School of Materials Science & Engineering, Tsinghua University, Beijing 100084, PR China
(3) Center for Nano and Micro Mechanics, Tsinghua University, Beijing 100084, PR China
ABSTRACT: For more than half a century, physicists rejected the existence of two-dimensional (2D) materials since they theoretically underestimated the stability. However, the discovery of one-atom-thick graphene proved the inapplicability of this theory. Due to the lack of a proper and universal theory, the prediction of new 2D materials has become a case-by-case process involving a large number of simulations and experiments, which limits the finding of new materials. In this paper, we develop a mechanics model that reveals the hexagonal nature of 2D lattices and elucidates the physical origin of the stability. The proposed model employs the bending stiffness and energy to provide insight into the stability of possible 2D lattices. For instance, chair-type buckled 2D lattices are easier to synthesize than washboard and boat-type lattices. These results are in agreement with the experimental findings. Furthermore, the proposed model can be used as a tool for predicting the stability of novel 2D lattices.


ABSTRACT: Multistable mechanical metamaterials are known for their unique mechanical characteristics, such as snap-through behaviors, negative stiffness effects, and reusability, thus they exhibit unique advantages in some applications. However, traditional multistable materials exhibit fairly low strength and stiffness. Herein, inspired by some activities and mechanisms in the biological organs, a new type of multistable metamaterial comprising a periodic arrangement of sleeves is designed and investigated. The compression experiments show that the material is characterized by typical multistable behaviors and exhibits other advantages such as lightweight, ultra-high stiffness and strength. Moreover, the cycle experiment shows that the material is reusable even though very large deformation occurs. The mechanism of those behaviors is analyzed, and a theory is established for the design of such materials. Based on this outcome, the effects of the important parameters that can control the materials to exhibit snap-through behavior or friction-dominated behavior are discussed.


ABSTRACT: Auxetic chiral structures with negative Poisson ratio (NPR) can contract its width along the directions perpendicular to compression loading direction, thus generate enhanced indentation resistance and enhanced impact energy absorption abilities. To enhance the dynamic mechanical performances of periodic anti-chiral structures and hybrid-chiral structures, geometrically graded ligaments are proposed, and the in-plane dynamic deformation mechanism and energy absorption capacity of the functionally graded anti-chiral and hybrid-chiral cellular structures are studied through finite element analysis (FEA). Numerical results in our work show that the crushing energy absorption performances of periodic chiral structures can be improved by introducing structural graded design, where the plateau stress and energy absorption efficiency can be optimized by means of adjusting the unit cell geometrical parameters. Our study can enrich insightful understanding of the dynamic behavior of chiral cellular materials, and can be employed for optimizing the design of automobile crash energy absorption and impact protection structures.

Fei Liu, Fan Xu and Chenbo Fu (Institute of Mechanics and Computational Engineering, Department of Aeronautics and Astronautics, Fudan University, 220 Handan Road, Shanghai 200433, PR China), “Orientable
ABSTRACT: Tensile wrinkles are widely observed in elastic thin films, with mono-orientation of wrinkles being usually perpendicular to the stretching direction. Here, by changing material orthotropic direction, we present orientable wrinkles in uniaxially stretched orthotropic membranes. To quantitatively explore orthotropy-related wrinkles and their morphological evolution, we develop a mathematical model by introducing orthotropic, elastic constitution into the extended Föppl–von Kármán nonlinear plate theory that can describe large in-plane anisotropic deformations. We find that degree of orthotropy and shear modulus significantly affect the critical buckling strain, restabilization point and wrinkling amplitude. A 3D phase diagram on stability boundaries is drawn and we find that no wrinkles emerge when the orthotropic parameters are located in the stability region. Orientable oblique wrinkles, depending on the angle between orthotropy and stretching direction, are carefully examined, which could be used to guide effective designs of wrinkle-tunable membrane surfaces and structures.

Alessandra Bonfanti (1,2) and Atul Bhaskar (2)
(1) Department of Engineering, University of Cambridge, Cambridge, UK
(2) Faculty of Engineering and Physical Sciences, Southampton Innovation Boldrewood Campus, University of Southampton, SO16 7QF, Southampton, UK

ABSTRACT: Thin elastic sheets and membranes are known to wrinkle when they are stretched — the associated physics is highly non-linear. The unusual behavior exhibited by thin films upon stretching when they possess auxetic structure, i.e. when their apparent Poisson’s ratio is negative, is reported here. Wrinkling is now suppressed within the bulk of auxetic films when tensioned, whereas localized creases confined to the clamps, which decay away exponentially, appear. These edge wrinkles are characterized for their amplitude and wavelength experimentally, theoretically, and computationally, which show excellent agreement with expected trends. The scaling for amplitude, wavelength and decay rate upon film properties and tension is obtained using simple analyses based on kinematic mismatch resulting from lateral Poisson’s expansion.

ABSTRACT: Attaining architected structures with unprecedented properties not found in natural materials is a long-sought goal for both materials science and additive manufacturing. Improving the mechanical behavior of engineered materials such as auxetics for bioengineering applications or bistable structures for mechanical actuation depends on the buckling mechanisms governing their response. Despite the fact that the design principles for two-dimensional buckling have been elucidated in previous studies, comprehending three dimensional buckling mechanisms is still tenuous. In this study, we aim to illuminate the buckling mechanisms governing the response of three-dimensional structures at the microscale, providing the critical guidelines for the design of novel metamaterials. In addition, finite element analysis and in-situ SEM — microindentation experiments are performed to investigate how scale effects affect the design principles to architect a controlled 3D buckling mechanism and reflect the mechanical response to the deformation of the structure in-situ. Our findings elicit the design process of tailored three dimensional buckling structures based on the geometric architecture instead of the behavior of the bulk material, while setting a broader framework to fabricate and characterize these structures at the microscale.

ABSTRACT: The mechanical instability of columns with a low width-to-length ratio under axial compression has been studied for more than 260 years, known as the Euler buckling. Such columns buckle at a critical strain on the order of 1%, after which the compressive load continuously increases with the displacement. Recently, in the advance of soft robotics and mechanical metamaterials, researchers have harnessed buckling of high width-
to-length ratio columns to achieve new functions. However, buckling and post-buckling of these columns are not well studied. Here we show hyperelastic columns, depending on their width-to-length ratio, can undergo continuous, snapping-through, or snapping-back buckling. In particular, we identify a new snapping-back mode of column buckling, in which the buckling mode of column bends to form a sub-critical crease. Our analytical discrete model reveals that snapping-back buckling results from strong coupling between stretching and bending. A phase diagram is constructed to demarcate the different buckling modes of axially compressed columns.

References listed at the end of the paper:
21 Chen D., Jin L., Suo Z., Hayward R.C., Controlled formation and disappearance of creases, Mater. Horizons, 1 (2014), pp. 207-213
29 Chen D., Cai S., Suo Z., Hayward R.C., Surface energy as a barrier to creasing of elastomer films: An elastic analogy to classical nucleation, Phys. Rev. Lett., 109 (2012), Article 038001
35 Poston T., Stewart I., Catastrophe Theory and Its Applications, Courier Corporation (2014)

ABSTRACT: Bistable structures featuring two stable shapes are commonplace in natural and engineered systems. They can quickly snap from one stable state to the other in response to certain external stimuli, and so have found a range of applications in microswitches, actuators, energy harvesters, and mechanical metamaterials. Buckled beams represent a sub-class of bistable structures extensively studied, yet the relation between relevant boundary conditions and their bifurcation behaviors remains incompletely understood. Here we examine the bifurcation behavior of a buckled, elastic beam with both ends clamped in the absence of any external body force. Through a systematic investigation combining experiments, theory, and computational analysis, we identify that the beam can go through saddle–node bifurcation or pitchfork bifurcation (subcritical or supercritical) under asymmetric or symmetric boundary conditions, respectively. We construct the stability diagram in terms of the independent control parameters that can provide a precise prediction of the critical point upon bifurcation. Our results can not only provide powerful guidance on the design of fast switches, mechanical metamaterials, energy harvesters, or micro-electro-mechanical systems (MEMS) that exploit the bistability of elastic beams with clamped ends, but also have implications on a variety of biophysical phenomena and biomimetic structures.

References listed at the end of the paper:
13 Pan D., Ma B., Dai F., Experimental investigation of broadband energy harvesting of a bi-stable composite piezoelectric plate, Smart Mater. Struct., 26 (2017), Article 035045, 10.1088/1361-660x/aa5b41
20 Plaut R.H., Virgin L.N., Vibration and snap-through of bent elastica strips subjected to end rotations, J. Appl. Mech., 76 (2009), Article 041011, 10.1115/1.3086783
ABSTRACT: Classical Euler buckled ribbon has become the cornerstone of many unprecedented applications such as the recently developed stretchable electronics and mechanical-guided 3D assembly. In practical applications, such Euler buckled ribbon may be subjected to out-of-plane loading. However, previous studies mostly concern about the buckling and post-buckling configurations of ribbons under in-plane compression, but the further mechanical behavior of buckled ribbons in response to out-of-plane loading is rarely involved. In this paper, the mechanical behaviors of Euler buckling ribbons under out-of-plane loading are systemically investigated, and distinct configurations evolution paths were observed, which are dependent on both axial in-plane compressive strain of Euler buckling and out-of-plane loading. An analytical model based on geometrical decomposition method and finite deformation beam theory is proposed to clarify the mechanism of the competitions between different configurations evolution paths, to construct phase diagrams to distinguish different deformation modes, and to draw the corresponding deformed profiles, which agree well with the experiments and finite elemental stimulations. Furthermore, the out-of-plane stiffness of Euler buckled ribbons with unusual characteristics (e.g., negative stiffness and stiffness reduction) is also quantified, which has general utility as an engineering design rule for exploiting Euler buckled ribbons in stretchable electronics, 3D bio-interfaces, mechanical-guided 3D assembly and mechanical metamaterials.

References listed at the end of the paper:

40 Yang H., Ma L., Multi-stable mechanical metamaterials by elastic buckling instability, J. Mater. Sci., 54 (2018), pp. 3509-3526

Zi-Long Zhao (1), Shiwei Zhou (1), Xi-Qiao Feng (2) and Yi Min Xie (1)

(1) Centre for Innovative Structures and Materials, School of Engineering, RMIT University, Melbourne 3001, Australia
(2) Institute of Biomechanics and Medical Engineering, Department of Engineering Mechanics, Tsinghua University, Beijing 100084, China


ABSTRACT: The mechanical properties and biological functions of tissues and organs in plants are closely related to their structural forms. In this study, we have performed systematic measurements and found that the leaves and stalks of several species of emergent plants exhibit morphologies of twisting and gradient chirality. Inspired by the experimental findings, we investigate, both theoretically and numerically, the static bending and vibrational properties of these plant organs. By modeling the leaves and stalks as pre-twisted cantilever beams, the effects of the cross-sectional geometry, loading condition, handedness perversion, twisting configuration, and morphological gradient, on their mechanical behavior are evaluated. Our analysis reveals that both static and dynamic responses of the beams can be easily tuned by changing their structural parameters. For any part of the beams, its chiral morphology has more significant influences on the overall structural performance (e.g., bending stiffness and natural frequencies) if it is closer to the clamped end. This work not only deepens our
understanding of the structure–property–function interrelations of chiral plants, but also holds potential applications in the bio-inspired design of innovative devices and structures.

References listed at the end of the paper:
3 Thompson D.W. On Growth and Form, Cambridge University Press (1942)
9 Liu J., et al., Experimental study and numerical simulation on the structural and mechanical properties of Typha leaves through multimodal microscopy approaches, Micron, 104 (2018), pp. 37-44
17 Chen W., Ruan D., Huang X., Optimization for twist chirality of structural materials induced by axial strain, Mater. Today Commun., 15 (2018), pp. 175-184


ABSTRACT: A micromechanically accurate Al-alloy foam model of relative density of 0.08 is crushed under displacement controlled axial compression at different levels of external pressure– triaxial loading. For all pressure levels the foam initial stiff elastic response terminates into a load maximum triggering localized crushing in a band of cells. Under further compression the crushed zone spreads with the stress tracing a plateau during which coexistence of crushed and essentially undeformed zones of cells co-exist. The material returns to
homogeneous deformation with increasing stress when the crushing has spread over the whole specimen. The level of external pressure tends to lower the limit stress, the stress plateau, and the rest of the response. This behavior is subsequently simulated at the continuum level using a Drucker–Prager type compressible constitutive model calibrated to a stress–strain response with a softening branch over part of the strain history (see Yang and Kyriakides [1]). It is demonstrated that the homogenized model captures the three-regime response of the random foam. The limit stress, the plateau stress, its extent, the hardening of the densified material, and the dependence of these on external pressure are reproduced with good accuracy. Since in such homogenized models the cellular microstructure of the foam is replaced by the finite element mesh, the evolution of localization as the stress plateau is traced can differ from the corresponding events in the foam.


ABSTRACT: We report a discrete differential geometry-based numerical method for the simulation of geometrically nonlinear dynamics of thick beam — known as Timoshenko beam. Our numerical framework discretizes the beam into a number nodes and uses the degrees of freedom of each node — position and rotation angle — to construct discrete elastic energies. Equations of motion resulting from balance of forces are formulated at each degree of freedom. These equations are integrated using a second order, implicit Newmark-beta time marching scheme. We find that the structural rigidity and natural frequency computed in Timoshenko beam framework are always lower than the one obtained using Euler–Bernoulli beam method for both naturally straight and curved beams. For quantitative comparison, we analytically solve the Euler–Lagrange equations using both Euler–Bernoulli and Timoshenko beam theories for a number of examples. A good match between the analytical solution and the numerical results in the geometrically linear regime indicates the correctness of our discrete model. The simulation can seamlessly handle geometrically nonlinear deformation that is often not amenable to an analytical approach.

Honglei Zhou (1), Weiyang Qin (1), Qingmin Yu (1,2), Xudong Yu (1), Huanyu Cheng (3) and Huaping Wu(4)
(1) Department of Engineering Mechanics, School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, Xi’an 710129, PR China
(2) Strength and Vibration of Mechanical Structures, Xi’an Jiaotong University, Xi’an 710049, PR China
(3) Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802, USA
(4) Key Laboratory of E&M (Zhejiang University of Technology), Zhejiang Province, Hangzhou 310014, PR China


ABSTRACT: As a novel tactic, controlled buckling of the stiff thin film device component on a compliant substrate with surface relief structures has been widely explored in the design and demonstration of various flexible and stretchable electronic devices. While flat substrates are mainly used in the current design and demonstration of the buckled thin film on a structured substrate, the use of cylindrical substrates presents alternative opportunities for this technique with direct applications in multifunctional catheters for the treatment of ventricular tachycardia, primary and metastatic malignancies, as well as various smart wearable devices. In this study, we will present the modeling analysis and design considerations of thin film device components on a soft cylindrical substrate with surface relief structures. By investigating the controlled circumferential buckling and postbuckling behaviors of stiff thin film integrated on a compliant cylindrical substrate with surface relief structures, the buckling/postbuckling amplitude and maximum strain in the thin film are found to depend on various material and geometric parameters. Additionally, the results predicted from the analytic model are validated by the finite element analysis, which provides a powerful toolset to inform experimental designs.

Jian Hua (1), Hongshuai Lei (2), Cun-Fa Gao (1), Xiaogang Guo (2) and Daining Fang (2)
ABSTRACT: We investigate the morphing of bilayer naturally curved beams and cylindrical shells due to oil extraction. Guided by the mechanics analysis, we construct self-folding composite sheets by incorporating 3D-printed stiff polylactic acid (PLA) patterns into soft poly(N-isopropylacrylamide) (PNIPAm) gels. The modulus of PLA exceeds that of PNIPAm by five orders of magnitude. Upon stimulation of elevated temperature, the PNIPAm/PLA composite sheets exhibit directional folding with folding axis parallel to the hard PLA strips, contrasting with most reported hybrid hydrogel sheets in which folding axes were perpendicular to the embedded fibers. Various 3D morphologies, including tubes, helices, scrolls, have been achieved by programming the embedded PLA patterns. We also generate an analog of curled leaves and the results offer mechanistic understandings of the curling process of leaves in nature. We hope this work can provide guidance for designing self-shaping soft machines that are made by integrating hard and soft materials together.

Daniele Battista (1), Valeri Lyuchnikov (2) and Paola Nardinocchi (1)
(1) Dipartimento di Ingegneria Strutturale e Geotecnica Sapienza Università di Roma, I-00184 Roma, Italy
(2) Institut de Science des Matériaux de Mulhouse 15 rue Jean Starcky Mulhouse, FR 68057, France


ABSTRACT: In this work, mechanical properties of a typical multistable mechanical metamaterial were analyzed in detail. When the maximum strain of the structure was kept constant during deflection, it was found that the largest peak force and best energy absorption efficiency can be obtained by adjusting its geometrical parameters. The influence of parameters on the force–displacement curve of the unit cell under large deformation is also discussed. Moreover, to further verify the conclusions from theoretical and finite element analysis (FEA), we experimentally investigated the mechanical performances of two different multilayer structures fabricated by a high-resolution 3D printer. It is noteworthy that both the FEA and experiments reveal the structure with $Q=3.6$ has significantly better performance than the structure with $Q=6$ both in terms of the properties of vibration isolation and energy absorption. The remarkable result of this work shows its potential in choosing the layouts of multistable mechanical metamaterials.
ABSTRACT: A major concern associated with skin, the largest organ of our body, is how to prevent it from wrinkling and aging. Understanding the mechanics of skin wrinkling can provide useful insight into skin aging prevention. However, despite decades of endeavors the underlying mechanism of skin wrinkling and aging remains poorly understood. This paper explores the effect of geometrical and mechanical properties of skin on its wrinkling via an integrated theoretical and computational analysis. The skin is modeled with a soft structure having different layers with various thicknesses and material properties. Innovatively, the pattern of skin microrelief is generated and mapped on the model to investigate its effect on the formation of primary lines, secondary lines, and big wrinkles of skin. Analytical interpretation provides preliminary insight into the critical compressive strain for the model skin to start wrinkling, while advanced computational models with surface microrelief offer clues for the skin’s post-wrinkling complex morphology. In particular, tissue geometry, material properties, and microrelief pattern are explored as the determinant parameters to control the location, size, and patterns of skin wrinkles. Our findings allude that the characteristics of compression-induced wrinkles are primarily determined by the geometrical and material property of skin layers rather than the genuine skin microrelief. However, microrelief plays a pivotal role in regulating and determining the locations of primary and secondary wrinkle lines. The edges of the microrelief units are favorable paths for evolving primary and secondary lines. Post-wrinkling analysis reveals that in addition to the periodic sinusoidal pattern, several secondary complex patterns such as non-symmetric periodic, period-doubling and self-contacting folds are observed in the compressed model of skin. Results of the study also show that wrinkle patterns highly depend on the thickness and material property of Stratum Corneum (SC), the outermost layer of skin.

Junjie Lin (1), Qiaohang Guo (2,3), Shiwen Dou (2), Nengbin Hua (2,3), Chan Zheng (2,3), Yian Pan (2), Youting Huang (2,3), Zi Chen (4) and Wenzhe Chen (1)
(1) College of Materials Science and Engineering, Fuzhou University, Fuzhou, Fujian 350108, China
(2) School of Materials Science and Engineering, Fujian University of Technology, Fuzhou, Fujian 350108, China
(3) Fujian Provincial Key Laboratory of Advanced Materials Processing and Application, Fuzhou, Fujian 350108, China
(4) Thayer School of Engineering, Dartmouth College, Hanover, NH 03755, USA
ABSTRACT: The deformation of a tri-layer composite rubber from a mono-stable saddle, a monostable state with wrinkles, a bistable cylinder, to a bistable state with wrinkles was investigated in this work. Among these forms, the wrinkled bi-stability was a unique shape that combined two different deformations into one structure and was primarily studied. The dependence of the rubber shape on the geometric and mechanical parameters was investigated. The phase diagram for the rubber transformation provides accurate pre-strain values and width of structure that correspond to various states. Finite element analysis could reproduce these deformation states well considering the above influencing factors. For the bistable surface, the inner layer was wrinkled, while the outer layer remained flat at the same pre-strain. The morphological differences could be related to the constraints in a manner that is analogous to unidirectional strain. Furthermore, the pre-strain field of the top and bottom layers could be simplified to one layer using Poisson’s ratio. The investigated deformation processes have potential applications for the precise control of flexible machines and robots.

Heran Jia (1), Hongshuai Lei (1), Panding Wang (1), Jinxin Meng (1), Chuanlei Li (1), Hao Zhou (2), Ciaoyu Zhang (2) and Daining Fang (1)
(1) Lightweight Multi-functional Composite Materials and Structures, Beijing Institute of Technology, Beijing 100081, PR China
(2) Intelligent Space Robotic Systems Technology and Applications, Beijing Institute of Spacecraft System Engineering, Beijing 100094, PR China

ABSTRACT: Recently, Schwarz Primitive triply periodic minimal surface (P-TPMS) structures have emerged as high-value engineering structures for a wide range of applications. The elastic modulus and ultimate strength of P-TPMS architecture are tunable and superior. Herein, the influence of structural porosity and shell thickness on the compressive response of a P-TPMS lattice structure has been separately studied. Moreover, an enhanced design method, based on local shell thickening, is proposed to obtain a lightweight structure with superior mechanical properties. A comparison between primary and enhanced architectures is carried out by using experimental characterization and finite element analysis (FEA). It has been demonstrated that the enhanced structure renders higher relative elastic modulus and ultimate strength than primary P-TPMS structures. In addition, P-TPMS structural models are reconstructed from micro X-ray tomography (-CT) images and compared with as-designed models. The results reveal that selective laser sintering (SLS) is a promising fabrication route to achieve desired geometric accuracy. In addition, the comparison of experimental and FEA results indicates that the proposed enhanced design method is effective and reliable to obtain shell-based lattices with better mechanical properties.

Diab W. Abueiddy (1), Mohamed Elhebeary (1), Cheng-Shen (Andrew) Shiang (1), Rashid K. Abu Al-Rub (2) and Iwona M. Jasiuk (1)

(1) Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, 1206 West Green Street, Urbana, IL 61801-2906, USA
(2) Department of Aerospace Engineering, Khalifa University of Science and Technology, Abu Dhabi, United Arab Emirates


ABSTRACT: New materials with enhanced properties are of high scientific and industrial interests. Microarchitected cellular materials possess robust mechanical properties such as high strength-to-weight ratios due to their architectures and size effect appearing in metals and ceramics. In this study, we investigate the mechanical properties of a novel microlattice based on the Neovius surface, a member of the triply periodic minimal surfaces. We show that the Neovius-microlattice exhibits high uniaxial modulus, energy absorption, and strength due to its architecture, which is free of self-intersecting elements. The polymeric Neovius-microlattice deforms locally by two mechanisms: buckling and plastic yielding, while the brittle fracture is not observed. Also, we show that the mechanical properties of the Neovius-microlattice can be enhanced further by coating it with a ceramic (alumina) layer. Additionally, the nature of instability in these architected materials (at the micro-scale, microns in dimensions) is explored through experiments and computational modeling. The two primary instability mechanisms, out-of-plane and in-plane buckling, in cellular materials, are distinguished. Such a study can pave the path for designing cellular materials that are stiff, strong, light, and buckling-resistant.


ABSTRACT: Nowadays, flexible pressure sensors have broad applications in healthcare monitoring, wearable electronics and so on. However, conventional fabrications are mostly time-consuming, complicated and even use toxic chemical reagents. It is in urgent need to fabricate pressure sensors with high sensitivity in a facile way. In nature, the fingertip skin of human has many epidermal ridges, which can sense small external stimuli. Here, inspired from the fingerprint, we propose a new type of pressure sensor made with reduced graphene oxide (rGO). The rGO film is designed to form a wrinkled structure by a facile stretching-releasing process, which mimics the morphology of fingertip skin. Owing to the fingertip-skin-like wrinkled structure, the pressure sensor exhibits high sensitivity of 5.77 kPa^{-1} (0 - 490 Pa). It also has a lot of attractive properties, such as fast response (< 100 ms), small detecting pressure (3 Pa) and good repeatability. We show the ability of the pressure sensor in small pressure detecting, human motion monitoring and motion pattern recognition.
Furthermore, a translation system and a multi-touch device with spatially resolved detection based on the pressure sensor are developed. This pressure sensor is hopeful to have potential applications in wearable electronics and human–machine interaction systems.

Zhiwei Zhang (1), Simon Pusateri (2), Binglin Xie (3) and Nan Hu (3)
(1) School of Civil Engineering, Harbin Institute of Technology, Harbin, China
(2) Department of Civil, Environmental and Geodetic Engineering, The Ohio State University, Columbus, USA
(3) School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, China


ABSTRACT: The concept of energy trapping has been recently demonstrated in modular architected materials at various length scales but most energy-trapping mechanisms retain its deformed shape and requires external loads to recover their initial states. Here, we demonstrated an on-demand, repeatable energy-trapping mechanism that enabled by interaction of buckled slender elements. Guided by experiments and numerical simulations, we proved that using a pre-defined imperfection on thin strips can generate a predictable and controllable element interaction, resulting trapped energy stored in the elements and a rapid energy release in a form of snap-through buckling. The amount of trapped energy can be tailored by changing imperfection design, imperfection amplitude, spacing between element and assembly of multiple components. The robustness of this mechanism is demonstrated by such a purely geometric design and thus can be applied over a range of scales and using different materials. We envision that the proposed mechanism can be integrated into buckling-induced smart devices such as energy harvesters and dampers.


ABSTRACT: Film structures have been widely used in flexible electronics, material science, metrology, biomedical engineering and aerospace engineering. When a thin film is loaded with compressive stresses, buckling accompanied by wrinkles is likely to occur under constrained boundaries. Many previous studies have focused on the wrinkling mechanism of a free-standing film or a film–substrate structure, in which compressive stresses in the film are caused by the mismatch between the film and the imposed constrains from its boundaries or the substrate. Instead of using the homogeneous substrate, here we propose a film-lattice structure consisting of a thin film bonded to a bottom-supported lattice. By controlling the buckling of the lattice structure, a distribution of compressive loads can be applied to the film, finally resulting in the generation of periodic wrinkles. Physical mechanism on the buckling-driven wrinkle pattern is investigated with the increasing loading. Dimensionless parameters and their effect on governing the wrinkling mode are also analyzed numerically. The exploration on features of the wrinkles on the film shows that the wrinkle pattern can be controlled by designing the lattice substrate. Our works could help understand the wrinkling caused by the buckling of a complex substrate and guide the harnessing of wrinkles in the design of new materials and structures.


ABSTRACT: Surface patterns driven by mechanical instability commonly form in thin-film structures with a compliant substrate. In this study a practical three-dimensional (3D) finite element modeling approach is employed to directly simulate surface instabilities. It is based on our previously developed embedded imperfection technique in two-dimensions, and is now successfully implemented in 3D to capture sinusoidal wrinkling under uniaxial compression and the checkerboard pattern under equi-biaxial compression. The numerical approach overcomes typical challenges in computationally modeling thin-film buckling instability without the need of sophisticated treatment. The simulation results show that instability-controlled surface patterning is not an instantaneous process. A local disturbance in deformation originates from the imperfection site and propagates outward, eventually leading to a uniform pattern across the entire surface.
ABSTRACT: Heterogeneous materials possess unique combinations of strength, toughness, and multifunctionality, which are derived from the interplay between the different material constituents. The performance of such materials can be further improved via hierarchical architecting, including down to the nanoscale. Here, a novel hierarchical nanoengineered layered architecture is created by harnessing the coherent buckling of vertically aligned carbon nanotube (CNT) arrays followed by their integration with existing aerospace-grade carbon microfiber polymer-matrix advanced composites. In-plane tensile and interlaminar shear strengths are improved beyond the aerospace composite by about 30% and 10%, respectively, and also beyond another CNT hierarchical architecture. Multiscale reinforcement mechanisms responsible for the strength enhancement, including nanofiber pullout, bridging, and suppression of delamination, are revealed by scanning electron microscopy and 3D X-ray computed tomography. The ability to design and create scalable, hierarchical materials with characteristic dimensions spanning from the nanoscale to the macroscale opens up a wide new avenue of next-generation advanced materials with enhanced mechanical and multifunctional properties.


ABSTRACT: Layered materials and structures (LMS), such as van der Waals two-dimensional (2D) layered materials and nacre-like layered structures, often exhibit highly anisotropic mechanical properties, i.e., strong in in-plane directions but weak in out-of-plane direction. Despite the strong anisotropy in their mechanical properties, Timoshenko beam model (TBM) is usually used to describe the bending deformation of LMS. We note, however, that there are two fundamental issues in using TBM to describe LMS: First, the stiffness of LMS approaches zero when the interlayer shear modulus $G$ approaches zero; and second, the first derivative of deflection becomes discontinuous at the point of concentrated force. Clearly, both are not true for LMS. In this work, by introducing the bending energy of monolayer into the potential energy of TBM, we develop a modified Timoshenko beam model (MTBM), which is able to not only address these two issues, but also correctly predict the bending stiffness of LMS without any fitting parameters. Our analysis shows that the bending behaviors of LMS are determined by a dimensionless parameter $L$, where $L$ is the length of the beam and $kGA$ and $n$ are, respectively, the shear and bending rigidity of the beam cross-section, is the bending rigidity of monolayer, and $n$ is the number of layer. When $kGA$ is much larger than 1, both MTBM and TBM degenerate to the classical Euler–Bernoulli beam model. We further perform molecular dynamics simulations, finite element simulations and experiments to validate the MTBM. Based on the MTBM, a couple of interesting applications of LMS are also demonstrated. Hence, the MTBM presented here captures the necessary intrinsic deformation modes of LMS and provides an accurate tool for the prediction and optimization of the mechanical properties of LMS. (Math in the abstract is not printed. Please do not insert math expressions in your abstracts.)


ABSTRACT: Recently discovered light-induced bilayered actuators comprising a light-responsive actuating layer supported by a passive layer are versatile in miniaturized robotics applications, owing to their simple, compact construction and wireless, self-contained mode of actuation. However, the chemo-mechanics and quantitative description of their actuation mechanisms are not sufficiently understood. Here, based on a chemo-mechanics model, a novel instability phenomenon leading to extraordinarily large magnitudes of the bending actuation of bilayered actuators is found and experimentally proven. At specific ratios of the elastic moduli and thicknesses of the active and passive layers, and activation volume of the actuation mechanism, the actuation of
the active layer will be put into a positive feedback mode where the actuation-induced bending of the cantilever structure triggers a compressive stress in a surface region of the active layer which enhances further contractive actuation of the latter by means of light-induced water de-intercalation. The beneficial instability is observed and analyzed for two active material systems that exhibit such a light-induced water de-intercalation mechanism, namely, cobalt-oxides/hydroxides (C-O-H) and nickel hydroxide/oxyhydroxide (N-H-O). Experimental results agree well with predictions of the chemo-mechanics model, thus verifying its applicability to design high-performing actuation systems.


ABSTRACT: The stability of structures continues to be scientifically fascinating and technically important. Shell buckling emerged as one of the most challenging nonlinear problems in mechanics in the middle of the last century when it was first intensively studied. The subject has returned to life motivated not only by structural applications but also by developments in the life sciences and in the field of soft materials. The challenge is that shell structures are susceptible to dramatic load-carrying reductions due to relatively small imperfections in their geometry. Imperfections must be factored into buckling load estimations. Recent work on spherical shells subject to external pressure will be used to illustrate some of the new developments in shell stability. Buckling mode localization, imperfection-sensitivity, energy barriers for stability, and probing to establish the stability landscape will be discussed. EML Webinar speakers and videos are updated at https://imechanica.org/node/24098.


ABSTRACT: While monolayer graphene is known strong and brittle, its three-dimensional (3D) scaleup to architected assemblies, such as graphene aerogels, leads to superior compressibility and resilience. 3D graphene assemblies feature nanoscale characteristic dimensions, and their constitutive mechanical behaviors arise from complex deformation modes. However, whether 3D graphene assemblies exhibit deformation mechanisms widely observed in conventional foams is unclear. Using molecular dynamics simulations, we explore the deformation and instability mechanisms in a 3D graphene honeycomb subjected to uniaxial in-plane compression. Our simulations capture the orientation-dependence of stress–strain response and deformation mode. Compression along the armchair direction causes progressive buckling and results in a structural transformation. In contrast, compression along the zigzag direction results in localized shearing. These findings demonstrate that deformation and instability mechanisms in 3D graphene honeycombs are very similar to those identified in hexagonal honeycombs at the macro-scale level, both experimentally and theoretically.


ABSTRACT: Smart soft materials that can flexibly respond to external multi-physics stimuli, have shown intriguing applications in shape-morphing and morphology control. Here, we present tunable wrinkling patterns in core–shell spheres under thermal load via controlling the orientation of director in nematic liquid crystal polymer (LCP). To analyze nonlinear instability and morphological evolution of LCP shell/core spheres, we develop a shallow core–shell model that accounts for director-induced anisotropic spontaneous strains. By tuning the alignment of liquid crystal director, we explore effects of anisotropy of spontaneous strains on wrinkling pattern formation and evolution. When the director is along the out-of-plane direction, the surface shell undergoes equi-biaxial expansion, resulting in hexagonal, checkerboard, herringbone or labyrinth pattern, determined by a single dimensionless parameter Cs which characterizes the stiffness ratio and curvature of the system. Moreover, stability analysis yields an analytical solution of the critical wrinkling strain and wavelength for equi-biaxially stressed shell/core spheres. When the director is in-plane aligned, leading to primary uniaxial expansion upon heating, the core–shell usually buckles into stripes. For general spatial director alignment, the ultimate wrinkling patterns depending on the anisotropy state of spontaneous strains, can be hexagonal, parallel bead-chain, stripe, herringbone, labyrinth or hybrid. Lastly, we provide director-affected phase diagrams on
pattern selection, which could be used to quantitatively guide the effective design of morphology-related smart surfaces such as anticounterfeiting system.


ABSTRACT: Lightweight lattice structures and chiral metamaterials have both received extensive attention during the past decades. This work builds up a systematic design procedure for an emerging class of architected materials, achieving chirality and achirality under the same framework of parameterization. The design of the so-called ‘hyperbolic unit cell’ takes inspiration ultimately from the double-layered morphology of the fore-wing shells of flying beetles, being intended to replicate the hyperbolic geometric feature. The tessellation schemes that populate the microstructure to a component level are stirred up by the similarity with Euclidean tiling of convex regular polygons. Numerical and experimental studies revealed a wide variation of elastic constants for hyperbolic materials maintaining the same volume fraction, making more visible their applications under various loading scenarios, including compression, tension and shear. Also, a significant twisting effect, observed on the chiral cellular material, is shown to be advantageous in the design of buffering plates and energy-absorbing devices.


ABSTRACT: Infinite circular cylindrical elastic inclusions, or rods, embedded in an unbounded elastic matrix display various modes of instability when they undergo sufficiently large expansion due to either swelling or volumetric growth. In this letter two modes of instability are examined: sinusoidal axisymmetric modes and sinusoidal bending modes. The rod and the matrix are neo-Hookean materials, and the full range of the modulus ratio of rod to matrix is considered. In the primary case examined, deformation is driven by an isotropic volumetric expansion, or transformation, of the rod. A three-dimensional bifurcation analysis of the rod constrained by the matrix reveals the onset of the critical instability mode as dependent on the modulus ratio. Comparisons with related results are discussed, including the compressive buckling of a stiff rod in a compliant matrix and the other limit when the modulus of the rod is very small compared to that of the matrix and behaves effectively as a fluid exerting pressure on the wall of the matrix cavity.


ABSTRACT: In this paper, novel dual scale hybrid mechanical metamaterials consisting of simple cubic structure (SC), body-centered cubic structure (BCC), face-centered cubic structure (FCC) unit cells at different scale levels were designed and proposed for impact energy absorption, where one large type A unit cell and eight (2 x 2 x 2) small periodically architected type B unit cells with half size of type A unit cell along X, Y and Z directions were integrated together for harvesting final hybrid metamaterials. Comparisons of specific energy absorption performances between novel hybrid mechanical metamaterials and constituent simple single type of unit cell lattice during compression process were performed through experimental investigation, where the failure and energy absorption process were recorded using the digital camera. Afterwards, finite element analysis (FEA) was performed and compared with experimental results for investigating the mechanical benefits of novel hybrid Plate-lattice mechanical metamaterials, it was found that the novel hybrid plate-lattice mechanical metamaterials can generate enhanced specific strength, specific stiffness and elevated energy absorption performances indicators, demonstrated promising industrial application potentials as energy-absorbing materials and structures for aerospace, vehicles, transport industrial sections.

Charalampos Androulidakis, Emmanuel N. Koukaras, Krishna Sampathkumar, Jaroslava Rahova, Costas Galiotis and Otakar Frank, “Hierarchy of nanoscale graphene wrinkles on compliant substrate: Theory and
ABSTRACT: Curved beams have been widely used in MEMS (Micro-electromechanical systems) devices and reconfigurable robotics. The present analysis can be applied further in all thin films on substrate and provides significant physical insight for the wrinkle phenomenology.


ABSTRACT: In this study, we examine a rapid and reversible origami folding method by exploiting a combination of resonance excitation, asymmetric bi-stability, and active control. The underlying idea is that, by harmonically exciting a bi-stable origami at its resonance frequencies, one can induce rapid folding between its different stable equilibria with a much smaller actuation magnitude than static folding. To this end, we use a bi-stable water-bomb base as an archetypal example to uncover the underlying principles of dynamic folding based on numerical simulation and experimental testing. If the water-bomb initially settles at its “weak” stable state, one can use a base excitation to induce the intra-well resonance. As a result, the origami would fold and remain at the other “strong” stable state even if the excitation does not stop. The origami dynamics starting from the strong state, on the other hand, is more complicated. The water-bomb origami is prone to show inter-well oscillation rather than a uni-directional switch due to a nonlinear relationship between the dynamic folding behavior, asymmetric potential energy barrier, the difference in resonance frequencies, and excitation amplitude. Therefore, we develop an active feedback control strategy, which cuts off the base excitation input at the critical moment to achieve robust and uni-directional folding from the strong stable state to the weak one. The results of this study can apply to many different kinds of origami and create a new approach for rapid and reversible (self-)folding, thus advancing the application of origami in shape morphing systems, adaptive structures, and reconfigurable robotics.


ABSTRACT: Surface wrinkling is an instability mode that is often observed in a wide variety of multilayer tubes under bending deformation. When the degree of applied bending exceeds a critical value, wrinkles appear at the intrados of the tube and release a large amount of in-plane strain energy stored by bending deformation. In the present work, we propose a simple theoretical model for evaluating the critical curvature and critical bending moment for the occurrence of wrinkling in multilayer tubes and apply the model to carbon nanotubes in a case study. Results indicate an inverse proportional relationship between the two critical properties, which holds true regardless of the number of layers and the size of the hollow core.


ABSTRACT: Curved beams have been widely used in MEMS (Micro-electromechanical systems) devices and energy absorption materials owing to its bistability. Almost all curved beams in previous studies have a constant thickness. Although better performance can be achieved by changing the thickness distribution, such as beams of uniform strength, lack of design and optimization tool limits the development and application of curved beams with varying thickness. In this paper, we demonstrate a new approach to design and optimize curved beams based on machine learning, which has been successful in many fields owing to its ability to process big data that can also be used in structural design and optimization. This machine learning-based model is able to achieve accurate predictions of nonlinear structure–property relationships. The optimized designs with different optimization objectives, such as stiffness, forward snapping force, and backward snapping force, are obtained efficiently and precisely. Experimental testing is conducted on specimens with optimized profiles, which are
fabricated using a high-resolution multi-material 3D printer. The computational results are validated by the experimental results. The machine learning-based optimization approach developed here can provide a promising tool for the design and optimization of beam-based structures and mechanical metamaterials.

Extreme Mechanics Letters, Vol. 41, Article 101002, November 2020,

**More papers published in the journal, Proceedings of the Royal Society Series A** (2019 and on)


ABSTRACT: As a sequel of part I (Kothari et al. 2018 Proc. R. Soc. A474, 20180054), we present a general thermodynamic framework of flexoelectric constitutive laws for multi-layered graphene (MLG), and apply these laws to explain the role of crinkles in peculiar molecular adsorption characteristics of highly oriented pyrolytic graphite (HOPG) surfaces. The thermodynamically consistent constitutive laws lead to a non-local interaction model of polarization induced by electromechanical deformation with flexoelectricity–dielectricity coupling. The non-local model predicts curvature and polarization localization along crinkle valleys and ridges very close to those calculated by density functional theory (DFT). Our analysis reveals that the non-local model can be reduced to a simplified uc-local or e-local model (Kothari et al. 2018 Proc. R. Soc. A474, 20180054) only when the curvature distribution is uniform or highly localized. For the non-local model, we calibrated and formulated the layer-number-dependent dielectric and intrinsic flexoelectric coefficients of MLGs. In addition, we also obtained layer-number dependent flexoelectric coefficients for uc-local and e-local models. Our DFT analysis shows that polarization-induced adsorption of neutral molecules at crinkle ridges depends on the molecular weight of the molecule. Furthermore, our detailed study of polarization localization in graphene crinkles enables us to understand previously unexplained self-organized adsorption of C60 buckyballs in a linear array on an HOPG surface.


ABSTRACT: Dynamic buckling is addressed for complete elastic spherical shells subject to a rapidly applied step in external pressure. Insights from the perspective of nonlinear dynamics reveal essential mathematical features of the buckling phenomena. To capture the strong buckling imperfection-sensitivity, initial geometric imperfections in the form of an axisymmetric dimple at each pole are introduced. Dynamic buckling under the step pressure is related to the quasi-static buckling pressure. Both loadings produce catastrophic collapse of the shell for conditions in which the pressure is prescribed. Damping plays an important role in dynamic buckling because of the time-dependent nonlinear interaction among modes, particularly the interaction between the spherically symmetric ‘breathing’ mode and the buckling mode. In general, there is not a unique step pressure threshold separating responses associated with buckling from those that do not buckle. Instead, there exists a cascade of buckling thresholds, dependent on the damping and level of imperfection, separating pressures for which buckling occurs from those for which it does not occur. For shells with small and moderately small imperfections, the dynamic step buckling pressure can be substantially below the quasi-static buckling pressure.

References listed at the end of the paper:


We demonstrate the complexity that can exist in the modelling of auxetic lattices. By introducing pin-jointed members and large deformations to the analysis of a re-entrant structure, we create a material which has both auxetic and non-auxetic phases. Such lattices exhibit complex equilibrium behaviour during the highly nonlinear transition between these two states. The local response is seen to switch many times between stable and unstable states, exhibiting both positive and negative stiffnesses. However, there is shown to exist an underlying emergent modulus over the transitional phase, to describe the average axial stiffness of a system comprising a large number of cells.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: The collapse of axially compressed cylinders by buckling instability is a classic problem in engineering mechanics. We revisit the problem by considering fully localized post-buckling states in the form of one or multiple dimples. Using nonlinear finite-element methods and numerical continuation algorithms, we trace the evolution of odd and even dimples into one axially localized ring of circumferentially periodic diamond-shaped waves. The growth of the post-buckling pattern with varying compression is driven by homoclinic snaking with even- and odd-dimple solutions intertwined. When the axially localized ring of diamond-shaped buckles destabilizes, additional circumferential snaking sequences ensue that lead to the Yoshimura buckling pattern. The unstable single-dimple state is a mountain-pass point in the energy landscape and therefore forms the smallest energy barrier between the pre-buckling and post-buckling regimes. The small energy barrier associated with the mountain-pass point means that the compressed, pre-buckled cylinder is exceedingly sensitive to perturbations once the mountain-pass point exists. We parameterize the compressive onset of the single-dimple mountain-pass point with a single non-dimensional parameter, and compare the lower-bound buckling load suggested by this parameter with over 100 experimental data points from the literature. Good correlation suggests that the derived knockdown factor provides a less conservative design load than NASA's SP-8007 guideline.

ABSTRACT: Mechanically guided assembly through buckling-induced two-dimensional (2D)-to-three-dimensional (3D) transformation represents a versatile approach to the formation of 3D mesostructures, thanks to the demonstrated applicability to a wide range of length scales (from tens of nanometres to centimetres) and material types (from semiconductors, metals to polymers and ceramics). In many demonstrated examples of device applications, the 2D precursor structures are composed of ribbon-type components, and some of them exhibit frame geometries consisting of multiple straight ribbons. The coupling of bending/twisting deformations among various ribbon components of the frame mesostructures makes the analyses more complicated than the case with a single component, which requires the development of a relevant theory to serve as the basis of design optimization in practical applications. Here, an analytic model of compressive buckling in such frame mesostructures is presented in the framework of energetic approach, taking into account the contributions of spatial bending deformations and twisting deformations. Three different frame geometries are studied, including ‘+’, ‘T’ and ‘H’ shaped designs. As validated by the experiments and finite-element analyses (FEA), the developed model can predict accurately the assembled 3D configurations during the postbuckling of different precursor shapes. Furthermore, the theoretical analyses provide approximate analytic solutions to some key physical quantities (e.g. the maximum out-of-plane displacements and maximum strains), which can be used as design references in practical applications.


ABSTRACT: Fluid-filled shells are near-ubiquitous in natural and engineered structures—a familiar example is that of glass harps comprising partially filled wineglasses or glass bowls, whose acoustic properties are readily noticeable. Existing theories modelling the mechanical properties of such systems under vibrational load either vastly simplify shell geometry and oscillatory modal shapes to admit analytical solutions or rely on finite-element black-box computations for general cases, the former yielding poor accuracy and the latter offering limited tractability and physical insight. In the present study, we derive a theoretical framework encompassing elastic shell deformation with structural and viscous dissipation, accommodating arbitrary axisymmetric shell geometries and fluid levels; reductions to closed-form solutions under specific assumptions are shown to be possible. The theory is extensively verified against a range of geometries, fluid levels and fluid viscosities in
experiments; an extension of the model encompassing additional solid objects within the fluid-filled shell is also considered and verified. The presented theoretical advance in describing vibrational response is relevant in performance evaluation for engineered structures and quality validation in manufacturing.

ABSTRACT: We analyse spatial bistable arches and present an analytical model incorporating axial, two transverse bending and torsion energy components. We extend the St. Venant and Michell relationship used in flexural-torsional buckling of planar arches and use it in modelling spatial arches. We study deformation pathways in spatial arches and their effect on critical characteristics of bistability such as back and forth switching forces, and the distance travelled by a point of the arch. We show that not considering spatial deformation leads to incorrect inferences concerning the bistability of planar arches too. Thus, this model serves as a generalized framework for the existing analysis on planar arches since they belong to a subset of spatial arches. Additionally, the effects of eccentric loading on spatial deformations are explored for arches with a range of as-fabricated shapes and boundary conditions, and the results are validated with finite-element analysis.

D. Misseroni (1), A. B. Movchan (2) and D. Bigoni (1)
(1) DICAM, University of Trento, via Mesiano 77, Trento 38123, Italy
(2) Department of Mathematical Sciences, University of Liverpool, Liverpool L69 3BX, UK
https://doi.org/10.1098/rspa.2019.0283
ABSTRACT: In elasticity, the design of a cloaking for an inclusion or a void to leave a vibrational field unperturbed by its presence, so to achieve its invisibility, is a thoroughly analysed, but still unchallenged, mechanical problem. The ‘cloaking transformation’ concept, originally developed in electromagnetism and optics, is not directly applicable to elastic waves, displaying a complex vectorial nature. Consequently, all examples of elastic cloaking presented so far involve complex design and thick coating skins. These cloakings often work only for problems of unidirectional propagation, within narrow ranges of frequency, and considering only one cloaked object. Here, a new method based on the concept of reinforcement, achieved via elastic stiffening and mass redistribution, is introduced to cloak multiple voids in an elastic plate. This simple technique produces invisibility of the voids to flexural waves within an extremely broad range of frequencies and thus surpassing in many aspects all existing cloaking techniques. The proposed design principle is applicable in mechanical problems ranging from the micro-scale to the scale of civil engineering. For instance, our results show how to design a perforated load-bearing building wall, vibrating during an earthquake exactly as the same wall, but unperforated, a new finding for seismic protection.

References listed at the end of the paper:


Missersoni D, Colquitt DJ, Movchan AB, Movchan NV, Jones IS. 2016 Cymatics for the cloaking of flexural vibrations in a structured plate. Sci. Rep. 6, 23929. (doi:10.1038/srep23929)


ABSTRACT: Long, shallow microchannels embedded in thick, soft materials are widely used in microfluidic devices for lab-on-a-chip applications. However, the bulging effect caused by fluid–structure interactions between the internal viscous flow and the soft walls has not been completely understood. Previous models either contain a fitting parameter or are specialized to channels with plate-like walls. This work is a theoretical study of the steady-state response of a compliant microchannel with a thick wall. Using lubrication theory for low-Reynolds-number flows and the theory for linearly elastic isotropic solids, we obtain perturbative solutions for the flow and deformation. Specifically, only the channel's top wall deformation is considered, and the ratio between its thickness $t$ and width $w$ is assumed to be $(t/w) \gg 1$. We show that the deformation at each streamwise cross section can be considered independently, and that the top wall can be regarded as a simply supported rectangle subject to uniform pressure at its bottom. The stress and displacement fields are found using Fourier series, based on which the channel shape and the hydrodynamic resistance are calculated, yielding a new flow rate–pressure drop relation without fitting parameters. Our results agree favourably with, and thus rationalize, previous experiments.


ABSTRACT: Recent years have seen a paradigm shift regarding the role of nonlinearities and elastic instabilities in engineering science and applied physics. Traditionally viewed as unwanted aberrations, when controlled to be reversible and well behaved, nonlinearity can enable novel functionalities, such as shape adaptation and energy harvesting. The analysis and design of novel structures that exploit nonlinearities and instabilities have, in part, been facilitated by advances in numerical continuation techniques. An experimental analogue of numerical continuation, on the other hand, has remained elusive. Traditional quasi-static experimental methods control the displacement or force at one or more load-introduction points over the test specimen. This approach fails at limit points in the control parameter, as the immediate equilibrium beyond limit points is statically unstable, causing the structure to snap to a different equilibrium. Here, we propose a quasi-static experimental path-following method that can continue along stable and unstable equilibria, and traverse limit points. In addition to controlling the displacement at the main load-introduction point, the technique relies on overall shape control of the structure using additional actuators and sensors. The proposed experimental method enables extended testing of the emerging class of structures that exploit nonlinearities and instabilities for novel functionality.

References listed at the end of the paper:

ABSTRACT: Symmetry plays an integral role in the post-buckling analysis of elastic structures. We show that the post-buckling response of engineering systems with given symmetry properties can be described using a preselected set of buckling modes. Therefore, the main original contribution of this paper is to prove the existence of these influential buckling modes and reveal some insights about them. From an engineering point of view, this study leads to the possibility of reducing computational effort in the analysis of large-scale systems. Firstly, symmetry groups for nonlinear elastic structural problems are discussed. Then, we invoke Curie’s principle and describe the relationship between these groups and related pre-buckling and linear buckling deformation patterns. Then, for structural systems belonging to a given symmetry group, we re-invoke Curie’s principle for describing the relationship between linear buckling modes and post-buckled deformation of the structure. Subsequently, we furnish a simplified asymptotic description which is obtained by projecting the equilibrium equations onto the subset of the most representative modes. As examples, classic bifurcation
problems including isotropic and composite laminate panels under compression loading are investigated. Finally, the accuracy and computational advantages given by this new approach are discussed.

References listed at the end of the paper:
Post-Buckling Behaviour with Modal Interaction in Cylindrical VAT Panels under Compression. Submitted.
Nemeth MP. 1990 Buckling and postbuckling behavior of square compression-loaded graphite-epoxy plates with circular cutouts. NASA TP 3007, August.
Nemeth MP. 1990 Buckling and postbuckling behavior of compression-loaded isotropic plates with cutouts. NASA TP 3024, September.
Nemeth MP. 1996 Buckling and postbuckling behaviour of laminated composite plates with a cutout. NASA TP 3024, July.
Barbero EJ. 2017 Introduction to composite materials design, 3rd edn. Boca Raton, FL: CRC Press.
Kelvin L. 1867 Treatise of natural philosophy (eds WP Thomso, PG Tait), article 644. Cambridge, UK: Cambridge University Press.

Luis Dorfmann (1) and Ray W. Ogden (2)
(1) Department of Civil and Environmental Engineering, Tufts University, Medford, MA 02155, USA
(2) School of Mathematics and Statistics, University of Glasgow, Glasgow G12 8SQ, UK

https://doi.org/10.1098/rspa.2019.0701

ABSTRACT: In two recent papers, conditions for which axisymmetric incremental bifurcation could arise for a circular cylindrical tube subject to axial extension and radial inflation in the presence of an axial load, internal pressure and a radial electric field were examined, the latter being effected by a potential difference between compliant electrodes on the inner and outer radial surfaces of the tube. The present paper takes this work further by considering the incremental deformations to be time-dependent. In particular, both the axisymmetric vibration of a tube of finite length with appropriate end conditions and the propagation of axisymmetric waves in a tube are investigated. General equations and boundary conditions governing the axisymmetric incremental motions are obtained and then, for purposes of numerical evaluation, specialized for a Gent electroelastic model. The resulting system of equations is solved numerically and the results highlight the dependence of the frequency of vibration and wave speed on the tube geometry, applied deformation and electrostatic potential. In particular, the bifurcation results obtained previously are recovered as a special case when the frequency vanishes. Specification of an incremental potential difference in the present work ensures that there is no incremental electric field exterior to the tube. Results are also illustrated for a neo-Hookean electroelastic model and compared with those previously obtained for the case in which no incremental potential difference (or charge) is specified and an external field is required.

References listed at the end of the paper:
Melnikov A, Ogden RW. 2018 Bifurcation of finitely deformed thick-walled electroelastic cylindrical tubes subject to a radial electric field. Z. Angew. Math. Phys. 69, 60. (doi:10.1007/s00033-018-0954-5)

Igor V. Andrianov (1), Vladyslav V. Danishevskyy (2) and Graham Rogerson (3)
(1) Institute of General Mechanics, RWTH Aachen University, Aachen, Germany
(2) Department of Structural Mechanics and Strength of Materials, Prydniprovska State Academy of Civil Engineering and Architecture, Dnipro, Ukraine
ABSTRACT: We aim to study how the interplay between the effects of nonlinearity and heterogeneity can influence on the distribution and localization of energy in discrete lattice-type structures. As the classical example, vibrations of a cubically nonlinear elastic lattice are considered. In contrast with many other authors, who dealt with infinite and periodic lattices, we examine a finite-size model. Supposing the length of the lattice to be much larger than the distance between the particles, continuous macroscopic equations suitable to describe both low- and high-frequency motions are derived. Acoustic and optical vibrations are studied asymptotically by the method of multiple time scales. For numerical simulations, the Runge–Kutta fourth-order method is employed. Internal resonances and energy exchange between the vibrating modes are predicted and analysed. It is shown that the decrease in the number of particles restricts energy transfers to higher-order modes and prevents the equipartition of energy between all degrees of freedom. The conditions for a possible reduction in the original nonlinear system are also discussed.

References listed at the end of the paper:


ABSTRACT: Based on previous work for the static problem, in this paper, we first derive one form of dynamic finite-strain shell equations for incompressible hyperelastic materials that involve three shell constitutive relations. In order to single out the bending effect as well as to reduce the number of shell constitutive relations, a further refinement is performed, which leads to a refined dynamic finite-strain shell theory with only two shell constitutive relations (deducible from the given three-dimensional (3D) strain energy function) and some new insights are also deduced. By using the weak formulation of the shell equations and the variation of the 3D Lagrange functional, boundary conditions and the two-dimensional shell virtual work principle are derived. As a benchmark problem, we consider the extension and inflation of an arterial segment. The good agreement between the asymptotic solution based on the shell equations and that from the 3D exact one gives verification of the former. The refined shell theory is also applied to study the plane-strain vibrations of a pressurized artery, and the effects of the axial pre-stretch, pressure and fibre angle on the vibration frequencies are investigated in detail.

References listed at the end of the paper:


ABSTRACT: Miura-ori is well known for its capability of flatly folding a sheet of paper through a tessellated crease pattern made of repeating parallelograms. Many potential applications have been based on the Miura-ori and its primary variations. Here, we are considering how to generalize the Miura-ori: what is the collection of rigid-foldable creased papers with a similar quadrilateral crease pattern as the Miura-ori? This paper reports some progress. We find some new variations of Miura-ori with less symmetry than the known rigid-foldable quadrilateral meshes. They are not necessarily developable or flat-foldable, and still only have single degree of freedom in their rigid folding motion. This article presents a classification of the new variations we discovered and explains the methods in detail.

References listed at the end of the paper:

Edward C. Ting (1) and Tung-Yueh Wu (2)
(1) Purdue University, West Lafayette, IN 47907, USA
(2) Atomic Energy Council, Taiwan, Republic of China


ABSTRACT: An alternative approach for the analysis of flexible structure is presented. Instead of following theories of definite deformation, classical structural models with infinitesimal strain and engineering stress are assumed as the basis of formulation. A compatible concept of description is developed to handle the large geometrical change due to load. The article first discusses: (i) the condition that a classical model can be
adopted to formulate a flexible theory of structure and (ii) the procedure to formulate a description of geometry that embraces assumptions of the classical model. Based on the discussion, a general procedure to develop the flexible structural model is proposed. Equations for the cylindrical deformation of a flexible panel are derived as an example. In an accompanying article: ‘Analysis of the changing geometry of flexible structure: 2. Analysis of flexible solid’, an algorithm is developed to study three-dimensional flexible solids. Numerical results are obtained to verify the concept and procedure.

References listed at the end of the paper:


ABSTRACT: We investigate the theoretical nonlinear response, Hessian stability, and possible wrinkling behaviour of a voltage-activated dielectric plate immersed in a tank filled with silicone oil. Fixed rigid electrodes are placed on the top and bottom of the tank, and an electric field is generated by a potential difference between the electrodes. We solve the associated incremental boundary value problem of superimposed, inhomogeneous small-amplitude wrinkles, signalling the onset of instability. We decouple the resulting bifurcation equation into symmetric and antisymmetric modes. For a neo-Hookean dielectric plate, we show that a potential difference between the electrodes can induce a thinning of the plate and thus an increase of its planar area, similar to the scenarios encountered when there is no silicone oil. However, we also find that, depending on the material and geometric parameters, an increasing applied voltage can also lead to a thickening of the plate, and thus a shrinking of its area. In that scenario, Hessian instability and wrinkling bifurcation may then occur spontaneously once some critical voltages are reached.

References listed at the end of the paper:


ABSTRACT: Origami structures demonstrate great theoretical potential for creating metamaterials with exotic properties. However, there is a lack of understanding of how imperfections influence the mechanical behaviour of origami-based metamaterials, which, in practice, are inevitable. For conventional materials, imperfection plays a profound role in shaping their behaviour. Thus, this paper investigates the influence of small random geometric imperfections on the nonlinear compressive response of the representative Miura-ori, which serves as the basic pattern for many metamaterial designs. Experiments and numerical simulations are used to demonstrate quantitatively how geometric imperfections hinder the foldability of the Miura-ori, but on the other hand, increase its compressive stiffness. This leads to the discovery that the residual of an origami foldability constraint, given by the Kawasaki theorem, correlates with the increase of stiffness of imperfect origami-based metamaterials. This observation might be generalizable to other flat-foldable patterns, in which we address deviations from the zero residual of the perfect pattern; and to non-flat-foldable patterns, in which we would address deviations from a finite residual.

References listed at the end of the paper:

this paper, the post-buckling analysis of functionally graded (FG) multilayer graphene platelets reinforced composite (GPLRC) cylindrical shells under axial compression is carried out to investigate the stability of such shells. Rather than the critical buckling limit, the focus of the present study is to obtain convergence post-buckling response curves of axially compressed FG multilayer GPLRC cylindrical shells. By introducing a unified shell theory, the nonlinear large deflection governing equations for post-buckling of FG multilayer GPLRC cylindrical shells with wide range of thickness are established, which can be easily changed into three widely used shell theories. Load-shortening curves for both symmetric and asymmetric post-buckling modes are obtained by Galerkin’s method. Numerical results illustrate that the present solutions agree well with the existing theoretical and experimental data. The effects of geometries and material properties on the post-buckling behaviours of FG multilayer GPLRC cylindrical shells are investigated. The differences in the three shell theories and their scopes are discussed also.

References listed at the end of the paper:
Embossing of metallic glass supercooled liquids into templates is emerging as a precision net-shaping and surface patterning technique for metals. Here, we report the effect of thickness of metallic glass on template-based embossing. The results show that the existing embossing theory developed for thick samples fails to describe the process when the thickness of metallic glass becomes comparable to the template cavity diameter. The increased flow resistance at the cavity entrance results in viscous buckling of supercooled liquid instead of filling. A phenomenological equation is proposed to describe the thickness dependent filling of template cavities. The buckling phenomenon is analyzed based on the folding model of multilayer viscous media. We show that controlled buckling can be harnessed in the fabrication of metal microtubes, which are desirable for many emerging applications.

Shanwen Sun (1), Ning An (1), Guoli Wang (1), Meie Li (2), and Jinxiong Zhou (1)
(1) State Key Laboratory for Strength and Vibration of Mechanical Structures, Shaanxi Engineering Laboratory for Vibration Control of Aerospace Structures, School of Aerospace, Xi’an Jiaotong University, Xi’an 710049, China
(2) State Key Laboratory for Mechanical Behavior of Materials, School of Materials Science and Engineering, Xi’an Jiaotong University, Xi’an 710049, China

ABSTRACT: We combine experiment and finite element simulation and come up with a design for a mechanical metamaterial which demonstrates snap-back induced hysteresis and energy dissipation. The resultant is an elastic system that can be used reversibly for many times. The underlying mechanism of the existence of hysteresis and the physics of snap-back induced elastic instability is unveiled. Our results open an avenue for the design and implementation of recoverable energy dissipation devices by harnessing mechanical instability.

PARTIAL INTRODUCTION: Mechanical hysteresis, characterized by noncoincident loading-unloading curves, is a ubiquitous phenomenon in many dissipative or rate-dependent systems such as viscoelastic and elastoplastic systems or systems where a phase transition occurs such as shape memory alloys. In general, an otherwise elastic system does not dissipate energy and exhibits hysteresis undergoing a loading-unloading cycle. Hysteresis, nevertheless, can be achieved in elastic systems by leveraging mechanical instability mainly through compression, opening the door for multistable mechanical metamaterials for various applications. In a system undergoing instability, the force-displacement curve is not monotonic. Snap-through instability occurs when the displacement jumps suddenly in a load-control case. A counterpart, the so-called snap-back instability, occurs in a displacement-control system when load jumps suddenly even without an increase in the prescribed displacement. Recently, a mechanical metamaterial sheet had a regular pattern of holes with two different sizes and confined deformation along one axis by compressing the sheet along the direction perpendicular to the confinement axis. Snap-back instability and hysteresis are achieved in a displacement-control way. However, the introduction of confinement complicates the implementation and entails the instability confinement-dependent.

An intriguing yet elusive question is that can snap-back instability be realized in a tensile loading case? Here, we explore the snap-back instability induced hysteresis in a mechanical metamaterial without confinement and under a tensile loading case. Snap-through instability was observed in a similar mechanical metamaterial under tensile load-control way. But as we explain later, such a system does not exhibit snap-back instability and hysteresis in a displacement-control scheme. From an experimental viewpoint, displacement-control is more favorable and more straightforward to realize.

We start with the numerical simulation of a mechanical metamaterial sheet with periodic patterns. Due to periodicity, we only need to model a representative volume element (RVE) and apply periodic boundary conditions. Fig. 1 (in the paper) shows the RVE of the mechanical metamaterial sheet which is stretched vertically at two edges. Periodic boundary conditions were enforced on the upper and lower horizontal and left and right vertical sides. The RVE consists of two centrally connected cosine-shaped slender segments, one is slim and the other is fat in thickness, with the door for multistable mechanical metamaterials for various applications. References listed at the end of the paper:


ABSTRACT: A wideband energy harvester is required for equipment whose vibration frequency fluctuates in low-frequency bands, such as a motor or a pump. This study proposes a cantilever structure, in which a cantilever (length = 10 mm, width = 10 mm, and thickness = 0.1 mm) is placed in a structure containing a liquid (viscosity = 50 mm/s and specific gravity = 0.96) between two soft thin membranes (thickness = 0.007 mm). The liquid increases the bandwidth of the cantilever by virtue of its viscous resistance. By vibrating the liquid up and down, a resonant frequency is generated due to the motion of the liquid. Based on measurements with prototypes, we confirmed that the bandwidth of the resonant frequency (100 Hz) with liquid is 450% wider than that of a cantilever in air. A weight was used to adjust the resonant frequency of the latter.


ABSTRACT: A relation between the boundary curvature $\kappa$ and the wrinkle wavelength $\lambda$ of a thin suspended film under boundary confinement is demonstrated. Experiments were performed with nanocrystalline diamond films of approximate thickness 184nm grown on glass substrates. By removing portions of the substrates after growth, suspended films with circular boundaries of radius 30–811μm were fabricated. Due to residual stresses, the portions of the film bonded to the substrate are of approximate compressive prestrain 11x10–4 and the suspended portions of the film are azimuthally wrinkled at their boundary. Measurements show that $\lambda$ decreases monotonically with $\kappa$, and a simple model that is in line with this trend is proposed. The model can be applied to design devices with functional wrinkles and can be adapted to gain insight into other systems such as plant leaves. A method for measuring residual compressive strain in thin films, which complements standard strain characterization methods, is also described.

References listed at the end of the paper:

Strain engineering plays a vital role in controlling the physical properties of two-dimensional (2D) materials. However, the nanomechanical behavior of atomically thin 2D crystals under strain has not been completely understood. Here, strain-induced hierarchical ripple nanostructures in triangular MoS₂ flakes were investigated by advanced atomic force microscopy and optical spectral measurements. The hierarchical nanoripples exhibited a threefold radial pattern, and their mechanical, electronic, and optical spectra characteristics were significantly modified due to the suffering from large tensile strain. Structure evolution of these hierarchical nanoripples was further discussed based on the geometry and thickness of MoS₂ flakes, and we attributed the curtain effect at the limit of a single atomic layer. Our study will be beneficial in designing nanomechanical structures and prototype electromechanical devices with 2D materials.

References listed at the end of the paper:
References do not give the titles of the papers. Therefore, they are not added here.


More papers pub

------------------ NOTE ------------------ NOTE ------------------ NOTE ------------------ NOTE ------------------

In December 2018 I added the following journals for a search of buckling/vibration of thin-walled structures:

**Nonlinear Dynamics**
Google the string, “Nonlinear Dynamics” and click on the entry, “Nonlinear Dynamics – Springer”, then click on “Browse Volumes and Issues”.

**Smart Materials and Structures**
Google the string, “Smart Materials and Structures”, then click on “Smart Materials and Structures – IOPscience”, then look for “Journal Archive” and choose the volume and year.

**Soft Matter**
Google the string, “Soft Matter”, then click on “Soft Matter – Royal Society of Chemistry”, then look for “Read this journal” and choose year.

**Earthquake Engineering & Structural Dynamics**
Google the string, “Earthquake Engineering & Structural Dynamics”, then click on “Earthquake Engineering & Structural Dynamics – Wiley Online Library”, click on “Articles” (blue strip at top), go to “All Issues”, click on “Back to dates” and choose year/volume.

**Shock and Vibration**
Google the string, “Shock and Vibration”, then click on “Shock and Vibration – An Open Access Journal – Hindawi”, click on “Table of Contents” (green strip near top), click on Table of Contents for Year 201x and scan titles. (Better: click on “Search”, then type the journal name (Shock and Vibration) and Volume (20xx))

**Mathematical Problems in Engineering**
Google the string, “Mathematical Problems in Engineering”, then click on “Mathematical Problems in Engineering – An Open Access Journal – Hindawi”, click on “Table of Contents” (green strip near top), click on Table of Contents for Year 201x and scan titles. (Better: click on “Search”, then type the journal name (Mathematical Problems in Engineering) and Volume (20xx))

The following journal was added September 3, 2019:

**Journal of the International Association for Shell and Spatial Structures**
Google the string, “Journal of the International Association for Shell and Spatial Structures”, then click on the entry that is followed by “https://www.ingentaconnect.com › content › iass › jiass” and search for “xx Issues are available”. Choose the volume number and issue.

The following journal was added October 24, 2020:

**Journal of the Acoustical Society of America**
Google the string, “Journal of the Acoustical Society of America”, Click on “Browse All Volumes”.

The following journal was added October 28, 2020:

**Structural and Multidisciplinary Optimization**
Google the string, “Structural and Multidisciplinary Optimization”, Click on “Volumes and Issues”.

...
The following journal was added November 16, 2020:

**Journal of Applied and Computational Mechanics**
Google the string, “Journal of Applied and Computational Mechanics, Click on “Journal Archive“

**Results of the December 2018 and September 2019 searches are presented here instead of in Part 1 because Part 1 already has the maximum allowable number of pages. Several of the journals covered are dated starting from 2014.**

--------- END NOTE ---------

**More papers published in the journal, Nonlinear Dynamics** (2014 and on)
Google the string, “Nonlinear Dynamics” and click on the entry, “Nonlinear Dynamics – Springer”, then click on “Browse Volumes and Issues”.


**ABSTRACT:** This paper is devoted to the analysis of nonlinear forced vibrations of two particular three degrees-of-freedom (dofs) systems exhibiting second-order internal resonances resulting from a harmonic tuning of their natural frequencies. The first model considers three modes with eigenfrequencies \( \omega_1 \), \( \omega_2 \), and \( \omega_3 \) such that \( 2\omega_1 \approx 4\omega_2 \approx 2\omega_3 \), thus displaying a 1:2:4 internal resonance. The second system exhibits a 1:2:2 internal resonance, so that the frequency relationship reads \( 2\omega_1 \approx 2\omega_2 \). Multiple scales method is used to solve analytically the forced oscillations for the two models excited on each degree of freedom at primary resonance. A thorough analytical study is proposed, with a particular emphasis on the stability of the solutions. Parametric investigations allow to get a complete picture of the dynamics of the two systems. Results are systematically compared to the classical 1:2 resonance, in order to understand how the presence of a third oscillator modifies the nonlinear dynamics and favors the presence of unstable periodic orbits.

**References listed at the end of the paper:**
References listed at the end of the paper:


Pezhman Mardanpour, Dewey H. Hodges and Reza Rezvani, “Nonlinear aeroelasticity of high-aspect-ratio wings excited by time-dependent thrust”, Nonlinear Dynamics, Vol. 75, No. 3, pp 475-500, February 2014 ABSTRACT: Effects of engine placement on flutter characteristics of a very flexible high-aspect-ratio wing are investigated using the code NATASHA (Nonlinear Aeroelastic Trim And Stability of HALE Aircraft). Gravity for this class of wings plays an important role in flutter characteristics. In the absence of aerodynamic and gravitational forces and without an engine, the kinetic energy of the first two modes are calculated. Maximum and minimum flutter speed locations coincide with the area of minimum and maximum kinetic energy of the second bending and torsion modes. Time-dependent dynamic behavior of a turboshift engine (JetCat SP5) is simulated with a transient engine model and the nonlinear aeroelastic response of the wing to the engine’s time-dependent thrust and dynamic excitation is presented. Below the flutter speed, at the wing tip and behind the elastic axis, the impulse engine excitation leads to a stable limit cycle oscillation; and for the ramp kind of excitation, beyond the flutter speed, at 75% span, behind the elastic axis, it produces chaotic oscillation in the wing. Both the excitations above the flutter speed are stabilized, inboard of the wing.

References listed at the end of the paper:


REFERENCES:

11. Lottati, I.: Flutter and divergence aeroelastic characteristics for composite forward swept cantilevered wing. J. Aircr. 22(11), 1001–1007 (1985)


ABSTRACT: This paper investigates the in-plane and out-of-plane dynamics of a curved pipe conveying fluid. Considering the extensibility, von Karman nonlinearity, and pulsating flow, the governing equations are derived by the Newtonian method. First, according to the modified inextensible theory, only the out-of-plane vibration is investigated based on a Galerkin method for discretizing the partial differential equations. The instability regions of combination parametric resonance and principal parametric resonance are determined by using the method of multiple scales (MMS). Parametric studies are also performed. Then the differential quadrature method (DQM) is adopted to discretize the complete pipe model and the nonlinear dynamic equations are carried out numerically with a fourth-order Runge–Kutta technique. The nonlinear dynamic responses are presented to validate the out-of-plane instability analysis and to demonstrate the influence of von Karman geometric nonlinearity. Further, some numerical results obtained in this work are compared with previous experimental results, showing the validity of the theoretical model developed in this paper.

References listed at the end of the paper:

piezoelectric actuator/sensor pair. In the structural modeling, Reddy’s third-order shear deformation theory is applied. Aerodynamic pressure is evaluated by the supersonic shear layer theory. Hamilton’s principle and the assumed strain method are used to derive the equation of motion. The proportional feedback and the optimal H∞ control methods are performed to design the controller. In the robust control, the uncertainty caused by omitting the nonlinear terms of the control equation is taken into account, and the mixed sensitivity method is used to solve the problem. The nonlinear aeroelastic property of the sandwich beam is analyzed and is compared with that of the equivalent isotropic beam with the same weight to show the superior aeroelastic characteristics of the lattice sandwich beam. Controlled vibration responses under the two different controllers are calculated and compared. Simulation results show that the robust controller is much more effective than the proportional feedback controller in the flutter suppression of the nonlinear sandwich beam.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: This paper presents the analysis on the nonlinear dynamics of a deploying orthotropic composite laminated cantilever rectangular plate subjected to the aerodynamic pressures and the in-plane harmonic excitation. The third-order nonlinear piston theory is employed to model the transverse air pressures. Based on Reddy’s third-order shear deformation plate theory and Hamilton’s principle, the nonlinear governing equations of motion are derived for the deploying composite laminated cantilever rectangular plate. The Galerkin method is utilized to discretize the partial differential governing equations to a two-degree-of-freedom nonlinear system. The two-degree-of-freedom nonlinear system is numerically studied to analyze the stability and nonlinear vibrations of the deploying composite laminated cantilever rectangular plate with the change of the realistic parameters. The influences of different parameters on the stability of the deploying composite laminated cantilever rectangular plate are analyzed. The numerical results show that the deploying velocity and damping coefficient have great effects on the amplitudes of the nonlinear vibrations, which may lead to the jumping phenomenon of the amplitudes for first-order and second-order modes. The increase of the damping coefficient can suppress the increase of the amplitudes of the nonlinear vibration.
This paper examines the effect of using independent finite rotation field in the large displacement analysis of flexible bodies. This finite rotation description is at the core of the large rotation vector formulation (LRVF), which has been used in the dynamic analysis of bodies experiencing large rotation and deformation. The LRVF employs two independently interpolated meshes for describing the flexible body dynamics: the rotation mesh and the position mesh. The use of these two geometrically independent meshes can lead to coordinate and geometric invariant redundancy that can be the source of fundamental problems in the analysis of large deformations. It is demonstrated in this paper that the two geometry meshes can define different space curves, which can differ by arbitrary rigid-body displacements. The material points of the two meshes occupy different positions in the deformed configuration, and as a consequence, the geometries of the two meshes can differ significantly. The paper also discusses other issues including the inextensibility of the rotation mesh. Simple examples are presented in order to shed light on these fundamental issues.

References listed at the end of the paper:


ABSTRACT: The capability of carbon nanotubes (CNTs) in efficient transporting of drug molecules into the biological cells has been the focus of attention of various scientific disciplines during the past decade. From applied mechanics points of view, translocation of a nanoparticle inside the pore of a CNT would result in vibrations. The true understanding of the interactive forces between the moving nanoparticle and the inner surface of the CNT is a vital step in factual realization of such vibrations. Herein, by employing the nonlocal Rayleigh beam theory, nonlinear vibrations of single-walled carbon nanotubes (SWCNTs) as nanoparticle delivery nanodevices are studied. The existing van der Waals interactional forces between the constitutive atoms of the nanoparticle and those of the SWCNT, frictional force, and both longitudinal and transverse inertial effects of the moving nanoparticle are taken into account in the proposed model. The nonlinear-nonlocal governing equations are explicitly obtained and then numerically solved using Galerkin method and a finite difference scheme in the space and time domains, respectively. The roles of the velocity and mass weight of the nanoparticle, small-scale effect, slenderness ratio, and vdW force on the maximum longitudinal and transverse displacements as well as the maximum nonlocal axial force and bending moment within the SWCNT are examined. In general, the obtained results reveal that the nonlinear analysis should be performed when the nanotube structure is traversed by a moving nanoparticle with high levels of the mass weight and velocity. References listed at the end of the paper:


In this paper, the static instability of a nanobeam with geometrical imperfections that is embedded in elastic foundation is investigated. Size-dependent effect is included in the nonlinear model. It is argued that...
nonlocal parameter may render the nanobeam initially unstable. Static response is studied and the condition for instability is stated. The exact postbuckling solution for both the straight and curved nanobeam is presented. It is shown that the bifurcation diagram of a curved nanobeam with initial sinusoidal configuration is similar to that of a straight nanobeam in its nearest buckling mode. The results are verified with pervious relevant works on straight nanobeams and classical theory of curved beams and excellent agreement is shown.

References listed at the end of the paper:


ABSTRACT: A new procedure on random uncertainty modeling is presented for vibration analysis of a straight pipe conveying fluid when the pipe is fixed at both ends. Taking real conveying condition into account, several
randomly uncertain loads and a motion constraint are imposed on the pipe and its corresponding equations of motion, which are established from the Euler–Bernoulli beam theory and the nonlinear Lagrange strain theory previously. Based on the stochastically nonlinear dynamic theory and the Galerkin method, the equations of motion are reduced to the finite discretized ones with randomly uncertain excitations, from which the vibration characteristics of the pipe are investigated in more detail by some previously developed numerical methods and a specific Poincaré map. It is shown that the vibration modes change not only with the frequency of the harmonic excitation but also with the strength and spectrum width of the randomly uncertain excitations, quasi-periodic–dominant responses can be observed clearly from the point sets in the Poincaré’s cross-section. Moreover, the nonlinear elastic coefficient and location of the motion constraint can be adjusted properly to reduce the transverse vibration amplitude of the pipe.

References listed at the end of the paper:


ABSTRACT: We investigate in detail the passive control of vortex-induced vibrations of a freely oscillating circular cylinder using a non-linear energy sink consisting of a secondary system having linear damping and an
essential non-linear cubic stiffness. The loads on the cylinder are calculated using a direct numerical simulation of the incompressible flow over the cylinder using a parallel computational fluid dynamics code. A strongly coupled fluid structure control numerical model is used to determine the responses of the cylinder and the sink as well as the flow. We vary the sink parameters (mass and damping) and determine their effects on the response of the coupled system. We find multiple stable responses of the coupled system for different mass ratios and damping coefficient of the sink, depending on the initial conditions.

References listed at the end of the paper:


ABSTRACT: A new family of explicit integration algorithms is developed based on discrete control theory for solving the dynamic equations of motion. The proposed algorithms are explicit for both displacement and velocity and require no factorisation of the damping matrix and the stiffness matrix. Therefore, for a system
with nonlinear damping and stiffness, the proposed algorithms are more efficient than the common explicit algorithms that provide only explicit displacement. Accuracy and stability properties of the proposed algorithms are analysed theoretically and verified numerically. Certain subfamilies are found to be unconditionally stable for any system state (linear elastic, stiffness softening or stiffness hardening) that may occur in earthquake engineering of a practical structure. With dual explicit expression and excellent stability property, the proposed family of algorithms can potentially solve complicated nonlinear dynamic problems.

References listed at the end of the paper:


ABSTRACT: The problem of minimizing the dynamics response of a damped cantilever Timoshenko beam subjected to earthquake excitation is investigated in this paper. The ground acceleration is expressed in terms of a Fourier series that is modulated by an enveloping function. The method of lines and modal approach are
developed for analyzing the eigenvalues and the flexural vibrations. A magneto rheological damper is proposed to reduce the vibration of the structure. The device is localized at a specific point of the beam. A modal shape which characterizes the vibration of the uncontrolled and controlled system is obtained. The condition of stability of the controlled system is derived using the Routh–Hurwitz criterion.


ABSTRACT: In this paper, a Fourier expansion-based differential quadrature (FDQ) method is developed to analyze numerically the transverse nonlinear vibrations of an axially accelerating viscoelastic beam. The partial differential nonlinear governing equation is discretized in space region and in time domain using FDQ and Runge–Kutta–Fehlberg methods, respectively. The accuracy of the proposed method is represented by two numerical examples. The nonlinear dynamical behaviors, such as the bifurcations and chaotic motions of the axially accelerating viscoelastic beam, are investigated using the bifurcation diagrams, Lyapunov exponents, Poincare maps, and three-dimensional phase portraits. The bifurcation diagrams for the in-plane responses to the mean axial velocity, the amplitude of velocity fluctuation, and the frequency of velocity fluctuation are, respectively, presented when other parameters are fixed. The Lyapunov exponents are calculated to further identify the existence of the periodic and chaotic motions in the transverse nonlinear vibrations of the axially accelerating viscoelastic beam. The conclusion is drawn from numerical simulation results that the FDQ method is a simple and efficient method for the analysis of the nonlinear dynamics of the axially accelerating viscoelastic beam.


ABSTRACT: Rectangular plates resting on elastic foundations are operational activities of large transportation aircraft on runways, footings, foundation of spillway dam, civil building in cold regions, and bridge structures. Hence, in the present work, nonlinear bending analysis of embedded rectangular plates is investigated based on orthotropic Mindlin plate theory. The elastic medium is simulated by orthotropic Pasternak foundation. Adopting the nonlinear strain–displacement relation, the governing equations are derived based on energy method and Hamilton’s principle. The generalized differential quadrature method is performed for the case when all four ends are clamped supported. The influences of the plate thickness, shear-locking, elastic medium constants, and applied force on the nonlinear bending of the rectangular plate are studied. Results indicate that increasing the plate thickness decreases the deflection of the plate. It is also observed that increasing the applied force increases the deflection of the plate. Furthermore, considering elastic medium decreases deflection of the plate, and the effect of the Pasternak-type is higher than the Winkler-type on the maximum deflection of the plate. Also, it is found that the present results have good agreement with previous researches.

References listed at the end of the paper:


ABSTRACT: The four modes of vibration of an isotropic rectangular plate with an inclined crack are investigated. It is assumed that the crack remains continuous and its center is located at the center of the plate. The governing nonlinear equation of the transverse vibration of the plate with the plate boundary conditions being simply-supported on all edges is developed. The multiple scale perturbation method is utilized as the solution procedure to find the steady-state frequency response equations for all the four modes of vibration. The equations for the free and forced vibrations are derived and their frequency responses are presented. A special case of large-scale excitation force has also been considered. The parameter sensitivity analysis for the angle of crack, length of crack and the position of the external applied excitation force is performed. It has been shown that according to the aspect ratio of the plate, the vibration modes can have either nonlinear hardening effect or nonlinear softening behavior.

References listed at the end of the paper:


ABSTRACT: In this study, the nonlinear vibrations of an axially moving beam are investigated by considering the coupling of the longitudinal and transversal motion. The Galerkin method is used to truncate the governing partial differential equations into a set of coupled nonlinear ordinary differential equations. By detuning the axially velocity, the exact parameters with which the system may turn to internal resonance are detected. The method of multiple scales is applied to the governing equations to study the nonlinear dynamics of the steady-state response caused by the internal–external resonance. The saturation and jump phenomena of such system have been reported by investigating the nonlinear amplitude–response curves with respect to external excitation, internal, and external detuning parameters. The longitudinal external excitation may trigger only longitudinal response when excitation amplitude is weak. However, beyond the critical excitation amplitude, the response energy will be transferred from the longitudinal motion to the transversal motion even the excitation is employed on the longitudinal direction. Such energy transfer due to saturation has the potential to be used in the vibration suppression.


ABSTRACT: We present chaotic dynamics of flexible curvilinear shallow Euler–Bernoulli beams. The continuous problem is reduced to the Cauchy problem by the finite-difference method of the second-order accuracy and finite element method (FEM). The Cauchy problem is solved through the fourth- and sixth-order Runge–Kutta methods with respect to time. This preserves reliability of the obtained results. Nonlinear dynamics is investigated with the help of a qualitative theory of differential equations. Frequency power spectra using fast Fourier transform, phase and modal portraits, autocorrelation functions, spatiotemporal dynamics of the beam, 2D and 3D Morlet wavelets, and Poincaré sections are constructed. Four first Lyapunov exponents are estimated using the Wolf algorithm. Transitions from regular to chaotic dynamics are detected, illustrated and discussed. Depending on signs of four Lyapunov exponents the chaotic, hyper chaotic, hyper-hyper chaotic, and deep chaotic dynamics is reported. Curvilinear beams are treated as systems with an infinite number of degrees of freedom. Charts of vibration character, elastic–plastic deformations, and stability loss zone versus control parameters of the studied beams are reported.

References listed at the end of the paper:

Interestingly, for some special cases, the Hopf bifurcations are both subcritical and supercritical. Interestingly, for some special cases, the Hopf bifurcations are both subcritical and supercritical.

The nonlinearity. The stability of LCOs is addressed on the basis of the equivalent linearized method. The location of the nonlinear motion constraints is intimately bound up with the type of Hopf bifurcations (subcritical or supercritical). Interestingly, for some special cases, the Hopf bifurcations are both subcritical and supercritical.
The two-multiple semi-stable limit cycle bifurcation due to the extreme point of the flutter curve is also determined. The analytical results predicted by the analysis scheme are sufficiently validated by numerical calculations.

References listed at the end of the paper:


ABSTRACT: This paper introduces Nonlinear Modified Positive Position Feedback (NMPPF) control approach for nonlinear vibration suppression at primary resonance. Nonlinearity in the system is due to large deformations caused by high-amplitude disturbances, while this control approach is applicable to all types of nonlinearities in resonant structures. NMPPF controller consists of a resonant second-order nonlinear compensator, which is enhanced by a lossy integrating compensator. The two compensators create a combination of exponential and periodic control inputs, which needs innovative time scaling for using the Method of Multiple Scales to obtain the analytical solution of the closed-loop system. The results of the analytical solution for the closed-loop NMPPF controller are presented and compared with the result of the conventional PPF controller. Effects of the control parameters on the system response are comprehensively
studied by parameter variations. The approximate solution is then verified using numerical simulations. According to the results, the NMPPF controller provides a higher level of suppression in the overall frequency domain, as the peak amplitude at the neighborhood frequencies of the primary mode is reduced by 44%, compared to the PPF method. The tunable control parameters also give more flexibility to create the expected type of system response.

References listed at the end of the paper:
ABSTRACT: The aim of the current study is to examine the in-plane and out-of-plane nonlinear size-dependent dynamics of a microplate resting on an elastic foundation, constrained by distributed rotational springs at boundaries. Employing the von Kármán plate theory as well as Kirchhoff’s hypotheses, the equations of motion for the in-plane and out-of-plane directions are derived by means of the Lagrange equations, based on the modified couple stress theory. The potential energies stored in a Winkler-type elastic foundation and the rotational springs at the edges of the microplate are taken into account. The set of second-order nonlinear ordinary differential equations, obtained via the Lagrange scheme, is recast into a double-dimensional set of first-order nonlinear ordinary differential equations with coupled terms by means of a change of variables. The linear natural frequencies of the system are obtained through use of an eigenvalue analysis upon the linear terms of the equations of motion. The nonlinear response, on the other hand, is obtained by means of the pseudo-arclength continuation method. The dynamical characteristics of the system are examined via plotting the frequency–response and force–response curves. The effect of the stiffness of the rotational and translational springs on the nonlinear size-dependent behaviour is also examined. Finally, the effect of employing the modified couple stress theory, rather than the classical theory, on the response is discussed.

References listed at the end of the paper:
ABSTRACT: In this study, a shear deformable shell element is developed based on the elastic middle surface approach using the absolute nodal coordinate formulation (ANCF) for the large deformation analysis of thin to moderately thick shell structures. The bilinear shape function is used to define the global position vector in the middle surface and the transverse gradient vector which defines the orientation and deformation of the cross section within the element. The plane stress assumption is used to remedy the Poisson’s thickness locking exhibited in the ANCF shell element formulated by the continuum mechanics approach, thus the stress distribution along the shell thickness is assumed to be constant. The cross-sectional frame is introduced to define strains of the initially curved shell element using the elastic middle surface approach. The curvature thickness and transverse shear lockings are alleviated using the assumed natural strain method, while the in-plane shear locking is removed using the enhanced assumed strain method. Several numerical examples are presented in order to demonstrate the performance of the shear deformable ANCF shell element based on the elastic middle surface approach developed in this study. The developed element is compared with the continuum mechanics-based ANCF shell element to shed light on the nature of the thickness locking exhibited in the bilinear shell element and its locking remedies.

References listed at the end of the paper:


ABSTRACT: In this manuscript, we investigated the fractional thin elastic system. We studied the obtained fractional Euler-Lagrange’s equations of the system numerically. The numerical study is based on Grünwald–Letnikov approach, which is power series expansion of the generating function. We present an illustrative example of the proposed numerical model of the system.
speed and axial load are assumed to be small and sinusoidal perturbations superimposed upon constant terms. Considering the time-varying rotating speed and axial load, the second-order differential equations of the system have time-periodic gyroscopic and stiffness coefficients. The multiple scales method is utilized to obtain the instability boundaries analytically. Numerical simulations based upon the discrete state transition matrix method are conducted to verify the analytical results. With the constant axial load varying from compressive to tensile loads, all of the instability regions move toward the high frequency range. Their widths almost have no change, except for the combination instability region of certain mode. When both the rotating speed and axial load are time periodic, the cylindrical shell system would always be unstable if the parametric phase does not equal to the integer multiple of \( \pi \). Applying the periodic rotation and axial load simultaneously brings significant impact on the combination instability region, while it almost has no influence on the primary instability regions. In certain conditions, the combination instability region induced by periodic rotating speed would be reduced (even vanished) by the operation of periodic axial load. However, in other conditions, such instability region would be enlarged continuously. The conditions for increasing or decreasing such instability region are obtained analytically and verified by numerical simulations.

References listed at the end of the paper:


ABSTRACT: In this paper, a nonlinear saturation controller is improved by using quadratic velocity coupling term with time delay instead of the original quadratic position coupling term in the controller and adding a negative time-delay velocity feedback to the primary system. The improved controller is utilized to control the high-amplitude vibration of a flexible, geometrically nonlinear beam-like structure when the primary resonance and the 1:2 internal resonance occur simultaneously. To explain analytically mechanism of the saturation controlled system, an integral iterative method is presented to obtain the second-order approximations and the amplitude equations. It is shown that the quadratic velocity coupling term can enlarge the effective frequency bandwidth and enhance the performance of the vibration suppression by comparison with the quadratic position coupling term, and the linear velocity feedback can suppress the transient vibrations. The effects of different control parameters on saturation control are investigated. We found that time delays can be used as control parameters to change the effective frequency bandwidth and avoid the controller overload risk. The analyses show that numerical simulations are in good agreement with the analytical solutions.


ABSTRACT: An analytical model is proposed for the dynamic behavior analysis of a dielectric elastomer (DE) membrane undergoing in-plane stretching. We employ the neo-Hookean model for describing the hyperelasticity feature of the DE membrane. The DE membrane is assumed to elongate only in length direction. For better understanding the dynamic responses of the DE membrane, both free and forced oscillations of the nonlinear system are analyzed. The results show that the system may display periodic oscillations in its length, no matter the DE membrane is constrained by linear or nonlinear cubic springs. It is found that quasi-periodic oscillations of the DE membrane fairly occur provided an in-plane harmonic force is applied. In addition, the response frequencies of the system are also addressed.

References listed at the end of the paper:

conducted via the Floquet theory. The nonlinear size extraction, are employed to solve the high techniques, i.e. the pseudo and then truncated into a reduced parameters and the displacement field. The continuous model is developed by means of Hamilton’s principle parameters and displacement field. Moreover, the kinetic energy is formulated as a function of the modified couple stress theory, the potential energy of the system is obtained in terms of the system over the buckled state, due to the axial load variations value is increased from zero and is set to a value in the supercritical regime; the nonlinear parametric instability


ABSTRACT: The multi-pulse homoclinic orbits and chaotic dynamics of a symmetric cross-ply composite laminated cantilever rectangular plate under in-plane and moment excitations are investigated with 1:2 internal resonance. Based on the explicit expressions of normal form associated with a double zero and a pair of pure imaginary eigenvalues, the energy-phase method proposed by Haller and Wiggins is employed to analyze the multi-pulse homoclinic bifurcations and chaotic dynamics of the composite laminated cantilever rectangular plate. The analysis of the global dynamics indicates that there exist the Shilnikov-type multi-pulse jumping orbits homoclinic to certain invariant sets for the resonance case which may lead to chaos in the sense of Smale horseshoes for the system. Homoclinic trees that describe the repeated bifurcations of multi-pulse solutions are presented. It can be found a gradual breakup of the homoclinic tree and the reducing of pulse numbers for the jumping homoclinic orbits if the dissipation factor is increased. The chaotic motions of the symmetric cross-ply composite laminated cantilever plate are also found by using the numerical simulation.


ABSTRACT: The supercritical parametric instability of a microbeam subject to a time-dependent axial load is examined. The axial load is comprised of a constant mean value along with harmonic fluctuations. The mean value is increased from zero and is set to a value in the supercritical regime; the nonlinear parametric instability over the buckled state, due to the axial load variations, is examined. From the modelling perspective, based on the modified couple stress theory, the potential energy of the system is obtained in terms of the system parameters and displacement field. Moreover, the kinetic energy is formulated as a function of system parameters and the displacement field. The continuous model is developed by means of Hamilton’s principle and then truncated into a reduced-order model via a weighted-residual technique. Three different numerical techniques, i.e. the pseudo-arclength continuation method, a direct time-integration scheme, and an eigenvalue extraction, are employed to solve the high-dimensional reduced-order model. A stability analysis is also conducted via the Floquet theory. The nonlinear size-dependent parametric response of the system over the
buckled configuration is presented in the form of frequency–response diagrams, force–response curves, time histories, phase-plane portraits, fast Fourier transforms, and Poincaré sections.


ABSTRACT: By Kirchhoff dynamic analogy, the thin elastic rod static equals to rotation of rigid body dynamic. The analytical mechanics methods reflect their advantages in the study of the modeling and equilibrium and stability of elastic rod static, especially for the constrained problems. The Lagrangian structure of the equation of motion for elastic rod is deduced from the integral variational principle. The definition of conformal invariance of Mei symmetry of elastic rod in Lagrangian form is given. The determining equation of conformal invariance of Mei symmetry is obtained based on the Lie point transformation group. The relation between conformal invariance of Mei symmetry and Mei symmetry is discussed. The structure equation and conserved quantity by using the Lagrangian structure along arc coordinate deduced from conformal invariance of Mei symmetry of elastic rod are constructed. Take rod with circular cross section as example to illustrate the application of the results get in this paper. These conserved quantities will be helpful in the study of exact solutions and stability, as well as the numerical simulation of the thin elastic rod nonlinear mechanics.


ABSTRACT: Chaotic behavior of the viscoelastic plates subjected to subsonic flow and simultaneous external excitation is studied in this paper. The equation of motion of the plate is derived using the von-Kármán theory. Galerkin’s approach is adopted as the solution method. Corresponding extended Melnikov’s integral is obtained for the non-Hamiltonian system by numerical and analytical approaches. A parametric study is carried out, and effects of different parameters such as linear and nonlinear stiffness and structural damping on the chaotic behavior of the dynamical system are investigated. Chaos thresholds are obtained, and the correlation between the analytical and numerical results is evaluated.


ABSTRACT: This paper investigates the nonlinear dynamic response of hybrid laminated plates resting on elastic foundations in thermal environments. The plate consists of conventional fiber-reinforced composite (FRC) layers and carbon nanotube-reinforced composite (CNTRC) layers. Each layer may have matrix cracks, and the damage is described by a refined self-consistent model. The motion equations are based on a higher-order shear deformation theory with a von Kármán type of kinematic nonlinearity. The thermal effects are included, and the material properties of both FRC and CNTRC are assumed to be temperature dependent. The plate–foundation interaction is also included. The motion equations are solved by a two-step perturbation technique to determine the dynamic response of matrix-cracked hybrid laminated plates. The boundary condition is assumed to be simply supported with in-plane displacements “movable” or “immovable.” The effects of stiffness reduction due to matrix cracks, the foundation stiffness, the temperature change, the percentage and distribution of carbon nanotubes in CNTRC layers are discussed in detail through a parametric study.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: Loop delays are taken into our consideration when positive position feedback controller is used to control the vibrations of forced and self-excited nonlinear beam. External excitation is a harmonic excitation caused by support motion of the cantilever beam. Self-excitation is caused by fluid flow and modeled by a nonlinear damping with a negative linear part (Rayleigh’s function). The multiple timescales perturbation technique is applied to obtain a first-order approximate solution. Effects of time delay on the system are extensively studied, and optimal conditions for the system operation are deduced. The equilibrium solution curves are plotted for several values of controller parameters. The stability of the steady-state solution is investigated using frequency-response equations. The analytical results are validated by numerical integration of the original closed-loop system model equations, time histories and Poincaré map for the system. We realized that all predictions from analytical solutions are in good agreement with the numerical simulation.


ABSTRACT: The forced vibration response of the pipe conveying fluid, with 3:1 internal resonance, is studied here for the first time. The straight equilibrium configuration becomes bent while the velocity of the fluid exceeds the critical value. As a result, the original mono-stable system transforms to a bi-stable system. Critical excitation which can cause global responses is solved out from the potential equation of the unperturbed system. The condition of 3:1 internal resonance is established after the partial differential equation is discretized. Global bifurcations are studied in simulation ways. By the method of multiple scales, local responses around the bent configuration are investigated. The analytical results are verified by simulations. Responses at the second mode bifurcate out another branch near the resonance frequency. It is very different with the triply harmonic responses without internal resonance. The triply harmonic response is a resonant excitation to the second mode. Responses will change largely with the detuning relationship between these two modes. Influences of the excited amplitude are also studied. Based on the analytical method, critical excited conditions of jumping and hysteretic phenomena are determined. The responses will have up- and down-bifurcations in the special region.

References listed at the end of the paper:


**ABSTRACT:** The influence of a nonlinear foundation on the dynamics of a periodically supported beam has been investigated by a novel model. By using Fourier transforms and Dirac comb properties, a relation between the displacement of the beam and the reaction forces of its supports in steady state has been established from the Euler–Bernoulli beam’s equation. This relation holds for any foundation behaviors. Therefore, the dynamic equation of a support has been built by combining this relation and the constitutive law of the foundation and the supports. This equation describes a forced nonlinear oscillator, provided that the moving loads are a periodical series. Then, an iteration procedure has been developed to compute the periodic solution. This procedure has been demonstrated converging to the analytic solution for linear foundations. The applications to bilinear and cubic nonlinear foundations have been performed as examples. Moreover, the influences of nonlinearity on the dynamic responses have been investigated by parametric studies.


**ABSTRACT:** We present a generalized shear deformation theory in combination with isogeometric (IGA) approach for nonlinear transient analysis of smart piezoelectric functionally graded material (FGM) plates. The nonlinear transient formulation for plates is formed in the total Lagrange approach based on the von Kármán strains, which includes thermo-piezoelectric effects, and solved by Newmark time integration scheme. The electric potential through the thickness of each piezoelectric layer is assumed to be linear. The material properties vary through the thickness of FGM according to the rule of mixture and the Mori–Tanaka schemes. Various numerical examples are presented to demonstrate the effectiveness of the proposed method.

References listed at the end of the paper:


ABSTRACT: Fiber-reinforced composite laminates (FRCL) is susceptible to the external impacting. Understanding the crack propagation and structural mechanical properties of the damaged FRCL under low-velocity oblique impact is of great value in practical application. A new analytical dynamic model is developed in this work to research the dynamic response and damage property of FRCL under oblique impacting. The displacement field and strain–displacement relations of the FRCL are established by utilizing higher-order shear plate theory. The matrix damage and fiber rupture in FRCL under oblique impacting are captured by an internal variable-based continuum damage constitutive relation. To accurately predict the oblique impacting force, an analytical dynamic impacting model is proposed basing on a developed contact model, where normal and tangential contact is coupled and solved simultaneously. The whole initial boundary value problem is iteratively solved by synthetically using finite differential method and Newmark-β method. The solving convergence and accuracy of the model is demonstrated and validated. Simulations show that the matrix damage is more easily to appear in FRCL under shear force due to oblique contact when under oblique impacting, and the damage profile is different from normal impacting. The dynamic responses of the FRCL plate under oblique impacting differ also greatly from normal impacting. The current research provides a theoretical basis for FRCL design and its engineering application when under low-velocity impacting.

References listed at the end of the paper:


ABSTRACT: Nonlinear dynamic behaviors of an aeroelastic airfoil with free-play in transonic air flow are studied. The aeroelastic response is obtained by using time-marching approach with computational fluid dynamics (CFD) and reduced order model (ROM) techniques. Several standardized tests of transonic flutter are presented to validate numerical approaches. It is found that in time-marching approach with CFD technique, the time-step size has a significant effect on the calculated aeroelastic response, especially for cases considering both structural and aerodynamic nonlinearities. The nonlinear dynamic behavior for the present model in transonic air flow is greatly different from that in subsonic regime where only simple harmonic oscillations are observed. Major features of the responses in transonic air flow at different flow speeds can be summarized as follows. The aeroelastic responses with the amplitude near the free-play are dominated by single degree of

freedom flutter mechanism, and snap-through phenomenon can be observed when the air speed is low. The bifurcation diagram can be captured by using ROM technique, and it is observed that the route to chaos for the present model is via period-doubling, which is essentially caused by the free-play nonlinearity. When the flow speed approaches the linear flutter speed, the aeroelastic system vibrates with large amplitude, which is dominated by the aerodynamic nonlinearity. Effects of boundary layer and airfoil profile on the nonlinear responses of the aeroelastic system are also discussed.

References listed at the end of the paper:


ABSTRACT: In this paper, stability and local bifurcation behaviors for the nonlinear aeroelastic model of an airfoil with external store are investigated using both analytical and numerical methods. Three kinds of degenerated equilibrium points of bifurcation response equations are considered. They are characterized as (1) one pair of purely imaginary eigenvalues and two pairs of conjugate complex roots with negative real parts; (2) two pairs of purely imaginary eigenvalues in nonresonant case and one pair of conjugate complex roots with negative real parts; (3) three pairs of purely imaginary eigenvalues in nonresonant case. With the aid of Maple software and normal form theory, the stability regions of the initial equilibrium point and the explicit expressions of the critical bifurcation curves are obtained, which can lead to static bifurcation and Hopf bifurcation. Under certain conditions, 2-D tori motion may occur. The complex dynamical motions are considered in this paper. Finally, the numerical solutions achieved by the fourth-order Runge–Kutta method agree with the analytic results.

References listed at the end of the paper:
ABSTRACT: A strictly nonlinear state feedback control law is designed for an aeroelastic system to eliminate subcritical limit cycle oscillations. Numerical continuation techniques and harmonic balance methods are employed to generate analytical estimates of limit cycle oscillation commencement velocity and its sensitivity with respect to the introduced control parameters. The obtained estimates are used in a multiobjective optimization framework to generate optimal control parameters which maximize the limit cycle oscillation commencement velocity while minimizing the control cost. Numerical simulations are used to show that the assumed nonlinear state feedback law with the optimal control parameters successfully eliminates any existing subcritical limit cycle oscillations by converting it to supercritical limit cycle oscillations, thereby guaranteeing safe operation of the system in its flight envelope.

References listed at the end of the paper:

http://digital.library.unt.edu/ark:/67531/metadc57724/

ABSTRACT: The current work presents an experimentally validated analytical model for low-velocity impact between a sphere and a plate. The model accounts for plastic deformation as well as flexural vibrations. The elastic phases are modeled with a nonlinear Hertzian contact model, and the plastic phase is linearized with a non-homogeneous expression. The results are compared against recently carried out experiments. The model well captures the effect of plate thickness-to-sphere diameter ratio, impact velocity, and material properties. The model’s generalized framework allows consideration for various expressions of contact parameters, critical velocity, and residual indentation. Moreover, the proposed methodology can be easily incorporated into particle-based or discrete element modeling approaches for granular flows to evaluate the real-time coefficient of restitution as opposed to assuming the constant value beforehand. Simplified relations are provided to assist in evaluating the coefficient of restitution.

References listed at the end of the paper:

REFERENCES LISTED AT THE END OF THE PAPER:


Yun-dong Li and Yi-ren Yang, “Nonlinear vibration of slightly curved pipe with conveying pulsating fluid”, Nonlinear Dynamics, Vol. 88, No. 4, pp 2513–2529, June 2017

ABSTRACT: The nonlinear governing motion equation of slightly curved pipe with conveying pulsating fluid is set up by Hamilton’s principle. The motion equation is discretized into a set of low dimensional system of nonlinear ordinary differential equations by the Galerkin method. Linear analysis of system is performed upon this set of equations. The effect of amplitude of initial deflection and flow velocity on linear dynamic of system is analyzed. Curves of the resonance responses about $\Omega\approx\omega_1$ and $\Omega\approx2\omega_1$ are performed by means of the pseudo-arclength continuation technique. The global nonlinear dynamic of system is analyzed by establishing the bifurcation diagrams. The dynamical behaviors are identified by the phase diagram and Poincare maps. The periodic motion, chaotic motion and quasi-periodic motion are found in this system.
ABSTRACT: In this paper, new planar isoparametric triangular finite elements (FE) based on the absolute nodal coordinate formulation (ANCF) are developed. The proposed ANCF elements have six coordinates per node: two position coordinates that define the absolute position vector of the node and four gradient coordinates that define vectors tangent to coordinate lines (parameters) at the same node. To shed light on the importance of the development of some of the new elements presented in this paper, the nonlinearity of sloshing flow, the roll motion amplitude is not linearly proportional to wave amplitude.


ABSTRACT: In this paper, the three degrees-of-freedom motion of a two-dimensional rectangular liquid tank under wave action is simulated by the boundary element method in time domain. The coupling effects between tank motion and internal sloshing flow are investigated in partially filled conditions. The fourth-order Runge–Kutta method is adopted to update the wave shape and velocity potential on the free surface. The fully nonlinear mutual dependence of the incident wave, tank motion and internal sloshing flow is decoupled through an auxiliary function method, by which the liquid tank acceleration can be obtained directly without knowing the pressure distribution. The corresponding validation of numerical model is carried out and indicates that the accuracy of the present method is satisfactory to evaluate the dynamic responses of tank and sloshing motion. The corresponding response amplitude operators of tank motions for various wave frequencies, amplitudes and filling conditions are obtained, and the nonlinear coupling effects of sloshing flow on the tank responses are analyzed. It is found that the coupling effects have significant influence on sway and roll motion while have little impact on heave motion. The most important coupling effects on roll motion are the split of peak. In addition, due to the nonlinearity of sloshing flow, the roll motion amplitude is not linearly proportional to wave amplitude.


ABSTRACT: In this paper, new planar isoparametric triangular finite elements (FE) based on the absolute nodal coordinate formulation (ANCF) are developed. The proposed ANCF elements have six coordinates per node: two position coordinates that define the absolute position vector of the node and four gradient coordinates that define vectors tangent to coordinate lines (parameters) at the same node. To shed light on the importance of the element geometry and to facilitate the development of some of the new elements presented in this paper, two different parametric definitions of the gradient vectors are used. The first parametrization, called area parameterization, is based on coordinate lines along the sides of the element in the reference configuration, while the second parameterization, called Cartesian parameterization, employs coordinate lines defined along the axes of the structure (body) coordinate system. The fundamental differences between the ANCF parameterizations used in this investigation and the parametrizations used for conventional finite elements are highlighted. The Cartesian parameterization serves as a unique standard for the triangular FE assembly. To this end, a transformation matrix that defines the relationship between the area and the Cartesian parameterizations is introduced for each element in order to allow for the use of standard FE assembly procedure and define the
structure (body) inertia and elastic forces. Using Bezier geometry and a linear mapping, cubic displacement fields of the new ANCF triangular elements are systematically developed. Specifically, two new ANCF triangular finite elements are developed in this investigation, namely four-node mixed-coordinate and three-node ANCF triangles. The performance of the proposed new ANCF elements is evaluated by comparison with the conventional linear and quadratic triangular elements as well as previously developed ANCF rectangular and triangular elements. The results obtained in this investigation show that in the case of small and large deformations as well as finite rotations, all the elements considered can produce correct results, which are in a good agreement if appropriate mesh sizes are used.

References listed at the end of the paper:

ABSTRACT: The global bifurcations and multi-pulse orbits of an aero-thermo-elastic functionally graded material (FGM) truncated conical shell under complex loads are investigated with the case of 1:2 internal resonance and primary parametric resonance. The method of multiple scales is utilized to obtain the averaged equations. Based on the averaged equations obtained, the normal form theory is employed to find the explicit expressions of normal form associated with a double zero and a pair of pure imaginary eigenvalues. The energy-phase method developed by Haller and Wiggins is used to analyze the multi-pulse homoclinic bifurcations and chaotic dynamics of the FGM truncated conical shell. The analytical results obtained here indicate that there exist the multi-pulse Shilnikov-type homoclinic orbits for the resonant case which may result in chaos in the system. Homoclinic trees which describe the repeated bifurcations of multi-pulse solutions are found. The diagrams show a gradual breakup of the homoclinic tree in the system as the dissipation factor is increased. Numerical simulations are presented to illustrate that for the FGM truncated conical shell, the multi-pulse Shilnikov-type chaotic motions can occur. The influence of the structural-damping, the aerodynamic-damping, and the in-plane and transverse excitations on the system dynamic behaviors is also discussed by numerical simulations. The results obtained here mean the existence of chaos in the sense of the Smale horseshoes for the FGM truncated conical shell.

References listed at the end of the paper:

A derived governing equation is solved by expressing the transverse displacement in terms of modal coordinates. Line spring model for crack terms are modified to accommodate the effect of electric and magnetic field. Dynamic analysis of functionally graded cracked magneto-electro-elastic plate is presented. Approximate solution for forced vibration of cracked MEE plate is also obtained using a perturbation approach. Nonlinear dynamic behavior of functionally graded cracked shell under complex loads. Nonlinear vibrations of a cantilever beam. J. Sound Vib.


ABSTRACT: A nonlinear analytical model for the transverse vibration of cracked magneto-electro-elastic (MEE) thin plate is presented using the classical plate theory (CPT). The MEE plate material selected is fiber-reinforced BaTiO3–CoFe2O4 composite, which contains a partial crack at the center. The CPT and the simplified line spring model for crack terms are modified to accommodate the effect of electric and magnetic field rigidities. The analysis considers in-plane forces for the MEE plate, which makes the model nonlinear. The derived governing equation is solved by expressing the transverse displacement in terms of modal coordinates. An approximate solution for forced vibration of cracked MEE plate is also obtained using a perturbation
technique. The effect of part-through crack, volume fraction of the composite on the vibration frequencies and structure response is investigated. The frequency response curves presented shows the phenomenon of hard or soft spring. Furthermore, the devised model is extended to the case of cracked MEE plate submerged in fluid. Velocity potential function and Bernoulli’s equation are used to incorporate the inertia effect of surrounding fluid. Both partially and totally submerged plate configurations are considered. The validation of the present results is carried out for intact submerged plate as to the best of the author’s knowledge the literature lacks in results for submerged-cracked plates. New results for cracked MEE plate show that the vibration characteristics are affected by volume fraction, crack length, fluid level and depth of immersion.

References listed at the end of the paper:

ABSTRACT: Modeling and nonlinear vibration analysis of graphene-reinforced composite (GRC) laminated beams resting on elastic foundations in thermal environments are presented. The graphene reinforcements are assumed to be aligned and are distributed either uniformly or functionally graded of piece-wise type along the thickness of the beam. The motion equations of the beams are based on a higher-order shear deformation beam theory and von Kármán strain displacement relationships. The beam–foundation interaction and thermal effects are also included. The temperature-dependent material properties of GRCs are estimated through a micromechanical model. A two-step perturbation approach is employed to determine the nonlinear-to-linear frequency ratios of GRC laminated beams. Detailed parametric studies are carried out to investigate the effects of material property gradient, temperature variation, stacking sequence as well as the foundation stiffness on the linear and nonlinear vibration characteristics of the GRC laminated beams.


ABSTRACT: This paper details the study of the aeroelastic effect on modal interaction and dynamic behavior of acoustically excited square metallic panels with fully clamped edges using finite element method. The first-order shear deformation plate theory and von Karman nonlinear strain–displacement relationships are employed to consider the structural geometric nonlinearity caused by large vibration deflections. Piston aerodynamic theory and Gaussian white noise are used to simulate the aerodynamic load and the acoustic load, respectively. Motion equations are derived by the principle of virtual work in the physical coordinates and then transformed into the truncated modal coordinates with reduced orders. Runge–Kutta method is employed to obtain the system response, and the modal interaction mechanism is quantitatively valued by the modal participation distribution. Results show that in the pre-/near-flutter regions, in addition to the dominant fundamental resonant mode, the first twin companion antisymmetric modes can be largely excited by the aeroelastic coupling mechanism; thus, aeroelastic modal participation distribution and the spectrum response can be altered, while the dynamic behavior still exhibits linear random vibrations. In the post-flutter region, the dominant flutter motion can be enriched by highly ordered odd order super-harmonic motion occurs due to 1:1 internal resonances. Correspondingly, the panel dynamic behavior changes from random vibration to highly ordered motions in the fashion of diffused limit-cycle oscillations (LCOs). However, this LCOs motion can be affected by the intensifying acoustic excitation through changing the aeroelastic modal interaction mechanism. Accompanied with these changes, the panel can experience various stochastic bifurcations.

References listed at the end of the paper:

interactions. Under higher mode on nonlinear dynamic characteristics of electrically actuated microbeam via considering nonlinear modal interactions. This article aims to theoretically investigate the influence of antisymmetry on nonlinear coupled vibration of electrostatically actuated clamped-clamped microbeams under higher-order modes excitation, two nonlinear coupled flexural modes to describe the coupling between vibrational modes. A review of the aeroelastic stability of plates and shells. AIAA J. 46(5), 1544–1555 (2009). doi: 10.2514/1.39214


Lei Li, Qichang Zhang, Wei Wang and Jianxin Han, “Nonlinear coupled vibration of electrostatically actuated clamped-clamped microbeams under higher-order modes excitation”, Nonlinear Dynamics, Vol. 90, No. 3, pp 1593-1606, November 2017

ABSTRACT: Nonlinear modal interactions have recently become the focus of intense research in microstructures for their use to improve oscillator performance and probe the frontiers of fundamental physics. Understanding and controlling nonlinear coupling between vibrational modes is critical for the development of advanced micromechanical devices. This article aims to theoretically investigate the influence of antisymmetry mode on nonlinear dynamic characteristics of electrically actuated microbeam via considering nonlinear modal interactions. Under higher-order modes excitation, two nonlinear coupled flexural modes to describe...
microbeam-based resonators are obtained by using Hamilton’s principle and Galerkin method. Then, the Method of Multiple Scales is applied to determine the response and stability of the system for small amplitude vibration. Through Hopf bifurcation analysis, the bifurcation sets for antisymmetry mode vibration are theoretically derived, and the mechanism of energy transfer between antisymmetry mode and symmetry mode is detailed studied. The pseudo-trajectory processing method is introduced to investigate the influence of external drive on amplitude and bifurcation behavior. Results show that nonlinear modal interactions can transit vibration energy from one mode to nearby mode. In what follows, an effective way is proposed to suppress midpoint displacement of the microbeam and to reduce the possibility of large deflection. The quantitative relationship between vibrational modes is also obtained. The displacement of one mode can be predicted by detecting another mode, which shows great potential of developing parameter design in MEMS. Finally, numerical simulations are provided to illustrate the effectiveness of the theoretical results.

ABSTRACT: In this study, a unified nonlinear dynamic buckling analysis for Euler–Bernoulli beam–columns subjected to constant loading rates is proposed with the incorporation of mercurial damping effects under thermal environment. Two generalized methods are developed which are competent to incorporate various beam geometries, material properties, boundary conditions, compression rates, and especially, the damping and thermal effects. The Galerkin–Force method is developed by implementing Galerkin method into force equilibrium equations. Then for solving differential equations, different buckled shape functions were introduced into force equilibrium equations in nonlinear dynamic buckling analysis. On the other hand, regarding the developed energy method, the governing partial differential equation for dynamic buckling of beams is also derived by meticulously implementing Hamilton’s principles into Lagrange’s equations. Consequently, the dynamic buckling analysis with damping effects under thermal environment can be adequately formulated as ordinary differential equations. The validity and accuracy of the results obtained by the two proposed methods are rigorously verified by the finite element method. Furthermore, comprehensive investigations on the structural dynamic buckling behavior in the presence of damping effects under thermal environment are conducted.

Ran Wang, Wen-zheng Zhang, Zhen-tao Zhao, Hong-wu Zhang, “Radially and axially symmetric motions of a class of transversely isotropic compressible hyperelastic cylindrical tubes”, Nonlinear Dynamics, Vol. 90, No. 4, pp 2481-2494, December 2017
ABSTRACT: In this paper, the radially and axially symmetric motions are examined for a hyperelastic cylindrical tube composed of a class of transversely isotropic compressible neo-Hookean materials about the radial direction. Firstly, a system of coupled nonlinear evolution equations describing the motions of the cylindrical tube is derived by Hamilton’s principle. Then the system is reduced to a system of nonlinear ordinary differential equations by the travelling wave transformations. According to the theory of planar dynamical systems, qualitative analyses on the solutions of the system are given in different parameter spaces. Specially, the influences of the material parameters on the qualitative and quantitative properties of the solutions are discussed. Two types of travelling wave solutions of the radially symmetric motion are obtained, including classical periodic travelling wave solutions and solitary wave solutions with the peak form. So does the axially symmetric motion, but solitary wave solutions with the valley form. Correspondingly, some numerical examples are shown.

References listed at the end of the paper:
Tianchen Yuan, Jian Yang and Li-Qun Chen, “Nonlinear characteristic of a circular composite plate energy harvester: experiments and simulations”, Nonlinear Dynamics, Vol. 90, No. 4, pp 2495-2506, December 2017

ABSTRACT: A piezoelectric energy harvester is investigated with the focus on its nonlinear behavior. The harvester consists of a circular composite plate with the clamped boundary, a proof mass and two steel rings. A reduced-order model of the harvester is established, and the parameters are identified from the experimental data. A technique is proposed to identify electrical parameters with the outcomes agreeing with the theoretical values, and a fifth-order polynomial is employed to approximate the nonlinear restoring force. Both the experimental and the numerical results demonstrate that the harvester changes its characteristic from linearity to a softening nonlinearity and finally to a combined softening and hardening nonlinearity as the excitation increases from low to high.

References listed at the end of the paper:


ABSTRACT: The nonlinear bending and vibrations of tapered beams made of axially functionally graded (AFG) material are analysed numerically. For a clamped–clamped boundary conditions, Hamilton’s principle is employed so as to balance the potential and kinetic energies, the virtual work done by the damping, and that done by external distributed load. The nonlinear strain–displacement relations are employed to address the geometric nonlinearities originating from large deflections and induced nonlinear tension. Exponential distributions along the length are assumed for the mass density, moduli of elasticity, Poisson’s ratio, and cross-sectional area of the AFG tapered beam; the non-uniform mechanical properties and geometry of the beam along the length make the system asymmetric with respect to the axial coordinate. This non-uniform continuous system is discretised via the Galerkin modal decomposition approach, taking into account a large number of symmetric and asymmetric modes. The linear results are compared and validated with the published results in the literature. The nonlinear results are computed for both static and dynamic cases. The effect of different tapered ratios as well as the gradient index is investigated; the numerical results highlight the importance of employing a high-dimensional discretised model in the analysis of AFG tapered beams.

References listed at the end of the paper:

ABSTRACT: The interaction between granular matter and the elastic body is a complex issue due to the complex properties of granular matter. An experiment involving a sinusoidally excited plate buried in glass bead particles contained in a box is conducted. The motion behavior of the plate is observed and recorded by the strain gauge. The amplitude–frequency and phase–frequency curves are recorded to study the natural property of the plate in granular matter. In this experiment, jump phenomena are found in both the amplitude–frequency and phase–frequency planes in circumstances with smaller particle sizes, lower buried depths, and larger amplitudes of the excitation force. Otherwise, the period-doubling bifurcation, especially $3T$, is found with the increase in the excitation force. These bifurcations usually occur in specific buried depth and excitation frequency band and require smaller particle sizes. The experiments with random-shaped particles exhibit no-jump phenomenon, but period-doubling bifurcation and chaos. These phenomena are sensitive to parameters and closely related to the varying process of the excitation frequency and force. Reasonable mechanisms are summarized qualitatively through some of our recent researches in this paper.

References listed at the end of the paper:


ABSTRACT: In this paper, the dynamic instability of thin laminated composite plates subjected to harmonic in-plane loading is studied based on nonlinear analysis. The equations of motion of the plate are developed using von Karman-type of plate equation including geometric nonlinearity. The nonlinear large deflection plate equations of motion are solved by using Galerkin’s technique that leads to a system of nonlinear Mathieu-Hill equations. Dynamically unstable regions, and both stable- and unstable-solution amplitudes of the steady-state vibrations are obtained by applying the Bolotin’s method. The nonlinear dynamic stability characteristics of both antisymmetric and symmetric cross-ply laminates with different lamination schemes are examined. A detailed parametric study is conducted to examine and compare the effects of the orthotropy, magnitude of both tensile and compressive longitudinal loads, aspect ratios of the plate including length-to-width and length-to-thickness ratios, and in-plane transverse wave number on the parametric resonance particularly the steady-state vibrations amplitude. The present results show good agreement with that available in the literature.

References listed at the end of the paper:

References listed at the end of the paper:


The effects of nonlinear energy sink (NES) on vibration suppression of a simply supported beam are investigated in this work. The slow flow equations of the system are derived by using complexification–averaging method, and the validity of the derivation is verified. By comparing the vibration absorption of single
and parallel NESs of equal mass, it is found that the latter exhibits superior vibration absorption performance. In addition, the parallel NES can eliminate higher branch responses of the system under the harmonic load. Furthermore, it is found that parallel NES can eliminate the higher branches of the system more effectively by tuning nonlinear stiffness and damping. Moreover, the thermal effect on natural frequencies of the simply supported beam is considered, and the influences of the parallel NES’s parameters on the energy dissipation rate under shock load are investigated. The nonlinear responses of the simply supported beam with parallel NES under harmonic load and with the increase of temperature are described.

Xu Sun, Shi-Zhao Wang, Jia-Zhong Zhang and Ze-Hua Ye, “Bifurcations of vortex-induced vibrations of a fixed membrane wing at Re less than or equal to 1000., Nonlinear Dynamics, Vol. 91, No. 4, pp 2097-2112, March 2018

ABSTRACT: Vortex-induced vibrations (VIVs) of a fixed two-dimensional perimeter-reinforced (PR) membrane wing at \(0 \leq \alpha \text{ Re}(\text{Reynolds number}) \leq 1000\) and \(0 \leq \alpha \text{ (angle of attack)} \leq 30\) are investigated using fluid–structure interaction simulations. By employing very fine increments for Re and \(\alpha\), bifurcation boundaries of the dynamic response of the membrane wing in the Re–\(\alpha\) plane are captured. With increase in Re and/or \(\alpha\), it is found that the VIV state of a fixed PR membrane wing will change progressively from static state to period 1 via a Hopf bifurcation and then from period 1 to multiple period and chaos via a succession of period-doubling bifurcations. The Hopf bifurcation is triggered by the shedding of the leading- and/or trailing-edge vortices, while the period-doubling bifurcations are induced by the appearance and evolution of the secondary vortices on the upper surface of the membrane wing at higher Re and \(\alpha\). With an increase in the structure rigidity or pre-strain, the overall responses of the membrane wing are not changed much in the Re–\(\alpha\) plane except that the period 1 response near \(700 \leq \text{Re} \leq 1000\) and \(14 \leq \alpha \leq 16\) is destroyed, due to the significant change of the shedding process of the leading-edge vortices. Moreover, it is also found that unsteady responses of the PR membrane wing at \(\alpha = 0\) can be suppressed by small pre-strain.


ABSTRACT: Characterization of nonlinear behavior of micro-mechanical components in MEMS applications plays an important role in their design process. In this paper, nonlinear dynamics, stability and pull-in mechanisms of an electrically actuated circular micro-plate subjected to a differential pressure are studied. For this purpose, a reduced-order model based on an energy approach is formulated. It has been shown that nonlinear dynamics of an electrically actuated micro-plate, in the presence of differential pressure, significantly differs from those under purely electrostatic loads. The micro-plate may lose stability upon either saddle-node or period-doubling bifurcations. It has also been found that in the presence of a differential pressure, increasing the DC or AC voltages may surprisingly help to stabilize the motion of the micro-plate.

References listed at the end of the paper:


developed in this paper based on the absolute nodal coordinate formulation (ANCF), no distinction is made between plate and shell structures. The proposed ANCF triangular plate/shell elements have 12 coordinates per node: three position coordinates and nine position gradient coordinates that define vectors tangent to coordinate lines at the nodes. The fundamental differences between the conventional FE and the new ANCF parameterizations are highlighted. In this investigation, two different parameterizations, each of which employs independent coordinates, are used. In the first parameterization, called volume parameterization, coordinate lines along the sides of the triangular element in the straight (un-deformed) configuration are used in order to facilitate the development of closed-form cubic shape functions. In the second parameterization, called Cartesian parameterization, coordinate lines along the global axes of the structure (body) coordinate system are used to facilitate the element assembly. The element transformation between the volume and the Cartesian parameterizations is developed and used to define the structure inertia and elastic forces. Three new fully parameterized ANCF triangular plate/shell elements are developed in this investigation: a four-node mixed-coordinate element (FNMC) and two three-node elements (TN1 and TN2). All the elements developed in this investigation lead to a constant mass matrix and zero Coriolis and centrifugal forces. A non-incremental total Lagrangian procedure is used for the numerical solution of the nonlinear equations of motion. The performance of the proposed ANCF triangular plate/shell elements is analyzed by comparison with the ANCF rectangular plate element and conventional three-node linear (TNL) and six-node quadratic (SNQ) triangular plate elements.

References listed at the end of the paper:


ABSTRACT: In this work, chaotic dynamics of flexible spherical axially symmetric shallow shells subjected to sinusoidal transverse load is studied with emphasis put on the vibration modes. Chaos reliability is verified and validated by solving the implemented mathematical model by partial nonlinear equations governing the dynamics of flexible spherical shells and by estimating the signs of the largest Lyapunov exponents with the help of qualitatively different approaches. It is shown how the scenario of transition of the investigated shells from regular to chaotic vibrations depends on the boundary condition. The following cases are considered: (1) movable and fixed simple supports along the shell contours, taking into account shell stiffness (Feigenbaum scenario) and shell damping (Ruelle–Takens–Newhouse scenario), and (2) movable clamping (regular shell vibrations). The presence of dents, the location and character of which essentially depend on the shell geometric parameters, boundary conditions, and the external load parameters, is detected in some regions of the shell surface and discussed.

References listed at the end of the paper:
geometrically nonlinear equations of motion of the doubly microshell are obtained for in-plane displacements as well as the out-of-plane one. These equations of partial differential type are reduced to a large set of ordinary differential equations making use of a two-dimensional Galerkin scheme. Extensive numerical simulations are conducted to obtain the nonlinear resonant response of the system for various principal radii of curvature and to examine the effect of modal interactions and the length-scale parameter.

References listed at the end of the paper:
Experimental data clearly show a strong and nonlinear dependence of damping from the amplitude vibrations of a rectangular plate (hardening system), a circular cylindrical panel (softening system), and a clamped rod made of zirconium alloy (weak hardening system). The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curved shallow shell panel. The experiments show that a damping value over six times larger than the linear one must be expected for vibration of thin plates when the vibration amplitude is moderately thick doubly curva...
increase with the peak vibration amplitude, and the model is capable of reproducing them with very good accuracy.

References listed at the end of the paper:


ABSTRACT: Seismic wave control is very important both in civil and mechanical engineering. Common passive methods for isolating a building or a device include base isolators and tuned mass dampers. In the present paper, a time-varying controllable spring is considered as a vibration isolator for a linear mechanical
system. The controller works as follows: When the seismic movement is active, the velocity of the moving mass is monitored as the reference velocity. When such reference velocity is positive, the stiffness is reduced; when it is negative, the stiffness is increased. Numerical investigations show that the controller is capable of filtering seismic excitation close to the natural frequency of the controlled system and reducing the total seismic energy transfer up to 5 times. The role played by the gravity in the active vibration filtering is pointed out by showing that no filtering action can be observed in gravity-free simulations. Moreover, control effectiveness has been proven for a measured seismic signal, showing its robustness in presence of noise.

References listed at the end of the paper:


ABSTRACT: The nonlinear response of a water-filled, thin circular cylindrical shell, simply supported at the edges, to multi-harmonic excitation is studied. The shell has opportune dimensions so that the natural frequencies of the two modes (driven and companion) with three circumferential waves are practically double than the natural frequencies of the two modes (driven and companion) with two circumferential waves. This introduces a one-to-one-to-two-to-two internal resonance in the presence of harmonic excitation in the spectral neighbourhood of the natural frequency of the mode with two circumferential waves. Since the system is excited by a multi-harmonic point-load excitation composed by first and second harmonics, very complex nonlinear dynamics is obtained around the resonance of the fundamental mode. In fact, at this frequency, both modes with two and three circumferential waves are driven to resonance and each one is in a one-to-one internal resonance with its companion mode. The nonlinear dynamics is explored by using bifurcation diagrams of Poincaré maps and time responses.

References listed at the end of the paper:


ABSTRACT: In present work, an effective method to research geometrically nonlinear free vibrations of elements of thin-walled constructions that can be modeled as laminated shallow shells with complex planform is applied. The proposed method is numerical–analytical. It is based on joint use of the R-functions theory, variational methods, Bubnov–Galerkin procedure and Runge–Kutta method. The mathematical formulation of the problem is performed in a framework of the refined first-order shallow shells theory. To implement the developed method, appropriate software was developed. New problems of linear and nonlinear vibrations of laminated shallow shells with clamped cutouts are solved. To confirm reliability of the obtained results, their comparison with the ones known in the literature is provided. Effect of boundary conditions is studied.

References listed at the end of the paper:

ABSTRACT: Unified 2D continuum formulation of the nonlinear dynamic problem for a von Kármán shear indefinite symmetric cross-ply composite plate in a thermomechanical environment is presented, along with the ensuing reduction procedure ending up to a three-mode discretized model with unknown transverse displacement and membrane/bending temperatures. Systematic numerical analyses in the case of thermal dynamics passively entrained by the solely active mechanical excitations allow to unveil the main features of the nonlinear response, while highlighting fundamental aspects associated with the thermomechanical coupling. Local and global dynamics of a single-layer orthotropic plate are investigated under varying in-plane/transverse excitations or thermal property of the material. Comparison with the response provided by partially coupled models and the uncoupled mechanical oscillator enables to identify situations in which thermomechanical coupling affects the nonlinear response even in the solely passive thermal setting and to frame the relevant effects within known literature results.

References listed at the end of the paper:

ABSTRACT: Nonlinear free vibration of functionally graded shallow shells with complex planform is investigated using the R-functions method and variational Ritz method. The proposed method is developed in the framework of the first-order shear deformation shallow shell theory. Effect of transverse shear strains and rotary inertia is taken into account. The properties of functionally graded materials are assumed to be varying continuously through the thickness according to a power law distribution. The Rayleigh–Ritz procedure is applied to obtain the frequency equation. Admissible functions are constructed by the R-functions theory. To implement the proposed approach, the corresponding software has been developed. Comprehensive numerical results for three types of shallow shells with positive, zero and negative curvature with complex planform are presented in tabular and graphical forms. The convergence of the natural frequencies with increasing number of admissible functions has been checked out. Effect of volume fraction exponent, geometry of a shape and boundary conditions on the natural and nonlinear frequencies is brought out. For simply supported rectangular FG shallow shells, the results obtained are compared with those available in the literature. Comparison demonstrates a good accuracy of the approach proposed.

References listed at the end of the paper:

· Matsunaga, H.: Free vibration and stability of functionally graded shallow shells according to a 2D higher-order deformation theory. Compos. Struct. 84, 132–146 (2008)


ABSTRACT: The resonant interaction of the nonlinear normal modes which belong to different vibration branches of the carbon nanotubes (CNTs) is studied by the efficient semi-inverse asymptotic method. Under the
condition of the 1:1 resonance of the beam-like and circumferential flexure modes we obtain the dynamical equations, the solutions of which describe the coupled stationary states. They are characterized by the non-uniform distribution of the energy along the circumferential coordinate. The non-stationary solutions for the obtained equations correspond to the slow change of the energy distribution. It is shown that adequate description of considered resonance processes can be achieved in terms of new variables, which correspond to the coordinates of some domains of the CNT. These variables are the linear combinations of the shell- and beam-like normal modes. Using such variables we have analysed not only nonlinear normal modes, but also the limiting phase trajectories describing the strongly non-stationary dynamics. The evolution of the considered resonance processes with the oscillation amplitude growth is analysed by the phase portrait method and verified by the numerical integration of the respective dynamical equations.

References listed at the end of the paper:


Xiuyu He and Zhijia Zhao, “Boundary control design for a vibrating flexible string system with input nonlinearities”, Nonlinear Dynamics, Vol. 93, No. 2, pp 323–333, July 2018

ABSTRACT: In this paper, the main concern lies in developing a vibration control scheme for globally stabilizing the string system under the influence of input nonlinearities and external disturbance. To that end, an
antidisturbance boundary control is presented by merging Lyapunov approach and disturbance observer control theory. Besides, the auxiliary system and auxiliary function are introduced to compensate for the input nonlinearities effects. Using the rigorous analysis without simplifying or discretizing the infinite-dimensional dynamics, the designed control laws can be proven to ensure the uniformly bounded stability of the controlled system. In the end, simulation results are presented for control performance verification.

References listed at the end of the paper:

15. He, W., Ge, S.S.: Cooperative control of a nonuniform gantry crane with constrained tension. Automatica 66(4), 146–154 (2016)
References listed at the end of the paper:

velocities. In doing so, period doubling, pitchfork bifurcations, grazing bifurcations, sticking, and chaos that phase portraits, a detailed comparison is made between the tip and the point of contact at the key flow velocities of interest. In addition to demonstrating the progression of the selected region and achieving full agreement, the bifurcation diagram at the point of contact is further investigated to select key tip of the cantilevered pipe. Using the full nonlinear equations of motion and the Galerkin discretization, a

ABSTRACT: Modern methods of nonlinear dynamics including time histories, phase portraits, power spectra, and Poincaré sections are used to characterize the stability and bifurcation regions of a cantilevered pipe conveying fluid with symmetric constraints at the point of contact. In this study, efforts are made to demonstrate the importance of characterizing the system at the arbitrarily positioned symmetric constraints rather than at the tip of the cantilevered pipe. Using the full nonlinear equations of motion and the Galerkin discretization, a nonlinear analysis is performed. After validating the model with previous results using the bifurcation diagrams and achieving full agreement, the bifurcation diagram at the point of contact is further investigated to select key flow velocities of interest. In addition to demonstrating the progression of the selected regions using primarily phase portraits, a detailed comparison is made between the tip and the point of contact at the key flow velocities. In doing so, period doubling, pitchfork bifurcations, grazing bifurcations, sticking, and chaos that
occur at the point of contact are found to not always occur at the tip for the same flow speed. Thus, it is shown that in the case of cantilevered pipes with constraints, more accurate characterization of the system is obtained in a specified range of flow velocities by characterizing the system at the point of contact rather than at the tip.

Qiansheng Tang, Chaofeng Li, Houxin She and Bangchun Wen, “Modeling and dynamic analysis of bolted joined cylindrical shell”, Nonlinear Dynamics, Vol. 93, No. 4, pp 1953-1975, September 2018

ABSTRACT: Based on Sanders shell theory, modeling and dynamic analysis of bolted joined cylindrical shell were studied in this paper. When subjected to external excitations, contact state such as stick, slip and separation may occur at those locations of bolts. Considering these three contact states, an analytical model of cylindrical shell with a piecewise-linear boundary was established for the bolted joined cylindrical shell. First, the model was verified by the simplified line system, and the effects of stiffness in connecting interface and the number of bolts on natural frequency and mode shape were investigated. Then, through the response under instantaneous excitation, damping characteristic of the system was proved which is caused by the friction model. Last, the effects of external load frequency, response location, excitation amplitude and connecting parameters including stiffness and preload were numerically investigated and fully explained by 3-D frequency spectrum. The results indicated that periodic motion, times periodic motion and even chaotic motion were observed based on different parameters.

References listed at the end of the paper:

Smale horseshoe sense in the truss core sandwich plate. Numerical simulations are performed to further verify on the slow manifold under the perturbation. The theoretical an heteroclinic orbit in the perturbation. The Melnikov method, which is called the first measure, is applied to study the persistence of the singular point occurs when the resonant torus on the fast manifold is broken under the perturbation. It is known appears when the homoclinic orbit is broken under the perturbation. Additionally, the saddle points in the neighborhood of the resonant torus for the nonlinear wave equation is investigated. It is found that the reductive perturbation method is used to simplify the partial differential equation. According to the exact solution of the unperturbed equation, two different kinds of the topological structures are derived, which one structure is the resonant torus and another structure is the heteroclinic orbit. The characteristic of the singular points in the neighborhood of the resonant torus for the nonlinear wave equation is investigated. It is found that there exists the homoclinic orbit on the unperturbed slow manifold. The saddle-focus type of the singular point appears when the homoclinic orbit is broken under the perturbation. Additionally, the saddle-focus type of the singular point occurs when the resonant torus on the fast manifold is broken under the perturbation. It is known that the dynamic characteristics are well consistent on the fast and slow manifolds under the condition of the perturbation. The Melnikov method, which is called the first measure, is applied to study the persistence of the heteroclinic orbit in the perturbed equation. The geometric analysis, which is named the second measure, is used to guarantee that the heteroclinic orbit on the fast manifold comes back to the stable manifold of the saddle on the slow manifold under the perturbation. The theoretical analysis suggests that there is the chaos for the Smale horseshoe sense in the truss core sandwich plate. Numerical simulations are performed to further verify
the existence of the chaotic wave and chaotic motions in the nonlinear wave equation. The damping coefficient is considered as the controlling parameter to study the effect on the propagation property of the nonlinear wave in the sandwich plate with truss core. The numerical results confirm the validity of the theoretical study.

References listed at the end of the paper:


ABSTRACT: The present paper deals with the investigation of large-amplitude vibration and post-buckling responses of functionally graded plates with initial geometric imperfection and microstructural defect. The mathematical formulation is based on nonpolynomial higher-order shear and normal deformation theory with a von Karman sense of nonlinear kinematic using modified $\phi_0$ continuity. The governing equations of motion for FGM plates are derived using variational approach. Through numerical experiments, the high numerical accuracy and the good convergence of the finite element solution are demonstrated for the structural response of FGM plate. The influence of geometric nonlinearity, geometric imperfection, microstructural defect (porosity) and geometric configuration on the nonlinear frequencies and buckling load is also investigated. Results are shown diagrammatically, which can serve as the benchmark for further research.

References listed at the end of the paper:


ABSTRACT: An isolated two-dimensional circular cylinder with two linear degrees of freedom, parallel and perpendicular to the free-stream direction, and owning a nonlinear energy sink (NES) is investigated by fluid-structure interaction (FSI) simulations to assess vortex-induced vibrations (VIV) at moderate Reynolds numbers. Subsequently, the wake-induced vibration (WIV) of a pair of identical cylinders under the action of two NESs in a tandem arrangement and in a proximity–wake interference regime is explored using the same approach. The NES parameters (mass, nonlinear stiffness and damping) are investigated to determine their effects on the dynamic response of a single degree of freedom (in transverse flow direction) coupled system by a reduced-order model based on an experimentally validated van der Pol oscillator. The CFD model coupled with FSI method is also validated against VIV experimental data for an isolated cylinder in a uniform flow. The study is aimed to investigate the effect of the passive suppression NES device on VIV and WIV. The amplitude response, trajectories of cylinder motion and temporal evolutions of vortex shedding are obtained by conducting a series of numerical simulations. It is found that placing a tuned NES in the cylinders can provide good suppression effect; however, the effectiveness is function of the reduced velocity.

Rui Zhou, Yaojun Ge, Yongxin Yang, Yanliang Du and Lihai Zhang, “Wind-induced nonlinear behaviors of twoin-box girder bridges with various aerodynamic shapes”, Nonlinear Dynamics,, Vol. 94, No. 2, pp 1095-1115, October 2018

ABSTRACT: Wind-induced nonlinear oscillations of twin-box girder bridges are very sensitive to the aerodynamic shape of the deck (i.e., slot width ratio (SWR) and wind fairing shape) due to the complicated flow characteristics around the bridge deck. This paper presents a fully integrated finite element (FE) model in time domain, involving a nonlinear aerodynamic force model and a bridge FE model, to allow the investigation of nonlinear oscillation behaviors of long-span twin-box girder bridges with various SWRs and wind fairing shapes. The parameters in integrated FE model were firstly identified by using CFD simulation, and then, the proposed model was validated by conducting wind tunnel testing using sectional models and full-bridge aeroelastic models. It demonstrates that the developed integrated model has the capability of simulating the
nonlinear flutter behaviors of twin-box girder bridges with various aerodynamic shapes. Furthermore, the prediction results show that the wind fairing shape has significant impact on the degree of freedom participation in coupled oscillation and failure modes, as well as flutter performance of the bridges. In addition, there is an increase in amplitudes of the limit cycle oscillations with the increase in the SWR of the twin-box girder bridges, and the relationships between the bending-torsional coupled oscillation, failure modes, and SWR of the bridges with anti-symmetric wind fairings are opposite to those with symmetric wind fairings.

Bo Zhu, Youheng Dong and Yinghui Li, “Nonlinear dynamics of a viscolastic sandwich beam with parametric excitations and internal resonance”, Nonlinear Dynamics, Vol. 94, No. 4, pp 2575–2612, December 2018

ABSTRACT: Nonlinear dynamical behaviors of an axially accelerating viscoelastic sandwich beam subjected to three-to-one internal resonance and parametric excitations resulting from simultaneous velocity and tension fluctuations are investigated. The direct method of multiple scales is adopted to obtain a set of first-order ordinary differential equations and associated boundary conditions. The frequency and amplitude response curves along with their stability and bifurcation are numerically studied. A great number of dynamic behaviors are presented in the form of phase portraits, time traces, Poincaré sections, and FFT power spectra. Due to modal interaction, various periodic, quasiperiodic, and chaotic behaviors are displayed, depending on the initial conditions. The largest Lyapunov exponent is carried out to determine the mildly chaotic response by the convergent form of exponents. Numerical results show various oscillatory behaviors indicating the influence of internal resonance and coupled effects of fluctuating axial velocity and tension.

References listed at the end of the paper:
ABSTRACT: A rotating pretwisted cylindrical shell model with a presetting angle is established to investigate nonlinear dynamic responses of the aero-engine compressor blade. The centrifugal force and the Coriolis force are considered in the model. The aerodynamic pressure is obtained by the first-order piston theory. The strain–displacement relationship is derived by the Green strain tensor. Based on the first-order shear deformation
theory and the isotropic constitutive law, nonlinear partial differential governing equations are derived by using the Hamilton principle. Discarding the Coriolis force effect, Galerkin approach is utilized to reduce nonlinear partial differential governing equations into a two-degree-of-freedom nonlinear system. According to nonlinear ordinary differential equations, numerical simulations are performed to explore nonlinear transient dynamic responses of the system under the effect of the single point excitation and nonlinear steady-state dynamic responses of the system under the effect of the uniform distribution excitation. The effects of the excitation parameter, damping coefficient, rotating speed, presetting angle and pretwist angle on nonlinear dynamic responses of the system are fully discussed.

References listed at the end of the paper:

The present study investigated the nonlinear harmonic vibration of functionally graded multilayer graphene nanoplatelet (GPL)-reinforced nanocomposite beams on the basis of the third-order shear deformation theory. The GPL volume fraction shows a layer-wise change, while in each individual layer GPLs are uniformly dispersed in the matrix. The effective Young’s moduli of the GPL-reinforced nanocomposite (GPLRC) beams were estimated through the Halpin–Tsai micromechanics model. The mass densities as well as the effective Poisson’s ratios of the GPLRC beams were predicted by the rule of mixture. The nonlinear partial differential equations of motion were discretized by means of the Galerkin procedure. A parametric study was carried out by using the multiple scales method to examine the effects of GPL distribution pattern, weight fraction, geometry, and size on the nonlinear response of the primary, secondary, and combination resonances. Results show that an addition of a very low weight fraction of GPL nanofillers significantly reduces the primary, superharmonic, subharmonic, and combinational resonant responses of the beams. The square-shaped GPLs with fewer graphene layers are the most favorable reinforcements.

References listed at the end of the paper:


ABSTRACT: The geometrically nonlinear forced vibration response of non-continuous elastic-supported laminated composite thin cylindrical shells is investigated in this paper. Two kinds of non-continuous elastic supports are simulated by using artificial springs, which are point and arc constraints, respectively. By using a set of Chebyshev polynomials as the admissible displacement function, the nonlinear differential equation of
motion of the shell subjected to periodic radial point loading is obtained through the Lagrange equations, in which the geometric nonlinearity is considered by using Donnell’s nonlinear shell theory. Then, these equations are solved by using the numerical method to obtain nonlinear amplitude–frequency response curves. The numerical results illustrate the effects of spring stiffness and constraint range on the nonlinear forced vibration of points-supported and arcs-supported laminated composite cylindrical shells. The results reveal that the geometric nonlinearity of the shell can be changed by adjusting the values of support stiffness and distribution areas of support, and the values of circumferential and radial stiffness have a more significant influence on amplitude–frequency response than the axial and torsional stiffness.

References listed at the end of the paper:

Eva Zupan and Dejan Zupan (Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana, Slovenia), “On conservation of energy and kinematic compatibility in dynamics of nonlinear velocity-based three-dimensional beams”, Nonlinear Dynamics, Vol. 95, No. 2, pp 1379-1394, January 2019

**ABSTRACT:** In this paper, we present an original energy-preserving numerical formulation for velocity-based geometrically exact three-dimensional beams. We employ the algebra of quaternions as a suitable tool to express the governing equations and relate rotations with their derivatives, while the finite-element discretization is based on interpolation of velocities in a fixed frame and angular velocities in a moving frame description. The proposed time discretization of governing equations directly relates the energy conservation constraint with the time-discrete kinematic compatibility equations. We show that a suitable choice of primary unknowns together with a convenient choice of the frame of reference for quantities and equations is beneficial for the conservation of energy and enables admissible approximations in a simple manner and without any additional effort. The result of this study is simple and efficient, yet accurate and robust numerical model. References listed at the end of the paper:

<table>
<thead>
<tr>
<th>Reference</th>
<th>Details</th>
</tr>
</thead>
</table>

ABSTRACT: Different from the both-end supported pipe conveying fluid as a conservative system, the cantilevered fluid-transporting pipe is a non-conservative system and its dynamic behavior is more complex with flutter instabilities when the flow velocity is beyond the critical value. Indeed, controlling such a flutter system is always challenging in engineering applications. This study presents nonlinear vibrations of cantilevered pipe conveying fluid passively controlled via a nonlinear energy sink (NES). Based on the Hamilton principle, the nonlinear dynamic equations coupling with the NES are derived and discretized using high-order Galerkin method. It is indicated that increasing the mass and damping of NES results in an increase in critical flow velocity. Importantly, the optimal placed position of NES where the critical flow velocity is highest has a strong relationship with the pipe’s flutter mode. In the following, the nonlinear analysis shows the dynamic controlling effect on vibration amplitude of the pipe can be classified to three suppression regions with increasing the flow velocity. Varying the mass, damping and stiffness of NES is followed by variations of the suppression regions which are associated with controlling effects and dynamic behaviors of the pipe system.

References listed at the end of the paper:

The repeated bifurcations of multi-Hamiltonian and dissipative perturbations which lead to exist Shilnikov first cylindrical shell subjected to complex loads are investigated in the case of 1 laminated cylindrical shell in supersonic air flow". Nonlinear Dynamics, Vol. 96, No. 2, pp 1095–1114, April 2019

ABSTRACT: The global bifurcations and chaotic motions in mode interaction of a composite laminated cylindrical shell subjected to complex loads are investigated in the case of 1/2 sub-harmonic resonance for the first-order mode, primary resonance for the second-order mode and 1:2 internal resonance. The energy-phase method is implemented to analyze the global dynamics of the shell. The analytical results illustrate that there exist Shilnikov-type multi-pulse jumping orbits for the resonant case homoclinic to certain invariant sets in both Hamiltonian and dissipative perturbations which lead to chaos in the system. Homoclinic trees which represent the repeated bifurcations of multi-pulse solutions are found. The diagrams also demonstrate the reducing of...
pulse numbers and the homoclinic tree break up gradually as the dissipation factor is increased. Numerical evidence of chaotic behaviors is presented to verify the theoretical predictions.

References listed at the end of the paper:

ABSTRACT: Over the past ten years, the energy harvesting community has focused on bistable structures as a means of broadening the working frequency range and, by extension, the effective efficiency of vibration-based power scavenging systems. In the current study, a new method is implemented to statically and dynamically analyze a bistable buckled, multi-component coupled structure designed specifically for low-frequency (<30 Hz) vibration energy harvesting. First, the system is divided into its individual components and the governing equations for each part are developed based on Euler–Bernoulli beam theory. These governing equations are then solved in one single system of equations by applying geometrical and force-moment boundary conditions at the connections. Solving the nonlinear static equations gives the critical buckling loads, as well as the exact static, post-buckled configuration of the system about which the dynamic response is formulated. The natural frequencies and mode shapes of the system are obtained by solving the free vibration case of the linearized buckled structure, which are then used as spatial functions in a Galerkin approach to discretize the nonlinear partial differential equations of the coupled system. To validate the modeling approach, the obtained results are compared with the ones captured from both finite element analysis model and the experimental setup, which shows good agreement between them. Furthermore, the amplitude-frequency response of the system and snap-through regime with the variation of various parameters, including exciting frequency, base vibration and buckling loads are investigated based on the developed model. It is shown that for a weakly buckled configuration, bistable motion can be captured for a wide range of frequencies, which is crucial for the performance of energy harvesting devices.

References listed at the end of the paper:

References listed at the end of the paper:

ABSTRACT: This paper focuses on investigating how high-frequency (fast) excitations affect the aeroelastic instability of a spinning disc immersed in a compressible fluid-filled enclosure. The method of multiple scales is used to recast the governing equations of motion into separate equations for fast and slow motions. The slow motions represent the dynamic behaviour of the non-autonomous coupled system. The stability boundaries of the coupled system are investigated through a bifurcation analysis with respect to the mean disc rotation speed and the forcing amplitude. The study reveals that an increase in the forcing amplitude of the fast parametric excitation results in a corresponding increase in the frequencies and the critical speeds of the coupled disc modes associated with the slow motions. Moreover, it is shown that the aeroelastic stability can be postponed or suppressed due to the stiffening and gyroscopic effects induced by the fast excitations.

References listed at the end of the paper:


References listed at the end of the paper:


ABSTRACT: A study on nonlinear flutter of damaged high-aspect-ratio wings is presented. Because an undamaged, high-aspect-ratio wing is long and slender, it may be properly modeled as a 1D beam, using a geometrically exact beam formulation. However, structural damages in the form of cracks and delaminations are in fact 3D phenomena. Therefore, the area near a crack cannot be accurately modeled as a reduced-dimensional beam. However, finite element analysis of a wing structure modeled entirely as a 3D continuum is computationally expensive. To address this issue, a joined 3D/1D finite element approach has been proposed in which a small area surrounding the crack is regarded as a 3D continuum, and the rest of the wing structure is modeled as a reduced-dimensional 1D beam undergoing large displacements and rotations. The continuity conditions at the intersection between the 3D and 1D models are derived using the variational asymptotic method, by which the two parts are rigorously connected. Hence, the joined 3D/1D method provides a computationally inexpensive, yet accurate, analysis for slender wings. The structural model is then coupled with a reduced-order unsteady aerodynamic model to compute the aerodynamic forces and moments acting on the wing. The resulting nonlinear aeroelastic element is integrated into Abaqus, a commercial finite element computer code as a nonlinear user-defined element. Through nonlinear time-marching, using a generalized \( \alpha \) method, limit-cycle oscillations associated with the free response of both undamaged and damaged wings undergoing large deformations are studied, and the differences are highlighted.

References listed at the end of the paper:

Daniel Cintra, Gwendal Cumunel, Pierre Argoul, “Experimental study of the argumental transverse vibration of a beam excited through intermittent elastic contact by a harmonic axial motion”, Nonlinear Dynamics, Vol. 97, No. 2, pp 903-919, July 2019

ABSTRACT: The transverse vibration of a beam excited axially by a harmonic motion transmitted through intermittent elastic contact is experimentally studied. The beam’s configuration is clamped (clamped–guided). It is shown that said transverse vibration can be considered essentially as the fundamental transverse mode of the beam and can occur when the frequency of the excitation is four or six times the frequency of said mode. The energy transfer between the excitation source and the beam occurs only when the beam is in certain spatial configurations. This constitutes an argumental phenomenon. Experimental results are given and compared with models.

References listed at the end of the paper:


Li Zhang, Fangqi Chen, “Multi-pulse jumping orbits and chaotic dynamics of cantilevered pipes conveying time-varying fluid”, Nonlinear Dynamics, Vol. 97, No. 2, pp 991-1009, July 2019

ABSTRACT: Global bifurcations and multi-pulse chaotic motions of cantilevered pipes conveying time-varying fluid under external excitation are investigated. The method of multiple scales and Galerkin’s approach are utilized on the partial differential governing equation to yield the four-dimensional averaged equation with 1:2 internal resonance and primary parameter resonance. Based on the averaged equations, the normal form theory is adopted to derive the explicit expressions of normal form associated with a double zeroes and a pair of purely imaginary eigenvalues. Then the energy-phase method is employed to analyze the chaotic dynamics by
identifying the existence of the multi-pulse Silnikov-type orbits in the perturbed phase space. The homoclinic trees which describe the repeated bifurcations of multi-pulse solutions are demonstrated in both Hamiltonian and dissipative perturbation. The diagrams indicate a gradual breakup of homoclinic tree in the system as the dissipative factor grows. Numerical simulations are performed to show the multi-pulse jumping orbits and Silnikov-type chaotic behaviors may occur. The influence of the external excitation and the flow velocity of the cantilevered pipe on the dynamics of the system is discussed simultaneously in numerical results. The global dynamics also exhibits the existence of the chaos in the sense of Smale horseshoes for the cantilevered pipe conveying time-varying fluid under external excitation.

References listed at the end of the paper:

2. Lundgren, T.S., Sethna, P.R., Bajaj, A.K.: Stability boundaries for flow induced motions of tubes with an inclined terminal nozzle. J. Sound Vib. 64, 553–571 (1979)
Dan Xie, Min Xu, Honghua Dai, “Effects of damage parametric changes on the aeroelastic behaviors of a damaged panel”, Nonlinear Dynamics, Vol. 97, No. 2, pp 1035-1050, July 2019

ABSTRACT: In this study, the aeroelastic responses and stability boundaries of a simply supported supersonic plate with structural damage are investigated to assess the effects of damage parametric changes on the stability regions as well as to explore some potential tools for damage detection. In the modeling, structural damage is a local bending stiffness loss with various levels, extents and positions. The effects of damage level, extent and position are presented via exploiting nonlinear tools such as bifurcation diagrams, stability regions, Poincaré maps and Lyapunov exponents. Specially, the proper orthogonal decomposition (POD) method is applied to extract the POD modes to detect the damage parametric variations. It is determined that (1) structural damage has a notable influence on the aeroelastic stability of the panel; (2) the damage level and extent affect in a similar way that a larger damage level/extent tends to reduce the flutter boundary for a flat plate, but conversely increase the flutter boundary for a buckled plate; (3) the damage occurring around the leading of the panel corresponds to the least stable panel compared to the other positions along the chordwise; (4) the stability region as a novel way for damage detection is proved to be sensitive and effective, and the largest Lyapunov exponent as a quantitative measure is powerful to reveal the subtle differences in the chaos induced by damage changes; (5) the higher-order POD modes are more sensitive to the subtle damage than the primary POD modes. References listed at the end of the paper:

ABSTRACT: Time-delay displacement and velocity feedback of different types of active control in a cantilever beam carrying an lumped mass with time-delay feedback is investigated in this paper. Based on Euler–Bernoulli beam theory, the nonlinear governing equation is studied with damping, harmonic distribution, displacement delay, velocity delay and two time delays. The multiple scales perturbation method is applied to obtain the frequency response equations near primary, superharmonic and subharmonic resonances. A thorough study on the stability is proposed, with a particular emphasis on delay feedback. The results show that the hardening and softening behaviors of the system depend on the location of lumped mass. Furthermore, the displacement feedback gain coefficient only makes the peak amplitude move to the low frequency, yet velocity feedback coefficient and their time delays can be used to effectively enhance the stability and quench the nonlinear vibration of the cantilever beam. Thus, reasonable selection of the control system parameters can effectively improve the level of vibration control for the mechanical system.

References listed at the end of the paper:

Nonlinear Dynamics, Vol. 97, No. 3, pp. 1785–1797, August 2019


ABSTRACT: Experiments show a strong increase in damping with the vibration amplitude during nonlinear vibrations of beams, plates and shells. This is observed for large size structures but also for micro- and nanodevices. The present study derives nonlinear damping from viscoelasticity by using a single-degree-of-freedom model obtained from standard linear solid material where geometric nonlinearity is inserted in. The solution of the problem is initially reached by a third-order harmonic balance method. Then, the equation of motion is obtained in differential form, which is extremely useful in applications. The damping model developed is nonlinear and the parameters are identified from experiments. Experimental and numerical results are compared for forced vibration responses measured for two different continuous structural elements: a free-edge plate and a shallow shell. The free-edge plate is interesting since it represents a case with no energy escape through the boundary.

References listed at the end of the paper:


ABSTRACT: In this paper, a nonlinear energy sink and a negative stiffness element are integrated for achieving enhanced, passive, and adaptive vibration suppression for a pipe conveying fluid. The enhanced NES simultaneously processes a negative linear and a cubic nonlinearity, which is implemented by two linear springs with a special configuration with preloaded deformation. The governing equation of the NES–pipe system is derived and simulated for examining the isolation effectiveness. The performance of the enhanced and classical NESs is compared. It is found that the enhanced NES can absorb vibration energy with a faster decay rate,
achieving simultaneous small threshold, high energy dissipation efficiency, and higher robustness. By performing optimal design, a maximum efficiency $\sim 98.19\%$ is realized, which is much higher than previous research.

References listed at the end of the paper:
A. I. Zemlyanukhin (1), I. V. Andrianov (2), A. V. Bochkarev (1) and L.I. Mogilevich (1)
(1) Yuri Gagarin State Technical University of Saratov, Saratov, Russia
(2) RWTH Aachen University, Aachen, Germany

ABSTRACT: The axisymmetric propagation of longitudinal waves in an integrally stiffened physically and geometrically nonlinear cylindrical shell is studied. The case is considered when the parameters characterizing nonlinearity, dispersion and thickness—radius ratio are the same order. Using the multiscale asymptotic method, the generalized Schamel equation is derived from the equations of motion of the shell. This equation contains an additional term with the fifth derivative with respect to the spatial coordinate which characterizes the high-frequency dispersion. It is shown that the derived equation does not pass the Painlevé test and therefore is not integrated by the inverse scattering transform. The geometric series method using Padé approximants is applied to construct exact solitary-wave solution of the equation. It has been established that for the existence of an exact bounded amplitude solution a “soft” type of physical nonlinearity is necessary. The Schamel–Kawahara equation containing the combined nonlinearity is considered; its exact soliton-like solution is given. Numerical simulation confirmed that the initial perturbation in the form of the exact solution generates a persistently propagating solitary wave.

References listed at the end of the paper:

consideration of the degradation behavior on the dynamic characteristics are investigated and evaluated. Environment, which are shown to be in good agreement. Also, the specific influences with and without the model are compared with experimental results at different degradation time and stabilize are undertaken. The first three natural frequencies, resonant responses and modal damping ratios obtained from degradation model, experimental measurements of E120 carbon fiber/FRD-YG-03 resin composite thin plates are undertaken. The first three natural frequencies, resonant responses and modal damping ratios obtained from the model are compared with experimental results at different degradation time and stabilized thermal environment, which are shown to be in good agreement. Also, the specific influences with and without consideration of the degradation behavior on the dynamic characteristics are investigated and evaluated.
ABSTRACT: Dynamic model of geometrical nonlinear deformations of functionally graded carbon nanotubes-reinforced composite cylindrical shells in supersonic flow is derived. The finite-degree-of-freedom nonlinear system, which describes the structure nonlinear self-sustained vibrations, is obtained using the assumed-mode method. The linear piston theory is used to describe the supersonic flow. The loss of the cylindrical shell dynamic stability owing to the Hopf bifurcations is analyzed. The self-sustained vibrations, which describe the circumferential traveling waves flutter, occur due to this bifurcation. The harmonic balance method is applied to analyze these self-sustained vibrations. The properties of the circumferential traveling waves are analyzed.

References listed at the end of the paper:

ABSTRACT: Theoretical modeling and dynamic analysis of cantilevered pipes conveying fluid are presented with particular attention to geometric nonlinearities in the case of large-amplitude oscillations. To derive a new version of nonlinear equation of motion, the rotation angle of the centerline of the pipe is utilized as the generalized coordinate to describe the motion of the pipe. By using variational operations on energies of the pipe system with respect to either lateral displacement or rotation angle of the centerline, two kinds of new equations of motion of the cantilever are derived first based on Hamilton’s principle. It is interesting that these two governing equations are geometrically exact, different-looking but essentially equivalent. With the aid of Taylor expansion, one of the newly developed equations of motion can be degenerated into previous Taylor-expansion-based governing equation expressed in the form of lateral displacement. Then, the proposed new equation of motion is linearized to determine the stability of the cantilevered pipe system. Finally, nonlinear analyses are conducted based on the current geometrically exact model. It is shown that the cantilevered pipe would undergo limit-cycle oscillation after flutter instability is induced by the internal fluid flow. As expected, quantitative agreement between geometrically exact model and Taylor-expansion-based model can be achieved when the oscillation amplitude of the pipe is relatively small. However, remarkable difference between the results of oscillation amplitudes predicted using these two models would occur for large-amplitude oscillations. The main reason is that in the Taylor-expansion-based model, high-order geometric nonlinearities have been neglected when applying the Taylor expansion, thus yielding some deviation when large-amplitude oscillations are generated. Consequently, the proposed new geometrically exact equation of motion is more reliable for large-amplitude oscillations of cantilevered pipes conveying fluid.

References listed at the end of the paper:

Renata M. Soares (1), Pedro F. T. Amaral (1), Frederico M. A. Silva (1) and Paulo Batista Goncalves (2)

(1) School of Civil and Environmental Engineering, Federal University of Goiás, UFG, Goiânia, Brazil
(2) Department of Civil and Environmental Engineering, Pontifical Catholic University, PUC-Rio, Rio de Janeiro, Brazil

“Nonlinear breathing motions and instabilities of a pressure-loaded spherical hyperelastic membrane”,
ABSTRACT: This work presents the mathematical modeling, based on a variational formulation, for the analysis of the nonlinear static and dynamic breathing motions of a hyperelastic spherical membrane subjected to internal pressure. The membrane is composed of an isotropic, homogeneous, incompressible, and hyperelastic material that is modeled using the Mooney–Rivlin constitutive law. The equilibrium equations are obtained using the fully nonlinear elasticity theory. First, the static nonlinear analysis is performed, and the principal stretches and stresses are obtained as a function of the internal pressure. Additionally, a parametric analysis is conducted to study the influence of the material constants on the nonlinear equilibrium path and potential energy. Depending on the value of the two material constants, a bistable behavior may be observed, having a profound influence on the nonlinear vibrations of the membrane. Then, the equations of motion of the pressure-loaded membrane subjected to increasing pressure and an additional harmonically varying internal pressure are obtained, considering a nonlinear damping force. A detailed parametric analysis clarifies the influence of the Mooney–Rivlin material parameters and static preload on the natural frequencies and particularly on the nonlinear frequency–amplitude relation. Precise results for the backbone curves are obtained by the shooting method, using the fully nonlinear equation of motion, and compared with several approximations obtained by the harmonic balance methods, highlighting the influence of higher order nonlinear terms on the nonlinear response of hyperelastic membranes. Finally, a parametric analysis of the harmonically excited preload membrane is conducted to reveal the importance of the two-well potential function, damping and constitutive law on the resonance curves, bifurcation diagrams, and basins of attraction.

References listed at the end of the paper:

ABSTRACT: The nonlinear dynamics of a polymeric cylindrical shell carrying a top mass under axial harmonic excitation are experimentally investigated; the tests have been carried out in a controlled environment under several conditions of homogeneous temperature and excitation amplitude. The thermal effects on shells dynamics have been studied. The purpose of this paper is to fill an important gap in the literature regarding the effect of the temperature on the complex dynamics of shells. The cylindrical shell is excited in the axial direction by means of a seismic excitation provided by an electrodynamic shaker. The analysis is focused on the range of frequencies of excitation close to the first axisymmetric mode resonance: the base motion induces a parametric excitation. A saturation phenomenon of the top mass vibration is observed; the vibrating energy directly transferred from the shaker to the first axisymmetric mode is transferred to radial motion of the shell. The experimental data are examined and discussed in detail; a complete dynamic scenario is analyzed by means of: amplitude–frequency curves, bifurcation diagrams, spectrograms, Poincaré maps, phase portraits, Fourier spectra and time histories. Results show that: (i) the temperature strongly affects the instability regions and the magnitude of the measured kinematic quantity, (ii) high environmental temperature leads to a more complex shell dynamics.

References listed at the end of the paper:


J. Awrejcewicz (1), V. A. Krysko (2), S. P. Pavlov (3), M. V. Zhigalov (2), L.A. Kalutsky (2) and A.V. Krysko(4)

(1) Department of Automation, Biomechanics and Mechatronics, Lodz University of Technology, Lodz, Poland
(2) Department of Mathematics and Modeling, Saratov State Technical University, Saratov, Russian Federation
(3) Department of Mathematical and Computer Modeling, Saratov State University, Saratov, Russian Federation
(4) Department of Applied Mathematics and Systems Analysis, Saratov State Technical University, Saratov, Russian Federation


ABSTRACT: The dependence of the quality factor of nonlinear microbeam resonators under thermoelastic damping for Timoshenko beams with regard to geometric nonlinearity has been studied. The constructed mathematical model is based on the modified couple stress theory which implies prediction of size-dependent effects in microbeam resonators. The Hamilton principle has yielded coupled nonlinear thermoelastic PDEs governing dynamics of the Timoshenko microbeams for both plane stresses and plane deformations. Nonlinear thermoelastic vibrations are studied analytically and numerically and quality factors of the resonators versus geometric and material microbeam properties are estimated. Results are presented for gold microbeams for different ambient temperatures and different beam thicknesses, and they are compared with results yielded by the classical theory of elasticity in linear/nonlinear cases.

References listed at the end of the paper:


Youheng Dong (1,2), Xiangyu Li (1), Kang Gao (2), Yinghui Li (1) and Jie Yang (2)

(1) School of Mechanics and Engineering, Southwest Jiaotong University, Chengdu, People’s Republic of China
(2) School of Engineering, RMIT University, Bundoora, Australia


ABSTRACT: This work investigates nonlinear harmonic resonance behaviors of graded graphene-reinforced composite spinning thin cylindrical shells subjected to a thermal load and an external excitation. The volume fraction of graphene platelets varies continuously in the shell’s thickness direction, which generates position-dependent useful material properties. Natural frequencies of shell traveling waves are derived by considering influences of the initial hoop tension, centrifugal and Coriolis forces, thermal expansion deformation, and thermal conductivity. A new Airy stress function is introduced. Harmonic resonance behaviors and their stable solutions for the spinning cylindrical shell are analyzed based on an equation of motion which is established by adopting Donnell’s nonlinear shell theory. The necessary and sufficient conditions for the existence of the subharmonic resonance of the spinning composite cylindrical shell are given. Besides the shell’s intrinsic structural damping, the Coriolis effect due to the spinning motion has a contribution to the damping terms of the system as well. Comparisons between the present analytical results and those in other papers are made to validate the existing solutions. Influences of main factors on vibration characteristics, primary resonance, and subharmonic resonance behaviors of the novel composite cylindrical shell are discussed. Furthermore, the mechanism of how the spinning motion affects the amplitude–frequency curves of harmonic resonances of the cylindrical shell is analyzed.

References listed at the end of the paper:

43. Li, X., Du, C.C., Li, Y.H.: Parametric instability of a functionally graded cylindrical
ABSTRACT: This paper is concerned with the static bifurcations in a simply supported nonlinear curved plate subjected to a steady incompressible axial airflow. The fluid velocity potential of the flow is considered as the sum of two parts: One is due to the plate deformation, and the other is to the plate initial shape. The fluid force theoretically solved from the Bernoulli’s equation has been successfully verified through a wind tunnel experiment. The von Karman’s theory for large deflection of plates is used for the plate modeling. Results show that the plate loses symmetry and becomes imperfect due to its initial shape. The system has a fundamental and another two asymmetric bifurcated equilibrium solutions. Compared with the symmetric bifurcations in a flat plate, these bifurcations are called as the imperfect ones. The imperfect pitchfork-like bifurcation has a non-bifurcating branch and an additional imperfect bifurcation. The bifurcation regions and features are explored in detail in various parametric planes. There are two types of imperfect pitchfork-like bifurcations. The first type involves an additional saddle-node bifurcation and could be either supercritical or subcritical. However, the second type is associated with a transcritical-like bifurcation and represents the coexistence of both the supercritical and the subcritical bifurcations. The hysteresis in nature is due to the asymmetry of the system and can be restrained by increasing the tension and the fluid dynamic pressure.

References listed at the end of the paper:
V. Iurasov (1) and P.-O. Mattei (2)
(1) Saint-Gobain Recherche Paris, Aubervilliers, France
(2) Aix Marseille Univ, LMA, CNRS, Centrale Marseille, Marseille, France


ABSTRACT: This article addresses a particular realization of a compact bistable nonlinear absorber based on the concept of nonlinear energy sink. The article presents both a detailed description of the absorber mechanics and an illustration of the targeted energy transfer between the absorber and a linear system. The experimental results are accompanied with the numerical simulations. Beside practical improvements linked to the features of absorber design, the obtained results stay in line with those found for simpler realizations of a bistable nonlinear energy sinks.

References listed at the end of the paper:


ABSTRACT: For the electrically actuated microbeam subjected to a combination of DC and AC voltage loadings, we studied the nonlinear dynamical responses and internal resonance analytically. The flexible boundary condition is considered. The modal interaction due to three-to-one internal resonance between the first and second modes is highlighted. The method of multiple scales is employed to get the modulation equation, which describes the amplitude and phases of the involving modes. Then, the equilibrium solutions of the modulation equation are calculated and their stability is examined. The frequency and force response curves reflecting the primary resonance (the first mode) are presented. We find that the first and second modes in the proposed model are coupled, and hence the energy transfer can occur between the involving modes. Moreover, it is found that the response of the system may encounter Hopf bifurcation for some specific parameters. As for simulation, the Galerkin scheme is applied to verify the analytical results in terms of time history, phase-plane portrait, Fourier spectrum, and Poincare section. The simulation results are in good agreement with the analytical ones.

References listed at the end of the paper:

ABSTRACT:  


ABSTRACT: For improved stability of fluid-conveying pipes operating under the thermal environment, functionally graded materials (FGMs) are recommended in a few recent studies. Besides this advantage, the
nonlinear dynamics of fluid-conveying FG pipes is an important concern for their engineering applications. The present study is carried out in this direction, where the nonlinear dynamics of a vertical FG pipe conveying hot fluid is studied thoroughly. The FG pipe is considered with pinned ends while the internal hot fluid flows with the steady or pulsatile flow velocity. Based on the Euler–Bernoulli beam theory and the plug-flow model, the nonlinear governing equation of motion of the fluid-conveying FG pipe is derived in the form of the nonlinear integro-partial-differential equation that is subsequently reduced as the nonlinear temporal differential equation using Galerkin method. The solutions in the time or frequency domain are obtained by implementing the adaptive Runge–Kutta method or harmonic balance method. First, the divergence characteristics of the FG pipe are investigated and it is found that buckling of the FG pipe arises mainly because of temperature of the internal fluid. Next, the dynamic characteristics of the FG pipe corresponding to its pre- and post-buckled equilibrium states are studied. In the pre-buckled equilibrium state, higher-order parametric resonances are observed in addition to the principal primary and secondary parametric resonances, and thus the usual shape of the parametric instability region deviates. However, in the post-buckled equilibrium state of the FG pipe, its chaotic oscillations may arise through the intermittent transition route, cyclic-fold bifurcation, period-doubling bifurcation and subcritical bifurcation. The overall study reveals complex dynamics of the FG pipe with respect to some system parameters like temperature of fluid, material properties of FGM and fluid flow velocity.

References listed at the end of the paper:

excited non-planar periodic oscillation can evolve to a planar quasi-periodic or periodic oscillation by adding the axial excitation. In such a fluid–structure interaction system, however, it is shown that a self-excited planar motion cannot be shifted to a non-planar one by adding the axial excitation, at least for the system parameters considered in this work.

References listed at the end of the paper:


ABSTRACT: This study dealt with the dynamic stability and geometrical nonlinear problems of carbon nanotube/fiber/polymer composite (CNTFPC) cylindrical panels without or with delamination around a central cutout. A multiscale analysis using the Hewitt and Malherbe model was performed to determine the carbon nanotube (CNT) weight ratios, thickness–radius ratios, thickness–length ratios, and delamination area ratios around a cutout. A delamination around a central cutout was modeled in two dimensions by introducing continuity conditions of displacements at the delamination boundaries. The proposed approach in this study has been verified by previous studies. Parametric results showed the significance of a proper CNT ratio and curvature for better structural performance on the dynamic instability and nonlinearity of delaminated CNTFPC cylindrical panels.

References listed at the end of the paper:


ABSTRACT: Nonlinear vibration absorption of a laminated composite beam is investigated with the account of complex environment (moisture and temperature). A passive efficient nonlinear energy sink (NES) vibration absorber is used to control the transverse vibration. The generalized Hamilton principle is applied to derive a dynamic model of the laminated composite beam coupled with the NES. Numerical simulations reveal the effects of temperature, moisture, and laying angle on natural frequencies. It is numerically found that the NES can rapidly reduce the vibration amplitude. Then, approximate analytical solutions are sought via the harmonic balance method. The approximate analytical solutions are confirmed by the numerical solutions. Amplitude–frequency response curves show that the NES can reduce the amplitude to very low values for various temperatures, moisture levels, and laying angles. In a certain ranges of the NES parameters, different control effects are determined via an approximate analysis. It is demonstrated that the NES is a promising approach to control vibration of a laminated composite beam in complex environment.

References listed at the end of the paper:


In this paper, two three-node triangular thin plate/shell elements are proposed based on the absolute nodal coordinate formulation. As the gradient deficient element, the thin plate/shell element does not possess a full Jacobian matrix for the mapping between different configurations. Thus, the formulation cannot be derived in the conventional method directly based on the continuum mechanics. The independent area coordinate gradients with obvious geometrical interpretation are introduced to simplify the derivation of the shape function. To account for the initially curved reference configuration, the curvilinear coordinate system is used as the global structure coordinate system to calculate the Green-Lagrange strain and formulate the elastic force. The tangent plane is built node-wise to transform the global curvilinear structural gradients to the local area gradients. In this way, the problem of the slope discontinuity associated with the area gradient is circumvented and the continuity of the structural gradient is guaranteed by the standard element assembly procedure. The generalized transformation between the vectors of the Bézier triangle control points and the nodal vectors of the triangular element is presented. Thus, the elements can be used for the integration of computer-aided design and analysis. Finally, the accuracy and convergence property of the new ANCF triangular plate/shell elements are verified by both static and dynamic numerical examples.

References listed at the end of the paper:

This work presents some experimental results for resonant nonlinear response of hyperelastic plates for 1:2 internal resonance. Previously developed topology optimization methods are used to design and fabricate candidate resonant plates using 3-D printing. One such plate is subjected to harmonic transverse excitation with increasing amplitudes in a frequency range where 1:2 internal resonances are expected to be activated. While the fabricated structure exhibits coupled mode internal resonance activated response when subjected to higher levels of excitation, the plate also displays other interesting nonlinear behavior. These include nonlinear periodic as well as amplitude modulated motions of the directly excited mode and these motions super-imposed on the coupled mode response.

References listed at the end of the paper:

ABSTRACT: The geometrically nonlinear vibration response of truncated thin conical shells is studied for the first time considering the one-to-one internal resonance, a phenomenon typically observed in symmetric structures such as conical shells. The Novozhilov nonlinear shell theory, retaining all nonlinear terms in the in-plane strain–displacement relationships of the three mid-surface displacements, is applied to study nonlinear vibrations of truncated conical shells. In-plane inertia is also taken into account, and a relatively large number of generalized coordinates, associated with the global discretization of the shell, is considered. This gives very accurate numerical solutions for simply supported, truncated thin conical shells. The effect of an exact one-to-one internal resonance, due to the axial symmetry of conical shells, is fully considered and the results are presented for different excitation levels. The numerical results show that also an almost exact one-to-one internal resonance with a mode presenting a different number of circumferential waves can also arise, which further complicates the nonlinear vibrations and leads to 1:1:1:1 internal resonance. The numerical model was augmented with additional generalized coordinates to capture this phenomenon. Pitchfork, Neimark–Sacker and period-doubling bifurcations of the forced vibration responses arising from internal resonances are detected, followed and presented, showing complex nonlinear dynamics.

References listed at the end of the paper:

https://doi.org/10.1177/10775469500100202
https://doi.org/10.1016/j.compstruct.2018.12.047
https://doi.org/10.1016/0029-5493(68)90053-8
The aim of this paper is to investigate quasi-periodic response of a fixed–fixed buckled beam experimentally studied in detail by Kreider and Nayfeh (Nonlinear Dyn 15(2):155–177, 1998.)
with an “unexplained” sideband structure. After a description of the equation of motion of the buckled beam with quadratic and cubic nonlinearities, it is shown that the proposed approach, the incremental harmonic balance (IHB) method with two time scales, can be used to find the quasi-periodic response of the buckled beam with the “unexplained” sideband structure and its understanding is revealed. The traditional IHB method with a single time scale is first used to automatically track periodic and period-doubling solutions of nonlinear responses of the buckled beam, and stability and bifurcations of periodic solutions are investigated using the Floquet theory. In the case of 1:1 internal resonance between the first two modes of the buckled beam, it is found that anti-symmetrical modes cannot be excited due to small excitation amplitudes. However, the anti-symmetrical modes are excited via period-doubling bifurcation with an increased excitation amplitude. By continuously increasing the excitation amplitude, Hopf bifurcation occurs, which leads to quasi-periodic response whose spectrum contains uniformly spaced sidebands around integer multiples of a half of the excitation frequency, where the uniformly spaced sidebands were called an “unexplained” sideband structure in Kreider and Nayfeh (1998). The results obtained from the IHB method with two time scales are shown to well correlate with the experimental results in Kreider and Nayfeh (1998). Moreover, results obtained from the IHB method with two time scales are in excellent agreement with those from numerical integration using the fourth-order Runge–Kutta method.

References listed at the end of the paper:


ABSTRACT: This paper presents full-scale modeling and nonlinear dynamic analysis of sandwich plates with auxetic 3D lattice core, which is further designed to possess three functionally graded (FG) configurations through the plate thickness direction for the first time. The effective Poisson’s ratio (EPR) and fundamental frequencies of auxetic 3D lattice metamaterials are analyzed and verified by static and vibration tests using specimens fabricated by 3D printing. Considering the large deflection nonlinearity of sandwich plates and the accompanying changes in effective properties of lattice microstructures, full-scale FE modeling and nonlinear dynamic thermal–mechanical analysis are performed, with material properties assumed to be temperature dependent. Numerical results revealed that the auxetic core can significantly reduce the dynamic deflections, in comparison with its counterpart with positive EPR. Furthermore, FG configurations have distinct effects on the natural frequencies and dynamic deflection–time curves of sandwich plates, along with EPR–deflection curves in the large deflection region.

References listed at the end of the paper:


ABSTRACT: In this paper, the nonlinear dynamic behaviors, especially, limit cycles and chaos, are investigated for the spherical shell composed of a class of visco-hyperelastic materials subjected to uniform radial loads at its inner and outer surfaces. To include the thickness effect, a more general model compared with the membrane and thin plate is proposed to investigate the dynamic characteristics of the visco-hyperelastic structure. Then, the coupled integro-differential equations describing the radially symmetric motion of the spherical shell are derived in terms of the variational principle and the finite viscoelasticity theory. Due to both the geometrical and physical nonlinearities, there exists an asymmetric homoclinic orbit for the hyperelastic structure. Particularly, under constant loads, the system converges to a stable equilibrium point, and the convergence speed is closely related to both the initial condition and the viscosity because of the existence of different basins, while under periodic loads, some complex phenomena, such as the limit cycles and chaos, are found, and the chaotic phenomena are analyzed by the bifurcation diagram and Lyapunov exponent. Moreover, by numerical analyses, parametric studies are carried out to illustrate the effects of viscosity, load amplitude, external frequency and initial condition.

References listed at the end of the paper:

https://doi.org/10.1007/s11071-020-05882-2

ABSTRACT: The present work investigates the out-of-plane nonlinear vibration of an electrostatically actuated cylindrical microbeam immersed in flowing fluid. The lift and drag forces as the two basic flow-induced factors affecting the dynamics of the microbeam are modeled using Van der Pol equation. The Euler–Bernoulli beam theory is used to simulate the new nonlinear model of beam cross fluid and inline motion with considering geometrical nonlinearities effects. The coupled nonlinear equations governing the microbeam out-of-plane motion and the wake oscillation are solved using the Galerkin and the step-by-step linearization methods to evaluate the response of the coupled structure to a combined applied voltage and fluid flow. Response of the microbeam to different input voltages in the presence of fluid flow is investigated in two directions of normal and parallel to fluid flow. It is shown that applying voltage not only can be used to control the lock-in regime, but also can increase the maximum dynamic amplitude up to 100 percent for a given flowing fluid. Moreover, ignoring inline vibration and geometrical nonlinearities effects may decrease the accuracy of the obtained maximum amplitude up to 18 percent in the lock-in regime.

References listed at the end of the paper:
17. Stappenbelt, B.: Vortex-induced motion of nonlinear compliant low aspect ratio cylindrical systems. ISOPE-11-21-4–280 21(04), 7 (2011)

ABSTRACT: Pull-in and snap-through are two representative bifurcation phenomena in electrically actuated microcomponents, based on which various microdevices are designed and applied in many sensing and actuating fields. In this paper, the nonlinear mechanisms of pull-in and snap-through in a two-electrode actuated microbeam due to asymmetric bias voltages are qualitatively identified. With the considerations of midplane stretching of clamped–clamped microbeam and nonlinear electrostatic force, a continuous dynamic equation of motion is introduced after which a generalized one-degree-of-freedom (1-DOF) model derived using the differential quadrature method is deduced. By the application of the singularity theory on the static equation, transient sets are theoretically obtained which separate two-parameter space of cubic stiffness and DC voltage into seven regions. Associated bifurcation diagrams show that initially straight microbeam can exhibit snap-through motion as well as pull-in behavior when loading proper bias voltages on two electrodes. Besides, detailed division on snap-through region is numerically done and the snap-through direction is discussed and then verified. In what follows, primary resonant frequency closely related to the static solution is examined which show various attractive scenarios versus bias voltage ratio. Moreover, the method of multiple scales is utilized to derive the primary resonant response for small vibration estimation. Combined with theoretical and numerical results, dynamic snap-through motion is observed which implies that dynamic saddle-node bifurcation and interwell jumping due to energy enhancement can both increase the possibility of dynamic snap-through. During dynamic snap-through procedure, microbeam may exhibit cross-well transient chaos.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: This work deals with snap-through flutter dynamics of thin-walled shallow panels accompanied by flexural mode transitions assuming cylindrical bending conditions. The problem is therefore multimodal and, in addition, essentially non-local due to the presence of multiple equilibrium positions. The corresponding analysis is based on the asymptotic of a perfectly flexible panel with a continuous manifold of equilibrium configurations. It is assumed that trajectories of the snap-through dynamics are close to such a manifold, which is interpreted as a family of generating solutions. It is shown that the two-mode approximation depicts major physical specifics of the snap-through process, whereas higher modes can be reasonably treated as a perturbation. As a main result of the analysis, the analytical estimate for the critical speed of airflow leading to the cyclical snap-through flutter is derived.

References listed at the end of the paper:

Shimon Regev and Oriel Shoshani, “Investigation of transverse galloping in the presence of structural nonlinearities: theory and experiment”, Nonlinear Dynamics, Vol. 102, No. 3, pp 1197-1207, November 2020, 
https://doi.org/10.1007/s11071-020-06026-2

ABSTRACT: We formulate and experimentally validate a theoretical reduced-order model for the transverse galloping of nonlinear structures, namely a pair of identical, parallel-oriented cantilever beams whose free ends are attached to square prisms. We derive the structural nonlinearities from (a) a single-mode approximation of the nonlinear (truncated at cubic order) equation of motion, calculated for conservative cantilever beams augmented by a non-conservative aerodynamic force acting on a prism; and (b) phenomenological linear, quadratic, and cubic damping forces. We estimate the coefficients of the damping forces from the ring-down responses of the structures in still air. We analyze the deterministic dynamics of transverse galloping that stem from the aerodynamic force of the quasi-steady theory, and the stochastic effect of spectral line broadening that stem from turbulence-induced random fluctuations. Our findings clearly show that standard nonlinear macroscopic structures exhibit considerably different steady-state response curves than the universal curve of Parkinson obtained for linear mass–spring–damper structures. Importantly, the amplitudes of the oscillations are attenuated at high upstream velocities due to nonlinear damping, while the spectral line broadens due to turbulence-induced random fluctuations and an amplitude-to-phase noise conversion, which lowers the quality of the self-sustained oscillations. These two phenomena should be considered in the design of efficient transverse galloping-based energy harvesters—a rapidly growing field of research.

References listed at the end of the paper:
ABSTRACT: This work investigates the amplitude-dependent dynamics of a locally resonant metamaterial beam with bistable attachments. The concept that was previously demonstrated for a discrete chain is extended to a continuous system, and the enhancement in vibration attenuation bandwidth is investigated through a cantilever beam under base excitation. The analysis approach combines the harmonic balance method and time-domain numerical integration to capture periodic and aperiodic responses for up-sweep and down-sweep harmonic excitation. The bistable attachments are shown to exhibit linear intrawell, nonlinear intrawell and nonlinearly enhanced synchronization domain. J. Microelectromech. Syst. 25(2), 297 (2016)


Experimental validations are then presented for a base-excited cantilever beam hosting seven magnetoeleastic beam attachments. For moderate-to-high amplitude excitation levels, the interwell oscillations of the attachments produce an attenuation frequency range that is 350% wider than the corresponding linear locally resonant bandgap (observed for low-amplitude excitation levels), yielding the suppression of modes outside the bandgap with increased excitation intensity.

References listed at the end of the paper:

ABSTRACT: Vibration experiments are carried out on a slightly corrugated circular cylindrical shell made of polyethylene terephthalate fabric. The shell is liquid-filled, it is pressurized by a liquid column that applies a pressure of 100 mmHg, and the two edges are clamped to fix supports. Forced vibrations of the shell are experimentally studied in the linear (small amplitude) and in the geometrically nonlinear (large amplitude) regime. The large-amplitude vibrations of the liquid-filled shell are characterized by a strong softening behavior that cannot be captured by any quadratic nonlinear stiffness. Since compressed fibers do not carry load, a piecewise linear stiffness with viscous damping is thus introduced in a reduced-order model, resulting in a very good agreement between experimental and simulated responses. The stiffness parameters and the damping ratios are identified from the experimental results. The damping ratio grows linearly with the excitation amplitude, indicating a predominant hydrodynamic damping. In particular, the damping ratio increases 2.75 times from the small-amplitude vibrations to a maximum amplitude of 1.26 mm. This is a very significant increase that highlights the necessity to introduce nonlinear damping to model shell structures.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: Piezoelectric devices with integrated actuation and sensing capabilities are often used for the development of electromechanical systems. The present paper addresses experimentally the nonlinear dynamics of a fully integrated circular piezoelectric thin structure, with piezoelectric patches used for actuation and other for sensing. A phase-locked loop control system is used to measure the resonant periodic response of the system under harmonic forcing, in both its stable and unstable parts. The single-mode response around a symmetric resonance as well as the coupled response around an asymmetric resonance, involving two companion modes in 1:1 internal resonance, is accurately measured. For the latter, a particular location of the patches and additional signal processing is proposed to spatially discriminate the response of each companion mode. In addition to a hardening behavior associated with geometric nonlinearities of the plate, a softening behavior predominant at low actuation amplitudes is observed, resulting from the material piezoelectric nonlinearities.


membrane machine driven by soft DE joints is proposed for space applications and this case is to demonstrate that dynamic modeling and simulation can aid the design of soft machines.

References listed at the end of the paper:


ABSTRACT: This paper is devoted to investigate the nonlinear vibration characteristics and active control of composite lattice sandwich plates using piezoelectric actuator and sensor. Three types of the sandwich plates with pyramidal, tetrahedral and Kagome cores are considered. In the structural modeling, the von Kármán large deflection theory is applied to establish the strain–displacement relations. The nonlinear equations of motion of the structures are derived by Hamilton’s principle with the assumed mode method. The nonlinear free and forced vibration responses of the lattice sandwich plates are calculated. The velocity feedback control (VFC) and H\textsuperscript{∞} control methods are applied to design the controller. The nonlinear vibration responses of the sandwich plates with pyramidal, tetrahedral and Kagome cores are compared. The influences of the ply angle of the laminated face sheets, the thicknesses of the lattice core and face sheets and the excitation amplitude on the nonlinear vibration behaviors of the sandwich plates are investigated. The correctness of the H\textsuperscript{∞} control algorithm is verified by comparing with the experiment results reported in the literature. The controlled nonlinear vibration response of the sandwich plate is computed and compared with that of the uncontrolled structural system. Numerical results indicate that the VFC and H\textsuperscript{∞} control methods can effectively suppress the large amplitude vibration of the composite lattice sandwich plates.

References listed at the end of the paper:

https://doi.org/10.1177/1077546320948330

Nonlinear Dynamics, Vol. 102, No. 4, pp 2179-2203, December 2020,

More papers published in the journal, Smart Materials and Structures (2014 and on)

ABSTRACT: A novel active method for multi-mode vibration control of an all-clamped stiffened plate (ACSP) is proposed in this paper, using the extended-state-observer (ESO) approach based on non-collated acceleration sensors and piezoelectric actuators. Considering the estimated capacity of ESO for system state variables, output superposition and control coupling of other modes, external excitation, and model uncertainties simultaneously, a composite control method, i.e., the ESO based vibration control scheme, is employed to ensure the lumped disturbances and uncertainty rejection of the closed-loop system. The phenomenon of phase hysteresis and time delay, caused by non-collated sensor/actuator pairs, degrades the performance of the control system, even inducing instability. To solve this problem, a simple proportional differential (PD) controller and acceleration feed-forward with an output predictor design produce the control law for each vibration mode. The modal frequencies, phase hysteresis loops and phase lag values due to non-collated placement of the acceleration sensor and piezoelectric patch actuator are experimentally obtained, and the phase lag is compensated by using the Smith Predictor technology. In order to improve the vibration control performance, the chaos optimization method based on logistic mapping is employed to auto-tune the parameters of the feedback channel. The experimental control system for the ACSP is tested using the dSPACE real-time simulation platform. Experimental results demonstrate that the proposed composite active control algorithm is an effective approach for suppressing multi-modal vibrations.


ABSTRACT: Free vibration of a magnetoelectroelastic plate resting on a Pasternak foundation is investigated based on Mindlin theory. The in-plane electric and magnetic fields can be ignored for plates. According to the Maxwell equation and magnetoelectric boundary condition, the variation of electric and magnetic potentials along the thickness direction of the plate is determined. Using Hamilton's principle, the governing equations of motion for the magnetoelectroelastic plate are derived. Numerical results reveal the effects of the electric and magnetic potentials, spring and shear coefficients of the Pasternak foundation on the vibration frequency. These results may be useful in the analysis and design of smart structures constructed from magnetoelectroelastic materials.


ABSTRACT: Magneto-rheological visco-elastomer (MRVE) is used to construct sandwich plates for micro-vibration control. The micro-vibration response of a sandwich plate with an MRVE core under stochastic support motion excitation is studied to evaluate the vibration suppression capability. The dynamic behavior of MRVE in micro-vibration is characterized by a non-homogeneous complex modulus dependent on the vibration frequency and controllable by an applied magnetic field, in which the effect of the localized magnetic field distribution is considered. The partial differential equations for the coupled transverse and longitudinal motions of the sandwich plate are derived from the dynamic equilibrium, constitutive and geometric relations. A frequency-domain solution method for the stochastic micro-vibration response of sandwich plates is develop based on the Galerkin method and random vibration theory. The partial differential equations are first converted into ordinary differential equations according to the Galerkin method. Then the expressions for the frequency-response function, response power spectral density and root-mean-square velocity spectrum in terms of the one-third octave frequency band for micro-vibration are obtained. Finally, numerical results are given to illustrate the high response reduction capacity of the MRVE sandwich plate under stochastic support motion excitation, and the influence of the MRVE parameters and localized magnetic field placement on the micro-vibration response.

ABSTRACT: This study investigates the dynamic properties of a laminated composite magnetorheological (MR) fluid sandwich plate. The governing differential equations of motion of a sandwich plate embedding a MR fluid layer as the core layer and laminated composite plates as the face layers are presented in a finite element formulation. The validity of the developed finite element formulation is demonstrated by comparing the results in terms of the natural frequencies derived from the present finite element formulation with those in the available literature. Various parametric studies are also performed to investigate the effect of a magnetic field on the variation of the natural frequencies and loss factors of the MR fluid composite sandwich plate under various boundary conditions. Furthermore, the effect of the thickness of the MR fluid layer and the ply orientation of the composite face layers on the variation of the natural frequencies and loss factors are studied. The free vibration mode shapes under various boundary conditions of a MR fluid laminated composite sandwich plate are also presented. The forced vibration response of a MR fluid composite plate is investigated to study the dynamic response of the sandwich plate under harmonic force excitations in various magnetic fields. The study suggests that the natural frequency increases with increasing magnetic field, irrespective of the boundary conditions. The reduction in peak deflection at each mode under a harmonic excitation force with variation of the applied magnetic field shows the effectiveness of the MR fluid layer in reducing the vibration amplitude of the composite sandwich plate.


ABSTRACT: Static behavior of a functionally graded magnetoelectroelastic hollow sphere subjected to hygrothermal loading in the spherically symmetric state is studied. The sphere could be rested on a Winkler elastic foundation on the inner and/or outer surfaces. It is assumed that the material properties obey a power law in the radial direction. Considering the axisymmetric heat conduction and moisture diffusion equations, temperature and moisture concentration distributions within the radius of the sphere are achieved. The governing coupled differential equations are exactly solved. Numerical examples are discussed in detail to show the significant influences of inhomogeneity index, hygrothermal loading, elastic foundation and electromagnetic boundary conditions on the static behavior of a functionally graded magnetoelectroelastic hollow sphere.


ABSTRACT: In this study, the nonlinear free vibration of piezoelectric nanobeams incorporating surface effects (surface elasticity, surface tension, and surface density) is studied. The governing equation of the piezoelectric nanobeam is derived within the framework of Euler–Bernoulli beam theory with the von Kármán geometric nonlinearity. In order to satisfy the balance conditions between the nanobeam bulk and its surfaces, the component of the bulk stress, $\sigma_z$, is assumed to vary linearly through the nanobeam thickness. An exact solution is obtained for the natural frequencies of a simply supported piezoelectric nanobeam in terms of the Jacobi elliptic functions using the free vibration mode shape of the corresponding linear problem. Then, the influences of the surface effects and the piezoelectric field on the nonlinear free vibration of nanobeams made of aluminum and silicon with positive and negative surface elasticity, respectively, have been studied for various properties of the piezoelectric field, various nanobeam sizes and amplitude ratios. It is observed that if the Young’s modulus of a nanobeam is lower, the effect of the piezoelectric field on the frequency ratios (FRs) of the nanobeam will be greater. In addition, it is seen that by increasing the nanobeam length so that the nanobeam cross section is set to be constant, the surface effects and the piezoelectric field with negative voltage values increases the FRs, whereas it is the other way around when the nanobeam cross section is assumed to be dependent on the length of the nanobeam.

ABSTRACT: The effects of surface and flexoelectricity have been found in the presence of strong size dependence and should be technically taken into account for nano-scaled dielectric structures. This paper proposes a Bernoulli-Euler beam model to investigate the electromechanical coupling response of piezoelectric nanostructures, in which the effects of surface elasticity, dielectricity and piezoelectricity as well as bulk flexoelectricity are all taken into consideration. The governing equations with non-classical boundary conditions are naturally derived from a variational principle. Then the present beam model is directly applied to solve the static bending problems of cantilever beams. Without considering the residual surface stresses, the bending rigidity can be defined the same as that in classical piezoelectricity theory. The bending rigidity is found to increase for silicon nanowires and decrease for silver nanowires. Also the flexoelectric effect in piezoelectric nanowires has a momentous influence on the bending rigidity. The residual surface stresses which are usually neglected are found to be more important than the surface elasticity for the bending of nanowires. However, this has no influence on the effective electromechanical coupling coefficient. The deflections reveal the significance of the residual surface stresses and the bulk flexoelectric effects. The effective electromechanical coupling coefficient for piezoelectric nanowires is dramatically enhanced, which demonstrates the significant effects of the bulk flexoelectricity and surface piezoelectricity. The effects of surface and flexoelectricity decrease with the increase of the beam thickness, and therefore these effects can be ignored for large-scale structures. This work is very helpful in designing cantilever-beam-based nano-electro-devices.


ABSTRACT: Auxetic materials and structures exhibit a negative Poisson's ratio while thick plates encounter shear deformation, which is not accounted for in classical plate theory. This paper investigates the effect of a negative Poisson's ratio on thick plates that are subjected to buckling loads, taking into consideration the shear deformation using Mindlin plate theory. Using a highly accurate shear correction factor that allows for the effect of Poisson's ratio, the elastic stability of circular and square plates are evaluated in terms of dimensionless parameters, namely the Mindlin-to-Kirchhoff critical buckling load ratio and Mindlin critical buckling load factors. Results for thick square plates reveal that both parameters increase as the Poisson's ratio becomes more negative. In the case of thick circular plates, the Mindlin-to-Kirchhoff critical buckling load ratios and the Mindlin critical buckling load factors increase and decrease, respectively, as the Poisson's ratio becomes more negative. The results obtained herein show that thick auxetic plates behave as thin conventional plates, and therefore suggest that the classical plate theory can be used to evaluate the elastic stability of thick plates if the Poisson's ratio of the plate material is sufficiently negative. The results also suggest that materials with highly negative Poisson's ratios are recommended for square plates, but not circular plates, that are subjected to buckling loads.


ABSTRACT: This paper presents a comprehensive theoretical model for predicting the energy generating performance of an energy harvesting device that uses a piezoelectric circular membrane subject to pressure fluctuation. PVDF (polyvinylidene fluoride) film is adopted for the membrane. In order to predict the power generating performance due to stretching and bending of the membrane, the total stress on the membrane, rather than the stress at the center point of the circular membrane, is determined using the energy method. Analytical results indicate that the theoretically predicted generated power of the device under normal blood pressure variation is close to experimental results available in the literature. This comprehensive model provides a useful design tool during parameter optimization for energy harvesters that use piezoelectric circular membranes for a pressure fluctuating system.


ABSTRACT: A linear analysis is performed to explore the stability of an azobenzene-containing glassy nematic film on a soft elastic foundation under uniform illumination by UV light. It is found that the film can buckle to form wrinkles when the light intensity and the geometric and material parameters of the system are properly
chosen. The results may help in the fabrication of photo-triggered wrinkled surfaces which are particularly attractive for applications where remote addressing is desired.

Jinling Zhao, Hongli Ji and Jinhao Qiu, “Modeling of Lamb waves in composites using new third-order plate theories”, Smart Materials and Structures, Vol. 23, No. 4, 045017, April 2014

ABSTRACT: The effect of shear deformation and rotatory inertia should be taken into account in modeling Lamb waves in composite laminates. However, the first and second-order shear deformation plate theories which do not satisfy the stress free boundary condition are uneconomic approximations, because one has to develop a complicated scheme to compute the shear correction factors. The stress free boundary condition requires an in-plane displacement field expanded at least as cubic functions of the thickness coordinate. Hence, in this paper, the dispersive curves of Lamb waves in laminates are calculated according to two new third-order shear deformation plate theories, considering the stress free boundary condition. The lower anti-symmetric Lamb mode results of the new theories are closest to the exact solutions from 3D elasticity theory, when compared to several existing plate theories.


ABSTRACT: Shape sensing, i.e., reconstruction of the displacement field of a structure from surface-measured strains, has relevant implications for the monitoring, control and actuation of smart structures. The inverse finite element method (iFEM) is a shape-sensing methodology shown to be fast, accurate and robust. This paper aims to demonstrate that the recently presented iFEM for beam and frame structures is reliable when experimentally measured strains are used as input data. The theoretical framework of the methodology is first reviewed. Timoshenko beam theory is adopted, including stretching, bending, transverse shear and torsion deformation modes. The variational statement and its discretization with C₀-continuous inverse elements are briefly recalled. The three-dimensional displacement field of the beam structure is reconstructed under the condition that least-squares compatibility is guaranteed between the measured strains and those interpolated within the inverse elements. The experimental setup is then described. A thin-walled cantilevered beam is subjected to different static and dynamic loads. Measured surface strains are used as input data for shape sensing at first with a single inverse element. For the same test cases, convergence is also investigated using an increasing number of inverse elements. The iFEM-recovered deflections and twist rotations are then compared with those measured experimentally. The accuracy, convergence and robustness of the iFEM with respect to unavoidable measurement errors, due to strain sensor locations, measurement systems and geometry imperfections, are demonstrated for both static and dynamic loadings.


ABSTRACT: As a widely used configuration for dielectric elastomer (DE) actuators, DE tube actuators (or cylindrical actuators) are also found to be susceptible to electromechanical instability (EMI), which may lead to a premature electrical breakdown (EB), and inhibit the potential actuation of DE actuators. This work investigates the electromechanical response of a DE tube actuator with and without boundary constraints to demonstrate an alternative to avoid EMI while achieving large actuation. Our simulation results based on the Gent strain energy model show that the EMI of a DE tube actuator can be eliminated, and larger actuation deformation can be achieved by applying boundary constraints. As a result of these constraints, consideration is also given to the possible mechanical buckling failure that may occur. Mechanisms of possible failure modes of constrained and unconstrained DE tube actuators, such as electromechanical instability, electrical breakdown and mechanical buckling, are elucidated. This paper should provide better theoretical guidance on how to improve the actuation performance of DE actuators, thus leading to the optimal design of DE-based devices.

ABSTRACT: Glass fiber reinforced composite material beams embedded with two types of polarimetric sensors are fabricated by the hand layup method and characterized. Two types of polarimetric sensors, a high strain sensitive Panda type fiber and a low strain sensitive polarization maintaining photonic crystal fiber (PM-PCF), are compared for low frequency vibration measurements from 0 to 100 Hz. Different lengths of glass fiber reinforced composite samples with embedded polarimetric sensors are fabricated and compared for different vibration amplitudes and vibration frequencies. The influence of the vibration amplitude of the composite beams on the accuracy of vibration measurements using the two types of polarimetric sensors is investigated. At high amplitude vibrations the low strain sensitive PM-PCF polarimetric sensors offer a wider linear range and thus reproduce the vibration frequency and vibration amplitude accurately. However for high amplitude vibrations the high sensitivity and low dynamic strain range of Panda type fibers result in a multiple-peak intensity pattern within one vibration cycle which leads to inaccurate vibration frequency and vibration amplitude measurements. The experimental results show that the strain sensitivity of polarimetric sensors limits the vibration measurements to a certain range of vibration amplitudes. The vibration amplitude range over which the polarimetric sensors provide accurate information about the vibration frequency is experimentally investigated and the results are presented. Also, for a composite beam undergoing deflections in the 'simply–simply supported' configuration, a theoretical method to predict the allowable maximum measurable vibration amplitude for any type of polarimetric sensor, is derived in this paper. It is envisaged that the results from the studies will provide significant information, which can be used in composite material applications such as marine and aerospace for selecting an appropriate type and length of polarimetric sensor for vibration measurements in composite materials.


ABSTRACT: Vibration-based energy harvesting using piezoelectric cantilevers has been extensively studied over the past decade. As an alternative to cantilevered harvesters, piezoelectric patch harvesters integrated to thin plates can be more convenient for use in marine, aerospace and automotive applications since these systems are often composed of thin plate-like structures with various boundary conditions. In this paper, we present analytical electroelastic modeling of a piezoelectric energy harvester structurally integrated to a thin plate along with experimental validations. The distributed-parameter electroelastic model of the thin plate with the piezoceramic patch harvester is developed based on Kirchhoff's plate theory for all-four-edges clamped (CCCC) boundary conditions. Closed-form steady-state response expressions for coupled electrical output and structural vibration are obtained under transverse point force excitation. Analytical electroelastic frequency response functions (FRFs) relating the voltage output and vibration response to force input are derived and generalized for different boundary conditions. Experimental validation and extensive theoretical analysis efforts are then presented with a case study employing a thin PZT-5A piezoceramic patch attached on the surface of a rectangular aluminum CCCC plate. The importance of positioning of the piezoceramic patch harvester is discussed through an analysis of dynamic strain distribution on the overall plate surface. The electroelastic model is validated by a comparison of analytical and experimental FRFs for a wide range of resistive electrical boundary conditions. Finally, power generation performance of the structurally integrated piezoceramic patch harvester from multiple vibration modes is investigated analytically and experimentally.


ABSTRACT: A major obstacle limiting the development of deployable sensing and actuation solutions is the scarcity of power. Converted energy from ambient loading using piezoelectric scavengers is a possible solution. Most of the previously developed research focused on vibration-based piezoelectric harvesters which are typically characterized by a response with a narrow natural frequency range. Several techniques were used to improve their effectiveness. These methods focus only on the transducer's properties and configurations, but do little to improve the stimuli from the source. In contrast, this work proposes to focus on the input deformations generated within the structure, and the induction of an amplified amplitude and up-converted frequency toward the harvesters' natural spectrum. This paper introduces the concept of using mechanically-equivalent energy converters and frequency modulators that can transform low-amplitude and low-rate service deformations into
ABSTRACT: This paper investigates the nonlinear analysis of energy harvesting from piezoelectric functionally graded carbon nanotube reinforced composite plates under combined thermal and mechanical loadings. The excitation, which derives from harmonically varying mechanical in-plane loading, results in parametric excitation. The governing equations of the piezoelectric functionally graded carbon nanotube reinforced composite plates are derived based on classical plate theory and von Kármán geometric nonlinearity. The material properties of the nanocomposite plate are assumed to be graded in the thickness direction. The single-walled carbon nanotubes (SWCNTs) are assumed to be aligned, straight and have a uniform layout. The linear buckling and vibration behavior of the nanocomposite plates is obtained in the first step. Then, Galerkin's method is employed to derive the nonlinear governing equations of the problem with cubic nonlinearities associated with mid-plane stretching. Periodic solutions are determined by using the Poincaré–Lindstedt perturbation scheme with movable simply supported boundary conditions. The effects of temperature change, the volume fraction and the distribution pattern of the SWCNTs on the parametric resonance, in particular the amplitude of vibration and the average harvested power of the smart functionally graded carbon nanotube reinforced composite plates, are investigated through a detailed parametric study.

ABSTRACT: The control of free-edge interlaminar stresses in laminated composite structures using a stress function-based approach is proposed. The assumed stress fields satisfy pointwise traction and free boundary conditions at surfaces. Governing equations are derived using the principle of complementary virtual work. A general eigenvalue solution procedure was adopted to obtain accurate stress states of the laminated composite structure. The results obtained from the proposed method were compared with those obtained by three-dimensional finite element analyses. It was found that interlaminar stresses generated by mechanical loadings could be significantly reduced by applying proper electric fields to piezoelectric actuators, which were surface bonded or embedded in composite laminates. Locations of piezoelectric actuators also influenced the distributions of interlaminar stresses. The results provided that piezoelectric actuators have potential in the application to actively control interlaminar stresses in composite laminates.

ABSTRACT: Bistable structures are attractive morphing components because they can transform from one stable state to another simply through the application of an external force or moment. Each stable state is preserved despite the absence of a continuous energy supply. However, its competency is quite limited because most bistable composites (unsymmetric laminated bistable composites) have limited equilibrium shape configurations after curing. Most of them are cylindrical in shape. In this paper, for the first time, we present a saddle-shaped bistable panel that can be used for various soft-morphing applications. The mechanics of the saddle-shaped, bistable panel are investigated using the Rayleigh–Ritz approximation. A simple analytical model is proposed to obtain saddle bistability and deformations. Finite element (FE) numerical analysis is also performed to validate the analytical model approach. The numerical FE analysis shows good correlation with simple analytical solutions. Furthermore, for practical, smart-structure applications of the saddle-shaped bistable panel, the FE method simulated a snap-through action induced by a shape memory alloy (SMA) spring actuator. A simple design criterion for the snap-through action of a saddle composite panel actuated by an SMA spring component is suggested, based on the FE analysis.

an amplified vibration input to the piezoelectric transducer. The introduced concept allows energy conversion within the unexplored quasi-static frequency range (≤ 1 Hz). The post-buckling behavior of bilaterally constrained columns is used as the mechanism for frequency up-conversion. A bimorph cantilever polyvinylidene fluoride (PVDF) piezoelectric beam is used for energy conversion. Experimental prototypes were built and tested to validate the introduced concept and the levels of extractable power were evaluated for different cases under varying input frequencies. Finally, finite element simulations are reported to provide insight into the scalability and performance of the developed concept.

ABSTRACT: Piezoelectric sensors are increasingly being used in active structural health monitoring, due to their durability, light weight and low power consumption. In the present work damage detection and characterization methodologies based on Lamb waves have been evaluated for aircraft panels. The applicability of various proposed delay-and-sum algorithms on isotropic and composite stiffened panels have been investigated, both numerically and experimentally. A numerical model for ultrasonic wave propagation in composite laminates is proposed and compared to signals recorded from experiments. A modified delay-and-sum algorithm is then proposed for detecting impact damage in composite plates with and without a stiffener which is shown to capture and localize damage with only four transducers.


ABSTRACT: The instability of geometrically imperfect shape memory alloy (SMA) fibers reinforced with hybrid laminated composite (SMAHC) plates and subjected to a uniform thermal loading is analytically investigated. The material properties of the SMAHC plates are assumed to be functions of temperature. Nonlinear equations of the plates’ thermal stability are derived based on a higher order shear deformation theory incorporating von Karman geometrical nonlinearity via stationary potential energy. The structural recovery stress, which is generated by martensitic phase transformation of the prestrained SMA fibers, is calculated based on the one-dimensional thermodynamic constitutive model by Brinson. Adopting the Galerkin procedure, the governing nonlinear partial differential equations are converted into a set of nonlinear algebraic equations, in which systems of equations are solved by introducing an analytical approach. Closed-form formulations are presented to determine the load-deflection path and critical buckling temperature of the plate. Based on the developed closed-form solutions, ample numerical results are presented to provide an insight into the effects of the volume fraction, prestrain, location and orientation of the SMA fibers, composite plate geometry, geometrical imperfection and temperature dependence on the stability of the SMAHC plates. It is shown that a proper application of SMA fibers results in a considerable delay of the thermal bifurcation and controllable thermal post-buckling deflection of the SMAHC plate.


EDITORIAL: Origami, the Japanese art of folding paper into various three-dimensional shapes, has inspired an emerging field of science and engineering that focuses on the realization of three-dimensional engineering structures from initially two-dimensional pre-forms through fold-like operations. The term origami is derived from the Japanese roots for 'folded' (ori) and 'paper' (kami), and the original purpose of the practice was not particularly utilitarian, but rather recreational and artistic. Traditional three-dimensional goal shapes have ranged from abstract forms to representations of realistic objects (e.g., the famous origami crane). One can imagine that the design of engineering applications associated with foldable structures might also benefit from such a framework and thought process, and that the ability of structural components to self-generate active folds might be especially enabling.

Recently, mathematical developments regarding realizable three-dimensional shapes and their optimal fold patterns have enabled new engineering and scientific pursuits toward utilizing fold-like behaviors in manufacturing, storage, and deployment of engineering structures. These realizable shapes have been demonstrated across scales, from the molecular to deployable structures for space exploration at the large scale. The flexibility of using active materials and thus physically realizing kinematically acceptable folds has provided new possibilities for design that have been utilized in recent years. Experimental and computational investigation, characterization, and design of advanced structural and active material concepts invoking the themes of origami are all currently being pursued. Collaborations among researchers in diverse fields such as material science, mechanics, computer science, design, topology, optimization, and the visual arts are essential to advancing this new field by creating desired integration and synergies. Given the various efforts to explore how this new field of ‘origami engineering’ intersects with that of active materials and smart structures, it is now the opportune time for an organized compilation of associated work from around the world.
This focus issue of Smart Materials and Structures presents a collection of original contributions and review papers that address active materials for self-folding. After a comprehensive review and synthesis article by E Peraza-Hernandez and coworkers highlighting the use of shape memory alloys for active folds, detailed developments associated with repeatable self-folding in dielectric elastomers (K McGough et al, S Ahmed et al) and magneto-active elastomers (R Sheridan et al) are described, as well as the work by S Miyashita and his team on electrically driven folding at the micro-scale. Thermally induced self-folding specifically for the purposes of self-assembly is described in the works led by M Tolley and Q Ge. Repeatable thermally driven (and pH-driven) self-folding is also demonstrated at the sub-millimeter scale by C Yoon and coworkers. The design and assessment of novel compliant structures based on origami principles is also discussed. In particular, bi-stable (B H Hanna et al) and corrugated (S S Tolman et al) structural configurations are considered.

Comprehensive analytical studies are also performed on cylindrical (i.e., barrel vault) structures (J Cai et al) and more generalized cellular configurations (K C Cheung et al), each displaying their own useful responses. Finally, the focus issue ends on the theme of design with a paper by D M Aukes and his team on the development of new design tools that will enable origami engineers and lead to novel manufacturing approaches.

It is hoped that this issue of Smart Materials and Structures, which includes new contributions compiled into a collection of state-of-the-art articles on this exciting topic, will open up new horizons and inspire members of our scientific community and especially young researchers to further develop this area of the engineering sciences.


ABSTRACT: Origami, the ancient art of paper folding, has inspired the design of engineering devices and structures for decades. The underlying principles of origami are very general, which has led to applications ranging from cardboard containers to deployable space structures. More recently, researchers have become interested in the use of active materials (i.e., those that convert various forms of energy into mechanical work) to effect the desired folding behavior. When used in a suitable geometry, active materials allow engineers to create self-folding structures. Such structures are capable of performing folding and/or unfolding operations without being kinematically manipulated by external forces or moments. This is advantageous for many applications including space systems, underwater robotics, small scale devices, and self-assembling systems. This article is a survey and analysis of prior work on active self-folding structures as well as methods and tools available for the design of folding structures in general and self-folding structures in particular. The goal is to provide researchers and practitioners with a systematic view of the state-of-the-art in this important and evolving area. Unifying structural principles for active self-folding structures are identified and used as a basis for a quantitative and qualitative comparison of numerous classes of active materials. Design considerations specific to folded structures are examined, including the issues of crease pattern identification and fold kinematics. Although few tools have been created with active materials in mind, many of them are useful in the overall design process for active self-folding structures. Finally, the article concludes with a discussion of open questions for the field of origami-inspired engineering.


ABSTRACT: Origami engineering aims to combine origami principles with advanced materials to yield active origami shapes, which fold and unfold in response to external stimuli. This paper explores the potential and limitations of dielectric elastomers (DEs) as the enabling material in active origami engineering. DEs are compliant materials in which the coupled electro-mechanical actuation takes advantage of their low modulus and high breakdown strength. Until recently, prestraining of relatively thick DE materials was necessary in order to achieve the high electric fields needed to trigger electrostatic actuation without inducing a dielectric breakdown. Although prestrain improves the breakdown strength of the DE films and reduces the voltage required for actuation, the need for a solid frame to retain the prestrain state is a limitation for the practical implementation of DEs, especially for active origami structures. However, the recent availability of thinner DE materials (50 μm, 130 μm, 260 μm) has made DEs a likely medium for active origami. In this work, the folding

ABSTRACT: This work seeks to provide a framework for the numerical simulation of magneto-active elastomer (MAE) composite structures for use in origami engineering applications. The emerging field of origami engineering employs folding techniques, an array of crease patterns traditionally on a single flat sheet of paper, to produce structures and devices that perform useful engineering operations. Effective means of numerical simulation offer an efficient way to optimize the crease patterns while coupling to the performance and behavior of the active material. The MAE materials used herein are comprised of nominally 30% v/v, 325 mesh barium hexaferrite particles embedded in Dow HS II silicone elastomer compound. These particulate composites are cured in a magnetic field to produce magneto-elastic solids with anisotropic magnetization, e.g. they have a preferred magnetic axis parallel to the curing axis. The deformed shape and/or blocked force characteristics of these MAEs are examined in three geometries: a monolithic cantilever as well as two- and four-segment composite accordion structures. In the accordion structures, patches of MAE material are bonded to a Gelest OE41 unfilled silicone elastomer substrate. Two methods of simulation, one using the Maxwell stress tensor applied as a traction boundary condition and another employing a minimum energy kinematic (MEK) model, are investigated. Both methods capture actuation due to magnetic torque mechanisms that dominate MAE behavior. Comparison with experimental data show good agreement with only a single adjustable parameter, either an effective constant magnetization of the MAE material in the finite element models (at small and moderate deformations) or an effective modulus in the minimum energy model. The four-segment finite element model was prone to numerical locking at large deformation. The effective magnetization and modulus values required are a fraction of the actual experimentally measured values which suggests a reduction in the amount of magnetic torque transferred from the particles to the matrix.


ABSTRACT: Self-folding is an approach used frequently in nature for the efficient fabrication of structures, but is seldom used in engineered systems. Here, self-folding origami are presented, which consist of shape memory composites that are activated with uniform heating in an oven. These composites are rapidly fabricated using inexpensive materials and tools. The folding mechanism based on the in-plane contraction of a sheet of shape memory polymer is modeled, and parameters for the design of composites that self-fold into target shapes are characterized. Four self-folding shapes are demonstrated: a cube, an icosahedron, a flower, and a Miura pattern; each of which is activated in an oven in less than 4 min. Self-sealing is also investigated using hot melt adhesive, and the resulting structures are found to bear up to twice the load of unsealed structures.


ABSTRACT: Elastic absorption of kinetic energy and distribution of impact forces are required in many applications. Recent attention to the potential for using origami in engineering may provide new methods for energy absorption and force distribution. A three-stage strategy is presented for selecting materials for such origami-inspired designs that can deform to achieve a desired motion without yielding, absorb elastic strain energy, and be lightweight or cost effective. Two material indices are derived to meet these requirements based on compliant mechanism theory. Finite element analysis is used to investigate the effects of the material stiffness in the Miura-ori tessellation on its energy absorption and force distribution characteristics compared with a triangular wave corrugation. An example is presented of how the method can be used to select a material.
for a general energy absorption application of the Miura-ori. Whereas the focus of this study is the Miura-ori tessellation, the methods developed can be applied to other tessellated patterns used in energy absorbing or force distribution applications.

ABSTRACT: The morphology of a foldable kirigami structure with modified Miura-ori patterns, which displays curvature during motion, was investigated in this paper. The principle of spherical trigonometry was used to obtain the radius, span, rise, and longitudinal length of the foldable structure during motion. The results show that the radius of curvatures decreases and that the span initially increases and then decreases during the deployment process. Furthermore, there is little change in the span over the greater part of the deployment range. Changing the values for the length, \(a\), and the vertex angle, \(\beta\), demonstrates that the deployment angle at the end of the motion, the span, and the maximal rise increase with the increase in the length \(a\). However, changing these values has no effect on the longitudinal length. At the same time, the effect of the vertex angle \(\beta\) on the geometry of the foldable kirigami is not significant.

ABSTRACT: A novel origami cellular material based on a deployable cellular origami structure is described. The structure is bi-directionally flat-foldable in two orthogonal (\(x\) and \(y\)) directions and is relatively stiff in the third orthogonal (\(z\)) direction. While such mechanical orthotropicity is well known in cellular materials with extruded two dimensional geometry, the interleaved tube geometry presented here consists of two orthogonal axes of interleaved tubes with high interfacial surface area and relative volume that changes with fold-state. In addition, the foldability still allows for fabrication by a flat lamination process, similar to methods used for conventional expanded two dimensional cellular materials. This article presents the geometric characteristics of the structure together with corresponding kinematic and mechanical modeling, explaining the orthotropic elastic behavior of the structure with classical dimensional scaling analysis.

Y.S. Li and W.J. Feng, “Microstructure-dependent piezoelectric beam based on modified strain gradient theory”, Smart Materials and Structures, Vol. 23, No. 9, 095004, September 2014
ABSTRACT: A microstructure-dependent piezoelectric beam model was developed using a variational formulation, which is based on the modified strain gradient theory and the Timoshenko beam theory. The new model contains three material length scale parameters and can capture the size effect, unlike the classical beam theory. To illustrate the new piezoelectric beam model, the static bending and the free vibration problems of a simply supported beam are numerically solved. These results may be useful in the analysis and design of smart structures that are constructed from piezoelectric materials.

Yanhui Yuan, Hejun Du, Xin Xia and Yoke-Rung Wong, “Analytical solutions to flexural vibration of slender piezoelectric multilayer cantilevers”, Smart Materials and Structures, Vol. 23, No. 9, 095005, September 2014
ABSTRACT: The modeling of vibration of piezoelectric cantilevers has often been based on passive cantilevers of a homogeneous material. Although piezoelectric cantilevers and passive cantilevers share certain characteristics, this method has caused confusion in incorporating the piezoelectric moment into the differential equation of motion. The extended Hamilton's principle is a fundamental approach to modeling flexural vibration of multilayer piezoelectric cantilevers. Previous works demonstrated derivation of the differential equation of motion using this approach; however, proper analytical solutions were not reported. This was partly due to the fact that the differential equation derived by the extended Hamilton's principle is a boundary-value problem with nonhomogeneous boundary conditions which cannot be solved by modal analysis. In the present study, an analytical solution to the boundary-value problem was obtained by transforming it into a new problem with homogeneous boundary conditions. After the transformation, modal analysis was used to solve the new boundary-value problem. The analytical solutions for unimorphs and bimorphs were verified with three-dimensional finite element analysis (FEA). Deflection profiles and frequency response functions under voltage, uniform pressure and tip force were compared. Discrepancies between the analytical results and FEA results were within 3.5%. Following model validation, parametric studies were conducted to investigate the effects of
thickness of electrodes and piezoelectric layers, and the piezoelectric coupling coefficient $d_{31}$ on the performance of piezoelectric cantilever actuators.

M.N. Rao and R. Schmidt, “Static and dynamic finite rotation FE-analyses of thin-walled structures with piezoelectric sensor and actuator patches or layers”, Smart Materials and Structures, Vol. 23, No. 9, 095006, September 2014

**ABSTRACT:** This paper deals with static and dynamic analysis of thin-walled structures with integrated piezoelectric layers as sensors and actuators in the geometrically nonlinear range of deformations. A variational formulation is derived by using the Reissner–Mindlin first-order shear deformation (FOSD) hypothesis and full geometrically nonlinear strain-displacement relations accounting for finite rotations. The finite rotations are treated by Rodriguez parameterization. In order to enhance the accuracy of a four-node shell element, a combination of an assumed natural strain (ANS) method for the shear strains, an enhanced assumed strain (EAS) method for the membrane strains and an enhanced assumed gradient (EAG) method for the electric field are employed. The present shell element has five mechanical degrees of freedom (DOFs) and three electrical DOFs per node. The Newton–Raphson method for static analysis and the Newmark method for dynamic analysis are used to perform linear and nonlinear simulations. In comparison to the results obtained by simplified nonlinear models reported in the existing literature, the finite-element simulations performed in this paper show the importance of the present model, precisely for structures undergoing finite deformations and rotations.


**ABSTRACT:** Free vibration of a simply-supported magneto-electro-elastic doubly-curved thin shell resting on a Pasternak foundation is investigated based on Donnell theory. The rotary inertia effect is considered in the formulation. Maxwell equations for electrostatics and magnetostatics are used to model the electric and magnetic behavior. The partial differential equations of motion are reduced to a single ordinary differential equation and an analytical relation is obtained for the natural frequency. After validation of the present study, several numerical studies is done to investigate the effects of the electric and magnetic potentials, spring and shear coefficients of the Pasternak foundation, and the geometry of the shell on the vibration frequency.


**ABSTRACT:** The nonlinear vibro-acoustic modulation technique is used for impact damage detection in light composite sandwich panels. The method utilizes piezo-based low-frequency vibration and high-frequency ultrasonic excitations. The work presented focuses on the analysis of modulation intensity. The results show that the method can be used for impact damage detection reliably separating damage-related from vibro-acoustic modulations from other intrinsic nonlinear modulations.


**ABSTRACT:** We report on the development of a PDMS-SMA composite whose surface micro wrinkles can be dynamically programmed by an electrical current supplied to the SMA wire. It is advantageous over other techniques for surface topographical modulation, including portability, real-time programmability, no requirement for specific surface chemistry, operability under ambient conditions, and relative ease of control. A simplified mechanical model is also developed to describe the force-deflection balance of the PDMS-SMA composite. The wavelengths and amplitudes of the wrinkles when different currents applied to the SMA are characterized, and the experimental results agree with the theoretical model. The developed composite device can be applied to programmable modulations of surface adhesion, friction, wettability, etc.

ABSTRACT: This study concerns new investigation of active vibration reduction of a stiffened plate bonded with discrete sensor/actuator pairs located optimally using genetic algorithms based on a developed finite element modeling. An isotropic plate element stiffened by a number of beam elements on its edges and having a piezoelectric sensor and actuator pair bonded to its surfaces is modeled using the finite element method and Hamilton's principle, taking into account the effects of piezoelectric mass, stiffness and electromechanical coupling. The modeling is based on the first order shear deformation theory taking into account the effects of bending, membrane and shear deformation for the plate, the stiffening beam and the piezoelectric patches. A Matlab finite element program has been built for the stiffened plate model and verified with ANSYS and also experimentally. Optimal placement of ten piezoelectric sensor/actuator pairs and optimal feedback gain for active vibration reduction are investigated for a plate stiffened by two beams arranged in the form of a cross. The genetic algorithm was set up for optimization of sensor/actuator placement and feedback gain based on the minimization of the optimal linear quadratic index as an objective function to suppress the first six modes of vibration. Comparison study is presented for active vibration reduction of a square cantilever plate stiffened by crossed beams with two sensor/actuator configurations: firstly, ten piezoelectric sensor/actuator pairs are located in optimal positions; secondly, a piezoelectric layer of single sensor/actuator pair covering the whole of the stiffened plate as a SISO system.


ABSTRACT: In the present work, the modal characteristics and vibration control performance of a cylindrical structure in air and water are experimentally investigated, and the results are presented in time and frequency domains. In order to achieve this goal, an end-capped cylindrical shell structure is considered as a host structure, and MFC (macro fiber composite) actuators, which are flexible, are bonded on the surface of the structure. After manufacturing a cylindrical shell structure with aluminum, a modal test is carried out, and the natural frequencies of the proposed structure are obtained and analyzed. To verify the modal test results, a finite element analysis is also performed, and the results are compared with the modal test results. By using the experimentally obtained modal characteristics, a state space control model is established. An optimal controller is then designed in order to control the unwanted vibration and is experimentally realized. It has been shown that the structural vibration can be effectively decreased with the optimal control methodology in both air and water environmental conditions.


ABSTRACT: A structural concept based upon the principles of adaptive morphing cells is presented whereby controlled bistability from a flat configuration into a textured arrangement is shown. The material consists of multiple cells made from silicone rubber with locally reinforced regions based upon kirigami principles. On pneumatic actuation these cells fold or unfold based on the fold lines created by the interaction of the geometry with the reinforced regions. Each cell is able to maintain its shape in either a retracted or deployed state, without the aid of mechanisms or sustained actuation, due to the existence of structural bistability. Mathematical quantification of the surface texture is introduced, based on out-of-plane deviations of a deployed structure compared to a reference plane. Additionally, finite element analysis is employed to characterize the geometry and stability of an individual cell during actuation and retraction. This investigation highlights the critical role that angular rotation, at the center of each cell, plays on the deployment angle as it transitions through the elastically deployed configuration. The analysis of this novel concept is presented and a pneumatically actuated proof-of-concept demonstrator is fabricated.

ABSTRACT: Metal thin films, which have high conductivity, are much stiffer and may fracture at a much lower strain than dielectric elastomers. In order to fabricate compliant electrodes for use in dielectric elastomer actuators (DEAs), metal thin films have been formed into either zigzag patterns or corrugations, which favour bending and only allow uniaxial DEA deformations. However, biaxially compliant electrodes are desired in order to maximize generated forces of DEA. In this paper, we present crumpled metal thin-film electrodes that are biaxially compliant and have full area coverage over the dielectric elastomer. These crumpled metal thin-film electrodes are more stretchable than flat metal thin films; they remain conductive beyond 110% radial strain. Also, crumpling reduced the stiffening effect of metal thin films on the soft elastomer. As such, DEAs using crumpled metal thin-film electrodes managed to attain relatively high actuated area strains of up to 128% at 1.8 kV (102 V μm⁻¹).


ABSTRACT: Based on the nonlocal Love's shell theory, this paper develops an embedded magneto-electro-elastic (MEE) cylindrical nanoshell model. This model incorporates effects of the small scale parameter and thermo-electro-magnetic loadings. The surrounding elastic medium is described as the Winkler model characterized by the spring. By using this model and the Hamilton principle, the governing equations and boundary conditions are derived for free vibration of the embedded MEE cylindrical nanoshells. The Navier's method is first utilized to obtain the analytical solution for the simply supported MEE nanoshell. Then, numerical solutions for MEE nanoshells under various boundary conditions are obtained by using the differential quadrature (DQ) method. A detailed parametric study is conducted to highlight the influences of the nonlocal parameter, temperature rise, external electric potential, external magnetic potential, spring constant, radius-to-thickness ratio and length-to-radius ratio on natural frequencies of MEE nanoshells.


ABSTRACT: In the past few decades, several concepts for morphing wings have been proposed with the aim of improving the structural and aerodynamic performance of conventional aircraft wings. One of the most interesting challenges in the design of a morphing wing is represented by the skin, which needs to meet specific deformation requirements. In particular when morphing involves changes of cord or curvature, the skin is required to undergo large recoverable deformation in the actuation direction, while maintaining the desired shape and strength in the others. One promising material concept that can meet these specifications is represented by lattice materials. This paper examines the use of alternative planar lattices in the embodiment of a skin panel for cord and camber morphing of an aircraft wing. We use a structural homogenization scheme capable of capturing large geometric nonlinearity, to examine the structural performance of lattice skin concepts, as well as to tune their mechanical properties in desired directions.


ABSTRACT: The present paper deals with the nonlinear thermal instability of geometrically imperfect sandwich cylindrical shells under uniform heating. The sandwich shells are made of a shape memory alloy (SMA)-fiber-reinforced composite and functionally graded (FG) face sheets (FG/SMA/FG). The Brinson phenomenological model is used to express the constitutive characteristics of SMA fibers. The governing equations are established within the framework of the third-order shear deformation shell theory by taking into account the von Karman geometrical nonlinearity and initial imperfection. The material properties of constituents are assumed to be temperature dependent. The Galerkin technique is utilized to derive expressions of the bifurcation points and bifurcation paths of the sandwich cylindrical shells. Using the developed closed-form solutions, extensive numerical results are presented to provide an insight into the influence of the SMA fiber volume fraction, SMA pre-strain, core thickness, non-homogeneity index, geometrical imperfection, geometry parameters of sandwich shells and temperature dependency of materials on the stability of shells. The results reveal that proper application of SMA fibers postpones the thermal bifurcation point and dramatically
ABSTRACT: Recently bistable composite laminates have been investigated for broadband energy harvesting, by taking advantage of their nonlinear oscillations around the first vibration mode. However, it has been reported that the excitation acceleration needed for the desired large amplitude limit cycle oscillation is too high, if the first vibration mode is elevated to relative higher frequencies (60 Hz e.g.). This study investigates the feasibility of exploiting the nonlinear oscillations around the second vibration mode of a rectangular piezoelectric bistable laminate (RPBL), for broadband vibration energy harvesting at relative higher frequencies, but with relative low excitation acceleration. The proposed RPBL has three oscillation patterns around the second vibration mode, including single-well oscillation, chaotic intermittency oscillation and limit cycle oscillation. The broadband characteristics and the considerable energy conversion efficiency of the RPBL are demonstrated in experiments. The static nonlinearity and the dynamic responses of the RPBL are investigated by finite element method. Finite element analysis (FEA) reveals that the enhanced dynamic responses of the RPBL are due to its softening bending stiffness and the local snap through phenomenon. The FEA results coincide reasonably well with experimental results.

ABSTRACT: In order to detect micro-structural damages accurately new methods are currently developed. A promising tool is the generation of higher harmonic wave modes caused by the nonlinear Lamb wave propagation in plate like structures. Due to the very small amplitudes a cumulative effect is used. To get a better overview of this inspection method numerical simulations are essential. Previous studies have developed the analytical description of this phenomenon which is based on the five-constant nonlinear elastic theory. The analytical solution has been approved by numerical simulations. In this work first the nonlinear cumulative wave propagation is simulated and analyzed considering micro-structural cracks in thin linear elastic isotropic plates. It is shown that there is a cumulative effect considering the S–S mode pair. Furthermore the sensitivity of the relative acoustical nonlinearity parameter regarding those damages is validated. Furthermore, an influence of the crack size and orientation on the nonlinear wave propagation behavior is observed. In a second step the micro-structural cracks are replaced by a nonlinear material model. Instead of the five-constant nonlinear elastic theory hyperelastic material models that are implemented in commonly used FEM software are used to simulate the cumulative effect of the higher harmonic Lamb wave generation. The cumulative effect as well as the different nonlinear behavior of the S–S and S–S mode pairs are found by using these hyperelastic material models. It is shown that, both numerical simulations, which take into account micro-structural cracks on the one hand and nonlinear material on the other hand, lead to comparable results. Furthermore, in comparison to the five-constant nonlinear elastic theory the use of the well established hyperelastic material models like Neo–Hooke and Mooney–Rivlin are a suitable alternative to simulate the cumulative higher harmonic generation.

ABSTRACT: This paper presents an experimental study on the low-velocity impact localization of complex composite structures. An impact localization algorithm, which localizes an impact source by comparing the normalized cross-correlation between the reference database and the obtained impact signals, was proposed. The proposed method was applied to a stiffened composite panel that consists of a main spar and stringers. Impact tests were conducted on the composite panel in which four multiplexed fiber Bragg grating (FBG) sensors were attached on the bottom surface. The verification results indicated that 20 verification points were successfully localized with the maximum error of 43.98 mm and average error of 14.23 mm using four FBG sensors. The effect of the number of sensors on the localization performance was also investigated. The comparison results revealed that the proposed method could localize an impact source using a reduced number.
of sensors. A single FBG sensor covered an area of $600 \times 900 \, \text{mm}^2$ of the stiffened composite panel with a maximum error of 64.76 mm and an average error of 17.86 mm using the proposed method.

Long-Xiang Chen, Shi-Hong Li, Kun Liu, Guo-Ping Cai and Hong-Guang Li, “Time delay control of hysteretic composite plate”, Smart Materials and Structures, Vol. 24, No. 4, 045046, April 2015

ABSTRACT: Due to boosting usage of flexible and damping materials, it is of great significance for both science and engineering to explore active control methods for vibration within time-delayed hysteretic structures. This paper conducts theoretical and experimental research on a time-delayed controller for a flexible plate with a single-layer rubber glued on its back. First of all, the dynamic equation for a composite plate is given on the base of the Kirchhoff–Love assumption, where damping-restoring force is described by the Bouc–Wen hysteresis model. Then, the influence of time delay is taken into account and the state equation of the plate with time delay is obtained. Next, a standard state equation, with implicit time delay, is derived using one specific form of integral transformation and vector augmentation. Finally, an instantaneous optimal control method is used to design an active controller. This controller does not only involve state feedback of the current step, but also a linear addition of former state feedbacks within several steps. In order to verify this method, experimental work is conducted. Problems encountered like differential computation and lifting of displacement signal are also handled. According to a comparison between simulations and experiments, the control method given in this paper is feasible and valid, and it is available for both small and large time delay.


ABSTRACT: Based on the higher order shear deformation theory and the geometric nonlinear theory, the nonlinear motion equations, to which the effects of the positive and negative piezoelectric and the thermal are introduced by piezoelectric fiber metal laminated (FML) plates in an unsteady temperature, are established by Hamilton's variational principle. Then, the control algorithm of negative-velocity feedback is applied to realize the vibration control of the piezoelectric FML plates. During the solving process, firstly, the formal functions of the displacements that fulfilled the boundary conditions are proposed. Then, heat conduction equations and nonlinear differential equations are dealt with using the differential quadrature (DQ) and Galerkin methods, respectively. On the basis of the previous processing, the time domain is dispersed by the Newmark-$\beta$ method. Finally, the whole problem can be investigated by the iterative method. In the numerical examples, the influence of the applied voltage, the temperature loading and geometric parameters on the nonlinear dynamic response of the piezoelectric FML plates is analyzed. Meanwhile, the effect of feedback control gain and the position of the piezoelectric layer, the initial deflection and the external temperature on the active control effect of the piezoelectric layers has been studied. The model development and the research results can serve as a basis for nonlinear vibration analysis of the FML structures.


ABSTRACT: A paradigm shift has emerged over the last decade pointing to an exciting research area dealing with the harnessing of elastic structural instabilities for 'smart' purposes in a variety of venues. Among the different types of unstable responses, buckling is a phenomenon that has been known for centuries, and yet it is generally avoided through special design modifications. Increasing interest in the design of smart devices and mechanical systems has identified buckling and postbuckling response as a favorable behavior. The objective of this topical review is to showcase the recent advances in buckling-induced smart applications and to explain why buckling responses have certain advantages and are especially suitable for these particular applications. Interesting prototypes in terms of structural forms and material uses associated with these applications are summarized. Finally, this review identifies potential research avenues and emerging trends for using buckling and other elastic instabilities for future innovations.

References listed at the end of the paper:
[27] Friedman N and Ibrahimbegovic A 2013 Overview of highly flexible, deployable lattice structures used in architecture and civil engineering undergoing large displacements YBL Journal of Built Environment 1 85–103
[33] Shan W and Chen Z 2013 Mechanical instability of thin elastic rods Journal of Postdoctoral Research February 1 8
[38] Daynes S, Potter K D and Weaver P M 2008 Bistable prestressed buckled laminates Compos. Sci. Technol. 68 3431–7
[40] Mao G, Li T, Zou Z, Qu S and Shi M 2014 Prestretch effect on snap-through instability of short-length tubular elastomeric
balloons under inflation Int. J. Solids Struct. 51 2109–15
[43] Santangelo C D 2009 Buckling thin disks and ribbons with non-Euclidean metrics EPL (Europhysics Letters) 86 34003
[45] Dias M A and Santangelo C D 2012 The shape and mechanics of curved-fold origami structures EPL (Europhysics Letters) 100 54005
[55] Li T, Qu S and Yang W 2012 Energy harvesting of dielectric elastomer generators concerning inhomogeneous fields and viscoelastic deformation J. Appl. Phys. 112 034119
[57] Li X, Chuang K and Tzou H 2010 Energy harvesting using a circular cylindrical shell laminated with a segmented piezoelectric layer Piezoelectricity, Acoustic Waves and Device Applications (SPAWDA), 2010 Symp. On pp 139–44
[58] Porter P A and Berfield T A 2014 A bi-stable buckled energy harvesting device actuated via torque arms Smart Mater. Struct. 23 075003
[63] Bisagni C and Cordisco P 2003 An experimental investigation into the buckling and post-buckling of CFRP shells under combined axial and torsion loading Compos. Struct. 60 391–402
[65] Bisagni C and Cordisco P 2006 Post-buckling and collapse experiments of stiffened composite cylindrical shells subjected to axial loading and torque Compos. Struct. 73 138–49
[77] Chen X, Ma LS, Zheng YM, Li XX and Lee DW 2012 The influences of transverse loads on electrothermal post-buckling microbeams J. Micromech. Microeng. 22 015011


[83] Luo Z., Luo Q., Tong L., Gao W. and Song C 2011 Shape morphing of laminated composite structures with photostriective actuators via topology optimization Compos. Struct. 93 406–18


[115] Higuchi K, Natori M C and Abe M 2002 Unexpected behavior of a flexible solar array at retraction under microgravity Acta Astronaut. 50 681–9
[118] Li H, Dai F, Weaver P M and Du S 2014 Bistable hybrid symmetric laminates Compos. Struct. 116 782–92
[120] Lamacchia E, Pirrera A, Chenchia I V and Weaver P M 2014 Non-axisymmetric bending of thin annular plates due to circumferentially distributed moments Int. J. Solids Struct. 51 622–32
[126] Montheiu P-O, Coulombier M, Pardo T, Raskin J-P and Jonas A M 2012 Overcurvature describes the buckling and folding of rings from curved origami to foldable tents Nat. Commun. 3 1290
[134] Yazdani M and Rahimi G H 2010 The effects of helical ribs’ number and grid types on the buckling of thin-walled GFRP-stiffened shells under axial loading J. Reinfr. Plast. Compos. 29 2568–75
[140] Pandey A, Moulton D E, Vella D and Holmes D P 2014 Dynamics of snapping beams and jumping poppers EPL (Europhysics Letters) 105 24001
[144] Dimitris V and Dimitris A S 2002 Nonlinear coupled mechanics and initial buckling of composite plates with piezoelectric
for phononic switching Nano Lett. 9 2113

dependent effective elastic modulus of silicon


[147] Li B, Chen H, Qiang J and Zhou J 2012 A model for conditional polarization of the actuation enhancement of a dielectric elastomer Soft Matter 8 311–7


[159] Li T and Zhang Z 2010 Snap-through instability of graphene on substrates Nanoscale Res. Lett. 5 169–73


[163] Lagoudas D C and Tadjbakhs I G 1992 Active flexible rods with embedded SMA fibers Smart Mater. Struct. 1 162


[172] Mukherjee A and Chaudhuri A S 2002 Active control of dynamic instability of piezolaminated imperfect columns Smart Mater. Struct. 11 874

[173] Srinivasan S and Sunjung K 2008 Piezoelectric control of columns prone to instabilities and nonlinear modal interaction Smart Mater. Struct. 17 035001

[174] Wang Q S 2010 Active buckling control of beams using piezoelectric actuators and strain gauge sensors Smart Mater. Struct. 19 065022


[179] Prasad J and Diaz A R 2008 A concept for a material that softens with frequency Journal of Mechanical Design 130 091703
[188] Lee H J and Lee J J 2000 A numerical analysis of the buckling and postbuckling behavior of laminated composite shells with embedded shape memory alloy wire actuators Smart Mater. Struct. 9 780
[207] Zhao X and Wang Q 2014 Harnessing large deformation and instabilities of soft dielectrics: theory, experiment, and application Applied Physics Reviews 1 021304

ABSTRACT: A model is developed for a non-uniform piezoelectric beam suitable for analyzing energy harvesting behavior. System dynamics are projected onto a numerically developed basis to produce energy functions which are used to derive equations of motion for the system. The resulting model reproduces the experimentally observed transition to chaos while providing a conservative estimate of power output and bandwidth.


ABSTRACT: In this paper, the feasibility of reversible bellows made of shape memory alloys (SMAs) in sensory and actuated applications to transfer pressure and/or temperature into a linear motion is investigated. An analytical three-dimensional model is developed to simulate key features of SMAs including martensitic transformation, reorientation of martensite variants, the shape memory effect, and pseudo-elasticity. Axisymmetric two-dimensional theory of thermo-inelasticity based on the non-linear Green–Lagrange strain tensor is employed to derive the equilibrium equations. A finite element method along with an iterative incremental elastic-predictor–inelastic-corrector procedure is developed to solve the governing equations with both material and geometrical non-linearities. The feasibility of reversible SMA bellows in transferring pressure and/or temperature into a linear motion is numerically demonstrated. In this respect, the effects of geometric parameters, magnitude of thermo-mechanical loadings and end conditions on the performances of SMA bellows are evaluated and discussed in depth. This study provides pertinent results toward an efficient and reliable design of reversible thermally-driven SMA bellows.


ABSTRACT: The Miura-ori is a classic flat-foldable tessellation which has its root in origami, but has been applied to the folding of reconfigurable structures for a variety of engineering and architectural applications. In recent years, researchers have introduced design variations on the Miura-ori which change both the form and the function of the pattern. This paper introduces the family of isomorphically generalized symmetric variations of the Miura-ori. We study the Miura crease pattern as a wallpaper pattern. We reduce the symmetry of the original crease pattern to design new patterns while at the same time preserving the symmetry group of the tessellation as well as the flat-foldability condition at each node. It will be shown that—through appropriate design variations on the original pattern—we are able to use the Miura-ori to design either globally planar, or globally curved, flat-foldable patterns.


ABSTRACT: The Miura fold pattern, or the Miura-ori, is a flat-foldable origami pattern with various applications in engineering and architecture. In addition to free-form variations, scholars have proposed a number of symmetric derivatives for this classic fold pattern over recent years. In a previous work, the authors of this paper studied isomorphic variations on the Miura-ori which led to the development of an ‘isomorphic family’ for this fold pattern. In this paper, we study non-isomorphic variations on the Miura-ori in order to develop a ‘non-isomorphic family’ for this pattern. Again we start with the Miura-ori, but reduce the symmetry by migrating from the original symmetry group to its subgroups, which may also include the enlargement of its unit cell. We systematically design and classify the non-isomorphic symmetric descendants of the Miura-ori which are either globally planar, or globally curved, flat-foldable tessellations.

Xiaopeng Zhang and Zhan Kang, “Topology optimization of magnetorheological fluid layers in sandwich plates for semi-active vibration control”, Smart Materials and Structures, Vol. 24, No. 8, 085024, August 2015

ABSTRACT: This paper investigates topology optimization of the magnetorheological (MR) fluid layer in a sandwich plate for improving the semi-active vibration control performance. Therein, a uniform magnetic field is applied across the MR fluid layer to provide a semi-active damping control effect. In the optimization model, the pseudo-densities describing the MR fluid material distribution are taken as design variables, and an artificial
magneto-rheological fluid model (AMRF) with penalization is proposed to suppress intermediate density values. For reducing the vibration level under harmonic excitations, the dynamic compliance under a specific excitation frequency, or the frequency-aggregated dynamic compliance in a given frequency band, is taken as the objective function to be minimized. In this context, the adjoint-variable sensitivity analysis scheme is derived. The effectiveness and efficiency of the proposed method are demonstrated by numerical examples, in which the structural dynamic performance can be remarkably improved through optimization. The influences of several key factors on the optimal designs are also explored. It is shown that the AMRF model is effective in yielding clear boundaries in the final optimal solutions without use of additional regularization techniques.

ABSTRACT: We evaluate the performance of fiber Bragg grating (FBG) sensors for the measurement of dynamic strains in complex composite structures. The particular structure used in this study is an integrally stiffened composite panel for which the stiffeners and skin are fabricated in a single layup and cure process. Surface-mounted FBG sensors are bonded to the panels after curing, whereas embedded FBG sensors are successfully incorporated during the fabrication process. A finite element model was also constructed of the stiffened panel. The panels were subjected to repeated impacts and the post-impact vibration response of the panel was measured through the FBG sensor responses. Little change to the global response of the panel was observed after the repeated impacts, through the dynamic response of the surface-mounted FBGs. Pulsed phase thermography and micro-computer-tomography imaging of the panel confirmed that the damage was localized near the impact locations, producing negligible changes to the global response of the panel. All of the embedded FBG sensors survived the fabrication and multiple impacts; however, as these were embedded close to the neutral axis of the panel, they were not very sensitive to the vibration modes. Excitation of the panel near the first natural frequency did produce a measurable response in the FBG sensors, confirming their functionality.

ABSTRACT: Energy harvesting from kinetic ambient energy is particularly effective to power autonomous sensors. This work proposes an innovative energy converter based on two counteracting Belleville springs and exploiting their peculiarity, for a height to thickness ratio equal to 1.414, of nearly zero stiffness over a wide deflection range. After analytical and numerical modelling a prototype is developed and experimentally investigated. The sub-optimal geometry of the commercial springs used in the prototype, together with a non-ideal response, makes the operating frequency for the prototype higher than in analytical and numerical predictions. Nevertheless, the harvester exhibits a significantly large bandwidth, together with a high output power, compared to similar solutions in the literature, for all the examined configurations and input excitations.

ABSTRACT: In this study, an impact energy identification method based on basis vectors is proposed to estimate the impact location and impact energy using piezoceramic sensors. A large number of parameterized impact experiments have been conducted on a composite plate to illustrate the linear relationship between signal energy and impact energy, which is also revealed by a theoretical analysis. The signal features of stress waves caused by different impactors are analyzed in the frequency domain to obtain a feature vector. A location basis vector including signal power and arrival time has been presented to determine the impact position without the need for the velocity of the stress wave. Furthermore, the energy basis vector has been defined to estimate the impact energy based on the relationship between the impact energy and signal energy. The results of this study show that the proposed method is able to effectively estimate the location and impact energy of the impact source on the composite plate.

Jie Hong, Wenzhong Yan, Yanhong Ma, Dayi Zhang and Xin Yang, “Experimental investigation on the vibration tuning of a shell with a shape memory alloy ring”, Smart Materials and Structures, Vol. 24, No. 10, 105007, October 2015
ABSTRACT: This paper presents a new design of a smart ring with motion actuators made of a shape memory alloy (SMA). The mechanical properties of the SMA actuator were investigated at room (25 °C) and high (90 °C) temperatures to better understand its characteristics. The results show that the smart ring with an SMA not only shows good stability and rapid effectiveness in the vibration control of the test shell, but observably eliminates the nonlinear vibration characteristics due to contact and rubbing between the ring and shell during the heating process. The smart ring also shows excellent performance in the isolation of transient vibration resulting from impact or random loads. With regard to impact loads, the response peak value can reduce by 57.4% in most cases, while the value is 38.7% for random excitations. The study shows the feasibility of using the SMA material for potential applications of vibration tuning the casings of aero-engines.


ABSTRACT: The symmetry breaking of inversion in solid crystals will induce electric polarization in all solid crystals, which is well known as flexoelectricity. At the nanometer scale, due to the large ratio of surface to volume, piezoelectric structures always exhibit distinct mechanical and electrical behaviors compared with their bulk counterparts. In the current work, the effects of surface and flexoelectricity on the buckling and vibration of piezoelectric nanowires is investigated based on a continuum framework and the Euler–Bernoulli beam hypothesis. Analytical solutions of the electric field in the piezoelectric nanobeam subjected to electrical and mechanical loads are obtained with the surface, flexoelectric and nonlocal electric effects. Numeric simulations demonstrate that the Young's modulus and bending rigidity of PZT and BaTiO3 (BT) nanowires are enhanced by flexoelectricity. The study demonstrates that the critical buckling voltage is calculated with consideration of the effects of surface and flexoelectricity, and it is found that the effects of surface piezoelectricity, flexoelectricity and residual surface stress play significant roles in determining the critical buckling voltage. Results obtained for the first resonance frequency also indicate that the effects of surface and flexoelectricity are more significant at a narrow range of beam thickness. The first resonance frequency of PZT and BT nanowires is also influenced by the residual surface stress and external applied voltage. The current work is expected to provide a fundamental study on the buckling and vibration behaviors of piezoelectric nanobeams, and it might also be helpful in devising piezoelectric nanowire-based nanoelectronics.

David McCoul and Qibing Pei, “Tubular dielectric elastomer actuator for active fluidic control”, Smart Materials and Structures, Vol. 24, No. 10, 105016, October 2015

ABSTRACT: We report a novel low-profile, biomimetic dielectric elastomer tubular actuator capable of actively controlling hydraulic flow. The tubular actuator has been established as a reliable tunable valve, pinching a secondary silicone tube completely shut in the absence of a fluidic pressure bias or voltage, offering a high degree of resistance against fluidic flow, and able to open and completely remove this resistance to flow with an applied low power actuation voltage. The system demonstrates a rise in pressure of ~3.0 kPa when the dielectric elastomer valve is in the passive, unactuated state, and there is a quadratic fall in this pressure with increasing actuation voltage, until ~0 kPa is reached at 2.4 kV. The device is reliable for at least 2000 actuation cycles for voltages at or below 2.2 kV. Furthermore, modeling of the actuator and fluidic system yields results consistent with the observed experimental dependence of intrasystem pressure on input flow rate, actuator prestretch, and actuation voltage. To our knowledge, this is the first actuator of its type that can control fluid flow by directly actuating the walls of a tube. Potential applications may include an implantable artificial sphincter, part of a peristaltic pump, or a computerized valve for fluidic or pneumatic control.


ABSTRACT: A piezoelectric vibration energy harvester is presented that can generate electricity from the weight of passing cars or crowds. The energy harvester consists of a piezoelectric beam, which buckles when the device is stepped on. The energy harvester can have a horizontal or vertical configuration. In the vertical (direct) configuration, the piezoelectric beam is vertical and directly sustains the weight of the vehicles or people. In the horizontal (indirect) configuration, the vertical weight is transferred to a horizontal axial force through a scissor-like mechanism. Buckling of the beam results in significant stresses and, thus, large power production. However, if the beam's buckling is not controlled, the beam will fracture. To prevent this, the axial deformation is constrained to limit the deformations of the beam. In this paper, the energy harvester is
analytically modeled. The considered piezoelectric beam is a general non-uniform beam. The natural frequencies, mode shapes, and the critical buckling force corresponding to each mode shape are calculated. The electro-mechanical coupling and the geometric nonlinearities are included in the model. The design criteria for the device are discussed. It is demonstrated that a device, realized with commonly used piezoelectric patches, can generate tens of milliwatts of power from passing car traffic. The proposed device could also be implemented in the sidewalks or integrated in shoe soles for energy generation. One of the key features of the device is its frequency up-conversion characteristics. The piezoelectric beam undergoes free vibrations each time the weight is applied to or removed from the energy harvester. The frequency of the free vibrations is orders of magnitude larger than the frequency of the load. The device is, thus, both efficient and insensitive to the frequency of the force excitations.


ABSTRACT: In this paper a nonlinear approach to studying the vibration characteristic of laminated composite plate with surface-bonded piezoelectric layer/patch is formulated, based on the Green Lagrange type of strain–displacements relations, by incorporating higher-order terms arising from nonlinear relations of kinematics into mathematical formulations. The equations of motion are obtained through the energy method, based on Lagrange equations and by using higher-order shear deformation theories with von Karman-type nonlinearities, so that transverse shear strains vanish at the top and bottom surfaces of the plate. An isoparametric finite element model is provided to model the nonlinear dynamics of the smart plate with piezoelectric layer/patch. Different boundary conditions are investigated. Optimal locations of piezoelectric patches are found using a genetic algorithm to maximize spatial controllability/observability and considering the effect of residual modes to reduce spillover effect. Active attenuation of vibration of laminated composite plate is achieved through an optimal control law with inequality constraint, which is related to the maximum and minimum values of allowable voltage in the piezoelectric elements. To keep the voltages of actuator pairs in an allowable limit, the Pontryagin's minimum principle is implemented in a system with multi-inequality constraint of control inputs. The results are compared with similar ones, proving the accuracy of the model especially for the structures undergoing large deformations. The convergence is studied and nonlinear frequencies are obtained for different thickness ratios. The structural coupling between plate and piezoelectric actuators is analyzed. Some examples with new features are presented, indicating that the piezo-patches significantly improve the damping characteristics of the plate for suppressing the geometrically nonlinear transient vibrations.

Farzad Ebrahimi and Erfan Salari, Size-dependent thermo-electrical buckling analysis of functionally graded piezoelectric nanobeams”, Smart Materials and Structures, Vol. 24, No. 12, 125007, December 2015

ABSTRACT: In the present study, thermo-electrical buckling characteristics of functionally graded piezoelectric (FGP) Timoshenko nanobeams subjected to in-plane thermal loads and applied electric voltage are carried out by presenting a Navier type solution for the first time. Three kinds of thermal loading, namely, uniform, linear and nonlinear temperature rises through the thickness direction are considered. Thermo-electro-mechanical properties of FGP nanobeam are supposed to vary smoothly and continuously throughout the thickness based on power-law model. Eringen's nonlocal elasticity theory is exploited to describe the size dependency of nanobeam. Using Hamilton's principle, the nonlocal governing equations together with corresponding boundary conditions based on Timoshenko beam theory are obtained for the thermal buckling analysis of graded piezoelectric nanobeams including size effect and they are solved applying analytical solution. According to the numerical results, it is revealed that the proposed modeling can provide accurate critical buckling temperature results of the FG nanobeams as compared some cases in the literature. In following a parametric study is accompanied to examine the effects of the several parameters such as various temperature distributions, external electric voltage, power-law index, nonlocal parameter and aspect ratio on the critical buckling temperature difference of the size-dependent FGP nanobeams in detail. It is found that the small scale effect and electrical loading have a significant effect on buckling temperatures of FGP nanobeams.

ABSTRACT: Piezoelectric shunt damping is a well-known technique to damp mechanical vibrations of a structure, using a piezoelectric transducer to convert mechanical vibration energy into electrical energy, which is dissipated in an electrical resistance. Resonant shunts consisting of a resistance and an inductance connected to a piezoelectric transducer are used to damp structural vibrations in narrow frequency bands, but their performance is very sensitive to variations in structural modal frequencies and transducer capacitance. In order to overcome this drawback, a piezoelectric shunt damping technique with improved performance and robustness is presented in this paper. The design of the adaptive circuit considers the variation of the host structure's natural frequency as a project parameter. This paper describes an adaptive resonant piezoelectric vibration absorber enhanced by a synthetic negative capacitance applied to a shell structure. The resonant shunt circuit autonomously adapts its inductance value by comparing the phase difference of the vibration velocity and the current flowing through the shunt circuit. Moreover, a synthetic negative capacitance is added to the shunt circuit to enhance the vibration attenuation provided by the piezoelectric absorber. The circuitry is implemented using analog components. Validation of the proposed method is done by bonding the piezoelectric absorber on a free-formed metallic shell.


ABSTRACT: We present a hybrid pneumatic/flexible sandwich structure with thermoplastic (TP) nanocomposite skins to enable the morphing of a nacelle inlet lip. The design consists of pneumatic inflatables as actuators and a flexible sandwich panel that morphs under variable pressure combinations to adapt different flight conditions and save fuel. The sandwich panel forms the outer layer of the nacelle inlet lip. It is lightweight, compliant and impact resistant with no discontinuities, and consists of graphene-doped thermoplastic polyurethane (G/TPU) skins that are supported by an aluminium Flex-core honeycomb in the middle, with near zero in-plane Poisson's ratio behaviour. A test rig for a reduced-scale demonstrator was designed and built to test the prototype of morphing nacelle with custom-made pneumatic actuators. The output force and the deflections of the experimental demonstrator are verified with the internal pressures of the actuators varying from 0 to 0.41 MPa. The results show the feasibility and promise of the hybrid inflatable/nanocomposite sandwich panel for morphing nacelle airframes.

Jianguo Cai, Xiaowei Deng, Jian Feng and Ya Zhou, “Geometric design and mechanical behavior of a deployable cylinder with Miura origami”, Smart Materials and Structures, Vol. 24, No. 12, 125031, December 2015

ABSTRACT: The folding and deployment of a cylinder with Miura origami patterns are studied in this paper. First, the geometric formulation of the design problem is discussed. Then the loading case of the axial strains and corresponding external nodal loads applied on the vertices of the top polygon during the motion is investigated analytically. The influence of the angle between the diagonal and horizontal fold lines $\alpha$ and $\beta$ and the number of Miura origami elements $n$ on the dynamic behavior of the basic segment is also discussed. Then the dynamic behavior is analyzed using numerical simulations. Finally, the deployment process of a cylinder with multi-stories is discussed. The numerical results agree well with the analytical predictions. The results show that the range of motion, i.e. the maximal displacement of top nodes, will also increase with the increase of angles $\alpha$ and $\beta$. This cylinder, with a smaller $n$, may have a bistable behavior. When $n$ is larger, the influence of $n$ on the axial strains and external nodal loads is slight. The numerical results agree well with the analytical predictions. Moreover, the deployment of the cylinder with multi-stories is non-uniform, which deploys from the upper story to the lower story.


ABSTRACT: A general anisotropic laminated plate model with thermal deformation and two-way coupled piezoelectric effect and pyroelectric effect is constructed using the variational asymptotic method. Total potential energy contains strain energy, electric potential energy and energy caused by temperature change and external loads. The feature of small thickness and large in-plane dimension of plate structures helps to asymptotically simplify the three-dimensional analysis to a two-dimensional analysis on the reference surface and a one-dimensional analysis through the thickness. Several numerical examples are studied. The present
model is validated by the excellent agreement between the results from 3D finite element analyses and the present model.

References listed at the end of the paper:
3 Irschik H 2002 A review on static and dynamic shape control of structures by piezoelectric actuation Eng. Struct. 24 5–11
5 Lee J S and Jiang L Z 1996 Exact electroelastic analysis of piezoelectric laminae via state space approach Int. J. Solids Struct. 33 977–90
6 Zhong Z and Shang E T 2003 Three-dimensional exact analysis of a simply supported functionally gradient piezoelectric plate Int. J. Solids Struct. 40 5335–52
12 Wang Q, Quek S T, Sun C T and Liu X 2001 Analysis of piezoelectric coupled circular plate Smart Mater. Struct. 10 229
13 Qu Z Q 2001 An efficient modelling method for laminated composite plates with piezoelectric sensors and actuators Smart Mater. Struct. 10 807
14 Figueiredo I M N and Leal C M F 2005 A piezoelectric anisotropic plate model Asymptotic Anal. 44 327–46
18 Krommer M and Irschik H 2000 A Reissner–Mindlin-type plate theory including the direct piezoelectric and the pyroelectric effect Acta Mech. 141 51–69
20 Kapuria S and Achary G G S 2005 A coupled consistent third-order theory for hybrid piezoelectric plates Compos. Struct. 70 120–33
23 Atilgan A R and Hodges D H 1992 On the strain energy of laminated composite plates Int. J. Solids Struct. 29 2527–43
24 Sutyrin V G and Hodges D H 1996 On asymptotically correct linear laminated plate theory Int. J. Solids Struct. 33 3649–71
26 Yu W 2002 Variational asymptotic modeling of composite dimensionally reducible structures PhD Thesis Georgia Institute of Technology
29 Yu W and Hodges D H 2004 A simple thermopiezoelectric model for smart composite plates with accurate stress recovery Smart Mater. Struct. 13 926
30 Liao L and Yu W 2008 Asymptotic construction of a fully coupled, Reissner–Mindlin model for piezoelectric composite plates, Smart Mater. Struct. 17 015010
31 Liao L and Yu W 2009 An electromechanical Reissner–Mindlin model for laminated piezoelectric plates Compos. Struct. 88 394–402
33 Danielson D A 1991 Finite rotation with small strain in beams and plates Proc. 2nd Pan American Congress of Applied Mechanics pp 2–4
34 Danielson D A and Hodges D H 1987 Nonlinear beam kinematics by decomposition of the rotation tensor J. Appl. Mech. 54 258–62

ABSTRACT: An experimental investigation has been carried out on the nonlinear dynamics of a clamped-clamped Magneto-Rheological Elastomer (MRE) sandwich beam with a point mass when subjected to a point excitation. Three sets of experiments have been conducted namely for (i) an aluminium beam, (ii) a MRE sandwich beam in the absence of a magnetic field and (iii) a MRE sandwich beam in the presence of a magnetic field. An electrodynamic shaker was used to excite each system and the corresponding displacement of the point mass was measured: for the third experiment (iii), an array of magnets has been placed at various distances away from the centre of the point mass to investigate the effect of changing stiffness and damping properties on the nonlinear dynamical behaviour. An interesting feature for the third group is the beam point mass displacement was no longer symmetric as the stiffness and damping of the system are increased when moving towards the magnets. Both the first and second groups exhibited distinct nonlinear behaviour; however, for the third group this work shows that for a low magnetic field the sandwich beam exhibits two distinct resonance peaks, one occurring above and the other below the fundamental natural frequency of the transverse motion, with the right one larger. For a larger magnetic field, these peaks even out until the magnetic force was large enough that the hardening-type nonlinear behaviour changes to a softening-type; a significant qualitative change in the nonlinear dynamical behaviour of the system, due to the presence of the magnetic field, was observed.


ABSTRACT: As a compact and durable design concept, piezoelectric energy harvesting skin (PEH skin) has been recently proposed for self-powered electronic device applications. This study aims to develop an electromechanically-coupled analytical model of PEH skin considering the inertia and stiffness effects of a piezoelectric patch. Based on Kirchhoff plate theory, Hamilton's principle is used to derive the electromechanically-coupled differential equation of motion. Due to the geometric discontinuity of the piezoelectric patch, the Rayleigh–Ritz method is applied to calculate the natural frequency and corresponding mode shapes. The electrical circuit equation is derived from Gauss's law. Output voltage is estimated by solving the equation of motion and electrical circuit equation, simultaneously. For the purpose of evaluating the predictive capability, the results of the electromechanically-coupled analytical model are compared with those of the finite element method in a hierarchical manner. The outstanding merits of the electromechanically-coupled analytical model of PEH skin are three-fold: (1) consideration of the inertia and stiffness effects of the piezoelectric patches; (2) physical parameterization between the two-dimensional mechanical configuration and piezoelectric transduction; (3) manipulability of the twisting modes of a cantilever plate with a small aspect ratio.


ABSTRACT: In the present study, the dynamic performance of the sandwich plate with magnetorheological elastomer (MRE) as the core layer and tapered laminated composite plates as the face layers is investigated. Various MRE tapered laminated composite sandwich plate models are formulated by dropping-off the plies longitudinally in top and bottom composite layers to yield tapered plates as the face layers and uniform MRE layer as the core layer. The governing equations of motion of tapered composite MRE sandwich plates are derived using classical laminated plate theory and solved numerically. Further, silicon based MRE is being fabricated and tested to obtain the shear and loss moduli using MR rheometer. The efficacy of the finite element formulation is validated by carrying out experiments on the various prototypes of tapered composite silicon based MRE sandwich plates and comparing the results in terms of natural frequencies obtained at various magnetic fields with those obtained numerically and with available literature. Also, the effects of magnetic field, taper angle of the top and bottom layers, aspect ratio, ply orientations and various end conditions on the various dynamic properties of tapered laminated composite MRE sandwich plate are investigated. Further, the transverse vibration responses of three different tapered composite MRE based sandwich plates under harmonic force excitation are analyzed at various magnetic fields.
ABSTRACT: The size-dependent bending and vibration behaviors of a clamped piezoelectric circular nanoplate are investigated by using a modified Kirchhoff plate model. The flexoelectricity, the surface effect and the non-local elastic effect are taken into account in the modified model by decomposing the electric Gibbs free energy into the bulk and surface parts and including the strain gradient and the electric field gradient terms into the bulk energy density function. Different from the results predicted by the classical plate model, the proposed model predicts size-dependent behaviors of the piezoelectric thin plate with nanoscale thickness. Comparisons among the models considering the flexoelectricity, the surface effect and the non-local elastic effect individually, the current model and the classical model are also given in this study. Simulation results indicate that the electromechanical coupling properties, the transverse displacements and the resonant frequencies of the plate are significantly influenced by each individual effect as well as their combined effects. It is also indicated that such effects are affected by the external applied electric potential and the plate geometries. Neglecting any individual effect may induce inaccurate characterization of the electromechanical coupling of the piezoelectric nanoplate. Therefore, the current plate model is expected to provide more accurate predictions of the electromechanical coupling and the mechanical behaviors of piezoelectric circular nanoplate-based devices in the nanoelectromechanical systems.

ABSTRACT: In this study, free vibration analysis of magneto-electro-thermo-elastic (METE) nanobeams resting on a Pasternak foundation is investigated based on nonlocal theory and Timoshenko beam theory. Coupling effects between electric, magnetic, mechanical and thermal loading are considered to derive the equations of motion and distribution of electrical potential and magnetic potential along the thickness direction of the METE nanobeam. The governing equations and boundary conditions are obtained using the Hamilton principle and discretized via the differential quadrature method (DQM). Numerical results reveal the effects of the nonlocal parameter, magneto-electro-thermo-mechanical loading, Winkler spring coefficients, Pasternak shear coefficients and height-to-length ratio on the vibration characteristics of METE nanobeams. It is observed that the natural frequency is dependent on the magnetic, electric, temperature, elastic medium, small-scale coefficient, and height-to-length ratio. These results are useful in the mechanical analysis and design of smart nanostructures constructed from magneto-electro-thermo-elastic materials.

ABSTRACT: The aim of this work was the development of sandwich structures formed by embedding magnetorheological elastomers (MRE) between constrained layers of carbon fibre–reinforced plastic (CFRP) laminates. The MREs were obtained by mechanical stirring of a reactive mixture of substrates with carbonyl-iron particles, followed by orienting the particles into chains under an external magnetic field. Samples with particle volume fractions of 11.5% and 33% were examined. The CFRP/MRE sandwich structures were obtained by compressing MREs samples between two CFRP laminates composed. The used A.S.SET resin was in powder form and the curing process was carried out during pressing with MRE. The microstructure of the manufactured sandwich beams was inspected using SEM. Moreover, the rheological and damping properties of the examined materials with and without a magnetic field were experimentally investigated. In addition, the free vibration responses of the adaptive three-layered MR beams were studied at different fixed magnetic field levels. The free vibration tests revealed that an applied non-homogeneous magnetic field causes a shift in natural frequency values and a reduction in the vibration amplitudes of the CFRP/MRE adaptive beams. The reduction in vibration amplitude was attributed mainly to the stiffening effect of the MRE core and only a minor contribution was made by the enhanced damping capacity, which was evidenced by the variation in damping ratio values.

ABSTRACT: The active flutter control of supersonic sandwich panels with regular honeycomb interlayers under impact load excitation is studied using piezoelectric patches. A non-dominated sorting-based multi-objective evolutionary algorithm, called non-dominated sorting genetic algorithm II (NSGA-II) is suggested to find the optimal locations for different numbers of piezoelectric actuator/sensor pairs. Quasi-steady first order supersonic piston theory is employed to define aerodynamic loading and the p-method is applied to find the flutter bounds. Hamilton's principle in conjunction with the generalized Fourier expansions and Galerkin method are used to develop the dynamical model of the structural systems in the state-space domain. The classical Runge–Kutta time integration algorithm is then used to calculate the open-loop aeroelastic response of the system. The maximum flutter velocity and minimum voltage applied to actuators are calculated according to the optimal locations of piezoelectric patches obtained using the NSGA-II and then the proportional feedback is used to actively suppress the closed loop system response. Finally the control effects, using the two different controllers, are compared.


ABSTRACT: This is an exploratory investigation on the self-sensing capabilities of nano-enriched glass/fibre laminates for damage detection purposes through changes in the dynamic responses, which are estimated by measuring the changes in voltage due to a dynamic strain. The deformation of the nano-enriched structure introduces changes in the resistance/voltage of the nanocomposites. The measured voltage signals contain information of the vibratory response of the laminated beam. This research uses a vibration-based data driven methodology for damage detection applied for the estimated vibratory signals using the conductivity properties of the embedded nano-particles. The structure considered in this study is a glass/fibre laminated beam enriched with carbon black nanoparticles (CB). The structure is subjected to a direct electric current and the voltage signal is measured. The vibration based monitoring method used is generally based on singular spectrum analysis applied on the estimated vibratory response. The voltage response signal is divided into a certain number of principal components which contain the oscillatory components distributed by their content of variance in the voltage signal. The components with more variance are used to define a reference state based on the status of the healthy structure. Consequently, the estimated vibratory signals from beams with a simulated damage are compared to the healthy state which eventually results in the damage detection procedure. The damage was simulated firstly by adding an additional mass on the beam tip and secondly by drilling a hole on the beam tip. The results demonstrate the potential for using the voltage estimated vibratory signals for self-sensing damage detection purposes in carbon nano-enriched glass/fibre structures.

N. Chandrasekharan and L.L. Thompson, “Increased power to weight ratio of piezoelectric energy harvesters through integration of cellular honeycomb structures”, Smart Materials and Structures, Vol. 25, No. 4, 045019, April 2016

ABSTRACT: The limitations posed by batteries have compelled the need to investigate energy harvesting methods to power small electronic devices that require very low operational power. Vibration based energy harvesting methods with piezoelectric transduction in particular has been shown to possess potential towards energy harvesters replacing batteries. Current piezoelectric energy harvesters exhibit considerably lower power to weight ratio or specific power when compared to batteries the harvesters seek to replace. To attain the goal of battery-less self-sustainable device operation the power to weight ratio gap between piezoelectric energy harvesters and batteries need to be bridged. In this paper the potential of integrating lightweight honeycomb structures with existing piezoelectric device configurations (bimorph) towards achieving higher specific power is investigated. It is shown in this study that at low excitation frequency ranges, replacing the solid continuous substrate of conventional bimorph with honeycomb structures of the same material results in a significant increase in power to weight ratio of the piezoelectric harvester. At higher driving frequency ranges it is shown that unlike the traditional piezoelectric bimorph with solid continuous substrate, the honeycomb substrate bimorph can preserve optimum global design parameters through manipulation of honeycomb unit cell parameters. Increased operating lifetime and design flexibility of the honeycomb core piezoelectric bimorph is
demonstrated as unit cell parameters of the honeycomb structures can be manipulated to alter mass and stiffness properties of the substrate, resulting in unit cell parameter significantly influencing power generation.


ABSTRACT: This paper investigates the active structural acoustic control of sound radiated from a smart cylindrical shell. The cylinder is equipped with piezoelectric sensors and actuators to estimate and control the sound pressure that radiates from the smart shell. This estimated pressure is referred to as a virtual microphone, and it can be used in control systems instead of actual microphones to attenuate noise due to structural vibrations. To this end, the dynamic model for the smart cylinder is derived using the extended Hamilton's principle, the Sanders shell theory and the assumed mode method. The simplified Kirchhoff–Helmholtz integral estimates the far-field sound pressure radiating from the baffled cylindrical shell. A modified higher harmonic controller that can cope with a harmonic disturbance is designed and experimentally evaluated. The experimental tests were carried out on a baffled cylindrical aluminum shell in an anechoic chamber. The frequency response for the theoretical virtual microphone and the experimental actual microphone are in good agreement with each other, and the results show the effectiveness of the designed virtual microphone and controller in attenuating the radiated sound.

Teik-Cheng Lim, “Refined shear correction factor for very thick simply supported and uniformly loaded isosceles right triangular auxetic plates”, Smart Materials and Structures, Vol. 25, No. 5, 054001, May 2016

ABSTRACT: For moderately thick plates, the use of First order Shear Deformation Theory (FSDT) with a constant shear correction factor of 5/6 is sufficient to take into account the plate deflection arising from transverse shear deformation. For very thick plates, the use of Third order Shear Deformation Theory (TSDT) is preferred as it allows the shear strain distribution to be varied through the plate thickness. Therefore no correction factor is required in TSDT, unlike FSDT. Due to the complexity involved in TSDT, this paper obtains a more accurate shear correction factor for use in FSDT of very thick simply supported and uniformly loaded isosceles right triangular plates based on the TSDT. By matching the maximum deflections for this plate according to FSDT and TSDT, a variable shear correction factor is obtained. Results show that the shear correction factor for the simplified TSDT, i.e. 14/17, is least accurate. The commonly adopted shear correction factor of 5/6 in FSDT is valid only for very thin or highly auxetic plates. This paper provides a variable shear correction for FSDT deflection that matches the plate deflection by TSDT. This variable shear correction factor allows designers to justify the use of a commonly adopted shear correction factor of 5/6 even for very thick plates as long as the Poisson's ratio of the plate material is sufficiently negative.


ABSTRACT: We study linear wave propagation in nonlinear hexagonal lattices capable of undergoing large deformations, under different levels of pre-load. The lattices are composed of a set of masses connected by linear axial and angular springs, with the nonlinearity arising solely from geometric effects. By applying different levels of pre-load, the small amplitude linear wave propagation response can be varied from isotropic to highly directional. Analytical expressions for the stiffness of a unit cell in the deformed configuration are derived and they are used to analyze the dispersion surfaces and group velocity variation with pre-load. Numerical simulations on finite lattices demonstrate the validity of our unit cell predictions and illustrate the wave steering potential of our lattice.


ABSTRACT: The work describes the vibroacoustic behavior of anti-tetrachiral and auxetic hexagonal gradient sandwich panels using homogenized finite element models to determine the mechanical properties of the auxetic structures, the natural frequencies and radiated sound power level of sandwich panels made by the auxetic cores. The mechanical properties and the vibroacoustic behavior of auxetic hexagonal sandwich panels are investigated as a benchmark. The radiated sound power level of the structure over the frequency range of 0–
1000 Hz is minimized by modifying the core geometry of the gradient auxetic sandwich panels. Several excitation cases are considered. First-order and random optimization methods are used for the minimization of radiated sound power level of the structures. The results of this study present significant insights into the design of auxetic structures with respect to their vibroacoustical properties.


ABSTRACT: Bistable energy harvesting has become a major field of research due to some unique features for converting mechanical energy into electrical power. When properly loaded, bistable structures snap-through from one stable configuration to another, causing large strains and consequently power generation. Moreover, bistable structures can harvest energy across a broad-frequency bandwidth due to their nonlinear characteristics. Despite the fact that snap-through may be triggered regardless of the form or frequency of exciting vibration, the external force must reach a specific snap-through activation threshold value to trigger the transition from one stable state to another. This aspect is a limiting factor for realistic vibration energy harvesting application with bistable devices. This paper presents a novel power harvesting concept for bistable composites based on a 'lever effect' aimed at minimizing the activation force to cause the snap through by choosing properly the bistable structures' constraints. The concept was demonstrated with the help of numerical simulation and experimental testing. The results showed that the actuation force is one order of magnitude smaller (3%–6%) than the activation force of conventionally constrained bistable devices. In addition, it was shown that the output voltage was higher than the conventional configuration, leading to a significant increase in power generation. This novel concept could lead to a new generation of more efficient bistable energy harvesters for realistic vibration environments.


ABSTRACT: This paper is concerned with the derivation of exact solutions for the static responses of simply supported nanobeams integrated with a flexoelectric layer acting as the distributed nano actuator. Considering both the direct and the converse flexoelectric effects, the governing equations and the associated boundary conditions of the overall beams are derived to obtain exact solutions for the displacements and the electric potential in the flexoelectric layer and the substrate beam. Due to the converse flexoelectric effect, the active flexoelectric layer significantly counteracts the deformations of the substrate beams caused by the applied mechanical load, resulting in the coupling of bending and stretching deformations in the substrate beams. For particular values of the length and thickness of the substrate beam and the applied voltage in the flexoelectric layer, the deflection of the substrate beam due to the converse flexoelectric effect increases with increasing thickness of the flexoelectric layer up to a certain value of the latter. Beyond this value, any further increase in the thickness of the flexoelectric layer causes a decrease in its ability to actuate the substrate beam. The electric potential varies linearly across the thickness of the flexoelectric layer. The benchmark results presented here may be useful for verifying further research and the present study suggests that the flexoelectric layer may be effectively exploited for advanced applications as a smart nano actuator.


ABSTRACT: The forced vibration of a sandwich beam integrating a shear thickening fluid (STF) core and with conductive skins subjected to a periodic excitation was investigated theoretically in this study. The rheological properties of the STF material including viscosity, plasticity, and elasticity may be changed under the periodic vibration, and hence they were considered. The governing equation of motion was derived based on the complex stiffness method and some key parameters were derived based on the Timoshenko beam theory. Effects of the excitation frequency, the excitation amplitude, the excitation location, and the skin/core thickness ratio on the nature frequency of the sandwich beam were investigated. It was found that the STF core has a significant effect on the dynamic property of the sandwich beam. Based on the findings, integrating the STF core in a sandwich beam can reduce the vibration of the beam.

ABSTRACT: In this work, the modeling of laminated composite plates with embedded piezoelectric layers is addressed through a variables separation approach. Both the displacement and electric potential fields are approximated as a sum of separated functions of the in-plane coordinates $x$, $y$ and the transverse coordinate $z$. This choice yields to a nonlinear problem that can be solved by an iterative process. That consists of solving a 2D and 1D problem successively at each iteration. In the thickness direction, a fourth and second-order expansion in each layer is considered for the displacements and the electric potential, respectively. For the in-plane description, classical eight-node quadrilateral finite element is used. Numerical examples involving several representative laminates are addressed to show the accuracy of the present LayerWise (LW) method. It is shown that it can provide quasi-3D results less costly than classical LW computations. In particular, the estimation of the transverse stresses which is of major importance for damage analysis is very good.


ABSTRACT: In this article, we focus on static finite element (FE) simulation of piezoelectric laminated composite plates and shells, considering the nonlinear constitutive behavior of piezoelectric materials under large applied electric fields. Under the assumptions of small strains and large electric fields, the second-order nonlinear constitutive equations are used in the variational principle approach, to develop a nonlinear FE model. Numerical simulations are performed to study the effect of material nonlinearity for piezoelectric bimorph and laminated composite plates as well as cylindrical shells. In comparison to the experimental investigations existing in the literature, the results predicted by the present model agree very well. The importance of the present nonlinear model is highlighted especially in large applied electric fields, and it is shown that the difference between the results simulated by linear and nonlinear constitutive FE models cannot be omitted.


ABSTRACT: The paper presents a unified solution for free and transient vibration analyses of a functionally graded piezoelectric curved beam with general boundary conditions within the framework of Timoshenko beam theory. The formulation is derived by means of the variational principle in conjunction with a modified Fourier series which consists of standard Fourier cosine series and supplemented functions. The mechanical and electrical properties of functionally graded piezoelectric materials (FGPMs) are assumed to vary continuously in the thickness direction and are estimated by Voigt's rule of mixture. The convergence, accuracy and reliability of the present formulation are demonstrated by comparing the present solutions with those from the literature and finite element analysis. Numerous results for FGPM beams with different boundary conditions, geometrical parameters as well as material distributions are given. Moreover, forced vibration of the FGPM beams subjected to dynamic loads and general boundary conditions are also investigated.

Maximilian Schaeffner, Benedict Goetz and Roland Platz, “Active buckling control of a beam-column with circular cross-section using piezoelectric supports and integral LQR control”, Smart Materials and Structures, Vol. 25, No. 6, 065008, June 2016

ABSTRACT: Buckling of slender beam-columns subject to axial compressive loads represents a critical design constraint for light-weight structures. Active buckling control provides a possibility to stabilize slender beam-columns by active lateral forces or bending moments. In this paper, the potential of active buckling control of an axially loaded beam-column with circular solid cross-section by piezoelectric supports is investigated experimentally. In the piezoelectric supports, lateral forces of piezoelectric stack actuators are transformed into bending moments acting in arbitrary directions at the beam-column ends. A mathematical model of the axially loaded beam-column is derived to design an integral linear quadratic regulator (LQR) that stabilizes the system. The effectiveness of the stabilization concept is investigated in an experimental test setup and compared with the uncontrolled system. With the proposed active buckling control it is possible to stabilize the beam-column in arbitrary lateral direction for axial loads up to the theoretical critical buckling load of the system.

ABSTRACT: We model in closed form a proven bistable shell made from a magnetic rubber composite material. In particular, we incorporate a non-axisymmetrical displacement field, and we capture the nonlinear coupling between the actuated shape and the magnetic flux distribution around the shell. We are able to verify the bistable nature of the shell and we explore its eversion during magnetic actuation. We show that axisymmetrical eversion is natural for a perfect shell but that non-axisymmetrical eversion rapidly emerges under very small initial imperfections, as observed in experiments and in a computational analysis. We confirm the non-uniform shapes of shell and we study the stability of eversion by considering how the landscape of total potential and magnetic energies of the system changes during actuation.

References listed at the end of the paper:
- 1 Loukaiades E G, Smoukov S K and Seffen K A 2014 Magnetic actuation and transition shapes of a bistable spherical cap Int. J. Smart Nano Mater. 5 270–82
- 3 Vidoli S and Maurini C 2008 Tristability of thin orthotropic shells with uniform initial curvature Proc. R. Soc. A 464 2949–66
- 4 Vidoli S 2013 Discrete approximations of the Föppl–von Kármán shell model: from coarse to more refined models Int. J. Solids Struct. 50 1241–52
- 5 Brodland G W and Cohen H 1987 Deflection and snapping of spherical caps Int. J. Solids Struct. 23 1341–56
- 9 Olver F W J 1974 Asymptotics and Special Functions (New York: Academic)
- 12 Coburn B H, Purrera A, Weaver P M and Vidoli S 2013 Tristability of an orthotropic doubly curved shell Compos. Struct. 96 446–54
- 13 Loukaiades E G 2013 Elementary morphing shells PhD Dissertation University of Cambridge
- 14 Blinder S M 2011 Magnetic field of a cylindrical bar magnet Wolfram Demonstrations Project
- 17 Xie, “A simple auxetic tubular structure with tuneable mechanical properties”, Smart Materials and Structures, Vol. 25, No. 6, 065012, June 2016

Xin Ren, Jianhu Shen, Arash Ghaedizadeh, Hongqi Tian and Yi Min Xie, “A simple auxetic tubular structure with tuneable mechanical properties”, Smart Materials and Structures, Vol. 25, No. 6, 065012, June 2016

ABSTRACT: Auxetic materials and structures are increasingly used in various fields because of their unusual properties. Auxetic tubular structures have been fabricated and studied due to their potential to be adopted as oesophageal stents where only tensile auxetic performance is required. However, studies on compressive mechanical properties of auxetic tubular structures are limited in the current literature. In this paper, we developed a simple tubular structure which exhibits auxetic behaviour in both compression and tension. This was achieved by extending a design concept recently proposed by the authors for generating 3D metallic auxetic metamaterials. Both compressive and tensile mechanical properties of the auxetic tubular structure were investigated. It was found that the methodology for generating 3D auxetic metamaterials could be effectively used to create auxetic tubular structures as well. By properly adjusting certain parameters, the mechanical properties of the designed auxetic tubular structure could be easily tuned.


ABSTRACT: This study presents an examination of nonlinear free vibration of a nanobeam under electro-thermo-mechanical loading with elastic medium and various boundary conditions, especially the elastic boundary condition. The nanobeam is modeled as an Euler–Bernoulli beam. The von Kármán strain-displacement relationship together with Hamilton's principle and Eringen's theory are employed to derive equations of motion. The nonlinear free vibration frequency is obtained for simply supported (S–S) and elastic supported (E–E) boundary conditions. E–E boundary condition is a general and actual form of boundary conditions and it is chosen because of more realistic behavior. By applying the differential transform method (DTM), the nanobeam's natural frequencies can be easily obtained for the two different boundary conditions.
mentioned above. Performing a precise study led to investigation of the influences of nonlocal parameter, temperature change, spring constants (either for elastic medium or boundary condition) and imposed electric potential on the nonlinear free vibration characteristics of nanobeam. The results for S-S and E-E nanobeams are compared with each other. In order to validate the results, some comparisons are presented between DTM results and open literature to show the accuracy of this new approach. It has been discovered that DTM solves the equations with minimum calculation cost.

Shijie Zheng, Zongjun Li, Ming Chen and Hongtao Wang, “Size-dependent static bending and free vibration of 0–3 polarized PLZT microcantilevers”, Smart Materials and Structures, Vol. 25, No. 8, 085025, August 2016

ABSTRACT: In this paper, analytical solutions for size-dependent static bending and free vibration of a pure 0–3 polarized PbLaZrTi (PLZT) cantilever are developed. This paper also makes the first attempt to investigate the static bending of a cantilever metal beam bonded with discretized 0–3 polarized PLZT actuator based on the modified couple stress theory and composite laminated beam theory. These models involve an internal material length scale parameter used to capture the size effect. In the limit when the internal material length scale parameter goes to zero, this model reduces to classical (local) solutions available in the literature. Exact solutions for the normalized static deflection are obtained as a function of the actuator thickness and the internal material length scale parameter. The simulations show that the size-dependent results developed by the present models have a remarkable difference with those got by the classical solutions when the ratio of the actuator thickness to the internal material length scale parameter is small. It is also observed that an increase in the stiffness parameter of the substrate beam gives rise to an increase in the effect of the material length scale parameter on tip deflections of the cantilever metal beam.

Xiaoli Wang, Youwei Yao, Tianchen Liu, Chian Liu, M.P. Ulmer and Jian Cao, “Deformation of rectangular thin gass plate coated with magnetostrictive material”, Smart Materials and Structures, Vol. 25, No. 8, 085038, August 2016

ABSTRACT: As magnetic smart materials (MSMs), magnetostrictive materials have great potential to be selected as coating materials for lightweight x-ray telescope mirrors due to their capability to tune the mirror profile to the desired shape under a magnetic field. To realize this potential, it is necessary to study the deformation of the mirror substrate with the MSM coating subjected to a localized magnetic field. In this paper, an analytical model is developed to calculate the deformation of rectangular coated samples locally affected by magnetostrictive strains driven by an external magnetic field. As a specific case to validate the model, a square glass sample coated with MSMs is prepared, and its deformation is measured in a designed experimental setup by applying a magnetic field. The measured deformation of the sample is compared with the results calculated from the analytical model. The comparison results demonstrate that the analytical model is effective in calculating the deformation of a coated sample with the localized mismatch strains between the film and the substrate. In the experiments, different shape patterns of surface profile changes are achieved by varying the direction of the magnetic field. The analytical model and the experimental method proposed in this paper can be utilized to further guide the application of magnetostrictive coating to deformable lightweight x-ray mirrors in the future.


ABSTRACT: In this paper, we present an exact closed-form solution for the three-dimensional deformation of a layered magnetoelctroelastic simply-supported plate with the nonlocal effect. The solution is achieved by making use of the pseudo-Stroh formalism and propagator matrix method. Our solution shows, for the first time, that for a homogeneous plate with traction boundary condition applied on its top or bottom surface, the induced stresses are independent of the nonlocal length whilst the displacements increase with increasing nonlocal length. Under displacement boundary condition over a homogeneous or layered plate, all the induced displacements and stresses are functions of the nonlocal length. Our solution further shows that regardless of the Kirchoff or Mindlin plate model, the error of the transverse displacements between the thin plate theory and the three-dimensional solution increases with increasing nonlocal length revealing an important feature for careful application of the thin plate theories towards the problem with nonlocal effect. Various other numerical examples are presented for the extended displacements and stresses in homogeneous elastic plate, piezoelectric
plate, magnetostrictive plate, and in sandwich plates made of piezoelectric and magnetostrictive materials. These results should be very useful as benchmarks for future development of approximation plate theories and numerical modeling and simulation with nonlocal effect.


ABSTRACT: This paper presents thermo-electro-mechanical postbuckling analysis of geometrically imperfect functionally graded carbon nanotube-reinforced composite (FG-CNTRC) hybrid beams that are integrated with surface-bonded piezoelectric actuators. The material properties of FG-CNTRCs are assumed to be temperature-dependent and graded in the thickness direction. By using a generic imperfection function, various possible imperfections with different shapes and locations in the beam are considered. The theoretical formulations are based on the first-order shear deformation beam theory with von-Kármán nonlinearity. A differential quadrature approximation based iteration process is employed to obtain the postbuckling equilibrium path of piezoelectric FG-CNTRC hybrid beams under thermo-electro-mechanical loading. Parametric studies are conducted to examine the effect of geometric imperfection, distribution pattern and volume fraction of carbon nanotubes, temperature rise, actuator voltage, beam geometry and boundary conditions on the thermo-electro-mechanical postbuckling behaviour. The results show that the thermo-electro-mechanical postbuckling is considerably affected by the imperfection mode, half-wave number, location and amplitude, as well as the temperature rise and boundary conditions. The effect of applied actuator voltage is much less pronounced but tends to be relatively more noticeable as the slenderness ratio increases.


ABSTRACT: The transverse vibration of a composed cantilever beam with magnetostrictive layer is analyzed, which is employed to simulate dynamic response of an actuator. The high-order shear deformation theory of beam and the coupling magnetoelastic constitutive relationship are introduced to construct the governing equations, all interface conditions between magnetostrictive film and elastic substrate as well as the free stress condition on the top and bottom surfaces of the beam can be satisfied. In order to demonstrate validity of the presented mathematical modeling, the verification examples are also given. Furthermore, the effect of geometry and material parameters on dynamic characteristics of magnetostrictive cantilever beam, such as the nature frequency and amplitude, is discussed. Moreover, through computing the magneto-mechanical coupling factor of the beam structure, the variation tendency curves of the factor along with different parameters and frequencies of magnetostrictive cantilever beam actuator have been presented. These numerical results should be useful for the design of beam-type with magnetostrictive thin-film actuators.


ABSTRACT: Considering the small scale effect together with the influences of transverse shear deformation, rotary inertia and the magneto-electro-thermo-mechanical coupling, the linear free vibration of magneto-electro-thermo-elastic (METE) rectangular nanoplates with various edge supports in pre- and post-buckled states is investigated herein. It is assumed that the METE nanoplate is subjected to the external in-plane compressive loads in combination with magnetic, electric and thermal loads. The Mindlin plate theory, von Kármán hypothesis and the nonlocal theory are utilized to develop a size-dependent geometrically nonlinear plate model for describing the size-dependent linear and nonlinear mechanical characteristics of moderately thick METE rectangular nanoplates. The nonlinear governing equations and the corresponding boundary conditions are derived using Hamilton's principle which are then discretized via the generalized differential quadrature method. The pseudo-arc length continuation approach is used to obtain the equilibrium postbuckling path of METE nanoplates. By the obtained postbuckling response, and taking a time-dependent small disturbance around the buckled configuration, and inserting them into the nonlinear governing equations, an eigenvalue problem is achieved from which the frequencies of pre- and post-buckled METE nanoplates can be calculated. The effects of nonlocal parameter, electric, magnetic and thermal loadings, length-to-thickness ratio and

ABSTRACT: This study sheds considerable light on the potential of superelastic shape memory alloy Belleville washers for innovative seismic resisting applications. A series of experimental studies were conducted on washers with different stack combinations under varying temperatures and loading scenarios. The washers showed satisfactory self-centring and energy dissipation capacities at room temperature, although slight degradations of the hysteretic responses accompanied by residual deformations were induced. The hysteretic loops became stable after a few number of cycles, indicating good repeatability. The washers also showed good flexibility in terms of load resistance and deformation, which could be easily varied via changes in the stack combination. Compromised self-centring responses were observed at temperatures below 0 °C or above 40 °C, and a numerical study, validated by the experimental results, was adopted to further investigate the deformation mechanism of the washers. A further phenomenological model, taking account of the degradation effects under varied temperatures, was developed to enable effective and accurate simulation of devices incorporating the washers. Good agreements were observed between the test and simulation results, and the model was shown to have good numerical robustness for wide engineering applications.


ABSTRACT: In this article, a nonlocal four-variable refined plate theory is developed to examine the buckling behavior of nanoplates made of magneto-electro-elastic functionally graded (MEE-FG) materials resting on Winkler–Pasternak foundation. Material properties of nanoplate change in spatial coordinate based on power-law distribution. The nonlocal governing equations are deduced by employing the Hamilton principle. For various boundary conditions, the analytical solutions of nonlocal MEE-FG plates for buckling problem will be obtained based on an exact solution approach. Finally, dependency of buckling response of MEE-FG nanoplate on elastic foundation parameters, magnetic potential, external electric voltage, various boundary conditions, small scale parameter, power-law index, plate side-to-thickness ratio and aspect ratio will be figure out. These results can be advantageous for the mechanical analysis and design of intelligent nanoscale structures constructed from magneto-electro-thermo-elastic functionally graded materials.


ABSTRACT: This paper deals with the theoretical analysis of free vibration and biaxial buckling of magneto-electro-elastic (MEE) microplate resting on Kelvin–Voigt visco-Pasternak foundation and subjected to initial external electric and magnetic potentials, using modified strain gradient theory (MSGT). Kirchhoff plate model and Hamilton's principle are employed to extract the governing equations of motion. Governing equations were analytically solved to obtain clear closed-form expression for complex natural frequencies and buckling loads using Navier's approach. Numerical results are presented to reveal variations of natural frequency and buckling load ratio of MEE microplate against different amounts of the length scale parameter, initial external electric and magnetic potentials, aspect ratio, damping and transverse and shear stiffness parameters of the visco-Pasternak foundation, length to thickness ratio, microplate thickness and higher modes. Numerical results of this study illustrate that by increasing thickness-to-material length scale parameter ratio, both natural frequency and buckling load ratio predicted by MSGT and modified couple stress theory are reduced because the non-dimensional length scale parameter tends to decrease the stiffness of structures and make them more flexible. In addition, results show that initial external electric and initial external magnetic potentials have no considerable influence on the buckling load ratio and frequency of MEE microplate as the microplate thickness increases.

ABSTRACT: Imitating origami principles in active or programmable materials opens the door for development of origami-inspired self-folding structures for not only aesthetic but also functional purposes. A variety of programmable materials enabled self-folding structures have been demonstrated across various fields and scales. These folding structures have finite thickness and the mechanical properties of the active materials dictate the folding process. Yet formalizing the use of origami rules for use in computer modeling has been challenging, owing to the zero-thickness theory and the exclusion of mechanical properties in current models. Here, we describe a physics-based finite element simulation scheme to predict programmable self-folding of temperature-sensitive hydrogel trilayers. Patterning crease and assigning mountain or valley folds are highlighted for complex origami such as folding of the Randlett's flapping bird and the crane. Our efforts enhance the understanding and facilitate the design of origami-inspired self-folding structures, broadening the realization and application of reconfigurable structures.


ABSTRACT: Morphing systems able to efficiently adjust their characteristics to resolve the conflicting demands of changing operating conditions offer great potential for enhanced performance and functionality. The main practical challenge, however, consists in combining the desired compliance to accomplish radical reversible geometry modifications at reduced actuation effort with the requirement of high stiffness imposed by operational functions. A potential decoupling strategy entails combining the conformal shape adaptation benefits of distributed compliance with purely elastic stiffness variability provided by embedded bi-stable laminates. This selective compliance can allow for on-demand stiffness adaptation by switching between the stable states of the internal elements. The current paper considers the optimal positioning of the bi-stable components within the structure while assessing the energy required for morphing under aerodynamic loading. Compared to a time-invariant system, activating specific deformation modes permits decreasing the amount of actuation energy, and hence the amount of actuation material to be carried. A concurrent design and optimisation framework is implemented to develop selective configurations targeting different flight conditions. First, an aerodynamically favourable high-lift mode achieves large geometric changes due to reduced actuation demands. This is only possible by virtue of the internally tailored compliance, arising from the stable state switch of the embedded bi-stable components. A second, stiff configuration, targets operation under increased aerodynamic loading. The dynamic adequacy of the design is proved via high fidelity fluid–structure interaction simulations.


ABSTRACT: Shape memory polymers (SMPs) are a class of intelligent materials, which are defined by their capacity to store a temporary shape and recover an original shape. In this work, the shape memory effect of SMP deployable hinged shell is simulated by using compiled user defined material subroutine (UMAT) subroutine of ABAQUS. Variations of bending moment and strain energy of the hinged shells with different temperatures and structural parameters in the loading process are given. The effects of the parameters and temperature on the nonlinear deformation process are emphasized. The entire thermodynamic cycle of SMP deployable hinged shell includes loading at high temperature, load carrying with cooling, unloading at low temperature and recovering the original shape with heating. The results show that the complicated thermo-mechanical deformation and shape memory effect of SMP deployable hinge are influenced by the structural parameters and temperature. The design ability of SMP smart hinged structures in practical application is prospected.


ABSTRACT: In this paper, based on the sinusoidal shear deformation plate theory, equations of motion for a sandwich nanoplate containing a nano core and two integrated piezo-magnetic face-sheets are derived. The piezo-magnetic face-sheets are subjected to three dimensional electric and magnetic potentials. Nonlocal piezo-magneto-elastic relations are derived in a thermal environment. Hamilton's principle is used to derive seven
equations of motion in terms of three deformation components of mid-surface, two shear components and electric and magnetic potentials. Natural frequencies of the sandwich nanoplate are derived in terms of nonlocal parameter. After finding solutions to the governing equations of motion, the effect of important parameters of the nanoplate are investigated on the mechanical, electrical and magnetic components of the nanoplate. Based on the present study, with increasing applied electric potential, dimensionless deflection is decreased and maximum electric and magnetic potentials are increased. Furthermore, with increasing applied magnetic potential, deflection is increased and maximum electric and magnetic potentials are decreased significantly. The numerical results of this problem indicate that one can control deformation or stress in the nano structure by changing the applied electric and magnetic potentials.


ABSTRACT: Axially compressed bilaterally constrained columns, which can attain multiple snap-through buckling events in their elastic postbuckling response, can be used as energy concentrators and mechanical triggers to transform external quasi-static displacement input to local high-rate motions and excite vibration-based piezoelectric transducers for energy harvesting devices. However, the buckling location with highest kinetic energy release along the element, and where piezoelectric oscillators should be optimally placed, cannot be controlled or isolated due to the changing buckling configurations. This paper proposes the concept of stiffness variations along the column to gain control of the buckling location for optimal placement of piezoelectric transducers. Prototyped non-prismatic columns with piece-wise varying thickness were fabricated through 3D printing for experimental characterization and numerical simulations were conducted using the finite element method. A simple theoretical model was also developed based on the stationary potential energy principle for predicting the critical line contact segment that triggers snap-through events and the buckling morphologies as compression proceeds. Results confirm that non-prismatic column designs allow control of the buckling location in the elastic postbuckling regime. Compared to prismatic columns, non-prismatic designs can attain a concentrated kinetic energy release spot and a higher number of snap-buckling mode transitions under the same global strain. The direct relation between the column's dynamic response and the output voltage from piezoelectric oscillator transducers allows the tailorable postbuckling response of non-prismatic columns to be used as multi-stable energy concentrators with enhanced performance in micro-energy harvesters.


ABSTRACT: A study into the shape and active vibration control of antenna reflectors, an important member of the space structures, is carried out in this paper. Geometric nonlinear analysis is considered for performance evaluation of antenna reflectors, as very high precision is an important aspect of space structures. An effort has been made to demonstrate the importance of functionally graded materials in space structures. Piezolaminated structures have been used for shape and vibration control applications for many years. However, due to the problems like debonding and delamination, the reliability of these materials in space structures is still uncertain. To overcome these problems, patches made of functionally graded piezoelectric material (FGPM) are used for shape and vibration control of antenna reflectors in this investigation. FGPM patches are also used to demonstrate the beam-shaping and beam-steering application of antenna reflectors. For the active vibration control application, a fuzzy-logic controller (FLC) is designed and validated with the experimental results. An experimental study has been conducted for comparing the performance of different controllers in the context of vibration reduction. The FLC is then used for active vibration control of an antenna reflector under the application of thermal impact and sinusoidal loading.


ABSTRACT: Piezoelectric shunting arrays are proposed to isolate low-frequency vibrations transmitted in sandwich plates. The performance is characterized through application of finite element method. The numerical result shows that a complete band gap, whose width is about 20 Hz, is produced in the desired low-frequency ranges. The band gap is induced by local resonances of the shunting circuits, whose location is strongly related to the inductance, while the resistance can broaden the band gap to some extent. Vibration experiments are
conducted on a 1200 × 1000 × 15 mm aluminum honeycomb plate with two arrays of 5 × 5 shunted piezoelectric patches bonded on the surface panels. Significant attenuation is found in the experimental results, which agree well with the theoretical predictions. Consequently, the proposed idea is feasible and effective.

ABSTRACT: This study aims to investigate the sound transmission loss (STL) capability of sandwich panels treated with Magnetorheological (MR) fluids at low frequencies. An experimental setup has been designed to investigate the effect of the intensity of applied magnetic field on the natural frequencies and STL of a clamped circular panel. It is shown that the fundamental natural frequency of the MR sandwich panel increases in proportion to the applied magnetic field. In addition, the STL of the panel at the resonance frequency increases as the magnetic field is amplified. Furthermore, the classical plate theory and Ritz method have been utilized to develop the governing equations of motion of the finite multilayered circular panels comprising two elastic face sheets and MR fluid core layer. The radiated sound power from the panel is derived using Rayleigh integral as a function of the transverse velocity of the panel which is subsequently used to evaluate the STL. The theoretical study is validated comparing the simulation results with the experimental measurements. Experimental and analytical parametric study have also been conducted to study the effect of the core layers' thickness on the natural frequency and the STL of sandwich panel.

ABSTRACT: Using Origami folded cores in sandwich structures for lightweight applications has attracted attention in different engineering applications, especially in the applications where the stiffness to weight ratio is a critical design parameter. Recently, common sandwich cores such as honey-comb and foamed cores have been replaced with origami core panels due to their way of force redistribution and energy absorption; these unique characteristics give origami cores high stiffness to weight ratio and high bending and twisting resistance. This paper presents the results of experimental investigations of the effect of base material on the mechanical properties and the impact resistance of Miura–Origami sandwich cores; then, the experimental results are compared with FEA simulation results. The materials used in the study for the origami cores were polymer blends composed of polylactic acid (PLA) and thermoplastic polyurethane (TPU). PLA/TPU blend compositions are (100/0, 80/20, 65/35, 50/50, 20/80, and 0/100) as a weight percentage. The geometrical parameters of the unit cell, base material thickness, and the panel thickness were considered to be constants in this study. The study shows the behavior of the origami cores under impact test and the energy absorbed by the origami folded cores. It was found that 20/80 PLA/TPU blend demonstrated the highest specific energy absorption efficiency both in quasi-static compression and impact tests. Fractured Origami structures were observed to fail at folded edges (creases lines), while the facets exhibit rigid body rotations. The FEM simulation showed a consistency in the impact behavior of the origami cores, and the directional deformational of origami core units which explain the ability of the structure to redistribute the applied force and absorb energy. In this work the origami folded core features were molded directly from the blended material.

ABSTRACT: A three-dimensional fully auxetic cellular structure with negative Poisson's ratio is presented. Samples are fabricated from Ti6Al4V powder via selective electron beam melting. The influence of the strut thickness and the amplitude of the strut on the mechanical properties and the deformation behaviour of cellular structures is studied.

References listed at the end of the paper:
4 Ashby M F 2006 The properties of foams and lattices Phil. Trans. R. Soc. A 364 15–30
8 Weißmann V, Wieding J, Hansmann H, Laufner N, Wolf A and Bader R 2016 Specific yielding of selective laser-melted Ti6Al4V open-porous scalds as a function of unit cell design and dimensions Metals 6 166
9 Hengsbach S and Lantada A D 2014 Direct laser writing of auxetic structures present capabilities and challenges Smart Mater. Struct. 23 085033
10 Sun J, Yang Y and Wang D 2013 Mechanical properties of regular hexahedral lattice structure formed by selective laser melting Laser Phys. 2 066101
13 Ahmadi S M, Yavari S A, Waathrle R, Pouran B, Schrooten J, Weinsans H and Zadpoor A A 2015 Additively manufactured open-cell porous biomaterials made from six different space-filling unit cells: the mechanical and morphological properties Materials 8 1871–96
14 Murr L E et al 2010 Next-generation biomedical implants using additively manufacturing of complex, cellular and functional mesh arrays Phil. Trans. R. Soc. A 368 1999–2032
21 Lakes R S 1987 Foam structures with a negative Poisson’s ratio Science 235 1038–40
27 Ma Z 2011 Three-dimensional auxetic structures and applications thereof Google Patents US Patent 7,910,193
28 Yang L, Harysson O, West H and Cormier D 2012 Compressive properties of Ti-6Al-4V auxetic mesh structures made by electron beam melting Acta Mater. 60 3370–9
29 Yang L, Harysson O, West H and Cormier D 2015 Mechanical properties of 3D re-entrant honeycomb auxetic structures realized via additive manufacturing Int. J. Solids Struct. 69 475–90
30 Ren X, Shen J, Ghaedizadeh A, Tian H and Xie Y M 2015 Experiments and parametric studies on 3D metallic auxetic metamaterials with tuneable mechanical properties Smart Mater. Struct. 24 095016
35 Ha C S, Plesha M E and Lakes R S 2016 Chiral three-dimensional lattices with tunable Poissons ratio Smart Mater. Struct. 25 054005
39 Bianchi M, Scarpa F L and Smith C W 2008 Stiffness and energy dissipation in polyurethane auxetic foams J. Mater. Sci. 43 5851–60
40 Bezazi A and Scarpa F 2007 Mechanical behaviour of conventional and negative Poissons ratio thermoplastic polyurethane foams under compressive cyclic loading Int. J. Fatigue 29 922–30
41 Bezazi A and Scarpa F 2009 Tensile fatigue of conventional and negative Poissons ratio open cell PU foams Int. J. Fatigue 31 488–94
49 Körner and Liebold-Ribeiro Y 2015 A systematic approach to identify cellular auxetic materials Smart Mater. Struct. 24 025013
50 Ackelid U and Svensson M 2009 Additive manufacturing of dense metal parts by electron beam melting Materials Science and Technology Conf. pp 2271–9
53 Masters I G and Evans K E 1996 Models for the elastic deformation of honeycombs Compos. Struct. 4 403–22


ABSTRACT: Two-dimensional hierarchical re-entrant honeycomb structures were designed and the mechanical behaviors of the structures were studied using a finite element method. Hierarchical re-entrant structure of order \(n (n \geq 1)\) was constructed by replacing each vertex of a lower order \((n - 1)\) hierarchical re-entrant structure with a smaller re-entrant hexagon with identical strut aspect ratio. The Poisson’s ratio and energy absorption capacity of re-entrant structures of different hierarchical orders were studied under different compression velocities. The results showed that the Poisson’s ratio of the first and second order hierarchical structures can reach –1.36 and –1.33 with appropriate aspect ratio, 13.8% and 12.1% lower than that of the zeroth order hierarchical structure. The energy absorption capacity of the three models increased with an increasing compression velocity; the second order hierarchical structure exhibited the highest rate of increase in energy absorption capacity with an increasing compression velocity. The plateau stresses of the first and second order hierarchical structures were slightly lower than that of the zeroth order hierarchical structure; however the second order hierarchical structure exhibited the highest energy absorption capacity at high compression velocity (60 m s\(^{-1}\)).


ABSTRACT: This paper makes a complete investigation of flexible longitudinal zigzag (FLZ) energy harvesters for the purpose of enhancing energy harvesting from low-frequency and low-amplitude excitation. A general theoretical model of the FLZ energy harvesters with large joint block mass is proposed. In order to verify the accuracy of the theoretical model, both experimental results and finite element analysis via ANSYS software are presented. Results show that the theoretical model can successfully predict the dynamic response and the output power of the FLZ energy harvesters. Both theoretical and experimental results demonstrate that the proposed energy harvesters can effectively harvest vibration energy even when the direction of excitation relative to the harvester varies from 0° to 90°. Under the low excitation level of 0.18 m s\(^{-1}\), the experimental maximum output power of a FLZ energy harvester with five beams was found to be 1.016 mW. Finally, the results indicate that the proposed structure is capable of effective energy conversion across a large range of excitation angles at low-frequency and low-amplitude excitations, which makes it suitable for a wide range of working conditions.

ABSTRACT: In the current study, stability analysis of cracked functionally graded material (FGM) columns under the effect of piezoelectric patches is analytically investigated. Configuration of the patches is somehow chosen to create axial load in the column. The crack is modeled by a rotational massless spring which connects the two intact parts of the column at the crack location. After applying the boundary and compatibility conditions at the crack location and the ends of the piezoelectric patches, the governing equation of buckling behavior of the cracked FGM column is derived. The effect of important parameters on the first and second buckling load of the column such as crack parameters (location and depth), location and length of the patches and also applied voltage is studied and discussed. Results show that a crack significantly reduces the column load capacity which is dependent on location and depth of the crack. By applying static load to the column, piezoelectric patches produce local torque, and controlling this torque leads to reduced crack effects on the column. Using piezoelectric patches with proper location and length compensates the effect of the crack. Despite the first buckling load, positive voltage increases the second buckling load of the column.


ABSTRACT: In this work, a bi-stable vibration energy harvester is presented to scavenge energy from ambient vibrations over a wide frequency range. This bi-stable harvester consists of a bi-stable hybrid composite plate as host structure and several pieces of piezoelectric ceramics. Three linear harvesters with the same geometry were employed as the control samples to illustrate the advantages of this bi-stable harvester. The voltage–frequency responses were measured with different g-level excitations, and the output powers across various resistances were measured at different frequencies and accelerations. Unlike the linear harvesters which are effective only near their natural frequencies, the obvious nonlinearities of this bi-stable harvester broaden its working bandwidth. Additionally, the characteristics of this bi-stable host structure contribute to the output power. Under the same condition, when this bi-stable harvester is under cross-well oscillation pattern the maximum output powers are several times higher than those of the linear harvesters. The measured highest output power of this bi-stable harvester is 36.2 mW with 38 Hz frequency and 5g acceleration (g = 9.8 m s−2).

Xiaobo Gong, Liwu Liu, Fabrizio Scarpa, Jinsong Leng and Yanju Liu, “Variable stiffness corrugated composite structure with shape memory polymer for morphing skin applications”, Smart Materials and Structures, Vol. 26, No. 3, 035052, March 2017

ABSTRACT: This work presents a variable stiffness corrugated structure based on a shape memory polymer (SMP) composite with corrugated laminates as reinforcement that shows smooth aerodynamic surface, extreme mechanical anisotropy and variable stiffness for potential morphing skin applications. The smart composite corrugated structure shows a low in-plane stiffness to minimize the actuation energy, but also possess high out-of-plane stiffness to transfer the aerodynamic pressure load. The skin provides an external smooth aerodynamic surface because of the one-sided filling with the SMP. Due to variable stiffness of the shape memory polymer the morphing skin exhibits a variable stiffness with a change of temperature, which can help the skin adjust its stiffness according different service environments and also lock the temporary shape without external force. Analytical models related to the transverse and bending stiffness are derived and validated using finite element techniques. The stiffness of the morphing skin is further investigated by performing a parametric analysis against the geometry of the corrugation and various sets of SMP fillers. The theoretical and numerical models show a good agreement and demonstrate the potential of this morphing skin concept for morphing aircraft applications. We also perform a feasibility study of the use of this morphing skin in a variable camber morphing wing baseline. The results show that the morphing skin concept exhibits sufficient bending stiffness to withstand the aerodynamic load at low speed (less than 0.3 Ma), while demonstrating a large transverse stiffness variation (up to 191 times) that helps to create a maximum mechanical efficiency of the structure under varying external conditions.

Xiaoling Jin, Yong Wang, Michael Z.Q. Chen and Zhilong Huang, “Response analysis of dielectric elastomer spherical membrane to harmonic voltage and random pressure”, Smart Materials and Structures, Vol. 26, No. 3, 035063, March 2017
ABSTRACT: Spherical membranes consisting of dielectric elastomer play important roles in flexible and stretchable devices, such as flexible actuators, sensors and loudspeakers. Executing various functions of devices depends on the dynamical behaviors of dielectric elastomer spherical membranes to external electrical and/or mechanical excitations. This manuscript concentrates on the random aspect of dielectric elastomer spherical membranes, i.e., the random response to combined excitations of harmonic voltage and random pressure. To analytically evaluate the response statistics of the stretch ratio, a specific transformation and stochastic averaging technique are successively adopted to solve the strongly nonlinear equation with respect to the stretch ratio. The stochastic differential equations for the system first integral and the phase difference between harmonic excitation and response are first derived through this transformation. The Fokker-Planck-Kolmogorov equation with respect to the stationary probability density of the system first integral and the phase difference is obtained. The stationary probability densities and the response statistics of the stretch ratio and its rate of change are then subsequently calculated. The phenomenon of stochastic jumps is found and the stochastic jump bifurcates with the variations of the frequency and the amplitude of the harmonic voltage and the intensity of the random pressure. The efficacy and accuracy of the analytical results are verified by comparing with the results from Monte Carlo simulation. Besides, the reliability of the dielectric elastomer spherical membrane is discussed briefly. The obtained results could provide options in implementing and designing dielectric elastomer structures for dynamic applications.


ABSTRACT: This paper presents a computationally efficient and robust nonlinear modeling framework for smart materials. The framework describes a smart material system through a new 3D inversion scheme for coupled nonlinear constitutive equations which can be integrated with the variational form of governing equations. Building on the Newton technique, the inversion scheme can be applied to any nonlinear smart material with a differentiable direct constitutive model. To further improve computational efficiency, the inversion scheme is integrated with a reduced dimensional (2D) model for smart composite structures. The resulting coupled 2D framework is applied to an aluminum-Galfenol composite plate that operates in actuation mode, and is solved using multiphysics finite element software. Major and minor magnetostriction curves are obtained for the actuator displacements at the tip of the Galfenol element by applying unbiased and biased magnetic fields. A significant advantage in numerical convergence and computational time, an almost six-time speedup for a dynamic simulation case, is demonstrated via comparison with an existing approach for magnetostrictive material modeling. The framework is suitable for fast design and optimization of nonlinear smart material structures.

Yangyiwei Yang, Shuai Wang, Peter Stein, Bai-Xiang Xu and Tongqing Yang, “Vibration-based energy harvesting with a clamped piezoelectric circular diaphragm: Analysis and identification of optimal structural parameters”, Smart Materials and Structures, Vol. 26, No. 4, 045011, April 2017

ABSTRACT: Due to many potential promising applications, vibration-based piezoelectric energy harvesters (VPEH) with a clamped circular diaphragm are an intensively studied design in the field of piezoelectric energy harvesters. Nonetheless, their performance still leaves space for improvement, which is the primary target of this article. We define two structural parameters, namely the ratio $\frac{d_1}{d_2}$, between the bonding area and the piezoceramic diameter as well as the ratio $\frac{d_2}{d_3}$, between the clamping rim and the substrate diameter, to characterize these structures. A vibration model is developed in order to provide an analytical foundation for the identification of optimal parameters $\frac{d_1}{d_2}$, and $\frac{d_2}{d_3}$. It is verified by finite-element simulations and substantive experiments. The results allow to relate the device performance, including resonance frequency and output power, to $\frac{d_1}{d_2}$, and $\frac{d_2}{d_3}$. This shows that the output rises with increasing $\frac{d_1}{d_2}$, and that the maximum output for a given $\frac{d_1}{d_2}$, always lies in the range (math). Based on this observation, an improved harvester structure with a pre-stress of 0.3 N is identified, that exhibits a matched power up to 16.3 mW at 219 Hz. This demonstrates the feasibility to achieve VPEHs with higher outputs and lower eigenfrequency through simultaneous modification of $\frac{d_1}{d_2}$, and $\frac{d_2}{d_3}$, which is highly beneficial for low-frequency energy harvesting.

ABSTRACT: The authors develop magnetically actuated Miura-ori structures through observation, experiment, and computation using an initially heuristic strategy followed by trade space visualization and optimization. The work is novel, especially within origami engineering, in that beyond final target shape approximation, Miura-ori structures in this work are additionally evaluated for the shape approximation while folding and for their efficient use of their embedded actuators. The structures consisted of neodymium magnets placed on the panels of silicone elastomer substrates cast in the Miura-ori folding pattern. Initially four configurations, arrangements of magnets on the panels, were selected based on heuristic arguments that (1) maximized the amount of magnetic torque applied to the creases and (2) reduced the number of magnets needed to affect all creases in the pattern. The results of experimental and computational performance metrics were used in a weighted sum model to predict the optimum configuration, which was then fabricated and experimentally characterized for comparison to the initial prototypes. As expected, optimization of magnet placement and orientation was effective at increasing the degree of theoretical useful work. Somewhat unexpectedly, however, trade space results showed that even after optimization, the configuration with the most number of magnets was least effective, per magnet, at directing its actuation to the structure's creases. Overall, though the winning configuration experimentally outperformed its initial, non-optimal counterparts, results showed that the choice of optimum configuration was heavily dependent on the weighting factors. These results highlight both the ability of the Miura-ori to be actuated with external magnetic stimuli, the effectiveness of a heuristic design approach that focuses on the actuation mechanism, and the need to address path-dependent metrics in assessing performance in origami folding structures.

Alessandro Airoldi, Stephane Fournier, Elena Borlandelli, Paolo Bettini and Giuseppe Sala, “Design and manufacturing of skins based on composite corrugated laminates for morphing aerodynamic surfaces”, Smart Materials and Structures, Vol. 26, No. 4, 045024, April 2017

ABSTRACT: The paper discusses the approaches for the design and manufacturing of morphing skins based on rectangular-shaped composite corrugated laminates and proposes a novel solution to prevent detrimental effects of corrugation on aerodynamic performances. Additionally, more complex corrugated shapes are presented and analysed. The manufacturing issues related to the production of corrugated laminates are discussed and tests are performed to compare different solutions and to assess the validity of analytical and numerical predictions. The solution presented to develop an aerodynamically efficient skin consists in the integration of an elastomeric cover in the corrugated laminate. The related manufacturing process is presented and assessed, and a fully nonlinear numerical model is developed and characterized to study the behaviour of this skin concept in different load conditions. Finally, configurations based on combinations of individual rectangular-shaped corrugated panels are considered. Their structural properties are numerically investigated by varying geometrical parameters. Performance indices are defined to compare structural stiffness contributions in non-morphing directions with the ones of conventional panels of the same weight. Numerical studies also show that the extension of the concept to complex corrugated shapes may improve both the design flexibility and some specific performances with respect to rectangular shaped corrugations. The overall results validate the design approaches and manufacturing processes to produce corrugated laminates and indicate that the solution for the integration of an elastomeric cover is a feasible and promising method to enhance the aerodynamic efficiency of corrugated skins.


ABSTRACT: This work is focused on the active vibration control of piezoelectric cantilever beam, where an adaptive feedforward controller (AFC) is utilized to reject the vibration with unknown multiple frequencies. First, the experiment setup and its mathematical model are introduced. Due to that the channel between the disturbance and the vibration output is unknown in practice, a concept of equivalent input disturbance (EID) is employed to put an equivalent disturbance into the input channel. In this situation, the vibration control can be achieved by setting the control input be the identified EID. Then, for the EID with known multiple frequencies, the AFC is introduced to perfectly reject the vibration but is sensitive to the frequencies. In order to accurately
identify the unknown frequencies of EID in presence of the random disturbances and un-modeled nonlinear dynamics, the time–frequency-analysis (TFA) method is employed to precisely identify the unknown frequencies. Consequently, a TFA-based AFC algorithm is proposed to the active vibration control with unknown frequencies. Finally, four cases are given to illustrate the efficiency of the proposed TFA-based AFC algorithm by experiment.

Junshi Zhang, Jianwen Zhao, Shu Wang, Hualing Chen and Dichen Li, “Large stable deformation of dielectric elastomers driven on mode of steady electric field”, Smart Materials and Structures, Vol. 26, No. 5, 05LT01, May 2017

ABSTRACT: Dielectric elastomers (DEs) are capable of large deformation under the actuation of applied voltage and sprayed charge. Actuation of DE under voltage control is prone to electromechanical instabilities, while the DE under charge control always survives from instabilities with sacrificing a large deformation. In this article, a novel actuation mode of steady electric field is proposed. By tuning applied voltage and sprayed charge during viscoelastic creep, an invariable electric field is generated. Such an actuation method can both avoid the occurrence of electromechanical instabilities and guarantee a large deformation in DE actuation.


ABSTRACT: We present a shape memory polymer (SMP) honeycomb with tuneable and shape morphing mechanical characteristics. Kirigami (Origami with cutting allowed) techniques have been used to design and manufacture the honeycomb. The cellular structure described in this work has styrene SMP hinges that create the shape change and the deployment actuation. To create a large volumetric deployment, the Kirigami open honeycomb configuration has been designed by setting an initial three-dimensional re-entrant auxetic (negative Poisson’s ratio) configuration, while the final honeycomb shape assume a convex (positive Poisson’s ratio) layout. A model was developed to predict the shape change of the structure, and compared to experimental results from a demonstrator honeycomb deployment test.

References listed at the end of the paper:
2 Tachi T 2009 One-dof cylindrical deployable structures with rigid quadrilateral panels Proc. IASS Symp. pp 2295–305 (http://riunet.upv.es/handle/10251/7277)
3 Schenk M, Kerr S G, Smyth a M and Guest S D 2013 Inflatable cylinders for deployable space structures Proc. First Conference Transformables 2013 (School of Architecture Seville, Spain, 18–20 September 2013)
6 Zhou X, Wang H and You Z 2014 Mechanical properties of Miura-based folded cores under quasi-static loads Thin-Walled Struct. 82 296–310
8 Bassik N, Stern G M and Gracias D H 2009 Microassembly based on hands free origami with bidirectional curvature Appl. Phys. Lett. 95 1–4
16 Sareh S and Rossiter J 2013 Kirigami artificial muscles with complex biologically inspired morphologies Smart Mater. Struct. 22 014004
17 Zhang Y et al 2015 A mechanically driven form of Kirigami as a route to 3D mesostructures in micro/nanomembranes Proc. Natl Acad. Sci. 112 201515602

ABSTRACT: A new device that combines vibration isolation and energy harvesting is modeled, simulated, and tested. The vibration isolating portion of the device uses post-buckled beams as its spring elements. Piezoelectric film is applied to the beams to harvest energy from their dynamic flexure. The entire device operates passively on applied base excitation and requires no external power or control system. The structural system is modeled using the elastica, and the structural response is applied as forcing on the electric circuit equation to predict the output voltage and the corresponding harvested power. The vibration isolation and energy harvesting performance is simulated across a large parameter space and the modeling approach is validated with experimental results. Experimental transmissibilities of 2% and harvested power levels of 0.36 μW are simultaneously demonstrated. Both theoretical and experimental data suggest that there is not necessarily a trade-off between vibration isolation and harvested power. That is, within the practical operational range of the device, improved vibration isolation will be accompanied by an increase in the harvested power as the forcing frequency is increased.


ABSTRACT: The optimized design of a smart post-buckled beam actuator (PBA) is performed in this study. A smart material based piezoceramic stack actuator is used as a prime-mover to drive the buckled beam actuator. Piezoceramic actuators are high force, small displacement devices; they possess high energy density and have high bandwidth. In this study, bench top experiments are conducted to investigate the angular tip deflections due to the PBA. A new design of a linear-to-linear motion amplification device (LX-4) is developed to circumvent the small displacement handicap of piezoceramic stack actuators. LX-4 enhances the piezoceramic actuator mechanical leverage by a factor of four. The PBA model is based on dynamic elastic stability and is analyzed using the Mathieu–Hill equation. A formal optimization is carried out using a newly developed meta-heuristic nature inspired algorithm, named as the bat algorithm (BA). The BA utilizes the echolocation capability of bats. An optimized PBA in conjunction with LX-4 generates end rotations of the order of 15° at the output end. The optimized PBA design incurs less weight and induces large end rotations, which will be useful in development of various mechanical and aerospace devices, such as helicopter trailing edge flaps, micro and nano aerial vehicles and other robotic systems.

M.H. Ansari and M. Amin Karami, “Experimental investigation of fan-folded piezoelectric energy harvesters for powering pacemakers”, Smart Materials and Structures, Vol. 26, No. 6, 065001, June 2017

ABSTRACT: This paper studies the fabrication and testing of a magnet free piezoelectric energy harvester (EH) for powering biomedical devices and sensors inside the body. The design for the EH is a fan-folded structure consisting of bimorph piezoelectric beams folding on top of each other. An actual size experimental prototype is fabricated to verify the developed analytical models. The model is verified by matching the analytical results of the tip acceleration frequency response functions (FRF) and voltage FRF with the experimental results. The generated electricity is measured when the EH is excited by the heartbeat. A closed loop shaker system is utilized to reproduce the heartbeat vibrations. Achieving low fundamental natural frequency is a key factor to generate sufficient energy for pacemakers using heartbeat vibrations. It is shown that the natural frequency of the small-scale device is less than 20 Hz due to its unique fan-folded design. The experimental results show that the small-scale EH generates sufficient power for state of the art pacemakers. The 1 cm EH with 18.4 gr tip mass generates more than 16 microwatts of power from a normal heartbeat waveform. The robustness of the device to the heart rate is also studied by measuring the relation between the power output and the heart rate.

Jifang Zeng, Hong Hu and Lin Zhou, “A study on negative Poisson’s ratio effect of 3D auxetic orthogonal textile composites under compression”, Smart Materials and Structures, Vol. 26, No. 6, 065014, June 2017

ABSTRACT: More and more researches have been focused on auxetic composite materials and a number of composite structures have been fabricated, synthesized or theoretically predicted. Since their structures are complex, their mechanical behavior is very difficult to be characterized. The purpose of the present paper is to systematically investigate the negative Poisson's ratio effect of a novel three-dimensional auxetic orthogonal
textile composite under compression. Firstly, a set of equations are derived for the theoretical calculation of the Poisson's ratio of the composite under uniaxial compression via an analytical analysis. Secondly, a finite element model (FEM) is created by ANSYS Parameter Design Language and is verified by experiment. The deviation between the simulation and experimental results are carefully discussed. Thirdly, the effects of geometry parameters and material properties on the negative Poisson's ratio behavior of the composite are discussed based on the FEM simulated results. At last, a general basis is concluded. It is expected that the outcomes of this study could be useful to guide the design and fabrication of auxetic textile composites with required negative Poisson's ratio behavior.

Farzad Ebrahimi and Mohammad Reza Barati, “Damping vibration analysis of smart piezoelectric polymeric nanoplates on viscoelastic substrate based on nonlocal strain gradient theory”, Smart Materials and Structures, Vol. 26, No. 6, 065018, June 2017

ABSTRACT: This paper develops a nonlocal strain gradient plate model for damping vibration analysis of smart piezoelectric polymeric nanoplates resting on visco-Pasternak medium. For more accurate analysis of piezoelectric nanoplate, the proposed theory contains two scale parameters related to the nonlocal and strain gradient effects. Viscoelastic effect is considered based on Kelvin–Voit model. Governing equations of a nonlocal strain gradient smart nanoplate on viscoelastic substrate are derived via Hamilton's principle. Galerkin's method is implemented to solve the governing equations. Effects of different factors such as viscoelasticity, nonlocal parameter, length scale parameter, applied voltage and Winkler–Pasternak parameters on damping vibration characteristics of a nanoplate are studied.


ABSTRACT: A thermo-mechanically coupled finite element (FE) for the simulation of multi-layered shape memory alloy (SMA) beams admitting large displacements and rotations (LDRs) is developed to capture the geometrically nonlinear effects which are present in many SMA applications. A generalized multi-field beam theory implementing a SMA constitutive model based on small strain theory, thermo-mechanically coupled governing equations and multi-field kinematic hypotheses combining first order shear deformation assumptions with a sixth order polynomial temperature field through the thickness of the beam section are extended to admit LDRs. The co-rotational formulation is adopted, where the motion of the beam is decomposed to rigid body motion and relative small deformation in the local frame. A new generalized multi-layered SMA FE is formulated. The nonlinear transient spatial discretized equations of motion of the SMA structure are synthesized and solved using the Newton–Raphson method combined with an implicit time integration scheme. Correlations of models incorporating the present beam FE with respective results of models incorporating plane stress SMA FEs, demonstrate excellent agreement of the predicted LDRs response, temperature and phase transformation fields, as well as, significant gains in computational time.


ABSTRACT: The deformed shape is a consequence of loading the structure and it is defined by the shape of the centroid line of the beam after deformation. The deformed shape is a universal parameter of beam-like structures. It is correlated with the curvature of the cross-section; therefore, any unusual behavior that affects the curvature is reflected through the deformed shape. Excessive deformations cause user discomfort, damage to adjacent structural members, and may ultimately lead to issues in structural safety. However, direct long-term monitoring of the deformed shape in real-life settings is challenging, and an alternative is indirect determination of the deformed shape based on curvature monitoring. The challenge of the latter is an accurate evaluation of error in the deformed shape determination, which is directly correlated with the number of sensors needed to achieve the desired accuracy. The aim of this paper is to study the deformed shape evaluated by numerical double integration of the monitored curvature distribution along the beam, and create a method to predict the associated errors and suggest the number of sensors needed to achieve the desired accuracy. The error due to the accuracy in the curvature measurement is evaluated within the scope of this work. Additionally, the error due to
the numerical integration is evaluated. This error depends on the load case (i.e., the shape of the curvature diagram), the magnitude of curvature, and the density of the sensor network. The method is tested on a laboratory specimen and a real structure. In a laboratory setting, the double integration is in excellent agreement with the beam theory solution which was within the predicted error limits of the numerical integration. Consistent results are also achieved on a real structure—Streicker Bridge on Princeton University campus.

Andrew J. Lee, Amin Moosavian and Daniel J. Inman, “Control and characterization of a bistable laminate generated with piezoelectricity”, Smart Materials and Structures, Vol. 26, No. 8, 085007, August 2017
ABSTRACT: Extensive research has been conducted on utilizing smart materials such as piezoelectric and shape memory alloy actuators to induce snap through of bistable structures for morphing applications. However, there has only been limited success in initiating snap through from both stable states due to the lack of actuation authority. A novel solution in the form of a piezoelectrically generated bistable laminate consisting of only macro fiber composites (MFC), allowing complete configuration control without any external assistance, is explored in detail here. Specifically, this paper presents the full analytical, computational, and experimental results of the laminate's design, geometry, bifurcation behavior, and snap through capability. By bonding two actuated MFCs in a [0°/90°]s layup and releasing the voltage post cure, piezoelectric strain anisotropy and the resulting in-plane residual stresses yield two statically stable states that are cylindrically shaped. The analytical model uses the Rayleigh–Ritz minimization of total potential energy and finite element analysis is implemented in MSC Nastran. The [0°/90°]s laminate is then manufactured and experimentally characterized for model validation. This paper demonstrates the adaptive laminate's unassisted forward and reverse snap through capability enabled by the efficiencies gained from simultaneously being the actuator and the primary structure.

Amir Darabi and Michael J. Leamy, “Analysis and experimental verification of multiple scattering of acoustoelastic waves in thin plates for enhanced energy harvesting”, Smart Materials and Structures, Vol. 26, No. 8, 085015, August 2017
ABSTRACT: Acoustoelastic wave energy harvesting in thin plates and other structures has recently gained attention from the energy harvesting research community. Metamaterial-inspired concepts for enhancing wave power generation have been investigated, including metamaterial funnels, mirrors, and defect-based resonators. In support of such concepts, this paper presents an electromechanically coupled, multiple scattering formulation for accurately modeling, exploring, and optimizing metamaterial-based harvesting systems incorporating scatterers (e.g., cylindrical inclusions and voids). Following development, the formulation is applied to determining optimal arrangements of scatterers, nominally in a semi-elliptical path, which maximize electrical power harvested. This is done, in part, by diminishing side lobes resulting from ellipse truncation. Optimization results exhibit minimized side lobes and harvester power nearly ten times that of the non-optimized case. Finally, an experimental study is presented which confirms many of the model predictions.

ABSTRACT: Smart materials in auxetic form present a great potential for various medical applications due to their unique deformation mechanisms along with durable infrastructure. Both analytical and finite element (FE) models are extensively used in literature to characterize mechanical response of auxetic structures but these structures are mostly thick enough to be considered as bulk material and 3D inherently. Auxetic plates in very thin form, a.e. foil, may bring numerous advantages such as very light design and better biodegradability when needed. However, there is a gap in literature on mechanical characterization of auxetic thin plates. In this study, structural analysis of very thin auxetic plates under uniaxial loading is investigated using both FE method and experimental method. 25 μm thick stainless steel (316L) plates are fabricated with reentrant texture for three different unit cell dimensions and tested under uniaxial loading using universal testing machine. 25 and 50 μm thick sheets with same cell dimensions were analyzed using implicit transient FE model including strain hardening and failure behaviors. FE results cover all the deformation schemes seen in actual tests and total deformation level matches with test results. Effect of plate thickness and cell geometry on auxetic behavior is discussed in detail using FE results. Finally, based on FE analysis results, an optimum geometry for prolonged auxetic behavior, high flexibility and high durability is suggested for future potential applications.
sections are examined. An energy-based theoretical model is herein developed to predict the post-buckling response of non-prismatic beams. The total potential energy is minimized under constraints that represent the physical confinement of the beam between the lateral boundaries. The experimentally validated results show that changing the shape and geometric dimensions of non-uniform beams allows for the accurate controlling of the snap-through location at different buckling transitions. A 78.59% improvement in harvested energy levels has been achieved by optimization of beam shape.

Sahil Kaira, Bishakh Bhattacharya and B.S. Munjal, “Design of shape memory alloy actuated intelligent parabolic antenna for space applications”, Smart Materials and Structures, Vol. 26, No. 9, 095015, September 2017

ABSTRACT: The deployment of large flexible antennas is becoming critical for space applications today. Such antenna systems can be reconfigured in space for variable antenna footprint, and hence can be utilized for signal transmission to different geographic locations. Due to quasi-static shape change requirements, coupled with the demand of large deflection, shape memory alloy (SMA) based actuators are uniquely suitable for this system. In this paper, we discuss the design and development of a reconfigurable parabolic antenna structure. The reflector skin of the antenna is vacuum formed using a metalized polycarbonate shell. Two different strategies are chosen for the antenna actuation. Initially, an SMA wire based offset network is formed on the back side of the reflector. A computational model is developed using equivalent coefficient of thermal expansion (ECTE) for the SMA wire. Subsequently, the interaction between the antenna and SMA wire is modeled as a constrained recovery system, using a 1D modified Brinson model. Joule effect based SMA phase transformation is considered for the relationship between input voltage and temperature at the SMA wire. The antenna is modeled using ABAQUS based finite element methodology. The deflection found through the computational model is compared with that measured in experiment. Subsequently, a point-wise actuation system is developed for higher deflection. For power-minimization, an auto-locking device is developed. The performance of the new configuration is compared with the offset-network configuration. It is envisaged that the study will provide a comprehensive procedure for the design of intelligent flexible structures especially suitable for space applications.


ABSTRACT: Tracking edge-reflected acoustic emission (AE) waves can allow the localization of their sources. Specifically, in bounded isotropic plate structures, only one sensor may be used to perform these source localizations. The primary goal of this paper is to develop a three-step probabilistic framework to quantify the uncertainties associated with such single-sensor localizations. According to this framework, a probabilistic approach is first used to estimate the direct distances between AE sources and the sensor. Then, an analytical model is used to reconstruct the envelope of edge-reflected AE signals based on the source-to-sensor distance estimations and their first arrivals. Finally, the correlation between the probabilistically reconstructed envelopes and recorded AE signals are used to estimate confidence contours for the location of AE sources. To validate the proposed framework, Hsu-Nielsen pencil lead break (PLB) tests were performed on the surface as well as the edges of an aluminum plate. The localization results show that the estimated confidence contours surround the actual source locations. In addition, the performance of the framework was tested in a noisy environment simulated by two dummy transducers and an arbitrary wave generator. The results show that in low-noise environments, the shape and size of the confidence contours depend on the sources and their locations. However, at highly noisy environments, the size of the confidence contours monotonically increases with the noise floor. Such probabilistic results suggest that the proposed probabilistic framework could thus provide more comprehensive information regarding the location of AE sources.

ZhongZhe Dong, Cassio Faria, Martin Hromcik, Bert Pluymers, Michael Sebek and Wim Desmet, “Equivalent force modeling of macro fiber composite actuators integrated into non-homogeneous composite plates for dynamic applications”, Smart Materials and Structures, Vol. 26, No. 9, 095040, September 2017

ABSTRACT: Smart structures with integrated macro fiber composite (MFC) piezoelectric transducers have been increasingly investigated in engineering. A simple but elaborate system model of such smart structure not only can predict system dynamics, but also can reduce challenges in application. Therefore, the equivalent force

ABSTRACT: Multifunctional thin film materials have opened many opportunities for novel sensing strategies for structural health monitoring. While past work has established methods of optimizing multifunctional materials to exhibit sensing properties, comparatively less work has focused on their integration into fully functional sensing systems capable of being deployed in the field. This study focuses on the advancement of a scalable fabrication process for the integration of multifunctional thin films into a fully integrated sensing system. This is achieved through the development of an optimized fabrication process that can create a broad range of sensing systems using multifunctional materials. A layer-by-layer deposited multifunctional composite consisting of single walled carbon nanotubes (SWNT) in a polyvinyl alcohol and polysodium-4-styrene sulfonate matrix are incorporated with a lithography process to produce a fully integrated sensing system deposited on a flexible substrate. To illustrate the process, a strain sensing platform consisting of a patterned SWNT-composite thin film as a strain-sensitive element within an amplified Wheatstone bridge sensing circuit is presented. Strain sensing is selected because it presents many of the design and processing challenges that are core to patterning multifunctional thin film materials into sensing systems. Strain sensors fabricated on a flexible polyimide substrate are experimentally tested under cyclic loading using standard four-point bending coupons and a partial-scale steel frame assembly under lateral loading. The study reveals the material process is highly repeatable to produce fully integrated strain sensors with linearity and sensitivity exceeding 0.99 and 5 V/ε respectively. The thin film strain sensors are robust and are capable of high strain measurements beyond 3000 microstrain.


ABSTRACT: Composite structures exhibiting magnetoelectric (ME) coupling behavior have applications in various fields such as energy harvesting, sensors and actuators. ME coupling behavior is considered to occur by transfer of strain through bonding of the constituent phases of the ME composite. Here, the influence of thermal environment on the constitutive behavior of ferroic phases was examined, firstly by conducting experiments at various temperatures. To mimic the constitutive behavior of ferroic phases, constitutive models were built based on a thermodynamic framework. In order to account for thermal effects, appropriate functions were introduced to the formulation. Model parameters were chosen based on experimental data and simulation studies were performed. The obtained results were found to be in agreement with the experiments. Additionally, an attempt was made to capture the mechanical, electrical, magnetic and ME coupling behavior of composites. To capture the response of ME composites, a homogenization technique was employed along with the proposed constitutive relation for the constituent phases of an ME composite.

ABSTRACT: This work investigates the porosity-dependent nonlinear forced vibrations of functionally graded piezoelectric material (FGPM) plates by using both analytical and numerical methods. The FGPM plates contain porosities owing to the technical issues during the preparation of FGPMs. Two types of porosity distribution, namely, even and uneven distribution, are considered. A modified power law model is adopted to describe the material properties of the porous FGPM plates. Using D'Alembert's principle, the out-of-plane equation of motion is derived by taking into account the Kármán nonlinear geometrical relations. After that, the Galerkin method is used to discretize the equation of motion, resulting in a set of ordinary differential equations with respect to time. These ordinary differential equations are solved analytically by employing the harmonic balance method. The approximate analytical results are verified by using the adaptive step-size fourth-order Runge–Kutta method. By means of the perturbation technique, the stability of approximate analytical solutions is examined. An interesting nonlinear broadband vibration phenomenon is detected in the FGPM plates with porosities. Nonlinear frequency-response characteristics of the present smart structures are investigated for various system parameters including the porosity type, the porosity volume fraction, the electric potential, the external excitation, the damping and the constituent volume fraction. It is found that these parameters have significant effects on the nonlinear vibration characteristics of porous FGPM plates.


ABSTRACT: The incorporation of smart materials such as electroactive polymers and magnetoactive elastomers in origami structures can result in active folding using external electric and magnetic stimuli, showing promise in many origami-inspired engineering applications. In this study, 3D finite element analysis (FEA) models are developed using COMSOL Multiphysics software for three configurations that incorporate a combination of active and passive material layers, namely: (1) a single-notch unimorph folding configuration actuated using only external electric field, (2) a double-notch unimorph folding configuration actuated using only external electric field, and (3) a bifold configuration which is actuated using multi-field (electric and magnetic) stimuli. The objectives of the study are to verify the effectiveness of the FEA models to simulate folding behavior and to investigate the influence of geometric parameters on folding quality. Equivalent mechanical pressure and surface stress are used as external loads in the FEA to simulate electric and magnetic fields, respectively. Compared quantitatively with experimental data, FEA captured the folding performance of electric actuation well for notched configurations and magnetic actuation for a bifold structure, but underestimated electric actuation for the bifold structure. By investigating the impact of geometric parameters and locations to place smart materials, FEA can be used in design, avoiding trial-and-error iterations of experiments.


ABSTRACT: Reports indicated that impact events accounted for 47% of offshore pipeline failures, which calls for impact detection and localization for subsea pipelines. In this paper, an innovative method for rapid localization of impacts on underwater pipelines utilizing a novel determination technique for both arrival-time and group velocity (ATGV) of ultrasonic guided waves with lead zirconate titanate (PZT) transducers is described. PZT transducers mounted on the outer surface of a model pipeline were utilized to measure ultrasonic guided waves generated by impact events. Based on the signals from PZT sensors, the ATGV technique integrates wavelet decomposition, Hilbert transform and statistical analysis to pinpoint the arrival-time of the designated ultrasonic guided waves with a specific group velocity. Experimental results have verified the effectiveness and the localization accuracy for eight impact points along a model underwater pipeline. All estimations errors were small and were comparable with the wavelength of the designated ultrasonic guided waves. Furthermore, the method is robust against the low frequency structural vibration introduced by other external forces.

ABSTRACT: The paper presents a Hamiltonian approach for extracting the dynamic instability parameters of homogeneously deforming dielectric elastomer actuators subjected to an unequal biaxial prestress, and driven by a suddenly applied electric load. The approach relies on setting up the balance between the kinetic, strain, and electrostatic energy at the point of maximum overshoot in an oscillation cycle. The equation of the stagnation curve, obtained by invoking aforesaid statement of energy-balance, is operated upon by the condition of instability to determine the instability parameters. The underlying principles of the approach are elucidated by considering the Ogden family of hyperelastic material models. The approach is however portrayed generically, and hence, can be extended to the other hyperelastic material models of interest. The estimates of the dynamic instability parameters are corroborated by examining the saddle-node bifurcation points in the time-history response obtained by integrating the equation of motion. A parametric study is conducted to bring out the effect of unequal biaxial prestress, and the trends of variation of the critical electric field and the thickness-stretch on the onset of dynamic instability are presented. A quantitative comparison with the static instability parameters reveals that the dynamic instability gets triggered for electric fields that are lower than those corresponding to the static instability. In contrast, the maximum stretch experienced by the actuator at the dynamic instability is significantly higher than that at the static instability. The crucial inferences can find their potential use in the design of DEAs subjected to a transient motion.


ABSTRACT: This paper proposes a novel adaptive sun tracker which is constructed by hybrid unsymmetric composite laminates. The adaptive sun tracker could be applied on spacecraft solar panels to increase their energy efficiency through decreasing the inclined angle between the sunlight and the solar panel normal. The sun tracker possesses a large rotation freedom and its rotation angle depends on the laminate temperature, which is affected by the light condition in the orbit. Both analytical model and finite element model (FEM) are developed for the sun tracker to predict its rotation angle in different light conditions. In this work, the light condition of the geosynchronous orbit on winter solstice is considered in the numerical prediction of the temperatures of the hybrid laminates. The final inclined angle between the sunlight and the solar panel normal during a solar day is computed using the finite element model. Parametric study of the adaptive sun tracker is conducted to improve its capacity and effectiveness of sun tracking. The improved adaptive sun tracker is lightweight and has a state-of-the-art design. In addition, the adaptive sun tracker does not consume any power of the solar panel, since it has no electrical driving devices. The proposed adaptive sun tracker provides a potential alternative to replace the traditional sophisticated electrical driving mechanisms for spacecraft solar panels.

Shengwei Chen and Seok Chang Ryu, “Design and characterization of rounded re-entrant honeycomb patterns for lightweight and rigid auxetic structures”, Smart Materials and Structures, Vol. 26, No. 11, 115026, November 2017

ABSTRACT: In the past decades, auxetic structures have received great attention because of their unique properties and outstanding performance over the traditional materials. However, the inherent porosity significantly reduce the moduli of the structures, making auxetic structures inappropriate for load-bearing components. This paper introduces a rounded re-entrant honeycomb (RH) pattern, in which the rounded corners stiffen the traditional RH pattern by suppressing the hinging mechanism. Four design parameters were identified to define a rounded RH unit cell, and the effect of each of them on structure properties was numerically studied. The results demonstrated the extended tunable range of mechanical properties and the possibility of building lightweight and stiffer structures, as well as significantly improved tensile and shear moduli. It is also noticed that the Poisson's ratio shifts towards positive as the radius of the rounded corner increases. Several design strategies were proposed for achieving different design goals. The proposed rounded RH pattern could be an alternative for the existing RH pattern design, especially in the applications requesting for the lightweight and rigid auxetic structure.
Masoud Hemmatian and Ramin Sedaghati, “Vibro-acoustic topology optimization of sandwich panels partially treated with MR fluid and silicone rubber core layer”, Smart Materials and Structures, Vol. 26, No. 12, 125015, December 2017

ABSTRACT: This study aims to investigate the topology optimization of sandwich panels partially treated with magnetorheological (MR) fluid and silicone rubber core layer. The finite element (FE) model of the partially treated sandwich panel has been developed using circular and 4-node quadrilateral elements. The FE model is then utilized to solve the free and forced vibration equations of motion to obtain the natural frequencies, loss factors and sound transmission loss (STL), respectively. Systematic parametric studies on the effect of the position of the MR fluid and silicone rubber on the first axisymmetric natural frequency, the corresponding loss factor and also the STL are presented. It has been shown that the vibrational and acoustical behavior of the sandwich panel changes considerably as the location of the MR treatment changes. To conduct optimization problems efficiently without using the full FE model, linear meta-models have been derived using random and D-optimal design points. The developed meta-models are then utilized to solve the topology optimization problems using the genetic algorithm and integer programming methods. The suitability of the identified optimal candidates are further evaluated using the developed FE model to determine the optimized topology for the constraint and unconstraint problems.

S.C. Kattimani, “Active damping of multiferroic composite plates using 1-3 piezoelectric composites”, Smart Materials and Structures, Vol. 26, No. 12, 125021, December 2017

ABSTRACT: A layer-wise shear deformation theory is used to analyze the smart damping of multiferroic composite or magneto-electro-elastic (MEE) plates. The intent of this analysis is to investigate the need for incorporating additional smart elements for controlling the vibrations of multiferroic composite plates. Active constrained layer damping (ACLD) treatment has been incorporated to alleviate the vibration of MEE plate. A layer of viscoelastic material is used as constrained layer for the ACLD treatment. The coupled constitutive equations of multiferroic (ferroelectric and ferromagnetic) composite materials along with the total potential energy principle are used to derive the finite element formulation for the overall multiferroic or MEE plate. Maxwell's electrostatic and electromagnetic relations are used to compute the electric and magnetic potential distribution. Influence of obliquely reinforced piezoelectric fibers in the piezoelectric layer of the ACLD treatment has also been investigated. In order to investigate the importance of using ACLD treatment for an active damping of multiferroic or MEE plate, an active control of MEE plate has also been analyzed by providing the control voltage directly to the piezoelectric layers of the MEE substrate plate without using the ACLD treatment. The present study suggests that for an optimal control of MEE plates, the smartness element such as the ACLD treatment is essentially required.


ABSTRACT: Compliance-based morphing structures have the potential to offer large shape adaptation, high stiffness and low weight, while reducing complexity, friction, and scalability problems of mechanism based systems. A promising class of structure that enables these characteristics are multi-stable structures given their ability to exhibit large deflections and rotations without the expensive need for continuous actuation, with the latter only required intermittently. Furthermore, multi-stable structures exhibit inherently fast response due to the snap-through instability governing changes between stable states, enabling rapid configuration switching between the discrete number of programmed shapes of the structure. In this paper, the design and utilisation of the inherent nonlinear dynamics of bi-stable twisting I-beam structures for actuation with low strain piezoelectric materials is presented. The I-beam structure consists of three compliant components assembled into a monolithic single element, free of moving parts, and showing large deflections between two stable states. Finite element analysis is utilised to uncover the distribution of strain across the width of the flange, guiding the choice of positioning for piezoelectric actuators. In addition, the actuation authority is maximised by calculating the generalised coupling coefficient for different positions of the piezoelectric actuators. The results obtained are employed to tailor and test I-beam designs exhibiting desired large deflection between stable states, while still enabling the activation of snap-through with the low strain piezoelectric actuators. To this end, the dynamic response of the I-beams to piezoelectric excitation is investigated, revealing that resonant excitations are insufficient to dynamically trigger snap-through. A novel bang–bang control strategy, which exploits the nonlinear dynamics of the structure successfully triggers both single and constant snap-through between the
stable states of the bi-stable twisting I-beam structures. The obtained optimal piezoelectric actuator positioning is not necessarily intuitive and when used with the proposed dynamic actuation strategy serve as a blueprint for the actuation of its. We have developed an optical fiber distributed sensing system based on optical frequency domain reflectometry (OFDR) that uses long-length fiber Bragg gratings (FBGs). This technique obtains strain data not as a point data from an FBG but as a distributed profile within the FBG. This system can measure the strain distribution profile with an adjustable high spatial resolution of the mm or sub-mm order in real-time. In this study, we applied this OFDR-FBG technique to a flying test bed that is a mid-sized jet passenger aircraft. We conducted flight tests and monitored the structural responses of a fuselage stringer and the bulkhead of the flying test bed during flights. The strain distribution variations were successfully monitored for various events including taxiing, takeoff, landing and several other maneuvers. The monitoring was effective not only for measuring the strain amplitude applied to the individual structural parts but also for understanding the characteristics of the structural responses in accordance with the flight maneuvers. We studied the correlations between various maneuvers and strains to explore the relationship between the operation and condition of aircraft.uch multi-stable compliant structures to produce fast and large deflections with highly embeddable actuators. This class of structures has potential applications in aerospace systems and soft/compliant robotics.

Daichi Wada, Hirotaka Igawa, Masato Tamayama, Tokio Kasai, Hitoshi Arizono, Hideaki Murayama and Katsuy Shiotsubo, “Flight demonstration of aircraft fuselage and bulkhead monitoring using optical fiber distributed sensing system”, Smart Materials and Structures, Vol. 27, No. 2, 025014, February 2018

ABSTRACT: We have developed an optical fiber distributed sensing system based on optical frequency domain reflectometry (OFDR) that uses long-length fiber Bragg gratings (FBGs). This technique obtains strain data not as a point data from an FBG but as a distributed profile within the FBG. This system can measure the strain distribution profile with an adjustable high spatial resolution of the mm or sub-mm order in real-time. In this study, we applied this OFDR-FBG technique to a flying test bed that is a mid-sized jet passenger aircraft. We conducted flight tests and monitored the structural responses of a fuselage stringer and the bulkhead of the flying test bed during flights. The strain distribution variations were successfully monitored for various events including taxiing, takeoff, landing and several other maneuvers. The monitoring was effective not only for measuring the strain amplitude applied to the individual structural parts but also for understanding the characteristics of the structural responses in accordance with the flight maneuvers. We studied the correlations between various maneuvers and strains to explore the relationship between the operation and condition of aircraft.

Yangyiwei Yang, Yuanbo Li, Yaqian Guo, Bai-Xiang Xu and Tongqing Yang, “Improved vibration-based energy harvesting by annular mass configuration of piezoelectric circular diaphragms”, Smart Materials and Structures, Vol. 27, No. 3, 035004, March 2018

ABSTRACT: Vibration-based energy harvesting using piezoelectric circular diaphragms (PCDs) with a structure featuring the central mass (C-mass) configuration has drawn much attention in recent decades. In this work, we propose a new configuration with the annular proof mass (A-mass) where an improved energy harvesting is promised. The numerical analysis was employed using the circuit-coupled piezoelectric simulation, and the experimental validation was implemented using PCDs with the even-width annular electrodes. Samples with different mass configurations as well as structural parameters \( \omega_1 \) and \( \omega_2 \), which indicate the ratio between the inner boundary radius and piezoelectric ceramic radius as well as the ratio between outer boundary radius and the substrate radius, respectively, were prepared and tested. The impedance-matched output power of full-electrode PCDs was also collected, and some distinct improvement was measured on samples with the certain structural parameters. The power increases from 14.1 mW to 19.0 mW after changing the configuration from C-mass to A-mass with the same parameters \(( \omega_1, \omega_2 ) = (0.16, 0.9)\), showing the considerable improvement in energy harvesting by using A-mass configuration.


ABSTRACT: This paper considers utilizing solar radiation pressure (SRP) to actively control the surface shape of a reflector consisting of a rigid hoop and slack membrane with embedded reflectivity control devices. The full nonlinear static partial differential governing equations for a reflector with negligible elastic deformations are established for the circumferential, radial and transverse directions respectively, in which the SRP force
with ideal/non-perfect models, the centripetal force caused by the rotation of the reflector and the internal stresses are considered. The inverse problem is then formulated by assuming that the required surface shape is known, and then the governing algebraic-differential equations used to determine the required surface reflectivity, together with the internal stresses where are presented accordingly. The validity of the approach is verified by comparing the results in this paper with corresponding published results as benchmarks. The feasible regions of the angular velocity and Sun angle for a paraboloidal reflector with an invariant radius and focal length (case 1), and the achievable focal lengths with a specific angular velocity and Sun angle (case 2) are presented for two SRP models respectively, both by considering the constraints on the reflectivity and internal stresses. It is then found that the feasible region is toward a larger angular velocity and Sun angle when using the non-perfect SRP model, compared with the ideal one in case 1. The angular velocity of the spinning reflector should be within a certain range to make the required reflectivity profiles within a practical range, i.e., [0, 0.88], as indicated from prior NASA solar sail studies. In case 2, it is found that the smallest achievable focal length of the reflector with the non-perfect SRP model is smaller than that with the ideal SRP model. It is also found that the stress level is extremely low for all cases considered and that the typical real material strength available for the reflector is sufficient to withstand these internal stresses.

ABSTRACT: Structural health monitoring (SHM) using ultrasonic guided waves has proven to be attractive for the identification of damage in composite plate-like structures, due to its realization of both significant propagation distances and reasonable sensitivity to defects. However, topographical features such as bends, lap joints, and bonded stiffeners are often encountered in these structures, and they are susceptible to various types of defects as a consequence of stress concentration and cyclic loading during the service life. Therefore, the health condition of such features has to be assessed effectively to ensure the safe operation of the entire structure. This paper proposes a novel feature guided wave (FGW) based SHM strategy, in which proper FGWs are exploited as a screening tool to rapidly interrogate the representative stiffener-adhesive bond-composite skin assembly. An array of sensors permanently attached to the vicinity of the feature is used to capture scattered waves from the localized damage occurring in the bond line. This technique is combined with an imaging approach, and the damage reconstruction is achieved by the synthetic focusing algorithm using these scattered signals. The proposed SHM scheme is implemented in both the 3D finite element simulation and the experiment, and the results are in good agreement, demonstrating the feasibility of such SHM strategy.

Yu Chen, Bin-Bin Zheng, Ming-Hui Fu, Lin-Hua Lan and Wen-Zhi Zhang, “Doubly unusual 3D lattice honeycomb displaying simultaneous negative and zero Poisson’s ratio properties”, Smart Materials and Structures, Vol. 27, No. 4, 045003, April 2018
ABSTRACT: In this paper, a novel three-dimensional (3D) lattice honeycomb is developed based on a two-dimensional (2D) accordion-like honeycomb. A combination of theoretical and numerical analysis is carried out to gain a deeper understanding of the elastic behavior of the new honeycomb and its dependence on the geometric parameters. The results show that the proposed new honeycomb can simultaneously achieve an in-plane negative Poisson's ratio (NPR) effect and an out-of-plane zero Poisson's ratio (ZPR) effect. This unique property may be very promising in some important fields, like aerospace, piezoelectric sensors and biomedicine engineering. The results also show that the geometric parameters, such as the slant angle, the strut thickness and the relative density, have a significant effect on the mechanical properties. Additionally, different dominant deformation models of the new honeycomb when compressed along the x (or y) and z directions are identified. This work provides a new concept for the design of honeycombs with a doubly unusual performance.

Chung-De Chen, “A distributed parameter electromechanical model for bimorph piezoelectric energy harvesters based on the refined zigzag theory”, Smart Materials and Structures, Vol. 27, No. 4, 045009, April 2018
ABSTRACT: In this paper, a distributed parameter electromechanical model for bimorph piezoelectric energy harvesters based on the refined zigzag theory (RZT) is developed. In this model, the zigzag function is incorporated into the axial displacement, and the zigzag distribution of the displacement between the adjacent layers of the bimorph structure can be considered. The governing equations, including three equations of motions and one equation of circuit, are derived using Hamilton’s principle. The natural frequency, its
corresponding modal function and the steady state response of the base excitation motion are given in exact forms. The presented results are benchmarked with the finite element method and two beam theories, the first-order shear deformation theory and the classical beam theory. Comparing examples shows that the RZT provides predictions of output voltage and generated power at high accuracy, especially for the case of a soft middle layer. Variation of the parameters, such as the beam thickness, excitation frequencies and the external electrical loads, is investigated and its effects on the performance of the energy harvesters are studied by using the RZT developed in this paper. Based on this refined theory, analysts and engineers can capture more details on the electromechanical behavior of piezoelectric harvesters.

Yilin Zhu, Zhen-Pei Wang and Leong Hien Poh, “Auxetic hexachiral structures with wavy ligaments for large elasto-plastic deformation”, Smart Materials and Structures, Vol. 27, No. 5, 055001, May 2018

ABSTRACT: The hexachiral structure is in-plane isotropic in small deformation. When subjected to large elasto-plastic deformation, however, the hexachiral structure tends to lose its auxeticity and/or isotropy—properties which are desirable in many potential applications. The objective of this study is to improve these two mechanical properties, without significantly compromising the effective yield stress, in the regime with significant material and geometrical nonlinearity effects. It is found that the deformation mechanisms underlying the auxeticity and isotropy properties of a hexachiral structure are largely influenced by the extent of rotation of the central ring in a unit cell. To facilitate the development of this deformation mechanism, an improved design with wavy ligaments is proposed. The improved performance of the proposed hexachiral structure is demonstrated. An initial study on possible applications as a protective material is next carried out, where the improved hexachiral design is shown to exhibit higher specific energy absorption capacity compared to the original design, as well as standard honeycomb structures.

Jianxun Cui, John G.M. Adams and Yong Zhu, “Controlled bending and folding of a bilayer structure consisting of a thin stiff film and a heat shrinkable polymer sheet”, Smart Materials and Structures, Vol. 27, No. 5, 055009, May 2018

ABSTRACT: Bending pre-designed flat sheets into three-dimensional (3D) structures is attracting much interest, as it provides a simple approach to make 3D devices. Here we report controlled bending and folding of a bilayer structure consisting of a heat shrinkable polymer sheet and a thin stiff film (not thermally responsive). Upon heating, the prestrained polymer sheet shrinks, leading to bending or folding of the bilayer. We studied the effect of relative dimensions of the two layers on the bending behavior and demonstrated the transition from longitudinal bending to transverse bending of the bilayer strip. Transverse bending was utilized to fold origami structures, including several flat letters, a crane, and a corrugated metal sheet via Miura-ori folding. We developed a method to further control the bending orientation based on bio-inspired anisotropic bending stiffness. By bending the metal foil in different orientations, several structures were obtained, including cylindrical surfaces and left-handed/right-handed helical structures.

Yunpeng Wang, Xinglong Gong and Shouhu Xuan, “Study of low-velocity impact response of sandwich panels with shear-thickening gel cores”, Smart Materials and Structures, Vol. 27, No. 6, 065008, June 2018

ABSTRACT: The low-velocity impact response of sandwich panels with shear-thickening gel cores was studied. The impact tests indicated that the sandwich panels with shear-thickening gel cores showed excellent properties of energy dissipation and stress distribution. In comparison to the similar sandwich panels with chloroprene rubber cores and ethylene-propylene-diene monomer cores, the shear-thickening gel cores led to the obviously smaller contact forces and the larger energy absorptions. Numerical modelling with finite element analysis was used to investigate the stress distribution of the sandwich panels with shear-thickening gel cores and the results agreed well with the experimental results. Because of the unique mechanical property of the shear-thickening gel, the concentrated stress on the front facesheets were distributed to larger areas on the back facesheets and the peak stresses were reduced greatly.


ABSTRACT: The natural modes as well as the aeroelastic stability of a plate with attached piezoelectric material in response to a change in electric potential are studied. A finite element model is developed based on
the classical lamented plate theory. The piezoelectric stiffening effect is obtained using the concept of a change in geometric stiffness. Three piezoelectric configurations are considered in the present work: (1) with the piezoelectric actuators covering the whole plate, (2) with the piezoelectric actuators covering a portion of the plate near the clamped support, and (3) with the piezoelectric actuators covering a portion of the plate near the free end. In all the three cases, the piezoelectric sheets cover the plate on both sides. The second configuration is effective in stiffening the plate, while the first and third configurations are effective in buckling the plate. We also find the piezoelectric force has a significant effect on wing natural modes and aeroelastic stability. An increase in negative applied voltage can increase the aeroelastic stability, while increasing the positive voltage can decrease the plate stability. The piezoelectric effect on the plate torsional modes is more significant than its effect on its bending modes. The selection of the piezoelectric material configuration as well as the applied voltage is important for stiffening or weakening a plate.

P. Chatterjee and M. Bryant, “Aeroelastic-photovoltaic ribbons for integrated wind and solar energy harvesting”, Smart Materials and Structures, Vol. 27, No. 8, 08LT01, August 2018

ABSTRACT: This letter investigates the energy harvesting capabilities of a novel hybrid wind and solar transduction device. The proposed device is an inverted-U shaped structure with a pair of piezoelectric benders connected by a flexible, tensioned photovoltaic ribbon. The tensioned photovoltaic ribbon member undergoes aeroelastic flutter limit cycle oscillations (LCOs) at low wind speeds, leading to time-varying tension forces applied to the piezoelectric benders, producing cyclic deflections and output voltage. Experimental characterization of the proof of concept energy harvester indicates that it is possible to obtain several milliwatts (mW) of power using the centimeter scale device, with an output power of ~12.1 mW at a combination of 12 m s\(^{-1}\) wind speed and 100 W m\(^{-2}\) of solar irradiance, for indirect solar applications. It is shown here that an optimal combination of applied tensile preload and preset angle of attack exists which produces the highest wind power output of the system. An explanation of this behavior is also provided through the analysis of data collected on the photovoltaic ribbon velocity, piezoelectric voltage signals, and high-speed imagery, providing further insight to the motion kinematics of the highly nonlinear system response. Interestingly, the solar power output has been observed to remain invariant with increasing vibration velocity. This suggests that the gain in solar power efficiency from vibration-induced convective cooling negates any losses from the deflected incidence angle of the photovoltaic ribbon. These results illustrate that there is a negligible performance penalty in adding wind energy harvesting capability to the solar cells with this device concept.

Bin-Bin Zheng, Ming-Hui Fu, Wei-Hua Li and Ling-Ling Hu, “A novel re-entrant honeycomb of negative thermal expansion”, Smart Materials and Structures, Vol. 27, No. 8, 085005, August 2018

ABSTRACT: By strengthening the pore with material different from that of matrix, a new type of negative thermal expansion materials with the re-entrant hexagonal honeycomb is designed in this paper. The equivalent Young's modulus, Poisson's ratio and the coefficient of thermal expansion (CTE) are studied by using Timoshenko beam theory and the analytical formulas of these equivalent parameters are derived. The results of analytical formulas and numerical simulation indicate that the CTE of the material can be controlled from positive to negative by changing the geometry features and material properties of the structure. Meanwhile, the negative Poisson's ratio effect of the original re-entrant honeycomb can be preserved. Moreover, this method for designing new metamaterials has also been generalized to three-dimensional materials.


ABSTRACT: Macro fiber composite (MFC) actuators developed by the NASA have been increasingly used in engineering structures due to their high actuation power, compatibility, and flexibility. In this study, an efficient two dimensional quadratic multi-layer shell element by using first order shear deformation theory (FOSDT) is developed to predict the linear strain–displacement static deformation of laminated composite plates induced by MFC actuators. FOSDT is adapted from the Reissner–Mindlin plate theory. An eight-node quadratic piezoelectric multi-layer shell element with five degrees of freedom is introduced to prevent locking effect and zero energy modes observed in nine-node degenerated shell element. Two types of MFC actuators are used: (1) MFC-\(d_1\), and (2) MFC-\(d_2\), which differ in their actuation forces. For result verification, the electromechanically coupled quadratic finite element (FE) model is compared with the ABAQUS results in various
examples. Comparison of the results showed good agreement. The proposed quadratic FE formulation is simple and accurate, which eliminates the need for costly FE commercial software packages. It was observed that earlier studies have mostly emphasized on the effect of actuation power and MFC fiber orientations on mechanical shape deformation of smart composite plates. In this study, a more comprehensive, in-depth investigation is conducted into host structure performance such as boundary conditions, laminate stacking sequence configuration, and symmetry/asymmetry layups.

Shubao Shao, Siyang Song, Minglong Xu and Wenjian Jiang, “Mechanically reconfigurable reflector for future smart space antenna application”, Smart Materials and Structures, Vol. 27, No. 9, 095014, September 2018
ABSTRACT: Smart space antennas with mechanically reconfigurable reflectors (MRRs) not only compensate for shape errors induced by distortions in the reflector but, depending on the purpose, also change the service coverage area on the ground with the reshaped reflector. Although several simulation studies regarding different types of MRRs have been performed in the past few years, MRR designs are few because of the difficulty in developing a reflector with the proper mechanical properties and actuators with sufficient drive capacity. Managing the array of actuators is also an issue, particularly in space applications. This paper presents a prototype of a MRR system that consists of a flexible reflector, an actuator array, and a servo controller. The reflector is a layered structure of simple construction with capability of flexible tailoring of its mechanical properties for reshaping. Piezoelectric inchworm actuators were developed, each with large driving stroke and load capacity. Thirteen actuators attached to the back of the reflector provide specified linear displacements that adjust the surface shape of the reflector. To reduce the overall size of the MRR prototype system and the operating power, a distributed time-sharing control strategy was designed to control the actuator array. For a given target shape, the actuation values of the array were optimized. The optimization algorithm and reconfiguration of the MRR prototype were validated in experiments where two different target shapes with extreme deformations and curvatures are specified.

ABSTRACT: This paper investigates the dynamic response of a clamped-free CNT-reinforced-MRE beam which is actuated by the combination of a constant and a harmonic time-dependent magnetic field. Using Hamilton's principle, the equation of motion has been obtained and discretized using the Galerkin method. This procedure transforms the governing PDE equation of motion into a nonlinear ODE equation in the form of the nonlinear Mathieu equation with cubic damping. Then, the method of multiple scales is employed to obtain the dynamic response of the system. Furthermore, a stability analysis is also performed and the effects of a magnetic field on the dynamic response and stability of the system is investigated. The stability analysis shows that as the amplitude of the constant magnetic field is increased, the stable region decreases. Also, a numerical bifurcation analysis has been performed and Feigenbaum diagrams are obtained, indicating that when the constant magnetic field is less than the harmonic one, the system approaches greater amplitudes and undergoes more chaos, and vice versa.

S. Xiang and X-F Li, “Elasticity solution of the bending of beams with the flexoelectric and piezoelectric effects”, Smart Materials and Structures, Vol. 27, No. 10, 105023, October 2018
ABSTRACT: This paper studies the bending behavior of a nanoscale elastic beam with flexoelectric and piezoelectric effects. Based on a two-dimensional theory of piezoelectricity and flexoelectricity, an exact elasticity solution is derived when applied transverse mechanical loading and/or electric potential difference between the top and bottom surfaces are prescribed. Obtained results may apply to not only pure piezoelectric beams without flexoelectricity only if setting all flexoelectric coefficients to zero but also beams of isotropic material with flexoelectricity only if setting all piezoelectric coefficients to zero. The solution can be taken as a benchmark solution of related models of beams as actuators, generators, etc. The influences of piezoelectricity and flexoelectricity on the transverse deflection, stress distribution and electric polarization are analyzed. Flexoelectricity plays a crucial role in altering bending deflection, electric polarization for a single homogeneous simply supported beam. The deflection and electric polarization of a beam with both piezoelectric and flexoelectric effects are not the sum of the corresponding ones of a purely piezoelectric beam and a purely flexoelectric beam.
Eliana Bortot, “Nonlinear dynamic response of soft thick-walled electro-active tubes”, Smart Materials and Structures, Vol. 27, No. 10, 105025, October 2018
ABSTRACT: Soft electro-active tubes are promising electromechanical transducers. Practical applications of such devices involve periodic loading cycles at high frequency and large strains. Hence, the understanding of their dynamic behaviour is important for an effective design. In this work, the dynamic response of soft thick-walled electro-active tubes, subjected to harmonic or suddenly applied constant electric loads, is theoretically studied within the framework of finite elastodynamics.

ABSTRACT: Current gossamer space structures such as solar sails usually rely on bracing structures, inflation gas, or centrifugal force to deploy and maintain a structural shape, which leads to a system that is sometimes complicated, while a concise system can be achieved if the gossamer structure could self-rigidise and support load. The present study proposes a self-folding polymer membrane based on space-qualified materials and is potentially mass-producible by industrial roll-to-roll processes. It can permanently transform a flat gossamer membrane into a load-bearing 3D configuration when heated by sunlight in space, while the folding-induced shape bifurcation and buckling are prevented using a kirigami hinge design. The shape transformation is demonstrated in lab by a tubular and an origami structure that are formed from a flat membrane when heated to 82 °C in oven. Thermal radiation analyses have also verified the feasibility of sunlight-activated folding in space when vapour-deposited metallic coatings are applied onto the hinges. The proposed material offers a new generation of gossamer space membrane that can automatically morph from a stowed configuration to a load-bearing structure, and potentially provide built-in functionalities.

Rafic M. Ajaj and Michael I. Friswell, “Aeroelasticity of compliant span morphing wings”, Smart Materials and Structures, Vol. 27, No. 10, 105052, October 2018
ABSTRACT: A low-fidelity aeroelastic model is developed to study the dynamic behaviour of uniform, cantilever span morphing wings. The wing structure is modelled using the shape functions of the bending and torsional modes of a uniform cantilever wing according to the Rayleigh–Ritz method. Theodosen's unsteady aerodynamic theory is used to model the aerodynamic loads. A Padé approximation for the Theodorsen's transfer function is utilised to allow time-domain simulation and analysis. The sensitivity of the aeroelastic behaviour of span morphing wings to different geometric parameters and mechanical properties is considered. Furthermore, the impact of morphing rate on the aeroelastic behaviour is studied. Finally, the use of two novel span morphing concepts for flutter suppression is assessed.

Katherine S. Riley, Hortense Le Ferrand and Andres F. Arrieta, “Modeling of snapping composite shells with magnetically aligned bio-inspired reinforcements”, Smart Materials and Structures, Vol. 27, No. 11, 114003, November 2018
ABSTRACT: Materials capable of exhibiting inherent morphing are rare and typically reliant on chemical properties. The resulting diffusion-driven shape adaptability is slow and limited to specific environmental conditions. In contrast, natural composites, such as those found in carnivorous plants, have evolved hierarchical architectures displaying remarkably fast adaptation in response to environmental stimuli. These biological materials have inspired the fabrication of snapping composite shells through the careful design of the internal microstructure of synthetic materials by magnetic alignment of reinforcements. The ability to accurately model such programmable materials using finite element analysis (FEA) is necessary to facilitate the design optimization of the resulting structures. Using similar material parameters as explored in previous experimental studies, we employ nonlinear FEA to investigate the effects of introducing curvilinear spatially distributed micro-reinforcements on the deformation of a shell with an unusual bioinspired geometry. The FEA model is subject to experimental validation with magnetically aligned specimens. Comparison to a traditional [90/0] composite layup demonstrates the advantages of magnetically aligned reinforcements to achieve complex, snapping morphing structures with tailored characteristics.
ABSTRACT: Vibration-based energy harvesting may hold tremendous impact for future applications of continuous machine and structural health monitoring. Here a novel resonant frequency tuning approach is proposed where the application of a bias voltage to a pre-stretched electroactive polymer (EAP) membrane results in changes in membrane tension which can be used to adjust the resonant frequency of the membrane. The effect of the bias voltage on the EAP membrane, which induces an electrostatic pressure and corresponding reduction in membrane thickness, is determined via an analytical model of the activation response of the EAP membrane, with the results confirmed using FEM simulation in ANSYS. Through a mass-loaded circular membrane vibration model, the effective resonant frequency of the membrane can be determined as a function of changes in membrane tension due to the applied bias voltage. In the case of an EAP membrane, pre-stretch contributes to the mechanical stiffness of the system while the applied bias voltage contributes to a change in electrical stiffness of the membrane. Experimental characterization of the EAP material VHB 4910 from 3 M verified the resonant frequencies corresponding to the bias voltages predicted from the appropriate models. Given an effective system stiffness range between 598 N m\(^{-1}\) (when \(\lambda = 1.5, \ U = 0\)) and 266 N m\(^{-1}\) (when \(\lambda = 5, \ U = 5000\)), the corresponding resonant frequency tuning range for a particular circular central loaded EAP membrane device is between 31.4 to 21.8 Hz. The proposed bias voltage tuning approach for the EAP membrane may provide a novel strategy to enable resonant frequency tuning of energy harvesting devices in particular application environments.


ABSTRACT: In this paper, the bending behavior of an active SMA-based beam, made up of a NiTi alloy strip externally joined to a PA66-GF30 polymeric lamina, is examined. Firstly, experimental investigations were conducted in a purpose-built test bench where a forced airflow promoted the reverse and forward phase transformations of the NiTi strip via heating and cooling ramps. The macroscopic shape changes associated with the shape memory effect deforms the structure in the cantilevered condition. The evolution of the shape memory behavior was investigated via digital image analysis, performed at both the end of heating and the end of the thermal cycle on cooling. Next, a theoretical prediction combining the classical beam model for bending with the assumption of incomplete recovery upon cooling was developed. The theoretical results indicate good agreement with experimental data showing how the proposed approach can be effectively used to predict the behavior in bending of SMA-based actuator working in controlled recovering condition.

S. Sudersan, S. Maniprakash and A. Arockiarajan, “Nonlinear magnetoelectric effect in unsymmetric laminated composites”, Smart Materials and Structures, Vol. 27, No. 12, 125005, December 2018

ABSTRACT: This work is aimed at the development of a finite element formulation for the analysis of unsymmetric magneto-electric (ME) laminated structures. While analytical solutions are readily available for symmetric structures, the coupling between axial and bending deformations in unsymmetric structures impedes such an analytical solution thus motivating the search for a numerical solution. The proposed finite element model includes this coupling under Euler–Bernoulli assumptions and further includes the material nonlinearity exhibited by the ferromagnetic phase. The enhancement of the ME coefficient under resonant conditions has also been studied under bending and axial resonant regimes. Resonant ME coefficients of magnitude at least 30 times higher than the quasi-static values were estimated. A parametric study has also been performed with the aim of optimizing the ME coefficient with respect to the applied DC bias field, operating frequency, volume fraction and the modulus ratio of the constituents and the different boundary conditions. The boundary conditions yielding a cantilever configuration were found to offer the least bending resonant frequency and the highest axial resonant ME coefficient, thus proving to be the most viable in practice.
ABSTRACT: Core panels made of origami structures provide effective force redistribution and energy dissipation. A wide range of origami patterns is proposed to create three-dimensional panels, which can be used as sandwich cores. The origami tessellation mainly consists of unit cells made of small faces joined together through crease lines. Ron-Resch is an origami pattern composed of star pleats joined together that exhibits pronounced shape flexibility and geometry forming as well as potential mechanical performance. These advantages can be employed for load dissipation and damping due to its high deformation and strain values. This study focuses on three different Ron-Resch-like origami tessellations based on the star pleat's number of branches and the area of internal facets of the star pleat. An additive manufacturing technique was used to manufacture the tested samples from polylactic acid filament. In addition, compression and impact tests were conducted to evaluate the effect of the folding angle for three different angles and then the results have been discussed. The ANSYS finite element package was used to numerically simulate the compression and impact events. Moreover, the study includes investigation of the shape memory effect based on the shape recovery of the unit element of the Ron-Resch-like origami tessellation.


ABSTRACT: This paper proposes a T-shaped cantilever energy harvester powered by flow-induced torsional vibration. To collect and convert the mechanical (kinetic) energy into electric power, a pair of symmetrical acrylic cylindrical bluff bodies were installed onto the bottom surface of the T-shaped cantilever beam, one at each end. There is also one patch of Macro Fibre Composite (MFC) used as an energy collector and converter which was attached to the fixed end of the cantilever beam. This proposed setup of the energy harvester is able to generate sustainable electric power by harvesting natural mechanical power resulted from the torsional vibration of the beam due to fluid's vortex shedding effects. The proposed energy harvester has the novelty in that our approach harvests fluid flow's energy in a reciprocal fashion making full use of renewable energy incurred in areas surrounding the two bluff bodies. Both the theoretical and experimental analyses on the proposed energy harvesting structure were performed and demonstrated in this paper. The case in the test rig we studied on the proposed energy harvester was able to generate sustainable electric power of approximately 1.0 \( \mu \text{W} \) when flow speed was measured to be 0.33 m s\(^{-1}\) flowing through two bluff bodies each of 29.5 mm diameter. This work also looks into and discusses pros and cons of various scenarios in terms of structural geometric variations for system optimization of the proposed energy harvester.


ABSTRACT: A comprehensive study is provided to compare the results of layer-wise theory (LWT) with one of the renowned equivalent single layer beam theories (ESLs) known as First-Order shear deformation beam theory (FOBT) on the study of transient nonlinear dynamic response of an SMA reinforced composite beam. Considering von Karman strain–displacement formulations, the governing equations of forced vibrations under transient impulsive loads are formulated by LWT and ESL methods. In order to simulate the constitutive behavior of SMA wires, the 3D SMA model developed by Panico and Brinson is adopted and reduced to a 1D model which enables one to reproduce pseudo-elastic (PE), martensite transformation/orientation and in particular ferro-elastic (FE) effects. General transient transverse loading is considered and the governing equations are discretized by combined method of differential–integral quadratures (DQ-IQ). Based on Newmark time marching technique, an incremental solution algorithm is developed for the problem in which nonlinear governing equations are solved by Newton–Raphson method. The results are assessed by comparing with available literature. Moreover, the FOBT and layerwise solutions are compared with each other and the effects of layup geometry and boundary conditions upon the composite beam responds are explored. The influence of volume fraction of SMA-wire reinforcements and the FE/PE behaviors of the wires upon the diverging results of FOBT/LWT analyses are studied in detail.

ABSTRACT: This paper proposes a novel origami-inspired cube pipe structure driven by magnetic force, and investigates its deformation and trigger force using experimental and numerical methods. The cube pipe is made of polyethylene terephthalate and its hinge parts are attached by bistable anti-symmetric carbon fibre-reinforced polymer shells with magnets. The magnetic force is generated by an electromagnet and applied on the shell's curve edge, which implements the stable state transformation of the bistable shells as well as that of the cube pipe. The required magnetic force for the snap-through process of the structure is experimentally obtained and the results agree well with the finite element results. This novel origami pipe can be extensively used in engineering fields, owing to the fact that the stable state can be transformed by a noncontact method and it can be maintained without external force.

Oleg Testoni, Andrea Bergamini, Sampada Bodkhe and Paolo Ermanni (Primarily from: CMASLab, ETH Zurich, Zurich, Switzerland), “Smart material based mechanical switch concepts for the variation of connectivity in the core of shape-adaptable sandwich panels”, Smart Materials and Structures, Vol. 28, No. 2, 025036, February 2019, https://doi.org/10.1088/1361-665X/aafa40

ABSTRACT: Smart material based variable internal connectivity has the potential to overcome the inherent conflicting requirements of lightweight shape adaptable structures by reducing the actuation force required for shape adaptation, and, consequently, volume and mass of the actuation system, by increasing the compliance of the structure temporarily. In this paper, we consider shape adaptable sandwich panels with a truss core and implement smart material based variable connections, called mechanical switches, in the trusses of the core. We present three concepts of mechanical switches based on electro-bonded laminates, dielectric elastomer actuators and shape memory alloys, and evaluate their performance in terms of variation in stiffness and in maximum transferable force. Based on these results, we show how the implementation of variable connections in the core trusses can be used to reduce the actuation force by different orders of magnitude for three simple types of deformation of the panel: change in thickness, in transverse shear angle and bending. Further, considering the influence of the mechanical switches on the out-of-plane stiffness of the core, we demonstrate that this approach can be used to obtain changes in thickness of the panel, a kind of deformation that is not possible to obtain with other approaches found in literature. Moreover, we show that mechanical switches can be used to selectively vary the shear stiffness of the panel in the desired direction. Finally, we analyze the limitations of this technology in terms of mechanical properties in order to identify possible applications.


ABSTRACT: The emergence of piezoelectric functionally graded materials (PFGMs) has sparked the present research interests toward their energy harvesting behaviors. This paper theoretically investigates the optimized energy harvesting characteristics of PFGM cantilever beams under harmonic excitation. The electromechanical coupling governing equations are formulated based on Euler–Bernoulli beam theory, and utilizing the Galerkin discretization yields the frequency-response relations of the voltage, current, and power parameters, and the analytical optimal resistance as well. The present theoretical model is validated by comparing with the experimental results in literature, and parametric studies are addressed to discuss the effects of the damping ratio, the inhomogeneous parameter of PFGMs and the electrical resistance on the structural responses. More importantly, the optimized energy harvesting characteristics of PFGM cantilever beams are captured during discussions on the optimal conditions of the frequency-ratio and the electrical resistance. Results reveal that the superiority of PFGM energy harvesters over the conventional piezoelectric laminate ones, basically, lies in the design toward constituent distribution of PFGMs enabling the control over the energy harvesting efficiency. Specifically, provides that both the optimal frequency-ratio and the optimal resistance hold simultaneously, there would be a critical value for the inhomogeneous parameter, which can be utilized to maximize the energy
ABSTRACT: Energy harvesting from ambient environment has attracted intensive attention over the years for powering low-power autonomous electronic devices. A conventional piezoelectric energy harvester (CPEH) can hardly meet the requirements of effective energy harvesting from wideband, low frequency and low amplitude vibration sources due to its simple substrate and single resonant peak response. Using sandwich structure comprised of a soft-core layer and two thin skins can drastically reduce the natural frequency and increase voltage output of the harvester. The stiffness of sandwich harvester and consequently its resonant frequency can be tuned more flexibly than the CPEH by choosing different materials and adjusting the geometric dimensions of the core and skins. In this paper, a novel multi-branch sandwich piezoelectric energy harvester (MSPEH) is proposed to harvest energy from wideband, low frequency and low amplitude vibration sources. The proposed harvester comprises of a main sandwich beam as substrate with a patch of piezoelectric layer bonded over it. Multiple inner single branches with tip masses are connected to the main substrate to generate multiple resonant peaks and tune the range of the interested frequency. Firstly, a mathematical model of the proposed harvester is presented, and the electromechanical coupling equations are obtained. Subsequently, a prototype of MSPEH with two inner single branches is fabricated and tested under harmonic base excitation to study its performance. When tested at a low harmonic excitation of 0.02 g, the harvester generates 2.48 V, 6.21 V and 1.55 V at three resonant frequencies of 18.18 Hz, 24.74 Hz and 28.12 Hz, respectively. Finally, the accuracy of derived mathematical model is verified by comparing with the predictions from finite element simulation and experimental results. The novel MSPEH offers excellent design flexibility to adjust resonant frequencies by choosing inner single branches and tip masses and thus it has potential to generate sufficient power output from wideband, low frequency and low amplitude vibration sources.

Shengwei Chen, Rohith Karthikeyan and Seok Chang Ryu (Texas A & M university, Department of Mechanical Engineering, 400 Bizzell St, College Station, TX 77840, United States of America), “Towards the design of mechanically superior tubular structures for microcatheters”, Smart Materials and Structures, Vol. 28, No. 3, 035032, March 2019, https://doi.org/10.1088/1361-665X/aae45

ABSTRACT: Cardiac catheterization (CC) procedures in children and adults, and especially within vasculature of small cross-section comes with the increased risk of complications due to acute occlusive arterial injuries and
(or) thrombosis. Micro-catheters play a vital role in enabling CC procedures, however, to extend their functionality beyond large blood vessels and into pediatric wards, necessitates superior mechanical attributes that are fundamental to their structure. There exists a strong correlation between tool footprint and the risk of these injuries, nevertheless, changes in tool-size are impeded by mechanical constraints and manufacturing. In this paper, we propose pattern geometries for tubular structures that can be tuned to obtain desired mechanical characteristics, while retaining a minimum tool cross-section. We perform numerical simulations to systematically investigate the effect of pattern design parameters on the tube's properties, and present guidelines for obtaining the preferred behavior. The rounded re-entrant honeycomb (RRH) is introduced as the base structure for more responsive catheters, and is contrasted with the dog-bone geometry (DB), and the conventional slot. Notably, the RRH patterned tubes are highly compliant in bending yet strong in torsion while the DB tubes are strong in both torsion and bending. Therefore, our results indicate positively for a wide-range of tunable behavior in patterned tubes, with the RRH poised as a promising alternative for achieving the design goals that are introduced.

Jinqiang Li and Fengming Li (College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin 150001, People's Republic of China), “Active control of thermal buckling for plates using a temperature feedback control method”, Smart Materials and Structures, Vol. 28, No. 4, 045001, April 2019, https://doi.org/10.1088/1361-665X/ab04e6

ABSTRACT: The active control of thermal buckling for sandwich, laminated, gradient and uniform plates with piezoelectric materials subjected to uniform temperature rise is studied. A temperature feedback control strategy with external control voltage is proposed to control the thermal buckling and the critical buckling temperature is enlarged obviously. The inter-laminar stresses for sandwich and laminated plates by the present temperature feedback control method is compared with those through the constant actuator voltage control method proposed by other researchers, and the advantage of the present method is discussed. The stress distributions of gradient plate are simulated and it is found that the variation law of stress distribution is consistent with the volume fraction distribution of the piezoelectric ceramics. The distribution of piezoelectric components on the active control of thermal buckling is also studied and it is observed from the results that the piezoelectric materials distributed near the surface of plate play more important role than near the center of plate.

Russell W. Mailen, Catherine H. Wagner, Rachel S. Bang, Mohammed Zikry, Michael D. Dickey and Jan Genzer (First author is from: Department of Aerospace Engineering, Auburn University, Auburn, AL 36849, United States of America), “Thermo-mechanical transformation of shape memory polymers from initially flat discs to bowls and saddles”, Smart Materials and Structures, Vol. 28, No. 4, 045011, April 2019, https://doi.org/10.1088/1361-665X/ab030a

ABSTRACT: This paper describes the transformation of shape memory polymer (SMP) discs, from flat sheets to complex three-dimensional (3D) shapes, in response to heat generated by localized absorption of external infrared (IR) light. The gray-scale ink darkness printed on the surface of the SMP sheet determines the amount of absorbed light and the amount of heat generated on the surface of the sheet. Consequently, the lateral pattern of the ink governs the out-of-plane deformation of the SMP sheets due to variations in localized heating and shrinking. While recent studies have focused primarily on out-of-plane deformations of planar, rectangular substrates printed with linear patterns of ink and featuring either discrete or gradient ink variation, only limited studies have been performed on circular substrates with axisymmetric ink patterns. When heated by IR light, the axial symmetry of these ink designs produces unique out-of-plane deformations of the sheets, such as saddle shapes or bowl-like structures. We investigate these designs by utilizing a finite element analysis of material shrinkage and deformation, and we validate the model with experimental measurements and observations. This investigation provides insights into the mechanisms that cause axisymmetric geometries and ink patterns to form non-axisymmetric 3D structures, which can lead to the ability to program planar geometries that form complex 3D shapes when exposed to external stimuli.

ABSTRACT: Ultralight materials present an opportunity to dramatically increase the efficiency of load-bearing aerostructures. To date, however, these ultralight materials have generally been confined to the laboratory bench-top, due to dimensional constraints of the manufacturing processes. We show a programmable material system applied as a large-scale, ultralight, and conformable aeroelastic structure. The use of a modular, lattice-based, ultralight material results in stiffness typical of an elastomer (2.6 MPa) at a mass density typical of an aerogel (math). This, combined with a building block based manufacturing and configuration strategy, enables the rapid realization of new adaptive structures and mechanisms. The heterogeneous design with programmable anisotropy allows for enhanced elastic and global shape deformation in response to external loading, making it useful for tuned fluid-structure interaction. We demonstrate an example application experiment using two building block types for the primary structure of a 4.27 m wingspan aircraft, where we spatially program elastic shape morphing to increase aerodynamic efficiency and improve roll control authority, demonstrated with full-scale wind tunnel testing.

Jiaying Zhang, Zhangming Wu, Chen Zhang, Lin Hao, Rui Nie and Jinhao Qiu (First author is from: College of Engineering, Swansea University, Swansea, SA1 8EN, United Kingdom), “Nonlinear dynamics of shape memory alloys actuated bistable beams”, Smart Materials and Structures, Vol. 28, No. 5, 055009, May 2019, https://doi.org/10.1088/1361-665X/ab0325

ABSTRACT: The phenomenon of bi-stable behaviour has been widely used in the structural design, as it can provide large deformation by switching between two stable equilibrium positions. This paper aims to investigate the intrinsic nonlinear dynamic characteristics of an actively controlled bistable beam using a simplified spring-mass model. The dynamic model for an active (heated) SMA wire driven bistable beam is established based on a polynomial constitutive equation to describe the thermomechanical behaviour of the shape memory alloy. The actively controlled bistable beams are designed, fabricated and experimentally tested to achieve the morphing behaviour snapping-through form one position to another. The results obtained from the experimental testing and the theoretical simulation are compared to validate the proposed model. Dynamic behaviour of the proposed SMA wires actuated bistable beam under varying external excitation is investigated to show the influence of the thermomechanical loadings. Analysis of the experimental data and simulation results shows that the SMA wires actuated bistable structure can be well-performed for the bistable switching. It also approved that the different behaviours of the system, including periodic responses, complex responses and chaos can be accurately predicted using the proposed simplified model.

Yu Wang, Chuang Feng, Xinwei Wang and Zhan Zhao, Carlos Santiuste Romero and Jie Yang (Primarily from: School of Engineering, RMIT University, Bundoora, VIC 3083 Australia), “Nonlinear free vibration of graphene platelets (GPLs)/polymer dielectric beam”, Smart Materials and Structures, Vol. 28, No. 5, 055013, May 2019, https://doi.org/10.1088/1361-665X/ab0b51

ABSTRACT: Nonlinear free vibration of graphene platelets (GPLs) reinforced dielectric composite beam subjected to electrical field is analysed. Effective medium theory is adopted to approximate the overall Young’s modulus and dielectric permittivity of the GPLs reinforced composite. The Poisson’s ratio and mass density of the composites are estimated by rule of mixture. Based on Timoshenko beam theory, governing equations for beam vibration are established by using Hamilton’s principle and nonlinear von Kármán strain–displacement relationship. Numerical solution to the governing equations is obtained through differential quadrature method. The effects of GPL concentration and size, and the electrical voltage and AC (alternating current) frequency upon the nonlinear vibration of the GPL reinforced composite beam are investigated. The results demonstrate that there exists a threshold for GPL weight fraction in the polymer matrix, above which the electrical field plays a dominant role on the vibration behaviours. Increasing the voltage of the electrical field will enhance the ratio of nonlinear frequency to linear frequency. A transition region for the AC frequency is observed, within which the vibration characteristics varies dramatically. The analysis conducted in present work is envisaged to provide guidelines for designing GPL reinforced smart composites and structures.


ABSTRACT: Self-folding, whereby a 2D net autonomously folds into a pre-ordained 3D shape when exposed to a stimulus, shows potential, in a manner similar to 3D printing, as a means of easily customisable digital
manufacture. It also presents some inherent advantages over conventional additive manufacturing techniques, such as the low cost associated with mass-production of polymer sheets and coatings, the compatibility with most planar manufacturing techniques, and the ease of storage and transportation. A self-folding mechanism was developed by inkjet printing silver nanoparticle suspensions onto polyethylene terephthalate (PET) sheets. By providing sufficient electrical power to the printed tracks, resistive heating causes folding to occur along the printed silver lines. A bilayer strip model was adapted to analyse the steady-state fold angle of the PET substrate, which shows good qualitative agreement, and reasonable quantitative agreement, with the experimental data. Furthermore, inkjet-printed silver tracks are known for a significant reduction in resistivity as the sintering temperature increases. Therefore, a power control system that utilises a real-time resistance sensor was developed to enable power reference tracking. The developed mechanism was able to achieve folds up to 90° and a fast actuation time of 35 s when 2.25 W was provided to a 3 mm by 40 mm silver track.


ABSTRACT: The uncertainty in modeling finite deformation membrane electromechanics is analyzed by comparing low and high fidelity models against data on the dielectric elastomer VHB 4910. Both models include electrically and mechanically induced stress during transverse deformation of the membranes. The low fidelity model approximates deformation to be homogeneous while the high fidelity model includes a more accurate kinematic assumption of inhomogeneous deformation. We illustrate the importance of model fidelity with regards to parameter uncertainty and the associated propagation of errors in predicting membrane forces and charges in realistic actuator configurations. Both the low and high fidelity models are shown to accurately predict membrane forces and charges under different applied displacements and voltages. However, there are significant differences in the estimation of the dielectric constant used to model the membrane electromechanics. Bayesian statistics are used to quantify the uncertainty of the modeling approaches in light of both force–displacement and charge–voltage measurements. We quantify the hyperelastic, electromechanical coupling, and dielectric model uncertainties self-consistently using all mechanical and electrical experiments conducted on the 3M elastomer VHB 4910. We conclude that the low fidelity model is useful for system dynamic and control applications yet is limited in self-consistent predictions of both forces and charges from applied displacements and voltages. In comparison, the high fidelity model provides a more accurate description of the electromechanical coupling and dielectric constitutive behavior, but requires more computational power due to finite element discretization. In addition, the high fidelity modeling illustrates that a deformation dependent dielectric constant is necessary to self-consistently simulate both force–displacement and charge–voltage data.


ABSTRACT: This study scrutinizes the static characteristics of a new category of bi-stable hybrid composite laminates (BHCLs) that contain multiple metallic strips (aluminum) distributed along the middle layer of a carbon fiber reinforced epoxy laminate. With this new class of BHCLs, the direction of curvature of the laminates does not change during the snap-through between the two stable states, unlike the conventional bi-stable cross-ply laminates. The laminates were modeled using finite element analysis and were experimentally validated. BHCLs with two to five metallic strips were fabricated for this purpose. The effect of the number, width, and thickness of the metallic strips on the static characteristics of the laminate were numerically investigated using ABAQUS. Further, the curvatures, out-of-plane displacement, and static snap-through load of the laminates were determined experimentally. The results showed a strong relationship between the residual curvature and the load-carrying capability of the laminate and the number, width, and thickness of the metallic strips, as well as the laminate geometry. Knowledge of this characteristic will allow designers to tune the parameters for a given application and to achieve the desired performance. Good qualitative and quantitative agreement was observed between the numerical and the experimental results.

References listed at the end of the paper:
ABSTRACT: The lattice metamaterials with zero, large positive or negative coefficients of thermal expansions (CTEs) have attracted much attention because of urgent demands in practical engineering structure. Due to the
porosity of the above lattice metamaterials, most of structures made of them are also porous and are unsuitable to the outermost need to seal, for example, the skin of supersonic vehicles. In this paper, a new design concept of dual-constituent sandwich panel with in-plane zero thermal expansion is proposed. Different from the structures made of porous metamaterial with zero CTE, the upper and lower face-sheets of sandwich panels are all solid and not porous. The counterintuitive properties come from the special design of face-sheets, which are comprised of bi-layer materials with different positive CTEs. The difference of CTEs of two bonded layers leads to transverse bending of face-sheet during temperature increase, which results in the in-plane contraction and thereby compensates the in-plane thermal expansion deformation. The core is connected to the special locations on face-sheets to ensure the desired thermal transverse deformation occurs. In order to verify the validity of the design concept, two kinds of specific examples of corrugated and lattice sandwich panels are separately presented. The results indicate they can separately achieve in-plane unidirectional and bidirectional zero thermal expansion if the appropriate structure parameters and materials are selected.


ABSTRACT: This study investigates a unique asymmetric quasi-zero stiffness (QZS) property from the pressurized fluidic origami cellular structure, and examines the feasibility and efficiency of using this nonlinear property for low-frequency vibration isolation. This QZS property of fluidic origami stems from the nonlinear geometric relationships between folding and internal volume change, and it can be programmed by tailoring the constituent Miura-Ori crease design. Different fluidic origami cellular structure designs are introduced and examined to obtain a guideline for achieving QZS property. A proof-of-concept prototype is fabricated to experimentally validate the feasibility of acquiring QZS. Moreover, a comprehensive dynamic analysis is conducted based on numerical simulation and harmonic balance method approximation. The results suggest that the QZS property of fluidic origami can successfully isolate base excitation at low frequencies. In particular, this study carefully examines the effects of an inherent asymmetry in the force–displacement curve of pressurized fluidic origami. It is found that such asymmetry could significantly increase the transmissibility index with certain combinations of excitation amplitude and frequency, and it could also induce a drift response. Outcome of this research can lay the foundation for new origami-inspired multi-functional metamaterials and meta-structures with embedded dynamic functionalities. Moreover, the investigations into the asymmetry in force–displacement relationship provide valuable insights for many other QZS structures with similar properties.


ABSTRACT: Vibration of a rotating functionally graded carbon nanotube-reinforced sandwich composite beam was controlled using two magnetostrictive actuator layers. A closed-loop velocity proportional feedback control approach was employed to mitigate the vibration amplitude. The Timoshenko beam theory (TBT) as well as the Hamilton's principle were used to derive the equations of motion. The differential quadrature method was implemented to solve the governing equations. Some convergence and comparison studies were performed to assess the stability and accuracy of results. The effects of distribution type and volume fraction of the carbon nanotubes (CNTs) and angular velocity on vibration suppression of different modes of the sandwich beam were investigated. Overshoot response of the rotating sandwich beam was significantly affected by the volume fraction and distribution type of CNTs.


ABSTRACT: Dielectric elastomer actuators (DEAs) are an emerging soft actuation technology that have advantages in large actuation strain, inherent compliance and low cost. Resonant actuation of DEAs has been shown to increase the actuation stroke and power output and has been utilized in applications such as robotic locomotion and loudspeakers. In this work, we present a planar circular dielectric elastomer oscillator (DEO) that can exert out-of-plane deformation as large as 80% of its own diameter at resonance. By experiments and
model simulation we show that this simple DEO design exhibits complex nonlinear responses, including multiple solutions, sub- and super-harmonics, and exhibits multiple resonant peaks. The DEO performance is characterized against membrane pre-stretch and the weight of the attached mass and its actuation signals (DC and AC amplitudes). The resonant frequency and the amplitude are found to be easily tuned by varying these parameters. Such large stroke output and highly tunable resonance make this DEO a promising candidate for applications such as active vibration absorption, embedded loudspeakers, soft pumps and robotic locomotion.


ABSTRACT: A new numerical magneto-dynamic model of viscoelastic-magnetorheological sandwiches is developed and validated with experimental results. The novelty of the model is that, in addition to the magnetorheological effect of the core, it also contemplates the magneto-elastic force generated in the sandwich as a result of the interaction between the magnetic vibrating sandwich and the applied magnetic field. The numerical results show the effect of magneto-elastic force on the magneto-dynamic behaviour of the sandwich in decreasing the natural frequency of the structure. Increasing the intensity of the magnetic field, the natural frequency and the vibration amplitude of the sandwich decrease in the first vibration mode, which agrees with experimental results observed in the literature. To the author's best knowledge, this is the first time magneto-elastic force has been identified as the mechanism responsible for decreasing the natural frequencies of viscoelastic-magnetorheological sandwiches and that this magneto-dynamic behaviour has been represented.


ABSTRACT: In this study, the nonlinear bending and free vibration of Timoshenko piezoelectric nanobeam incorporating flexoelectricity and surface effect are investigated for the first time. To take size effect into account, a size-dependent Timoshenko nanobeam model containing additional material length scale parameters is developed based on strain gradient theory. The governing equations and corresponding boundary conditions are obtained by electric enthalpy variation and Hamilton's principle. By adjusting the values of material length scale parameters, the current Timoshenko piezoelectric nanobeam formulations can be transformed to those based on modified couple stress theory. The generalized differential quadrature method (GDQM) is employed to discretize governing differential equations and boundary conditions into a series of nonlinear algebraic equations. Then the algebraic equations are solved by using the Newton iteration method. It is found that strain gradient elastic effect, flexoelectricity, surface effect and applied electric voltage have significant influences on the nonlinear mechanical behaviors of nanobeam. Simulation results indicate that both the strain gradient effect and flexoelectric effect have considerable impacts on the electric field distribution in nanobeams. Moreover, the results also indicate that the influence of flexoelectricity is weakened to some extent due to the consideration of surface effect. The numerical analysis reveals that the present model can be considered reliable to quantitatively investigate size-dependent nonlinear bending and nonlinear free vibration of the piezoelectric nanobeam incorporating flexoelectric and surface effects.


ABSTRACT: A novel 3D re-entrant chiral auxetic (RCA) structure has been proposed for the first time in this study. The unit cell has been developed with solid cubes and struts based on the topological features of both re-entrant honeycomb and chiral honeycomb. A recently developed powerful 3D printing process, Multi Jet Fusion (MJF), has been employed to print six samples from polyamide 12 (PA 12). Uniaxial quasi-static compressive tests have been performed in the X, Y and Z directions to investigate the deformation, Poisson's ratio and energy absorption of the proposed structure. Finite element (FE) models have been developed using ANSYS/LS-DYNA and verified by the respective experimental data. The experimental microscopic measurements reveal high accuracy of MJF process to produce robust parts with smooth internal morphology. The designed cubes are found to demonstrate a similar rotation function to that of cylinders of the corresponding 2D RCA structure. The plastic bending and buckling are found to be the dominated deformation

...
mechanisms for the samples compressed in the Y direction, while plastic bending is the dominated deformation mechanism for the samples compressed in the X and Z directions. The proposed structure displays auxetic feature under uniaxial compression in all three directions, which facilitates a more severe compaction of the structure and results in an improved load carrying capacity. It is also found that the compressed RCA structure when loaded in the X direction outperforms in terms of auxeticity and energy absorption compared with the other (Y and Z) directions. The proposed 3D RCA structure has anisotropic properties.


ABSTRACT: Bistable piezoelectric structures exhibit snap-through motions in response to applied voltage and play important roles in achieving functions such as fast actuation and structural morphing. However, modeling the nonlinear snap-through behaviors in such structures remains a challenge. In this paper, we develop a theoretical framework to model the voltage-actuated snap-through in bistable piezoelectric composites. Based on a revised continuum theory capable of characterizing the coupled finite deformation and electric field in piezoelectric materials, we establish a universal nonlinear finite element framework where the unknowns are the displacement and a scalar factor characterizing the magnitude of the applied voltage. By using the traditional Riks method, a supplementary arc-length equation related to the increment of the displacement and the scalar factor is constructed to complete the linearized incremental equation. A general solution scheme for obtaining the increments of all unknowns is developed, which enables automatic tracing of the nonmonotonic equilibrium path evolution. The feasibility and efficiency of this numerical method were demonstrated by the voltage-actuated snap-through phenomena for several bistable piezoelectric structures, including a simply-supported bilayer beam, a 3D square bilayer plate with free ends and a 3D constrained circular bilayer plate. This method will benefit the numerical design of high-performance bistable piezoelectric structures.

V Ammovilli, M Bilasse and I Charpentier, “Continuous nonlinear eigenvalue solver with applications to the design of electro/magnetorheological sandwich structures”, Smart Materials and Structures, Vol. 28, No. 8, 085038, August 2019, https://doi.org/10.1088/1361-665X/aae8be

ABSTRACT: Smart sandwich structures comprising an electro- or a magnetorheological material have the potential to attenuate vibration over a wide range of frequencies. The analysis of their vibration behaviour with respect to the continuous variation of the field intensity is thus a major challenge for research and industry to maximize damping treatments. The numerical higher order homotopy method we propose models the effects of a continuous variation of the field intensity on resonant frequencies and loss factors by means of Taylor expansions. Comparisons between our continuous approach and the classical incremental method are proposed for state of the art sandwich beams and plate structures comprising ER/MR fluids to highlight the benefits of our continuous methods in terms of maximal damping determination.


ABSTRACT: The paper presents time-delayed feedback control to reduce the nonlinear resonant vibration of a piezoelectric elastic beam. Specifically, we examine three single-input linear time-delayed feedback control methodologies: displacement, velocity and acceleration time-delayed feedback. Moreover, the multi-input time-delayed feedback control methodologies are discussed. Utilizing the method of multiple scales, the modulation equation and the first order approximations of the primary resonances are derived and the effect of time delay on the resonances is analyzed. Then the effect of time delays and control gains on the stability, amplitude, frequency-response behavior, peak amplitude and critical excitation amplitude are investigated. Optimal values of the controllers gains and delay are obtained, simulated, and compared. The time-delayed feedback control acts as a vibration absorber at specific values of time delay. On the other hand, using mixed delay feedback controllers demonstrates an excellent improvement in mitigating the first-mode vibration.

ABSTRACT: In this work, a thermally induced bistable plate made of functionally graded carbon nanotube-reinforced composite (FG-CNTRC) with integrated piezoelectric patches is proposed for broadband energy harvesting. Single-walled carbon nanotubes (SWCNTs) in this nano-composite are assumed to have two kinds of functionally graded distributions in the thickness direction. Based on Hamilton's principle and the first-order shear deformation theory of laminates with considering von Kármán geometrical nonlinearity, a finite element (FE) model is developed to predict the energy harvesting performance of the proposed bistable plate. By applying thermal field and harmonic excitation to the plate, the cooling-down process and nonlinear dynamic response are analyzed for the bistable behavior of the plate, respectively. The simulation results are validated through comparing with the results obtained from the commercial FE software package ABAQUS. The developed FE model is then used to predict the open-circuit voltages for the proposed bistable energy harvester under different excitation levels. Frequency response diagrams of the root mean square (rms) voltage for the plates with and without bistability are simulated and compared. It is found that bistable FG-CNTRC plates can operate over a wide range of frequencies with delivering higher power than their linear counterparts. Effects of volume fractions and distribution types of SWCNTs on the dynamic behaviors of FG-CNTRC plate are also discussed. It is demonstrated that FG-CNTRC plates show different dynamic characteristics when changing CNTs volume fractions and distributions in it.


ABSTRACT: The purpose of this work is to develop a topology optimization scheme for thin-shell piezoelectric smart structures under the linear quadratic regulator optimal control for suppressing transient vibrations. The transient responses of the dynamic system are found by the finite element method based on the classical plate theory and a time-integration algorithm. A mode superposition method is employed to improve the computational efficiency. The pseudo-densities indicating the layout of piezoelectric actuators are taken as the design variables. The sensitivity analysis for a general time-integral function of transient structure response under optimal control is derived with the adjoint-variable method. A Lyapunov equation is solved to determine the derivative of the feedback gain in the sensitivity analysis. In the numerical examples, the integral of the structural response over a specified time interval is chosen as the objective function. Then, the optimization problem is solved with a gradient-based programming algorithm. The optimization results illustrate the validity of the proposed method. It is shown that the effects of active control have been substantially improved through optimization. The influences of some key factors on the optimized design are also discussed.
ABSTRACT: This research investigates the dynamic behavior of microelectromechanical systems (MEMS) containing curved electrodes, under a combined loading of electrostatic force, axial force, mechanical shock loading and squeeze-film damping (SQFD). The dynamic governing equation of a curved microbeam (micro-arch) is solved by utilizing a nonlinear finite element method, while the effect of the fluid film damping on the microbeam is modeled by the nonlinear Reynolds equation. The response of the micro-arch under different loading conditions and the influence of the MEMS device parameters on its behavior are studied and discussed in detail. In particular, the snap-through and pull-in instabilities of the curved microbeam are thoroughly investigated, and the maximum deflections of the micro-arch subjected to different types of loadings are analyzed. Finally, the phase diagram of the curved beam under various loading conditions is presented for guiding the design and analysis of the MEMS in the future.

Xiongfei Lv (1), Liwu Liu (1), Jinsong Leng (2) and Yanju Liu (1)
(1) Department of Astronautic Science and Mechanics, Harbin Institute of Technology (HIT), PO Box 301, No. 92 West Dazhi Street, Harbin 150001, People's Republic of China
(2) Centre for Composite Materials and Structures, Science Park of Harbin Institute of Technology (HIT), PO Box 3011, No. 2 Yikuang Street, Harbin 150080, People's Republic of China


ABSTRACT: When a dielectric elastomer (DE) tube is subjected to mechanical pressure and electrical voltage, electromechanical (EM) phase transition may happen. In recent experiment, it has been shown that the EM phase transition process can be highly time-dependent: the bulged section can propagate along the tube under fixed voltage. In this article, we adopt a nonlinear viscoelastic model for the DE material to investigate the time-dependent EM phase transition of a DE tube under fixed amount of air and fixed voltage. Using the model of viscoelasticity, we demonstrate that a DE tube may experience a transition from a homogeneous shape to an inhomogeneous shape with bulged and unbulged sections coexisting in the tube under electrical loading, then the bulged section can gradually propagate at the expense of the unbulged section under the fixed initial coexistent voltage, which well captures the experimental observations. We have further shown that the EM phase transition condition and propagation of the bulged section of the DE tube also depend on the volume of the air chamber connected to the tube and the ramping rate of the applied voltage.

Hongbin Fang (1,2), Tse-Shao Chang (2) and K W Wang (2)
(1) Institute of AI and Robotics, Fudan University, Shanghai 200433, People's Republic of China
(2) Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI 48105, USA


ABSTRACT: Origami provides a flexible platform for constructing three-dimensional multi-stable mechanical metamaterials and structures. While possessing many interesting features originating from folding, the development of multi-stable origami structures is faced with tremendous demands for acquiring tunability and adaptability. Through an integration of origami folding with magnets, this research proposes a novel approach to synthesize and harness multi-stable magneto-origami structures. Based on the stacked Miura-ori and the Kresling-ori structures, we reveal that the embedded magnets could effectively tune the structure's potential energy landscapes, which includes not only altering the position and the depth of the potential wells but essentially eliminating the intrinsic potential wells or generating new potential wells. Such magnet-induced evolutions of potential energy landscapes would accordingly change the origami structure's stability profiles and the constitutive force–displacement relations. Based on proof-of-concept prototypes with permeant magnets, the theoretically predicted effects of magnets are verified. The exploration is also extended to the dynamics realm. Numerical studies suggest that the incorporated magnets not only could translate the critical frequencies for achieving certain dynamical behaviors but also fundamentally adjust the frequency-amplitude relationship.
Overall, this study shows that the proposed approach would provide a novel means to control the stability profile as well as the mechanics and dynamic characteristics of origami structures, and thus, inspire new innovations in designing adaptive mechanical metamaterials and structures.


ABSTRACT: This paper proposes a level set based topology optimization method for finding optimal layout of the magneto-rheological (MR) fluid layer in an MR sandwich plate such that the vibration characteristics of the plate be improved. For this purpose, we consider the eigenfrequency and the loss factor as objective functions that should be maximized. The storage and loss modulus of the MR fluid are assumed to be magnetic field and frequency dependent. A finite element model utilizing the Mindlin plate theory is developed to derive the governing equations of motion. The topological derivative of the Lagrangian is computed at a certain point by measuring the influence of removing element on the Lagrangian and then applied to an evolutionary equation to update the level set function. In this study, we employ a density filter to regularize the continuity of the resulting level set function and consequently the complexity of the optimal configuration. Finally, several examples are presented to confirm the validity and efficiency of the method.

Jianwei Tu (1,2), Jiarui Zhang (1,2), Zhao Li (1), Kui Gao (1) and Muyu Liu (1,2)
(1) Silicate Materials for Architecture, Wuhan University of Technology, Wuhan, People's Republic of China
(2) Roadway Bridge & Structure Engineering, Wuhan University of Technology, Wuhan, People's Republic of China


ABSTRACT: Macro fiber composite (MFC) is a new type of high-performance smart piezoelectric material with an ultrathin section, which is used to decrease vibration and the noise of plate and shell structures due to high output and good flexibility. At present, the classical plate theory (CPT) has been adopted to study actuation performance of MFC. It does not consider shear deformation of an MFC integrated plate structure and cannot obtain the actuation force distribution of MFC, so that the accurate exerting position of the actuation force cannot be obtained. To solve this problem, this paper proposes that the third order shear deformation theory (TSDT) should be used to deduce the MFC actuation force formula which considers shear deformation of the MFC integrated plate structure and introduces a local displacement distribution function to ensure that the adhered interface between the MFC and the plate satisfy deformation compatibility and stress balance. Consider the end displacement calculation of an MFC integrated beam structure, for example. The comparison among the MFC actuation force formula based on TSDT, the MFC actuation force formula based on CPT, and the MFC integrated beam experiment indicates that the first can obtain higher calculation accuracy. On the basis of studying the MFC actuation force formula, the actuation simulation calculation of the plate by MFC is performed through making MFC equivalent to the actuation force and bending moment acting on plate structure to carry out the actuation experiment of an MFC integrated plate structure under the actuation of harmonic voltage of different amplitude values. The result shows that the experiment well matches the acceleration time history of simulation.

Yinghao Zhao (1), Amal Jerald Joseph Maria Joseph (2), Zhiwei Zhang (3,4), Chunping Ma (4), Davut Gul (4), Andrew Schellenberg (3) and Nan Hu (4)
(1) Department of Civil Engineering, South China University of Technology, Guangzhou, China
(2) Department of Mechanical and Aerospace Engineering, The Ohio State University, Columbus, USA
(3) School of Civil Engineering, Harbin Institute of Technology, Harbin, China
(4) Department of Civil, Environmental and Geodetic Engineering, The Ohio State University, Columbus, USA

ABSTRACT: Harnessing elastic instabilities has enabled recent advances in new classes of materials and devices due to the characteristics of amplifying force and augmented motion. Achieving these enhanced effects usually relies on using buckled beam or strips as the building block. In response to such a need, we investigate the contact-induced energy trapping of axially-loaded strips. To achieve the feature of energy trapping, we implement an 'imperfection by design' approach to trigger a controllable and predictable interactive buckling in axially-loaded strips. By combining finite-element simulations and desktop-scale experiments, we found that the contact of strip elements can be induced by strategically controlled the number, the location and the layout of local predefined geometric defects, leading to a deterministic on-demand snap-through buckling response compared to the ones without such geometric defects. Our study thereby opens avenues for the design of the next generation of compliant mechanisms with high fidelity and low sensitivity over a wide range of length scales.

ABSTRACT: Multi-layered, self-actuated devices have been the focus of recent studies due to their ability to exhibit large displacements and achieve complex shapes. Such devices have been constructed using active materials responsive to varying stimuli including electro-active and magneto-active materials to perform useful functions and achieve a wider variety of target shapes compared to single-field actuated unimorph/bimorph structures. However, fabrication of these devices for experimentation is time-consuming and expensive, which warrants the use of simulations as a means of designing high-performing structures. This work seeks to optimize structures employing materials response to magnetic and electric fields for multiple objective functions selected based on the needs of soft robotics applications such as grippers. A multi-objective optimization problem is constructed, utilizing a model developed for any arbitrary number of segments, layers, and material types, accommodating for large displacements and simultaneously applied fields. Three objective functions are chosen: (1) target shape approximation, based on the errors between the coordinates of the computed and desired shapes, (2) cost based on volume of magnetic material, and (3) work performed on a tip-force. The arbitrary optimization problem is reduced to a specific case study containing eight segments to alleviate the computational cost of an unwieldy number of parameters. The parameters are narrowed to: (1) segment lengths, (2) magnetic material in each magneto-active layer. The structure is pre-set to three material types: electro-active polymer, magneto-active elastomer, and a passive substrate. The case study’s optimization problem is performed by a genetic algorithm developed by MATLAB for multiple objective functions. The results of the optimization on the case study are analyzed by studying the feasible designs on the Pareto front of the objective functions. Different trade-offs between objective functions are identified, and various feasible designs are found more suitable than others, based on the needs and priorities of an application.

ABSTRACT: Post-buckled and curved structures experience snap-through instabilities when external loads from mechanical, fluid, or thermal environments result in a loss of local stability and a dramatic jump to a remote stable equilibrium. Fatigue caused by snap-through is a concern in many engineered systems because of the large stress reversals involved. This paper studies the extent to which the strategic placement and actuation of piezoelectric materials bonded to clamped-clamped post-buckled beams can influence the loads at which snap-through occurs. The electromechanical system is modeled using elastica theory with extensions to account for the influence of piezoelectric actuation on the structure. Static equilibrium positions and their stability are computed across a large configuration space using numerical integration and a shooting method. The results indicate that the effect of piezoelectric actuation on critical snap-through load depends on the degree to which the beam is buckled, the location of the external load, the placement of the piezoelectric material, and the applied actuation voltage. Experiments are performed to validate the numerical results and provide a physical demonstration of changing snap-through loads with piezoelectric actuation. Experimental results demonstrate that critical snap-through loads can be altered by factors ranging from 0.4 to 2.0, and numerical results indicate that even larger changes to snap-through loads are physically realizable.

ABSTRACT: A stepped functionally graded piezoelectric (FGPM) plate model is proposed for the first time, and its free and forced vibration are studied by using the domain energy decomposition method. The segmentation technique is used to discretize the structure along the length direction. At the structural boundary and piecewise interface, the weight parameters are introduced to satisfy the boundary conditions and the coordination conditions between the piecewise interfaces. On this basis, the boundary conditions of subdomains can be regarded as free boundary a constraint, which reduces the difficulty in constructing the displacement admissible function. Because all the structures of subdomains are the same, the displacement admissible functions of them are uniformly obtained by the two-dimensional Jacobian orthogonal polynomial expansion. The potential energy function of the plate is based on the first-order shear deformation theory. The displacement admissible function is substituted into the potential energy function, then the standard variational operation is used to obtain the solution equation of the dynamic characteristics of the FGPM plate. Through the numerical calculation, the superior calculation performance of the method is proved, and it is not limited to the boundary conditions. On this basis, the effects of geometric and material parameters on free and forced vibration of FGPM plate are also discussed.


ABSTRACT: The effect of several mechanical boundary conditions on the dynamic magnetoelectric (ME) effect is analytically investigated for layered cylindrical composites. The study consists of deriving a mechanics-based model for two concentric cylinders made of lead-zirconate-titanate (PZT) and cobalt ferrite (CoFe₂O₄), separated by a thin elastic layer, which is treated as strain mediator with no effect on the functional behavior of the system. Different thicknesses of the cylindrical composites and the elastic layer are considered in this study. For each case, nine sets of boundary conditions, four traditional and five non-traditional, were applied. Results show the dependence of the ME effect on the boundary conditions as well as on the inclusion of the elastic layer between the two cylinders, where both affect the strain transduction between the active layers; namely the piezomagnetic (CoFe₂O₄) and piezoelectric (PZT) layers. It was found that the maximum ME effect is attained for conditions in which the outer boundary is subjected to a uniform mechanical pressure. The inclusion of a thin elastic bonding layer was found to increase the ME response, the thickness of which was further investigated to establish limits of applicability of the reported model.

Wei Xu (1,2,3), Zhongqing Su (2), Jingqiang Liu (4), Maosen Cao (1,3) and Wiesław Ostachowicz (5)
(1) Environmental Geotechnical Engineering and Disaster Control, Jiangxi University of Science and Technology, Ganzhou 341000, People's Republic of China
(2) Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, People's Republic of China
(3) Department of Engineering Mechanics, Hohai University, Nanjing 210098, People's Republic of China
(4) College of Water Conservancy and Civil Engineering, Shandong Agricultural University, Taian 271018, People's Republic of China
(5) Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Gdańsk 80-231, Poland

“Singular energy component for identification of initial delamination in CFRP laminates through piezoelectric actuation and non-contact measurement”, Smart Materials and Structures, Vol. 29, No. 4, 045001, April 2020, https://doi.org/10.1088/1361-665X/ab6fe6

ABSTRACT: Delamination is typically barely visible impact damage in carbon fiber reinforced polymer (CFRP) laminates. It is important to identify initial delamination in the early stage. The concept of 2D multi-resolution modal Teager–Kaiser energy (MRM-TKE²) was recently proposed to reveal delamination-caused
singularity in a mode shape for delamination identification with high robustness against environmental noise. However, inadequate sensitivity impairs its capability to identify initial delamination. A damage indicator needs to be further formulated to characterize the presence and location of initial delamination. To address this problem, a scheme of decomposing the MRM-TKE$^2$ into components is proposed for identification of initial delamination. Among the energy components of the MRM-TKE$^2$ for a CFRP laminate with an initial delamination, a singular energy component is dominated by the delamination and can be determined by its spectral entropy. In the singular energy component, energy converges into the delamination region to form a singular peak and almost vanishes in other places, from which the presence and location of the initial delamination can be characterized by the singular peak. This method is numerically verified on CFRP laminates with initial delamination. Its applicability is experimentally validated by identifying an initial delamination in a CFRP laminate, the mode shapes of which are acquired by piezoelectric actuation using a lead-zirconate-titanate actuator and non-contact measurement using a scanning laser vibrometer. Numerical and experimental results show that singular energy components are capable of identifying initial delamination under noisy environments.

Chao Tang (1), Bo Li (2), Lei Liu (3), Shuzhi Sam Ge (1,4), Langquan Shui (5) and Hualing Chen (2)
(1) Institute for Future, Qingdao University, Qingdao 266071, People's Republic of China
(2) Shaanxi Key Lab for Intelligent Robots, School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, People's Republic of China
(3) School of Mechanical and Precision Instrument Engineer, Xi'an University of Technology, Xi'an 710048, People's Republic of China
(4) Department of Electrical and Computer Engineering, National University of Singapore 117576, Singapore
(5) Department of Engineering Mechanics, School of Civil Engineering, Wuhan University, Wuhan, 430072, People's Republic of China


ABSTRACT: A dielectric elastomer (DE) membrane can generate nonlinear out-of-plane vibrations under an alternating voltage. The generation mechanism and vibration characteristics were investigated in this paper. Multi-order superharmonic resonance occurred as the AC voltage increased. After the introduction of DC offset voltage, both superharmonic and subharmonic resonance occurred. The frequency characteristics of the superharmonic resonance with and without DC voltage were different. The nonlinear out-of-plane vibration characteristics can be potentially harnessed in a DE vibration-driven system.

Mingfei Wang (1), Hao Shi (1), Tingfeng Ma (1), Zhenghua Qian (2), Iren Kuznetsova (3), Lili Yuan (1), Ji Wang (1), Jianke Du (1) and Chao Zhang (4)
(1) School of Mechanical Engineering and Mechanics, Ningbo University, Ningbo 315211, China
(2) Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and astronauts, Nanjing 210016, China
(3) Kotelnikov Institute of Radio Engineering and Electronics of RAS, Moscow 125009, Russia
(4) Research Institute of Tsinghua University in Shenzhen, Shenzhen 518057, People's Republic of China


ABSTRACT: In this work, the coupled thickness-shear and flexural vibrations of the LiTaO$_3$ piezoelectric plates excited by lateral electric fields produced by surface electrodes under viscous liquid loadings are modeled and analyzed based on Mindlin's plate theory. The influences of liquid properties on the admittance characteristics and frequency shifts of the piezoelectric bulk acoustic wave devices operate in the lateral field excitation (LFE) mode are examined. In addition, the effects of the structure parameters, such as the electrode gap width, electrode/plate mass ratio and the electrode width, on the frequency sensitivity are investigated. It is shown that with the increasing electrode/plate mass ratio $R$, the sensitivities of the device on liquid viscosity and density increase first and then decrease, there is a maximal sensitivity when $R$ is with a certain value. The varying trends of the frequency shifts with various liquid properties and sensitivities with various structural parameters are verified by the FEM simulations. The results are crucial to obtain good vibration characteristics and sensitivities for liquid-phase LFE piezoelectric sensors by using LiTaO$_3$ piezoelectric crystals.
ABSTRACT: According to electric enthalpy variation and Hamilton's principle, governing differential equations and boundary conditions of functionally gradient piezoelectric nanobeams with porosities are established. The generalized differential quadrature method plays the role of transforming governing differential equations into a group of linear algebraic equations. Based on the strain gradient theory, a size-dependent functionally gradient piezoelectric nanobeam formulation including additional material length scale parameters is established. The static bending and free vibration analysis of a nanobeam made up of porous functionally gradient piezoelectric materials is researched. Two kinds of porosity distributions are considered in this paper. The influences of power law index, porosity parameter, porosity distribution, external electrical voltage, flexoelectric effect, length scale parameter and boundary conditions on static deformation and natural frequencies of the nanobeam are researched in detail.

ABSTRACT: The paper proposes a new hybrid approach technique to simulate acousto-ultrasonic wave excitation and propagation due to operation of the partially debonded piezoelectric transducer attached to a plate-like structure. The semi-analytical boundary integral equation method is applied to calculate guided waves propagation in the unbounded structures and to separate different guided waves in the piezo-induced wavefields. The obtained model is verified experimentally using the scanning laser Doppler vibrometry. Eigenfrequencies are calculated and analysed for various sizes of the transducer and for different bonding conditions between the transducer and the waveguide. The impact of the transducer's height, size and debonding area on symmetric and antisymmetric Lamb waves excitation is analysed. The paper demonstrates that one-sided debonding of the transducer exerts intense influence on the distribution of the wave energy among the excited Lamb wave modes, while center debonding has a sizable impact only at relatively high frequencies. The references are listed at the end of the paper.
ABSTRACT: Several solutions for multimodal vibration damping of thin mechanical structures based on piezoelectric coupling have been developed over the years. Among them, piezoelectric network damping consists in using piezoelectric transducers to couple a structure to an electrical network, where the transferred electrical energy can be dissipated. In particular, the effectiveness of coupling rods, beams and plates to their analogous electrical networks has been proven. This work is the first step going towards more complex structures. After defining and experimentally validating a fully passive electrical analogous network of a simply-supported plate, the study is extended to the damping of a non-periodic plate. The non-periodicities here studied include the addition of a local mass and a variable thickness. Numerical simulations and experiments show that in these cases, a broadband damping is achieved once the piezoelectric transducers are coupled to an adequate analogous network. A finite element model of the structure coupled to a 2D non-periodic electrical network is concurrently developed and validated, which is another contribution of the present work.


ABSTRACT: Several solutions for multimodal vibration damping of thin mechanical structures based on piezoelectric coupling have been developed over the years. Among them, piezoelectric network damping consists in using piezoelectric transducers to couple a structure to an electrical network, where the transferred electrical energy can be dissipated. In particular, the effectiveness of coupling rods, beams and plates to their analogous electrical networks has been proven. This work is the first step going towards more complex structures. After defining and experimentally validating a fully passive electrical analogous network of a simply-supported plate, the study is extended to the damping of a non-periodic plate. The non-periodicities here studied include the addition of a local mass and a variable thickness. Numerical simulations and experiments show that in these cases, a broadband damping is achieved once the piezoelectric transducers are coupled to an adequate analogous network. A finite element model of the structure coupled to a 2D non-periodic electrical network is concurrently developed and validated, which is another contribution of the present work.

Amer Alomarah (1,2), Shanqing Xu (1), Syed H Masood (1) and Dong Ruan (1)
(1) Faculty of Science, Engineering and Technology, Swinburne University of Technology, Hawthorn, VIC 3122, Australia
(2) Mechanical engineering department, Faculty of Engineering, Wasit University, Al-Kut 52001, Iraq


ABSTRACT: In this study, the in-plane mechanical properties of auxetic structures subjected to dynamic compression have been investigated experimentally and numerically. The studied auxetic structures, which have negative Poisson's ratios, include a recently developed auxetic structure named re-entrant chiral auxetic (RCA)
structure, re-entrant honeycomb, tetrachiral honeycomb and anti-tetrachiral honeycomb. All structures studied were fabricated from polyamide12 (PA12) powder using multi jet fusion. Compressive tests were conducted at a constant crushing velocity of \(5 \text{ m s}^{-1}\) on an Instron VHS 8800 high speed testing machine. The experimental results showed that the RCA structure crushed in the Y direction offered better energy absorption capacity than the other three types of honeycomb. It was also found that loading direction had a significant influence on deformation modes and auxetic features of the RCA structure, while it had a moderate influence on the energy absorption capacity. Numerical models were developed using ABAQUS/explicit and verified by experimental results. Parametric study was conducted to investigate the effects of crushing velocity and geometrical parameters on the dynamic performance of the RCA structure.

Xiaozhou Xin (1), Liwu Liu (1), Yanju Liu (1) and Jinsong Leng (2)
(1) Department of Astronautical Science and Mechanics, Harbin Institute of Technology (HIT), P.O. Box 301, No. 92 West Dazhi Street, Harbin 150001, People's Republic of China
(2) Advanced Composites in Special Environments, Harbin Institute of Technology (HIT), No.2 Yikuang Street, P.O. Box 3011, Harbin 150080, People's Republic of China

**ABSTRACT:** 4D printing provides more design freedom for the static structures by adding time dimension in 3D printing. In recent years, some types of active origami structures fabricated by 4D printing have been developed, but most of these structures were thin sheets, which may lead to poor mechanical properties of the structures. In this work, honeycomb sandwich structures were designed to improve the stiffness and recovery force of origami structures. The in-plane tension, in-/out-plane three-point bending, recovery force and shape memory performances of the sandwich structures were investigated. The shape fixity and shape recovery ratio of the active sandwich structures were 98% and 99%, indicating excellent shape memory performance. The application of the sandwich structures in thermally activated self-deployment origami structures was verified. These developed origami structures have the advantages of large area change ratio and fast response speed, demonstrating the great application prospects in the space deployable structures such as antennas.


**ABSTRACT:** This paper reports a hula-hooping-like nonlinear buckled elastic string electromagnetic energy harvester for wideband vibration energy harvesting. The harvester is comprised of a magnetic rotor attached at the middle of a clamped-clamped buckled elastic string and a stator with an embedding coil array. Attributed to the geometric nonlinear characteristic of the elastic string, the harvester can convert the reciprocate vibration in arbitrary in-plane direction to a hula-hooping-like curvilinear translation plane motion. A hardening nonlinear wideband voltage response was demonstrated by sweep excitation from \(5\text{~Hz}\) to \(23\text{~Hz}\). The output peak power for a single coil can reach \(1.12 \text{~mW}\) at a \(5 \text{~ms}^{-1}\) excitation. To overcome the phase delay effects between the voltages of three spatially distributed coils, they were rectified separately and connected serially or parallely to provide the final output. An open circuit peak voltage of \(0.53 \text{~V}\) was obtained from the serial connection at a \(4 \text{~ms}^{-1}\) up-sweep excitation, under which a \(100\mu\text{F}\) capacitor was successfully charged to \(0.35 \text{~V}\) within \(120 \text{~s}\). The omnidirectional energy scavenging performance of the harvester was further validated experimentally, suggesting its great promise for practical vibration energy harvesting.


**ABSTRACT:** This paper presents modal characteristics of a flexible cantilever beam with its free-end immersed in a magnetorheological (MR) fluid. Immersing the beam in MR fluid allows to change boundary conditions of the free-end by controlling the magnetic field intensity across MR fluid. Hence, the modal characteristics of the beam, such as natural frequency are varied as a function of the magnetic field applied to MR fluid domain. First, a thin cantilever beam was manufactured according to a design comprising a macro fiber composite (MFC)
actuator for the beam excitation. Then, the dynamic responses of the beam were measured under two conditions: the free-end vibrating in air and the free-end immersed in MR fluid with different magnetic field intensities. The changes in the dynamic characteristics, such as resonance frequency, damping ratio, and resonant amplitude were evaluated and compared for various conditions. A significant reduction in the natural frequency was observed when the free-end of the beam was immersed in MR fluid and changed further when coil current was applied. In addition, the multiphysics simulation of the system was performed using finite element method. The numerical results of the dynamic response of the system showed good agreement with experimental results.


ABSTRACT: Bistable laminates offer opportunities for shape morphing, energy harvesting, and flow control devices. Smart materials such as piezoelectric macrofiber composites and shape memory alloys have been embedded in bistable laminates to actuate or harvest energy. However, sensor systems capable of measuring bistable shapes and snap-through events are lacking. In this paper, we present curved bistable laminates layered with piezoelectric PVDF films that can sense smooth shape changes as well as abrupt snap-through transitions. Near-static measurement is facilitated by a drift compensated charge amplifier with a large time constant that converts the sensor's charge output into a measurable voltage with minimal drift error. The sensing function is demonstrated on mechanically-prestressed bistable laminates. The laminated composites include two sensor layers such that one measures the changes in curvature and the other measures snap-through events. An analytical model is presented in which strains and curvatures calculated using a laminated-plate model are fed into a linear piezoelectric model to calculate voltage. Shapes measured by the sensors correlate well with shapes measured using a 3D motion capture system. A model-based analysis is performed to understand the laminates' design space.


ABSTRACT: There is limited understanding on interaction mechanisms that govern vibration attenuation when a small coverage of lightweight resonators are applied to practical engineering structures. To shed light on the unknowns, this research investigates lightweight elastomeric half cylindrical resonators attached to an aluminum panel using a small mass ratio around 3% and only around 1.7% coverage over the panel area. Finite element modeling of the system dynamics is complemented by corresponding experimental undertaking. The eigenfrequencies and eigenmodes of the resonators are scrutinized for the respective contributions provided towards broadband panel vibration suppression. The first order eigenmodes of the resonators are found to exert great influence on the starting mode for greater vibration attenuation, which may be tuned by the Young's modulus of the resonators. The concept of displacement polarization is established to probe how the resonator eigenmodes quantitatively contribute to attenuate the forced panel vibration. This study reveals how flexural panel vibration may be attenuated by transferring the vibration from the panel to resonators by virtue of modal interaction, and prepares a generalized analytical technique that may be used by other researchers studying multi-modal interactions between host structures and applied resonators. These findings may guide the future development of lightweight resonators with a small coverage area for vibration suppression in engineering applications.


ABSTRACT: Fiber reinforced composites have wide structural applications and vast research has been going on to improve their mechanical performance when subjected to quasi-static loading but, study of their dynamic behavior is still underdeveloped. For this reason, scientists have been continuously working on developing methods to improve their dynamic characteristics and addition of nanofillers such as Carbon Nanotubes (CNTs) as reinforcement is considered a possible solution for developing future generation high-quality fiber
reinforced nanocomposites. In this study, composite specimens are manufactured using Epon 862 Epoxy resin and T300 6 k carbon fibers, and each specimen contained different weight percentages of multi-walled Carbon nanotubes (MWCNTs) i.e. 0% as a reference, 0.5%, and 2%. Specimens were tested experimentally using the Split Hopkinson pressure bar device (SHPB) under different pressures to examine their dynamic response and damage behavior at high strain rates. During the dynamic compression tests, a high-speed camera was used to monitor and record the damage kinetics. The experimental characterization showed that the integration of CNTs in matrix has greatly influenced the dynamic response and damage mechanism of the Carbon Fiber Reinforced Polymers composite (CFRP). Mechanical behavior of specimens with each percentage demonstrated the enhancement of the mechanical properties and showed the increase of the dynamic characteristics and fracture resistance because of the increase in stiffness of matrix material and interfacial bonding between matrix and fiber reinforcement.


ABSTRACT: Inspired by natural systems, such as seed pods, pine cones, wheat seeds, flytraps, and vines, representative deformations, including bending, folding, and twisting, have been realized by designing structures and programming deformation for smart materials. In this paper, we present an innovative method of controlled helical structures by designing and fabricating a bilayer structure with a smart material. Our design was numerically studied and experimentally tested. Theoretical analyses were performed to guide the design of the helixing processes. When the bilayer structure was heated above the glass transition temperature, the top layer shrunk and the bottom layer expanded along the printing angle, which resulted in a self-helixing behavior. The parameters affecting the self-helixing behavior of the bilayer structure were studied and discussed. We found that left- and right-handed helical structures were achieved by controlling the printing angle of the top layer. A constitutive model with four main programming parameters was fitted and a helical structure with the desired curvature and gradient angle was achieved and was successfully triggered by heat. An underwater robot gripper programmable structure was achieved to test the feasibility and potential applications of the proposed method. The self-helixing structures could change their shape after fabrication using heat, and this technology has potential applications in the fields of biomedical devices, soft-robotics, and optoelectronic devices.


ABSTRACT: Laminated carbon fiber reinforced shape memory polymer composites (CFRSMPCs) have the advantages of simple structures and flexible properties in achieving a high loading capacity and novel shape memory effects. Because the mechanical properties of the laminated CFRSMPCs decrease rapidly during the process of carbon fiber failure, it should be avoided in application. To address this issue, modeling approach for the laminated CFRSMPCs is proposed by using a refined sinusoidal shear deformation plate theory (RPT) together with the simplified constitutive model of the CFRSMPCs, for the first time. Because the carbon fiber is liable to buckle under compression in the soft SMP matrix, the buckling behavior is studied here. For comparison, the pre-buckling loading capacities of the simply supported plates with different components are simulated. Furthermore, the effect of raising fiber volume fraction or adding layers on the loading capacity is studied. Therefore, this study provides useful guidance for reasonable design of laminated CFRSMPCs.


ABSTRACT: To predict electrical generation in piezoelectric small-scale beam energy harvesting devices, it is important to have a complete mathematical model that captures the different associated phenomena. In the literature, some authors propose several alternatives of non-linear mathematical formulations, with non-linearities coming from different physical aspects. All these formulations present good aptitudes to predict the nonlinear behavior of the system under different values of accelerations, geometry and boundary conditions. At
CFRP plates are clearly visualized in the ultimate damage maps. The algorithm is then successfully used in the imaging of a single delamination zone in a carbon fiber reinforced polymer (CFRP) plate. The locations, sizes, and shapes of the delamination zones in the GFRP and CFRP plates are clearly visualized in the ultimate damage maps.


ABSTRACT: The use of piezoelectric materials in various applications, including the development of bio-inspired structures, vibration control, energy harvesting, among others, has been investigated by several researchers over the last few decades. In most cases, linear piezoelectricity is assumed in modeling and analysis of such systems. However, the recent literature shows that non-linear manifestations of piezoelectric materials are relevant and can modify the electromechanical behavior especially around the resonance. This work extends the investigation of non-linear piezoelectricity, by adding geometric nonlinearities and aerodynamic effects, to aeroelastic problems such as wind energy harvesting. A piezoaeroelastic model that combines a non-linear coupled finite element model and the doublet lattice model of unsteady aerodynamics is presented. The electromechanically coupled finite element model includes the non-linear behavior of piezoelectric material under weak electric fields. Model predictions are validated by experimental data for 1) a double bimorph actuation case and 2) a vibration based energy harvesting case. Later, the piezoaeroelastic behavior of a generator plate-like wing for wind energy harvesting is numerically investigated when linear as well as non-linear piezoelectricity is considered. The experimentally validated geometrically and materially non-linear framework presented here is applicable to both energy harvesting and actuation problems in the presence of air flow.


ABSTRACT: Delamination is a commonly encountered type of damage in composite structures, which may lead to degraded performance and even failure of structures. Thus, detection of delaminations is considered a vital task to maintain structural integrity and reliability. This paper presents a delamination imaging method based on the analysis of guided wavefields. The method relies on the fact that delaminations in a structure will cause wavefield anomalies, which in turn can be utilized for the indication of delamination zones. Such anomalies, however, could be easily masked by the major components of the wavefield signals including incident waves from actuators and reflected waves from structural boundaries. To address the problem, one-dimensional wavelet transform (WT) is used to process the wavefields leading to WT wavefields. The WT wavefields can highlight signal anomalies associated with delaminations. A WT wavefield imaging algorithm is first constructed step by step in detecting multiple delaminations in a glass fiber reinforced polymer (GFRP) plate. The algorithm is then successfully used in the imaging of a single delamination zone in a carbon fiber reinforced polymer (CFRP) plate. The locations, sizes, and shapes of the delamination zones in the GFRP and CFRP plates are clearly visualized in the ultimate damage maps.
ABSTRACT: This paper presents the design, fabrication, and characterization of a self-foldable Active Origami Reflector Antenna (AORA) of parabolic form. Self-folding of the AORA is enabled by smooth uncreased folds composed of shape memory polymer (SMP) composites. Design methods for origami with smooth folds are applied to determine the shape and fold pattern of a planar sheet that can be folded to reach the parabolic antenna shape. A proof-of-concept prototype of the AORA is fabricated and self-folding of the AORA driven by thermal actuation of the SMP composite folds is demonstrated. The far-field electromagnetic (EM) characteristics of the AORA prototype are investigated through numerical simulations and experimental measurements in an anechoic chamber. A design-of-experiment study is conducted to investigate the effects of the antenna shape parameters on its EM characteristics such as far-field antenna gain and beamwidth, and to compare the performance of the AORA to that of equivalent smooth and faceted parabolic reflectors. Applications of the AORA include high-gain directional radio telescopes and satellite telecommunication.

ABSTRACT: Shape memory polymer (SMP) is a kind of intelligent material that produces shape changes under external stimulus conditions. 4D printing is a comprehensive technology based on deformable materials and 3D printing. Based on 4D printing technology of SMP, this paper presents a smart reentrant honeycomb that is shape reconfigurable, self-deployable, mechanically tunable and reusable. The shape programming and the process of self-deployment of the smart honeycomb are demonstrated and analyzed, and its switching stiffness and energy absorption function are characterized quantitatively and qualitatively. Based on the analysis of the honeycomb parameters on the mechanical behavior, unidirectional and bidirectional gradient honeycombs are obtained, and the controllability and selectivity of any local deformation and stress–strain curves are realized. Two of honeycombs can achieve the orderly regulation of trapezoidal and concave deformation modes, respectively. The gradient design can achieve continuous adjustment of the stress–strain curve in the compression process. This kind of intelligent honeycomb with novel deformation effect has a good application prospect in applications such as morphing wings, soft robots, and mechanical vibration damping devices.

ABSTRACT: This paper presents a dynamic characterization of the delaminated composite plate structure. The governing Equation of the delaminated composite plate developed using finite element method (FEM) formulation grounded on a classical laminated plate theory. The FEM formulation designed for the delaminated composite plate under bending validated by comparing the natural frequencies evaluated using the present FEM formulation through MATLAB coding and experimental results. Various parametric studies have investigated. Simulation study conducted for different interfaces with different delamination location problems solved by the FEM. It shows that percentage of natural frequency decrease in the delaminated composite plate when compared to the intact composite plate. The significant variation in the natural frequency depends on the delamination location and delamination interface. This study is useful for the designers to tailor the structures with various interface delamination present in the arrangements. Artificial neural network algorithm implemented to study the effect of delamination in laminated composite plate structures.

ABSTRACT: This paper presents a dynamic characterization of the delaminated composite plate structure. The governing Equation of the delaminated composite plate developed using finite element method (FEM) formulation grounded on a classical laminated plate theory. The FEM formulation designed for the delaminated composite plate under bending validated by comparing the natural frequencies evaluated using the present FEM formulation through MATLAB coding and experimental results. Various parametric studies have investigated. Simulation study conducted for different interfaces with different delamination location problems solved by the FEM. It shows that percentage of natural frequency decrease in the delaminated composite plate when compared to the intact composite plate. The significant variation in the natural frequency depends on the delamination location and delamination interface. This study is useful for the designers to tailor the structures with various interface delamination present in the arrangements. Artificial neural network algorithm implemented to study the effect of delamination in laminated composite plate structures.
ABSTRACT: With the rapid advancement of technology comes the need for lighter weight and higher strength materials, so studies on new materials and manufacturing techniques are needed. The aeronautics industry is always at the forefront of researching new materials, where the weight factor is crucial. In contrast, aircraft suffer from intense mechanical vibration and the ability to control these vibrations is of paramount importance for stability of the aircraft and its structural integrity. To control these intense vibrations, intelligent materials have been pointed as a possible resource for vibration control, since it is possible to vary the modal frequencies of the structure through electrical or magnetic excitations. The objective of this study is to analyze the dynamic behavior under the influence of vibrations in sandwich beams, which have honeycomb cores filled with magnetorheological (MR) gels and composite material skins. The development of the work has an experimental analysis through free and forced vibration tests to determine the modal parameters of the beams built according to the applied magnetic field intensity, and a statistical analysis to determine the design factors that most impacted this process. With the results obtained, the use of these materials is promising in structures, due to the fact that they achieve reductions in the value of natural frequencies in the order of 54%, increase in damping factors of up to 390% and decrease in forced vibration amplitude of 40% in relation to the use of a magnetic field. Results obtained from design of experiments showed that the factor that most influenced the response of free and forced vibration assays was the gel. For this, it is proposed new models of smart beams, since there are few studies in the honeycomb core filled with MR gel.

Andreas M Damm, Claudio Spitzmüller, Andreas T S Raichle, Andre Bühler, Philipp Weißgraeber and Peter Middendorf, “Deep learning for impact detection in composite plates with sparsely integrated sensors”, Smart Materials and Structures, Vol. 29, No. 12, 125014, December 2020, https://orcid.org/0000-0002-9051-8377
ABSTRACT: In this paper, both location and energy of impacts on an anisotropic carbon fiber reinforced plate (CFRP) are detected with the help of deep learning. We introduce sparse low-cost sensor array integration in CFRP plates that allows for structural monitoring of lightweight structures. Using a resin transfer moulding process microelectromechanical systems (MEMS) and piezoelectric transducers (PZT) sensors are integrated into CFRP plates. We developed an automated test bench to perform weight drop impact loadings with impact energies ranging between 0.22–0.56 mJ on a 1 × 1 cm-grid with 441 locations. The obtained sensor signals were processed by means of a short-time fourier transformation and used as input for the training of a deep learning model. This model was implemented with a convolutional neural network. To accelerate the training phase we introduce a coarse analytical model that generates artificial sensor signals we use for pretraining of the neural network. Yielding high prediction accuracies of 99.82% and 98.68% for a correct classification of impact location and energy, respectively, the capability of the proposed approach was demonstrated. Despite their limited resolution the low-cost MEMS accelerometers were able to correctly locate an impact and its energy with 99.76% and 97.04%, respectively. The pretraining led to an increased robustness of the training process. Additionally, for the case of PZT sensors, it also reduced the number of required epochs for convergence significantly.

ABSTRACT: Delamination is a type of damage frequently occurring in laminated composite plates. Delamination detection is crucial to ensure structural integrity and safety. This paper presents a delamination imaging algorithm based on the space-wavenumber analysis of guided wavefields using two-dimensional (2D) continuous wavelet transform (CWT). The premise of this algorithm is that delaminations in a structure will alter wavenumbers in the delamination regions. The state of the art uses the short-space Fourier transform (SSFT) for local wavenumber analysis in order to capture these wavenumber alterations. However, window size in local wavenumber analysis using SSFT needs to be determined according to the wavelength in the delamination regions, which is not known a priori. Moreover, window size in SSFT is fixed and cannot adapt to the wavenumber alterations in varying damage scenarios. To address these disadvantages, the 2D CWT is introduced to analyze the guided wavefield data in the space-wavenumber domain leading to 2D CWT-wavefields. The wavenumber alterations induced by delaminations are well isolated in the 2D CWT-wavefields at fine scales. Window size in wavelet analysis is flexibly adapted to guided wavefields from varying damage
cases by adjusting wavelet scale factor that is seen as the pseudo-wavenumber. A final damage map is developed by fusing the 2D CWT-wavefield images. The algorithm is successfully used in detecting multiple delaminations in a GFRP plate with the accurate location, size, and shape of each delamination clearly visualized in the final damage map.


ABSTRACT: Unlike well-studied locally resonant (LR) metamaterials with a periodic array of identical resonators, 'graded' LR metamaterials consist of an array of resonators with a spatially varying parameter, yielding wideband wave attenuation and mode trapping/localization, among other features. In this work, we explore a graded LR piezoelectric metamaterial-based structure (i.e. metastructure) in which the grading parameter, namely the inductive shunt resonant frequency of the unit cells, follows a predefined variation pattern in space (e.g. first-order, quadratic, or fractional). We investigate the effect of such patterns on (i) the vibration attenuation bandwidth, (ii) the localization of vibration modes, and (iii) the harvested power. To this end, we consider a piezoelectric bimorph cantilever hosting an array of piezoelectric unit cells with spatially varying inductive shunts. Fully coupled electromechanical equations describing the metastructure's linear transverse displacement and unit cell voltages are given with a modal analysis framework and solved using the matrix inversion method. The results show that (i) the first-order grading pattern yields the widest bandgap with 65% increase in the bandwidth compared to the standard uniform LR pattern, (ii) the localization of vibration modes follows in shape the corresponding frequency grading pattern, and (iii) the largest power is harvested for the fractional grading pattern. Furthermore, all of the graded resonator configurations result in wider bandwidth in energy harvesting as compared to the uniform resonators case. Overall, the results unveil the fundamental characteristics of this class of graded piezoelectric metastructures and support the design of such multifunctional piezoelectric metastructures for concurrent vibration attenuation and energy harvesting.


ABSTRACT: Manufacturing of three-dimensional structures of millimeter and sub-millimeter sizes is required in emerging applications in microelectronics, packaging, and particle entrapment. This paper presents a manufacturing method for three-dimensional polyhedral structures at such scales enabled by programmable, self-foldable polymer films. The manufacturing method starts with a three-dimensional target shape and uses origami design to generate the outline and fold pattern of a planar film that can be folded towards the target shape. Double-exposure photolithography is employed to pattern a polymer film based on the generated geometry along with stiff faces of high crosslinking density and flexible folds of low crosslinking density. During the development step of the photolithography process, the folds absorb the developer solution from one side, creating a concentration gradient across their thickness. The non-uniformly absorbed developer in the folds is evaporated when the film is heated, causing non-uniform strains across their thickness and enabling self-folding. It is experimentally determined that the fold angles exhibited by the folds are directly proportional to the ratio between their width along the folding direction and the film thickness, which enables programming of the folding response through modulation of the fold dimensions. Different structures are fabricated to demonstrate the effectiveness of the developed manufacturing method.

ABSTRACT: Theory and experiment are presented to show that an interface between two soft materials under compression can form creases, a type of bifurcation distinct from wrinkles. While creases bifurcate from a state of flat interface by a deformation localized in space and large in amplitude, wrinkles bifurcate from a state of flat interface by a deformation nonlocal in space and infinitesimal in amplitude. The interfacial creases set in at a lower critical compression than interfacial wrinkles, but higher than surface creases. The condition for the onset of interfacial creases is scale-free, and is calculated in terms of elastic moduli, pre-strains and applied strains.

ABSTRACT: We investigated swelling induced instabilities in porous membranes with a square array of micron-sized circular holes prepared from a pH and temperature dual-responsive hydrogel, poly(2-hydroxyethyl methacrylate-co-N-isopropylacrylamide-co-acrylic acid) (PHEMA-co-PNIPAAm-co-PAA). At room temperature (25 °C), the hydrogel swelled to ~1.5 to 8 times of its dried volume when pH was increased from 2 to 7. Within this regime, we observed four distinctive morphologies of the hydrogel membrane, including a “breathing” mode of the membrane having circular pore arrays, a buckled pore array of alternating mutually orthogonal ellipses, twisted snap-shut pores forming “S” shaped slits, and cusps formed in local regions that perturbed the 2D periodicity of the hydrogel membrane. Using a 3D confocal imaging technique, we followed the post-buckling behaviors of the porous membranes and investigated the pattern evolution process as a function of pH. Amplification of buckling and symmetry breaking were observed when we increased the pH of the buffer solutions from pH 4.0 to 5.0, leading to the transition from an achiral buckled state (pH 4.0) to a chiral twisted state (pH 5.0) driven by the compaction of the hydrogel domains within the space to completely close the pores. When the pH of the aqueous environment was further increased to 7, star-shaped patterns appeared randomly in the film, where the hydrogel domains were compressed by the adjacent neighbors, thus resulting in out-of-plane deformation. Finally, we demonstrated the temperature-dependent reversible switching of the hydrogel membrane among the chiral twisted state, buckled state, and circular state via changing the temperature between 20 °C and 45 °C.

ABSTRACT: Wrinkled patterns are useful for a wide variety of technological applications ranging from microfluidics to microelectronics. In order to use wrinkled patterns for these applications, both the location and the morphology, i.e. wavelength and amplitude of the wrinkled features, must be precisely controlled. In this paper, a surface was fabricated by placing a thin, flat, continuous glassy film on a topographically-patterned elastomeric substrate to control different wrinkling morphologies and mechanisms on a single surface. With this configuration, we achieved unique surfaces with two distinct regions of wrinkling morphology without changing the film material properties; a region where the film is unsupported and the wrinkling mechanics is dictated only by the film property and the pattern geometry, and a region where the film is supported and wrinkling length scales are dictated by the film and elastomer properties. We demonstrated that the wrinkling wavelength and amplitude scales with geometry and applied strain differently and can be independently controlled in each of the distinct regions.

ABSTRACT: Microtubules (MTs) are cytoplasmic protein polymers that are essential for fundamental cellular processes including the maintenance of cell shape, organelle transport and formation of the mitotic spindle. Microtubule dynamic instability is critical for these processes, but it remains poorly understood, in part because the relationship between the structure of the MT tip and the growth/depolymerization transitions is enigmatic. In previous work, we used computational models of dynamic instability to provide evidence that cracks (laterally...
unbonded regions) between protofilaments play a key role in the regulation of dynamic instability. Here we use computational models to investigate the connection between cracks and dynamic instability in more detail. Our work indicates that while cracks contribute to dynamic instability in a fundamental way, it is not the depth of the cracks per se that governs MT dynamic instability. Instead, what matters more is whether the cracks terminate in GTP-rich or GDP-rich regions of the MT. Based on these observations, we suggest that a functional “GTP cap” (i.e., one capable of promoting MT growth) is one where the cracks terminate in pairs of GTP-bound subunits, and that the likelihood of catastrophe rises significantly with the fraction of crack-terminating subunits that contain GDP. In addition to helping clarify the mechanism of dynamic instability, this idea could also explain how MT stabilizers work: proteins that introduce lateral cross-links between protofilaments would produce islands of GDP-bound tubulin that mimic GTP-rich regions in having strong lateral bonds, thus reducing crack propagation, suppressing catastrophe and promoting rescue.


ABSTRACT: Wrinkle configurations can provide brittle Si ribbons with excellent stretchability via mechanical buckling. We propose a strategy using micro-patterns to control the wrinkle configurations in ‘pop-up’ and ‘pop-down’ styles, as well as the wrinkle’s wavelength. After the wrinkle configuration is stretched flat, the micro-patterns will deform to buffer the Si ribbons, which enhances the additional stretchability of such structures. The experimental results show that the micro-patterns determine the wrinkle configurations of Si ribbons and their stretchability can reach 51.2%. The analytical modeling and FEM simulation reveal the mechanism of such a phenomenon.


ABSTRACT: When stretched uniaxially, a thin elastic sheet may exhibit buckling. The occurrence of buckling depends on the geometrical properties of the sheet and the magnitude of the applied strain. Here we show that an elastomeric sheet initially stable under uniaxial stretching can destabilize when exposed to a solvent that swells the elastomer. We demonstrate experimentally and computationally that the features of the buckling pattern depend on the magnitude of stretching, and this observation offers a new way for controlling the shape of a swollen homogeneous thin sheet.


ABSTRACT: The bioactivity of nanoparticles crucially depends on their ability to cross biomembranes. Recent simulations indicate the cooperative wrapping and internalization of spherical nanoparticles in tubular membrane structures. In this article, we systematically investigate the energy gain of this cooperative wrapping by minimizing the energies of the rotationally symmetric shapes of the membrane tubes and of membrane segments wrapping single particles. We find that the energy gain for the cooperative wrapping of nanoparticles in membrane tubes relative to their individual wrapping as single particles strongly depends on the ratio \( \frac{\rho}{R} \) of the particle radius \( R \) and the range \( \rho \) of the particle–membrane adhesion potential. For a potential range of the order of one nanometer, the cooperative wrapping in tubes is highly favorable for particles with a radius of tens of nanometers and intermediate adhesion energies, but not for particles that are significantly larger.


ABSTRACT: The motion of red blood cells (RBCs) in microcirculation plays an important role in blood flow resistance and in the cell partitioning within a microvascular network. Different shapes and dynamics of RBCs in microvessels have been previously observed experimentally including the parachute and slipper shapes. We employ mesoscale hydrodynamic simulations to predict the phase diagram of shapes and dynamics of RBCs in cylindrical microchannels, which serve as idealized microvessels, for a wide range of channel confinements and flow rates. A rich dynamical behavior is found, with snaking and tumbling discocytes, slippers performing a
swinging motion, and stationary parachutes. We discuss the effects of different RBC states on the flow resistance, and the influence of RBC properties, characterized by the Föppl–von Kármán number, on the shape diagram. The simulations are performed using the same viscosity for both external and internal fluids surrounding a RBC; however, we discuss how the viscosity contrast would affect the shape diagram.

ABSTRACT: We study the shearing rheology of dense suspensions of elastic capsules, taking aggregation-free red blood cells as a physiologically relevant example. Particles are non-Brownian and interact only via hydrodynamics and short-range repulsive forces. An analysis of the different stress mechanisms in the suspension shows that the viscosity is governed by the shear elasticity of the capsules, whereas the repulsive forces are subdominant. Evidence for a dynamic yield stress above a critical volume fraction is provided and related to the elastic properties of the capsules. The shear stress is found to follow a critical jamming scenario and is rather insensitive to the tumbling-to-tank-treading transition. The particle pressure and normal stress differences display some sensitivity to the dynamical state of the cells and exhibit a characteristic scaling, following the behavior of a single particle, in the tank-treading regime. The behavior of the viscosity in the fluid phase is rationalized in terms of effective medium models. Furthermore, the role of confinement effects, which increase the overall magnitude and enhance the shear-thinning of the viscosity, is discussed.

ABSTRACT: Elastic instabilities, when properly implemented within soft, mechanical structures, can generate advanced functionality. In this work, we use the voltage-induced buckling of thin, flexible plates to pump fluids within a microfluidic channel. The soft electrodes that enable electrical actuation are compatible with fluids, and undergo large, reversible deformations. We quantified the onset of voltage-induced buckling, and measured the flow rate within the microchannel. This embeddable, flexible microfluidic pump will aid in the generation of new stand-alone microfluidic devices that require a tunable flow rate.

ABSTRACT: Linear alkanes CH\textsubscript{n} in vacuum isolation are finite models for an infinite polyethylene chain. Using spontaneous Raman scattering in supersonic jet expansions for n = 13–21 in different spectral ranges, we determine the minimal chain length \( n \) for the cohesion-driven folding of the preferred extended all-trans conformation into a hairpin structure. We treat fully stretched all-trans alkanes as molecular “nanorods” and derive Young's modulus \( E \) for the stretching of an isolated single-strand polyethylene fibre by extrapolating the longitudinal acoustic mode to infinite chain length. Two key quality parameters for accurate intra- and intermolecular force fields of hydrocarbons (\( n = 18 \pm 1, E = 305 \pm 5 \text{ GPa} \)) are thus derived with high accuracy from experimental spectroscopy.

ABSTRACT: We investigate the buckling of a slender rod embedded in a soft elastomeric matrix through a combination of experiments, numerics and theory. Depending on the control parameters, both planar wavy (2D) or non-planar coiled (3D) configurations are observed in the post-buckling regime. Our analytical and numerical results indicate that the rod buckles into 2D configurations when the compression forces associated to the two lowest critical modes are well separated. In contrast, 3D coiled configurations occur when the two buckling modes are triggered at onset, nearly simultaneously. We show that the separation between these two lowest critical forces can be controlled by tuning the ratio between the stiffness of the matrix and the bending stiffness of the rod, thereby allowing for specific buckling configurations to be target by design.

Nakul P. Bende, Ryan C. Hayward and Christian D. Santangelo, “Nonuniform growth and topological defects

ABSTRACT: We demonstrate that shapes with zero Gaussian curvature, except at singularities, produced by the growth-induced buckling of a thin elastic sheet are the same as those produced by the Volterra construction of topological defects in which edges of an intrinsically flat surface are identified. With this connection, we study the problem of choosing an optimal pattern of growth for a prescribed developable surface, finding a fundamental trade-off between optimal design and the accuracy of the resulting shape which can be quantified by the length along which an edge should be identified.


ABSTRACT: When a stiff film on a soft substrate is compressed, the surface of the film forms wrinkles, with tunable wavelengths and amplitudes that enable a variety of applications. As the compressive strain increases, the film undergoes post-wrinkling bifurcations, leading to period doubling and eventually to formation of localized folds or ridges. Here we study the post-wrinkling bifurcations in films on pre-stretched substrates. Through a combination of experiments and simulations, we demonstrate that pre-stretched substrates not only show substantial shifts in the critical strain for the onset of post-wrinkling bifurcations, but also exhibit qualitatively different post-wrinkled states. In particular, we report on the stabilization of wrinkles in films on pre-tensioned substrates and the emergence of ‘chaotic’ morphologies in films on pre-compressed substrates.


ABSTRACT: A new structural design is proposed for wrinkling to improve mechanical durability by exploiting a porous polymer film embedded on the surface of an elastomer, which acts as a hard layer, buckles into wrinkles and effectively suppresses fatal failures such as delamination and cracking.


ABSTRACT I.: We analyze the rheology of dilute red blood cell suspensions in pressure driven flows at low Reynolds number, in terms of the morphologies and elasticity of the cells. We focus on narrow channels of width similar to the cell diameter, when the interactions with the walls dominate the cell dynamics. The suspension presents a shear-thinning behaviour, with a Newtonian-behaviour at low shear rates, an intermediate region of strong decay of the suspension viscosity, and an asymptotic regime at high shear rates in which the effective viscosity converges to that of the solvent. We identify the relevant aspects of cell elasticity that contribute to the rheological response of blood at high confinement. In a second paper, we will explore the focusing of red blood cells while flowing at high shear rates and how this effect is controlled by the geometry of the channel.

ABSTRACT II.: We study the focusing of red blood cells and vesicles in pressure-driven flows in highly confined microchannels (10–30 μm), identifying the control parameters that dictate the cell distribution along the channel. Our results show that an increase in the flow velocity leads to a sharper cell distribution in a lateral position of the channel. This position depends on the channel width, with cells flowing at outer (closer to the walls) positions in thicker channels. We also study the relevance of the object shape, exploring the different behaviour of red blood cells and different vesicles. We also analyze the implications of these phenomena in the cell suspension rheology, highlighting the crucial role of the wall confinement in the rheological properties of the suspension.


ABSTRACT: Molecular dynamics simulations of bilayers in a surfactant/co-surfactant/water system with
explicit solvent molecules show formation of topologically distinct gel phases depending upon the bilayer composition. At low temperatures, the bilayers transform from the tilted gel phase, L, to the one dimensional (1D) rippled, P. phase as the surfactant concentration is increased. More interestingly, we observe a two dimensional (2D) square phase at higher surfactant concentration which, upon heating, transforms to the gel L phase. The thickness modulations in the 1D rippled and square phases are asymmetric in two surfactant leaflets and the bilayer thickness varies by a factor of ~2 between maximum and minimum. The 1D ripple consists of a thinner interdigitated region of smaller extent alternating with a thicker non-interdigitated region. The 2D ripple phase is made up of two superimposed square lattices of maximum and minimum thicknesses with molecules of high tilt forming a square lattice translated from the lattice formed with the thickness minima. Using Voronoi diagrams we analyze the intricate interplay between the area-per-head-group, height modulations and chain tilt for the different ripple symmetries. Our simulations indicate that composition plays an important role in controlling the formation of low temperature gel phase symmetries and rippling accommodates the increased area-per-head-group of the surfactant molecules.


ABSTRACT: This communication describes a novel strategy to achieve programmable shape transformation of hybrid hydrogel sheets by modulating both the in-plane and out-of-plane mismatches in mechanical properties. Both our experimental and computational results demonstrate that the shape transformation of hybrid hydrogel sheets shows rich features (e.g., rolling direction, axis, chirality, etc.) and versatile tunability (e.g., via various external stimuli, material properties, pattern geometry, etc.). This work can provide guidance for designing soft materials that are able to undergo more precise and complex shape transformation.


ABSTRACT: We investigate the complex dispersion relationship of a transverse antisymmetric wave on a horizontal soap film. Experimentally, the complex wave number k at a fixed forcing frequency is determined by measuring the vibrating amplitude of the soap film: the wavelength (linked to the real part of k) is determined by the spatial variation of the amplitude; the decay length (linked to the imaginary part of k) is determined by analyzing the resonance curves of the vibrating wave as a function of frequency. Theoretically, we compute the complex dispersion relationship taking into account the physical properties of the bulk liquid and gas phase, and of the gas–liquid interfaces. The comparison between the computation (developed to the leading order under our experimental conditions) and the experimental results confirms that the phase velocity is fixed by the interplay between surface tension, and liquid and air inertia, as reported in previous studies. Moreover, we show that the attenuation of the transverse antisymmetric wave originates from the viscous dissipation in the gas phase surrounding the liquid film. This result is an important step in understanding the propagation of an acoustic wave in liquid foam, using a bottom-up approach.


ABSTRACT: We study the buckling of elastic spherical shells under osmotic pressure with the osmolyte concentration of the exterior solution as a control parameter. We compare our results for the bifurcation behavior with results for buckling under mechanical pressure control, that is, with an empty capsule interior. We find striking differences for the buckling states between osmotic and mechanical buckling. Mechanical pressure control always leads to fully collapsed states with opposite sides in contact, whereas uncollapsed states with a single finite dimple are generic for osmotic pressure control. For sufficiently large interior osmolyte concentrations, osmotic pressure control is qualitatively similar to buckling under volume control with the volume prescribed by the osmolyte concentrations inside and outside the shell. We present a quantitative theory which also captures the influence of shell elasticity on the relationship between osmotic pressure and volume. These findings are relevant for the control of buckled shapes in applications. We show how the osmolyte concentration can be used to control the volume of buckled shells. An accurate analytical formula is derived for the relationship between the osmotic pressure, the elastic moduli and the volume of buckled capsules. This also
allows use of elastic capsules as osmotic pressure sensors or deduction of elastic properties and the internal osmolyte concentration from shape changes in response to osmotic pressure changes. We apply our findings to published experimental data on polyelectrolyte capsules.


ABSTRACT: The influence of peeling angle on the dynamics observed during the stick-slip peeling of an adhesive tape has been investigated. This study relies on a new experimental setup for peeling at a constant driving velocity while keeping constant the peeling angle and peeled tape length. The thresholds of the instability are shown to be associated with a subcritical bifurcation and bistability of the system. The velocity onset of the instability is moreover revealed to strongly depend on the peeling angle. This could be the consequence of peeling angle dependence of either the fracture energy of the adhesive-substrate joint or the effective stiffness at play between the peeling front and the point at which the peeling is enforced. The shape of the peeling front velocity fluctuations is finally shown to progressively change from typical stick-slip relaxation oscillations to nearly sinusoidal oscillations as the peeling angle is increased. We suggest that this transition might be controlled by inertial effects possibly associated with the propagation of the peeling force fluctuations through elongation waves in the peeled tape.


ABSTRACT: Nanocapsules that can be tailored intelligently and specifically have drawn considerable attention in the fields of drug delivery and bioimaging. Here we conduct a theoretical study on cell uptake of a spherical nanocapsule which is modeled as a linear elastic solid thin shell in three dimensions. It is found that there exist five wrapping phases based on the stability of three wrapping states: no wrapping, partial wrapping and full wrapping. The wrapping phase diagrams are strongly dependent on the capsule size, adhesion energy, cell membrane tension, and bending rigidity ratio between the capsule and membrane. Discussion is made on similarities and differences between the cell uptake of solid nanocapsules and fluid vesicles. The reported results may have important implications for biomedical applications of nanotechnology.


ABSTRACT: We present theoretical scaling and computational analysis of nanostructured free surfaces formed in chiral liquid crystals (LC) and plant-based twisted plywoods. A nemato-capillary model is used to derive a generalized equation that governs the shape of cholesteric free surfaces. It is shown that the shape equation includes three distinct contributions to the capillary pressure: area dilation, area rotation, and director curvature. To analyse the origin of periodic reliefs in plywood surfaces, these three pressure contributions and corresponding surface energies are systematically investigated. It is found that for weak homeotropic surface anchoring, the nano-wrinkling is driven by the director curvature pressure mechanism. Consequently, the model predicts that for a planar surface with a uniform tangential helix vector, no surface nano-scale wrinkling can be observed because the director curvature pressure is zero. Scaling is used to derive the explicit relation between the wrinkling’s amplitude to the wavelength ratio as a function of the anisotropic surface tension, which is then validated with experimental values. These new findings can be used to characterize plant-based twisted plywoods, as well as to inspire the design of biomimetic chiro-optical devices.


ABSTRACT: We report on the first systematic study of vesicle conformational change caused by Coulomb interaction between surface charges on a lipid vesicle. The equilibrium configuration of a charged vesicle is found, as the result of the competition between the local bending elastic energy and the long-range electrostatic interaction within the membrane where the counter-ion effects are neglected. Because of the Rayleigh instability, a charged vesicle undergoes conformational transitions as a function of the surface charge density.

ABSTRACT: We examine the buckling of a thin elastic film floating on a viscous liquid layer which is itself supported on a prestretched rubber sheet. Releasing the prestretch in the rubber induces a viscous stress in the liquid, which in turn induces a compressive stress in the elastic film, leading to buckling. Unlike many previous studies on wrinkling of floating films, the buckling process in the present study is dominated by viscous effects whereas gravitational effects are negligible. An approximate shear lag model predicts the evolution of the stress profile in the unbuckled film that depends on three parameters: the rate at which the prestretch is released, the thickness of the liquid layer, and the length of the elastic film. A linear perturbation analysis is developed to predict the wavelength of wrinkles. Numerical simulations are conducted to predict nonlinear evolution of the wrinkle wavelength and amplitude. Experiments using elastic polymer films and viscous polymer liquids show trends that are qualitatively consistent with the predictions although quantitatively, the experimentally-observed wrinkle wavelengths are longer than predicted. Although this article is focused only on small-strain wrinkling behavior, we show that application of large nominal strains (on the order of 100%) leads to sharply localized folds. Thus this approach may be useful for developing buckled features with high aspect ratio on surfaces.


ABSTRACT: Swelling-induced, spontaneously generated surface instability patterns in substrate-attached hydrogel films can be harnessed for advanced applications, however, methods to control their formation and morphology are missing. Here we propose that their generation may be guided by intentionally pre-introduced line structures. While uniform gel films produce irregular polygonal instability patterns, instability patterns generated in pre-patterned films with hexagonal line structures are regular hexagons with long-range order. The pre-introduced line structures act as defects in the generation of the surface instability patterns, which determine the position of the creases, regulate their rearrangement and determine their final morphology. The contrast between the pre-introduced structures and the surrounding area should be high enough for the pre-introduced structures to act as defects. Only when the characteristic wavelength of the pre-introduced pattern matches with the one of the gel film, perfect hexagonal patterns can be obtained. The gel films with uniform topographic features may find various advanced applications.

Senjiang Yu, Xiaofei Zhang, Xiaofei Xiao, Hong Zhou and Miaogen Chen (Department of Physics, China Jiliang University, Hangzhou 310018, P. R. China), “Wrinkled stripes localized by cracks in metal films deposited on soft substrates”, Soft Matter, Vol. 11, No. 11, pp 2203-2212, 2015, http://dx.doi.org/10.1039/C5SM0105F

ABSTRACT: Homogeneous global wrinkling patterns such as labyrinths, herringbones, ripples and straight stripes can be widely observed in natural and artificial systems, but localized wrinkling patterns (not including buckle-driven delaminations, folds, ridges and creases) are seldom observed in experiments. Here we report on the spontaneous formation of highly ordered wrinkled stripes localized by cracks in metal films deposited on soft substrates. The experiment shows that the metal film is under a large tensile stress during deposition, which is relieved by the formation of networked cracks. After deposition, a compressive stress is stored up in the film and it always focuses near the new formed cracks due to the plastic deformation of the film, resulting in the formation of localized wrinkled stripes composed of a large number of straight wrinkles perpendicular to the cracks. The morphological characteristic, formation mechanism and evolution behaviors of the localized wrinkled stripes have been described and discussed in detail.

References listed at the end of the paper:
ABSTRACT: Understanding the transients of buckling in drying colloidal suspensions is pivotal for producing new functional microstructures with tunable morphologies. Here, we report first observations and elucidate the logics. Here, we report first observations and elucidate the logics. Here, we report first observations and elucidate the logics. Here, we report first observations and elucidate the logics.
symmetric cavities is initiated by capillary pressure that is two to three orders of magnitude greater than the acoustic radiation pressure, thus indicating that the standing pressure field has no influence on the buckling front kinetics. With an increase in heat flux, the growth rate of surface cavities and their post-buckled volume increase while the buckling time period reduces, thereby altering the buckling pathway and resulting in distinct precipitate structures. However, irrespective of the heating rate, the volumetric droplet deformation exhibits a linear time dependence and the droplet vaporization is observed to deviate from the classical $D^{2/3}$-law.


ABSTRACT: We demonstrate a novel approach for controlling the formation of line-defects in wrinkling patterns by introducing step-like changes in the Young's modulus of elastomeric substrates supporting thin, stiff layers. Wrinkles are formed upon treating the poly(dimethylsiloxane) (PDMS) substrates by UV/Ozone (UVO) exposure in a uniaxially stretched state and subsequent relaxation. Line defects such as minutiae known from fingerprints are a typical feature in wrinkling patterns. The position where these defects occur is random for homogenous substrate elasticity and film thickness. However, we show that they can be predetermined by using PDMS substrates consisting of areas with different cross-linking densities. While changing the cross-linking density is well known to influence the wrinkling wavelength, we use this parameter in this study to force defect formation. The defect formation is monitored in situ using light microscopy and the mechanical parameters/film thicknesses are determined using imaging AFM indentation measurements. Thus the observed wrinkle-wavelengths can be compared to theoretical predictions. We study the density and morphology of defects for different changes in elasticity and compare our findings with theoretical considerations based on a generalized Swift–Hohenberg-equation to simply emulate the observed pattern-formation process, finding good agreement. The fact that for suitable changes in elasticity, well-ordered defect patterns are observed is discussed with respect to formation of hierarchical structures for applications in optics and nanotechnology.

É. Lintingre (1,2), G. Ducouret (1,2), F. Lequeux (1,2), L. Olanier (1,2), T. Périé (3) and L. Talini (1,2)
(1) École Supérieure de Physique et de Chimie Industrielles de la Ville de Paris ParisTech, PSL Research University, Sciences et Ingénierie de la matière Molle, CNRS UMR7615, 10, Rue Vauquelin, F-75231 Paris Cedex 05, France
(2) Sorbonne-Universités, UPMC Univ. Paris 06, SIMM, 10, Rue Vauquelin, F-75231 Paris Cedex 05, France
(3) Saint-Gobain CREE, 550 avenue Alphonse Jauffret, BP 20224, 84306 Cavaillon, France


ABSTRACT: The present study focuses on the drying of droplets of colloidal suspensions using the Leidenfrost effect. At the end of drying, grains show different morphologies: cups or spheres depending on the ionic strength or zeta potential of the initial suspension. High ionic strengths and low absolute zeta potential values lead to spherical morphologies. A model based on the calculations of DLVO potentials has been implemented to extract a critical pressure, which provides a quantitative criterion for buckling whatever the initial formulation is. Particularly, the buckling time is quantitatively predicted from the interparticle interactions and shows an excellent agreement with experimental values.


ABSTRACT: Surface wrinkling may occur in a film–substrate system when the applied strain exceeds the critical value. However, the practically required strain for the onset of surface wrinkling can be different from the theoretically predicted value. Here we investigate the film size effect-dependent critical strain for the mechanical strain-induced surface wrinkling via a combination of experiments and theoretical analysis. In the poly(dimethylsiloxane)-based system fabricated by the smart combination of mechanical straining and selective O plasma (OP) exposure through Cu grids, the film size effect on the critical wrinkling strain is systematically studied by considering OP exposure duration, the mesh number and geometry of Cu grids. Meanwhile, a simple analytical solution revealing the film size effect is well established, which shows good consistency with the experimental results. This study provides an experimental and theoretical basis for finely tuning the critical

ABSTRACT: We computationally investigate the dynamics of a vesicle exposed to uniform DC or AC electric fields. We employ the two-dimensional boundary integral method in order to simulate vesicle deformation under experimental conditions where peculiar drum-like (“squared”) shapes have been observed. The vesicle membrane is modeled as an infinitely thin, capacitive, area-incompressible interface, with the surrounding fluids acting as leaky dielectrics. Our simulations capture the “squaring” phenomenon, in which vesicles deform into rectangular profiles with corner-like regions of high curvature, as vesicles undergo dynamic transitions between oblate and prolate ellipsoidal shapes.


ABSTRACT: Understanding and controlling the shape of thin, soft objects has been the focus of significant research efforts among physicists, biologists, and engineers in the last decade. These studies aim to utilize advanced materials in novel, adaptive ways such as fabricating smart actuators or mimicking living tissues. Here, we present the controlled growth-like morphing of 2D sheets into 3D shapes by preparing geometric composite structures that deform by residual swelling. The morphing of these geometric composites is dictated by both swelling and geometry, with diffusion controlling the swelling-induced actuation, and geometric confinement dictating the structure’s deformed shape. Building on a simple mechanical analog, we present an analytical model that quantitatively describes how the Gaussian and mean curvatures of a thin disk are affected by the interplay among geometry, mechanics, and swelling. This model is in excellent agreement with our experiments and numerics. We show that the dynamics of residual swelling is dictated by a competition between two characteristic diffusive length scales governed by geometry. Our results provide the first 2D analog of Timoshenko's classical formula for the thermal bending of bimetallic beams – our generalization explains how the Gaussian curvature of a 2D geometric composite is affected by geometry and elasticity. The understanding conferred by these results suggests that the controlled shaping of geometric composites may provide a simple complement to traditional manufacturing techniques.


ABSTRACT: A simple, coarse-grained model of chiral, helical filaments is used to study the polymorphism of fibrous aggregates. Three generic morphologies of the aggregates are observed: ribbons, in which the filaments are joined side-by-side, twisted, helicoidal fibrils, in which filaments entwine along each other and tubular forms, with filaments wound together around a hollow core of the tube. A relative simplicity of the model allows us to supplement numerical simulations with an analytic description of the elastic properties of the aggregates. The model is capable of predicting geometric and structural characteristics of the composite structures, as well as their relative stabilities. We also investigate in detail the transitions between different morphologies of the aggregates.


ABSTRACT: Dielectric elastomer (DE) transducers frequently undergo voltage-induced large deformation, which may lead to mechanical instabilities. Here, we investigate wrinkle formation and propagation on the surface of a DE membrane mounted on an air chamber and subjected to a step voltage. Our experiments show that the geometric characteristics of the wrinkle morphology and the nucleation sites depend on the inflation pressure and the applied voltage. As the inflation pressure increases, the critical voltage used to nucleate the
wrinkle decreases, while the location where the wrinkle nucleates shifts from the center to the boundary of the membrane. Moreover, by increasing the amplitude of the applied voltage, wrinkle morphology changes from stripe-like wrinkles to labyrinth-like wrinkles. Furthermore, we develop an analytical model to validate the experimental observations and map out the various wrinkle morphologies as a function of the applied pressure and voltage. A three dimensional phase diagram is constructed to help design new soft actuators.


ABSTRACT: When an inflated soft tube such as a cylindrical balloon is twisted, mechanical instability can arise and produces a kink-like radius collapsing in the middle of the tube. Here this phenomenon inspires us to theoretically analyze a standard non-linear model of rubber elasticity for soft tubes. We show that there exists a critical pressure beyond which such instability arises. The critical pressure depends on the elastic properties of the tube material and the geometric dimensions of the thin-walled tube. This general theory covers a large class of soft materials and explains why twist-induced collapsing is observable in soft and thin elastic tubes such as balloons, but not in hard and thick tubes such as water hoses.


ABSTRACT: We report a nonlinear finite element analysis (FEA) of the thermo-mechanical shrinking and self-folding behavior of pre-strained polystyrene polymer sheets. Self-folding is useful for actuation, packaging, and remote deployment of flat surfaces that convert to 3D objects in response to a stimulus such as heat. The proposed FEA model accounts for the viscoelastic recovery of pre-strained polystyrene sheets in response to localized heating on the surface of the polymer. Herein, the heat results from the localized absorption of light by ink patterned on the surface of the sheet. This localized delivery of heat results in a temperature gradient through the thickness of the sheet, and thus a gradient of strain recovery, or shrinkage, develops causing the polymer sheet to fold. This process transforms a 2D pattern into a 3D shape through an origami-like behavior. The FEA predictions indicate that shrinking and folding are sensitive to the thermo-mechanical history of the polymer during pre-straining. The model also shows that shrinkage does not vary linearly through the thickness of the polymer during folding due to the accumulation of mass in the hinged region. Counterintuitively, the maximum shrinkage does not occur at the patterned surface. Rather, it occurs considerably below the top surface of the polymer. This investigation provides a fundamental understanding of shrinking, self-folding dynamics, and bending angles, and provides design guidelines for origami shapes and structures.


ABSTRACT: If a soft solid is compressible, its volume changes with imposed loading. The extent of the volume change depends on its Poisson's ratio. Here, we study the effect of the mechanical-driven volumetric change on buckling and post-buckling behaviors of a hard thin film perfectly bound on a compliant substrate through the theoretical analysis and finite element method. Poisson's ratio of the substrate has been chosen to be in the range of −1 to 0.5, allowing its volume change during deformation. We find that Poisson's ratio cannot only shift the critical strain for the onset of buckling, but also affect the buckling modes. When Poisson's ratio of the substrate is close to −1, the surface instabilities of the thin film can be suppressed and delayed to large deformation. The present study demonstrates a new way to control surface instabilities of a bilayered system by changing Poisson's ratio of the material.


ABSTRACT: The surfactant lining the walls of the alveoli in the lungs increases pulmonary compliance and prevents collapse of the lung at the end of expiration. In premature born infants, surfactant deficiency causes problems, and lung surfactant replacements are instilled to facilitate breathing. These pulmonary surfactants,
which form complex structured fluid–fluid interfaces, need to spread with great efficiency and once in the alveolus they have to form a thin stable film. In the present work, we investigate the mechanisms affecting the stability of surfactant-laden thin films during spreading, using drainage flows from a hemispherical dome. Three commercial lung surfactant replacements Survanta, Curosurf and Infasurf, along with the phospholipid dipalmitoylphosphatidylcholine (DPPC), are used. The surface of the dome can be covered with human alveolar epithelial cells and experiments are conducted at the physiological temperature. Drainage is slowed down due to the presence of all the different lung surfactant replacements and therefore the thin films show enhanced stability. However, a scaling analysis combined with visualization experiments demonstrates that different mechanisms are involved. For Curosurf and Infasurf, Marangoni stresses are essential to impart stability and interfacial shear rheology does not play a role, in agreement with what is observed for simple surfactants. Survanta, which was historically the first natural surfactant used, is rheologically active. For DPPC the dilatational properties play a role. Understanding these different modes of stabilization for natural surfactants can benefit the design of effective synthetic surfactant replacements for treating infant and adult respiratory disorders.


ABSTRACT: A fundamental understanding of the interactions between nanoparticles (NPs) and the cell membrane is essential to improve the performance of the NP-based biomedical applications and assess the potential toxicity of NPs. Despite the great progress in understanding the interaction between individual NP and the membrane, little is known about the interaction between multiple NPs and the membrane. In this work, we investigate the wrapping of two parallel elongated NPs by the membrane, taking the NP–NP electrostatic interaction and van der Waals interaction into consideration. Three types of NPs, namely rigid NPs with circular and elliptic cross-sections and the deformable NPs, are systematically investigated. The results show that the electrostatic interaction would enhance the tendency of the independent wrapping and inhibit the rotation of the elongated and equally charged NPs with elliptic cross-sections. Under the vdW interaction, the competition of the NP–NP adhesion and the membrane elastic energies with the NP–membrane adhesion energy leads the NPs to be wrapped cooperatively or independently. For the system with elongated NPs with elliptic cross-sections, the NPs are more likely to be wrapped independently as the shapes become more anisotropic and the NPs would rotate to contact each other with the flat sides in the cooperative wrapping configuration. Moreover, the soft NPs are more likely to be wrapped cooperatively compared with the stiff NPs. These results may provide guidelines to control the internalization pathway of NPs and improve the efficiency of NP-based drug delivery systems.


ABSTRACT: The free surface of a thin soft polymer film is often found to become unstable and self-organizes into various meso-scale structures. In this article we classify the instability of a thin polymer film into three broad categories, which are: category 1: instability of an ultra-thin (<100 nm) viscous film engendered by amplification of thermally excited surface capillary waves due to interfacial dispersive van der Waals forces; category 2: instability arising from the attractive inter-surface interactions between the free surface of a soft film exhibiting room temperature elasticity and another rigid surface in its contact proximity; and category 3: instability caused by an externally applied field such as an electric field or a thermal gradient, observed in both viscous and elastic films. We review the salient features of each instability class and highlight how characteristic length scales, feature morphologies, evolution pathways, etc depend on initial properties such as film thickness, visco-elasticity (rheology), residual stress, and film preparation conditions. We emphasize various possible strategies for aligning and ordering of the otherwise isotropic structures by combining the essential concepts of bottom-up and top-down approaches. A perspective, including a possible future direction of research, novelty and limitations of the methods, particularly in comparison to the existing patterning techniques, is also presented for each setting.

ABSTRACT: When a thin stiff film adhered to a compliant substrate is subject to compressive stresses, the film will experience a geometric instability and buckle out of plane. For high film/substrate stiffness ratios with relatively low levels of strain, the primary mode of instability will either be wrinkling or buckling delamination depending on the material and geometric properties of the system. Previous works approach these systems by treating the film and substrate as homogenous layers, either consistently perfectly attached, or perfectly unattached at interfacial flaws. However, this approach neglects systems where the film and substrate are uniformly weakly attached or where interfacial layers due to surface modifications in either the film or substrate are present. Here we demonstrate a method for accounting for these additional thin surface layers via an analytical solution verified by numerical results. The main outcome of this work is an improved understanding of how these layers influence global behavior. We demonstrate the utility of our model with applications ranging from buckling based metrology in ultrathin films, to an improved understanding of the formation of a novel surface in carbon nanotube bio-interface films. Moving forward, this model can be used to interpret experimental results, particularly for systems which deviate from traditional behavior, and aid in the evaluation and design of future film/substrate systems.


ABSTRACT: Elastic fibers embedded in a soft matrix are frequently encountered in nature and engineering across different length scales, ranging from microtubules in cytosol and filament networks to dissociative slender fish bones in muscles and fiber-reinforced soft composites. Fibers may buckle when the composite is subjected to compression; this study investigates this issue through a combination of experiments, finite-element simulations and theoretical analysis. Analysis reveals the important role of the interfacial shear forces and leads to an explicit solution to predict the occurrence of buckling for a slender fiber with finite length. The results reported in this paper will help understand the formation of shapes in some natural systems and provide guidelines for the design of soft biocomposites.


ABSTRACT: The flat surface of a thin elastomer on a conducting substrate can be deformed by applying an electric field to a percolating network of metallic nanowires randomly dispersed over the surface. The magnitude of the field-induced surface undulations increases with the applied field and can locally be several times the diameter of the nanowires. Optical imaging indicates that the effect is reversible and the surface flatness is recovered when the electric field is removed. It is found that it is the field-induced changes in the surface morphology rather than the nanowires themselves that strongly scatter light. The optical effects could be exploited in functional devices including tunable privacy windows, displays, and camouflage. There is also the potential for tuning the adhesion of elastomers to other materials.


ABSTRACT: To understand the deformation and internal stress of a red blood cell when it is pushed through a slit by an incoming flow, we conduct a numerical investigation by combining a fluid–cell interaction model based on boundary-integral equations with a multiscale structural model of the cell membrane that takes into account the detailed molecular architecture of this biological system. Our results confirm the existence of cell ‘infolding’, during which part of the membrane is inwardly bent to form a concave region. The time histories and distributions of area deformation, shear deformation, and contact pressure during and after the translocation are examined. Most interestingly, it is found that in the recovery phase after the translocation significant dissociation pressure may develop between the cytoskeleton and the lipid bilayer. The magnitude of this pressure is closely related to the locations of the dimple elements during the transit. Large dissociation pressure in certain cases suggests the possibility of mechanically induced structural remodeling and structural damage such as vesiculation. With quantitative knowledge about the stability of intra-protein, inter-protein and protein-to-lipid linkages under dynamic loads, it will be possible to achieve numerical prediction of these processes.

ABSTRACT: The surface instability of monolayer graphene supported by a soft (polymer) substrate under equal-biaxial compression has been explored through large scale coarse-grained molecular simulations. Regardless of the interfacial adhesion strength between the graphene and the substrate, herringbone wrinkles have always been observed due to their lowest energy status, compared with the checkerboard, hexagonal, triangular and one dimensional sinusoidal modes. Moreover, the graphene–polymer substrate interaction energy has a negligible effect on the critical strain for the onset of these wrinkles. Yet, if the graphene is bonded to a rigid (non-deformable) substrate, the critical strain increases with increasing graphene–substrate interfacial strength. The surface wrinkles of graphene are delayed and suppressed by the strong bonding of graphene to the rigid substrate. Besides, only localized folds and crumples have been observed on the surface of graphene, when graphene–substrate interaction energy is strong enough. All these observations signal that the deformability (stiffness) of the substrate plays an essential role in determining the morphology of supported graphene under compression. In addition, when a flat graphene is attached on a highly pre-strained (50%) polymer substrate, wrinkles will be formed on its surface during the relaxation of pre-strain within the polymer substrate. The wrinkled graphene could be stretched up to 50% without fracture, accompanied by the diminishing of surface wrinkles. Therefore, it opens a new avenue to enhance the stretchability of graphene materials, and enables the future applications of graphene and other 2D materials in stretchable and flexible electronics.


ABSTRACT: We introduce a general theoretical framework to study the shape dynamics of actively growing and remodeling surfaces. Using this framework we develop a physical model for growing bacterial cell walls and study the interplay of cell shape with the dynamics of growth and constriction. The model allows us to derive constraints on cell wall mechanical energy based on the observed dynamics of cell shape. We predict that exponential growth in cell size requires a constant amount of cell wall energy to be dissipated per unit volume. We use the model to understand and contrast growth in bacteria with different shapes such as spherical, ellipsoidal, cylindrical and toroidal morphologies. Coupling growth to cell wall constriction, we predict a discontinuous shape transformation, from partial constriction to cell division, as a function of the chemical potential driving cell wall synthesis. Our model for cell wall energy and shape dynamics relates growth kinetics with cell geometry, and provides a unified framework to describe the interplay between shape, growth and division in bacterial cells.


ABSTRACT: The gradual in-plane compression of a solid film bonded to a soft substrate can lead to surface wrinkling and even to the formation of a network of folds for sufficiently high strain. An understanding of how these folds initiate, propagate, and interact with each other is still lacking. In a previous study, we developed an experimental system to observe the wrinkle-to-fold transition of layered elastic materials under biaxial compressive stresses. Here we focus on the dynamic interaction of a pair of propagating folds under biaxial compression. We find experimentally that their behavior is mediated through their tips and depends on the separation of the tips and their angle of interception. When the angle is lower than 45°, the two folds either form a unique fold by the coalescence of their tips when close enough, or bend their trajectories to intersect each other and form a lenticular region in analogy with cracks. When the angle is higher then 45°, the folds simply intersect and form a T-like junction. We rationalize this behavior by conducting numerical simulations to visualize the stress field around the two tips and find that the initial geometric position of the tips primarily determines the final state of the folds.


ABSTRACT: In this study, we combine the elastic instability and non-linear rate-dependent phenomena to achieve microstructure tunability in soft layered materials. In these soft composites, elastic instabilities give rise
to formation of wrinkles or wavy patterns. In elastic materials, the critical wavelength as well as amplitude at a particular strain level are exclusively defined by the composite microstructure and contrast in the elastic moduli of the phases. Here, we propose to use rate-dependent soft constituents to increase the admissible range of tunable microstructures. Through the experiments on 3D printed soft laminates, and through the numerical simulation of the visco-hyperelastic composites, we demonstrate the existence of various instability-induced wavy patterns corresponding to the identical deformed state of the identical soft composites.

ABSTRACT: We use a two-dimensional discrete, lattice-based model to show that Möbius bands made with stretchable materials are less likely to crease or tear. This stems from a delocalization of twisting strain that occurs if stretching is allowed. The associated low-energy configurations provide strategic target shapes for the guided assembly of nanometer and micron scale Möbius bands. To predict macroscopic band shapes for a given material, we establish a connection between stretchability and relevant continuum moduli, leading to insight regarding the practical feasibility of synthesizing Möbius bands from materials with continuum parameters that can be measured experimentally or estimated by upscale averaging.

ABSTRACT: Vesicles provide an attractive model system to understand the deformation of living cells in response to mechanical forces. These simple, enclosed lipid bilayer membranes are suitable for complementary theoretical, numerical, and experimental analysis. A recent study [Narsimhan, Spann, Shaqfeh, J. Fluid Mech., 2014, 750, 144] predicted that intermediate-aspect-ratio vesicles extend asymmetrically in extensional flow. Upon infinitesimal perturbation to the vesicle shape, the vesicle stretches into an asymmetric dumbbell with a cylindrical thread separating the two ends. While the symmetric stretching of high-aspect-ratio vesicles in extensional flow has been observed and characterized [Kantsler, Segre, Steinberg, Phys. Rev. Lett., 2008, 101, 048101] as well as recapitulated in numerical simulations by Narsimhan et al., experimental observation of the asymmetric stretching has not been reported. In this work, we present results from microfluidic cross-slot experiments observing this instability, along with careful characterization of the flow field, vesicle shape, and vesicle bending modulus. The onset of this shape transition depends on two non-dimensional parameters: reduced volume (a measure of vesicle asphericity) and capillary number (ratio of viscous to bending forces). We observed that every intermediate-reduced-volume vesicle that extends forms a dumbbell shape that is indeed asymmetric. For the subset of the intermediate-reduced-volume regime we could capture experimentally, we present an experimental phase diagram for asymmetric vesicle stretching that is consistent with the predictions of Narsimhan et al.

Jiangshui Huang, Jiawei Yang, Lihua Jin, David R. Clarke and Zhigang Suo (School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA), “Pattern formation in plastic liquid films on elastomers by ratcheting”, Soft Matter, Vol. 12, No. 16, pp 3820-3827, 2016, http://dx.doi.org/10.1039/C6SM000124F
ABSTRACT: Plastic liquids, also known as Bingham liquids, retain their shape when loads are small, but flow when loads exceed a threshold. We discovered that plastic liquid films coated on elastomers develop wavy patterns under cyclic loads. As the number of cycles increases, the wavelength of the patterns remains unchanged, but the amplitude of the patterns increases and then saturates. Because the patterns develop progressively under cyclic loads, we call this phenomenon as “patterning by ratcheting”. We observe the phenomenon in plastic liquids of several kinds, and studied the effects of thickness, the cyclic frequency of the stretch, and the range of the stretch. Finite element simulations show that the ratcheting phenomenon can occur in materials described by a commonly used model of elastic–plastic deformation.

ABSTRACT: Regular surface patterns induced by the wrinkling of thin films have received intense attention in both science and engineering. We investigate the wrinkling of structured thin films that consist of two types of materials arranged in periodic patterns. A mechanical model is proposed to understand the physics of the wrinkling, and a set of scaling laws for the wrinkle wavelength is obtained. Periodic wrinkles are generated in the local regions of structured films via in-plane contrasted elastic modulus between heterogeneous materials. The wrinkle morphology and location can be tailored by designing structured thin films in a controllable way. Our findings provide the basis for understanding the wrinkling of structured thin films and for the manufacture of regular surface patterns via wrinkling.


ABSTRACT: Compression of a film/substrate bilayer system with different surface/interfacial structures can lead to diverse buckling patterns including sinusoidal wrinkles, ridges, folds, creases and tilted sawtooth wrinkles. In this paper, we show that elastic wave band gaps in the film/substrate bilayer system largely depend on the wrinkling patterns. More interestingly, we find that different wrinkling patterns investigated here can coexist and evolve in one bilayer system and the elastic wave propagation behaviors can be controlled by manipulating the hybrid wrinkling patterns. Our analysis also reveals that the periodic stress pattern plays a dominant role in tuning the bandgap structures in comparison to geometrical patterns caused by surface instability. A careful investigation of the transmission spectra of the composite systems has validated the main findings given by the analysis based on the Bloch wave theory. Potential use of the method and materials reported here to gain wide attenuation frequency ranges and the design of nesting Fibonacci superlattices have been demonstrated.


ABSTRACT: Superhydrophobic surfaces have attracted great attention for drag reduction application. However, these surfaces are subject to instabilities, especially under fluid flow. In this work, we in situ examine the stability and wetting transition of underwater superhydrophobicity under laminar flow conditions by confocal microscopy. The absolute liquid pressure in the flow channel is regulated to acquire the pinned Cassie–Baxter and depinned metastable states. The subsequent dynamic evolution of the meniscus morphology in the two states under shear flow is monitored. It is revealed that fluid flow does not affect the pressure-mediated equilibrium states but accelerates the air exchange between entrapped air cavities and bulk water. A diffusion-based model with varying effective diffusion lengths is used to interpret the experimental data, which show a good agreement. The Sherwood number representing the convection-enhanced mass transfer coefficient is extracted from the data, and is found to follow a classic 1/3-power-law relation with the Reynolds number as has been discovered in channel flows with diffusive boundary conditions. The current work paves the way for designing durable superhydrophobic surfaces under flow conditions.


ABSTRACT: We investigate how thin sheets of arbitrary shapes morph under the isotropic in-plane expansion of their top surface, which may represent several stimuli such as nonuniform heating, local swelling and differential growth. Inspired by geometry, an analytical model is presented that rationalizes how the shape of the disk influences morphing, from the initial spherical bending to the final isometric limit. We introduce a new measure of slenderness that describes a sheet in terms of both thickness and plate shape. We find that the mean curvature of the isometric state is three fourths the natural curvature, which we verify by numerics and experiments. We finally investigate the emergence of a preferred direction of bending in the isometric state, guided by numerical analyses. The scalability of our model suggests that it is suitable to describe the morphing of sheets spanning several orders of magnitude.

ABSTRACT: The evaporation of a nanocolloidal sessile droplet exhibits preferential particle assembly, nanoporous shell formation and buckling to form cavities with unique morphological features. Here, we have established many universal trends that explain the buckling dynamics under one umbrella irrespective of hydrophobicity, evaporation mode and particle loading. We provide a regime map explaining the droplet morphology and buckling characteristics for droplet evaporation on various substrates. Specifically, we find that the final droplet volume and the radius of curvature at the buckling onset are universal functions of particle concentration. Furthermore, we establish that post-buckling cavity growth is evaporation driven regardless of the substrate.


ABSTRACT: Shape programmable materials capable of morphing from a flat sheet into controlled three dimensional (3D) shapes offer promise in diverse areas including soft robotics, tunable optics, and bio-engineering. We describe a simple method of ‘grayscale gel lithography’ that relies on a digital micromirror array device (DMD) to control the dose of ultraviolet (UV) light, and therefore the extent of swelling of a photocrosslinkable poly(N-isopropyl acrylamide) (PNIPAm) copolymer film, with micrometer-scale spatial resolution. This approach allows for effectively smooth profiles of swelling to be prescribed, enabling the preparation of buckled 3D shapes with programmed Gaussian curvature.


ABSTRACT: Shape programmable materials capable of morphing from a flat sheet into controlled three dimensional (3D) shapes offer promise in diverse areas including soft robotics, tunable optics, and bio-engineering. We describe a simple method of ‘grayscale gel lithography’ that relies on a digital micromirror array device (DMD) to control the dose of ultraviolet (UV) light, and therefore the extent of swelling of a photocrosslinkable poly(N-isopropyl acrylamide) (PNIPAm) copolymer film, with micrometer-scale spatial resolution. This approach allows for effectively smooth profiles of swelling to be prescribed, enabling the preparation of buckled 3D shapes with programmed Gaussian curvature.


ABSTRACT: During cerebellar development, anchoring centers form at the base of each fissure and remain fixed in place while the rest of the cerebellum grows outward. Cerebellar foliation has been extensively studied; yet, the mechanisms that control anchoring center initiation and position remain insufficiently understood. Here we show that a tri-layer model can predict surface wrinkling as a potential mechanism to explain anchoring center initiation and position. Motivated by the cerebellar microstructure, we model the developing cerebellum as a tri-layer system with an external molecular layer and an internal granular layer of similar stiffness and a significantly softer intermediate Purkinje cell layer. Including a weak intermediate layer proves key to predicting surface morphogenesis, even at low stiffness contrasts between the top and bottom layers. The proposed tri-layer model provides insight into the hierarchical formation of anchoring centers and establishes an essential missing link between gene expression and evolution of shape.

ABSTRACT: We study the fully nonlinear, nonlocal dynamics of two-dimensional vesicles in a time-dependent, incompressible viscous flow at finite temperature. We focus on a transient instability that can be observed when the direction of applied flow is suddenly reversed, which induces compressive forces on the vesicle interface, and small-scale interface perturbations known as wrinkles develop. These wrinkles are driven by regions of negative elastic tension on the membrane. Using a stochastic immersed boundary method with a biophysically motivated choice of thermal fluctuations, we investigate the wrinkling dynamics numerically. Different from deterministic wrinkling dynamics, thermal fluctuations lead to symmetry-breaking wrinkling patterns by exciting higher order modes. This leads to more rapid and more realistic wrinkling dynamics. Our results are in excellent agreement with the experimental data by Kantsler et al. [Kantsler et al., Phys. Rev. Lett., 2007, 99, 17802]. We compare the nonlinear simulation results with perturbation theory, modified to account for thermal fluctuations. The strength of the applied flow strongly influences the most unstable wavelength characterizing the wrinkles, and there are significant differences between the results from perturbation theory and the fully nonlinear simulations, which suggests that the perturbation theory misses important nonlinear interactions. Strikingly, we find that thermal fluctuations actually have the ability to attenuate variability of the characteristic wavelength of wrinkling by exciting a wider range of modes than the deterministic case, which makes the evolution less constrained and enables the most unstable wavelength to emerge more readily. We further find that thermal noise helps prevent the vesicle from rotating if it is misaligned with the direction of the applied extensional flow.


ABSTRACT: Wrinkling of a soft elastomer surface capped by a relatively hard thin film or modified by some physical treatments to induce hardening has been widely studied for applications in fields such as low-cost micro-fabrication, optics and tribology. Here we show that a biaxial textile sheet embedded on the surface of an elastomer buckles and selectively forms anisotropic wrinkles when experiencing a compressive strain in the fibre axial direction. The wrinkles also possess a fine surface structure that originates from the periodic structure of the biaxial textile sheet. Depending on whether the surface is wrinkled or not, the unique frictional property due to which the friction on wrinkles significantly decreases by a factor of less than 0.1 because of the localized contact regions on the protrusions originating from the textile structure is shown.


ABSTRACT: We investigate mismatch strain driven programmable shape transformation of spherical domes and report the effects of different geometric and structural characteristics on dome behavior in response to applied mismatch strain. We envision a bilayer dome design where the differential swelling of the inner layer with respect to the passive outer layer in response to changes in dome surroundings (such as the introduction of an organic solvent) introduces mismatch strain within the bilayer system and causes dome shape transformation. Finite element analysis reveals that, in addition to snap-through, spherical domes undergo bifurcation buckling and eventually gradual bending to morph into cylinders with increasing mismatch strain. Besides demonstrating how the snap-through energy barrier depends on the spherical dome shape, our analysis identifies three distinct groups of dome geometries based on their mismatch strain-transformed configuration relationships. Our experiments with polymer-based elastic bilayer domes that exhibit differential swelling in organic solvents qualitatively confirm the finite element predictions. We establish that, in addition to externally applied stimuli (mismatch strain), bilayer spherical dome morphing can be tuned and hence programmed through its geometry and structural characteristics. Incorporation of an elastic instability mechanism such as snap-through within the framework of stimuli-responsive functional devices can improve their response time which is otherwise controlled by diffusion. Hence, our proposed design guidelines can be used to realize deployable, multifunctional, reconfigurable, and therefore, adaptive structures responsive to a diverse set of stimuli across multiple length scales.
Folds, highly deformed structures, have received extensive attention for their nonlinear responses due to a large strain on soft matters. To investigate the folding phenomena, here, we exploit residual tensile stress during metal deposition, which is large enough to compress a thin film coating and introduce a photocurable viscous fluid to decrease the resistance of the substrate against compressive stress. The system has the advantages of the abilities for freezing the highly deformed surfaces by post-UV exposure to the UV-crosslinkable substrate and manipulating the substrate effect by controlling the thickness of the substrate. We theoretically investigated the dependence on the substrate thickness using scaling analysis and demonstrated self-generated ladder and flower-like graphoepitaxial structures originated from the thickness design of the viscous substrate.

D. Pihler-Puzovic (1), A.L. Hazel (2) and T. Mullin (1)
(1) Manchester Centre for Nonlinear Dynamics and School of Physics and Astronomy, University of Manchester, Oxford Road, Manchester, UK
(2) Manchester Centre for Nonlinear Dynamics and School of Mathematics, University of Manchester
“Buckling of a holey column”, Soft Matter, Vol. 12, No. 34, pp 7112-7118, 2016,
http://dx.doi.org/10.1039/C6SM00948D

ABSTRACT: We report the results from a combined experimental and numerical investigation of buckling in a novel variant of an elastic column under axial load. We find that including a regular line of centred holes in the column can prevent conventional, global, lateral buckling. Instead, the local microstructure introduced by the holes allows the column to buckle in an entirely different, internal, mode in which the holes are compressed in alternate directions, but the column maintains the lateral reflection symmetry about its centreline. The internal buckling mode can be accommodated within a smaller external space than the global one; and it is the preferred buckling mode over an intermediate range of column lengths for sufficiently large holes. For very short or sufficiently long columns a modification of the classical, global, lateral buckling is dominant.


ABSTRACT: A cylindrical elastomer tube can stay in an everted state without any external forces. If the thickness of the tube is small, the everted tube, except for the regions close to the free ends of the tube, maintains a cylindrical shape, and if the thickness is larger than a critical value, the cross-section of the everted tube becomes noncircular, which is caused by mechanical instability. Although eversion-induced instability in an elastomer tube has been reported several decades ago, a satisfying explanation of the phenomenon is still unavailable. In all previous studies, linear analyses have been adopted to predict the critical thickness of the tube for eversion-induced instability. The discrepancy between prediction and experiment is significant. In this communication, based on experiments and theoretical analyses, we show that crease formation on the inner surface of an everted tube is the mechanical instability mode, which cannot be captured by linear stability analyses. Instead, a combination of energetic analyses and numerical simulations of finite deformation in an everted tube enables us to correctly predict both the critical tube thickness for the onset of creases and the profile of the noncircular cross-section of an everted tube.

Zhi-Chun Shao, Yan Zhao, Wanyu Zhang, Yanping Cao and Xi-Qiao Feng, “Curvature induced hierarchical wrinkling patterns in soft bilayers”, Soft Matter, Vol. 12, No. 38, pp 7977-7982, 2016,
http://dx.doi.org/10.1039/C6SM01088A

ABSTRACT: Sinusoidal wrinkling will occur in a planar film-substrate bilayer when the uniaxial compressive strain imposed to the system exceeds a critical value. However, when a core–shell soft cylinder is subjected to axial compression, surface wrinkling patterns may evolve from the sinusoidal mode to the diamond-like mode, depending on the modular ratio and the curvature of the system. Inspired by this phenomenon, we here propose a simple yet robust strategy to fabricate hierarchical wrinkling patterns by controlling the curvature of a film-substrate system. To quantitatively understand the experimental results, a three-dimensional finite element model has been built to track the wrinkling pattern evolution. Furthermore, a phase diagram is provided based on the theoretical analysis and finite element simulations, which may guide the experimental design. In
addition, the wetting properties of the surface with hierarchical micropatterns fabricated using the proposed method are investigated. The results show that the hierarchical surface wrinkles lead to anisotropic wetting behavior, which can be tuned by controlling the imposed compressive strain. The tunable anisotropic wetting surface fabricated here may find a broad range of applications such as in the development of sensors, fluidic devices, micro-reactors and biomedical devices.


ABSTRACT: Worm-like filaments, which are propelled by a tangential homogeneous force along their contour, are studied as they push loads of different shapes and sizes. The resulting dynamics is investigated using Langevin dynamics simulations. The effects of size and shape of the load, propulsion strength, and thermal noise are systematically explored. The propulsive force and hydrodynamic friction of the load cause a compression in the filament that results in a buckling instability and versatile motion. Distinct regimes of elongated filaments, curved filaments, beating filaments, and filaments with alternating beating and circular motion are identified, and a phase diagram depending on the propulsion strength and the size of the load is constructed. Characteristic features of the different phases, such as beating frequencies and rotational velocities, are demonstrated to have a power-law dependence on the propulsive force.


ABSTRACT: Soft elastic layers with top and bottom surfaces adhered to rigid bodies are abundant in biological organisms and engineering applications. As the rigid bodies are pulled apart, the stressed layer can exhibit various modes of mechanical instabilities. In cases where the layer's thickness is much smaller than its length and width, the dominant modes that have been studied are the cavitation, interfacial and fingerling instabilities. Here we report a new mode of instability which emerges if the thickness of the constrained elastic layer is comparable to or smaller than its width. In this case, the middle portion along the layer's thickness elongates nearly uniformly while the constrained fringe portions of the layer deform nonuniformly. When the applied stretch reaches a critical value, the exposed free surfaces of the fringe portions begin to undulate periodically without debonding from the rigid bodies, giving the fringe instability. We use experiments, theory and numerical simulations to quantitatively explain the fringe instability and derive scaling laws for its critical stress, critical strain and wavelength. We show that in a force controlled setting the elastic fingering instability is associated with a snap-through buckling that does not exist for the fringe instability. The discovery of the fringe instability will not only advance the understanding of mechanical instabilities in soft materials but also have implications for biological and engineered adhesives and joints.


ABSTRACT: We study the effect of film density on the uniaxial compression of thin elastic films at a liquid–fluid interface. Using a combination of experiments and theory, we show that dense films first wrinkle and then fold as the compression is increased, similarly to what has been reported when the film density is neglected. However, we highlight the changes in the shape of the fold induced by the film's own weight and extend the model of Diamant and Witten [Phys. Rev. Lett., 2011, 107, 164302] to understand these changes. In particular, we suggest that it is the weight of the film that breaks the up-down symmetry apparent from previous models, but elusive experimentally. We then compress the film beyond the point of self-contact and observe a new behaviour dependent on the film density: the single fold that forms after wrinkling transitions into a closed loop after self-contact, encapsulating a cylindrical droplet of the upper fluid. The encapsulated drop either causes the loop to bend upward or to sink deeper as the compression is increased, depending on the relative buoyancy of the drop–film combination. We propose a model to qualitatively explain this behaviour. Finally, we discuss the relevance of the different buckling modes predicted in previous theoretical studies and highlight the important role of surface tension in the shape of the fold that is observed from the side—an aspect that is usually neglected in theoretical analyses.

ABSTRACT: Polymer encapsulation of drugs is conventionally used as a strategy for controlled delivery and enhanced stability. In this work, a novel encapsulation approach is demonstrated, in which the organic molecule clotrimazole is enclosed into wrinkles of defined sizes. Having defined wrinkles at the drug/encapsulant interface, the contact between the encapsulating polymer and the drug can be improved. In addition, this can also allow for some control on the drug delivery as the available surface area changes with the wrinkle size. For this purpose, thin films of clotrimazole were deposited onto silica substrates and were then encapsulated by crosslinked poly(2-hydroxyethyl methacrylate) (pHEMA) via initiated chemical vapor deposition (iCVD). The thickness and the solid state (crystalline or amorphous) of the clotrimazole layer were varied so that the conditions under which surface wrinkles emerge can be determined. A (critical) clotrimazole thickness of 76.6 nm was found necessary to induce wrinkles, whereby the wrinkle size is directly proportional to the thickness of the amorphous clotrimazole. When the pHEMA was deposited on top of crystalline clotrimazole instead, wrinkling was absent. The wrinkling effect can be understood in terms of elastic mismatch between the relatively rigid pHEMA film and the drug layer. In the case of amorphous clotrimazole, the relatively soft drug layer causes a large mismatch resulting in a sufficient driving force for wrinkle formation. Instead, the increased elastic modulus of crystalline clotrimazole reduces the elastic mismatch between drug and polymer, so that wrinkles do not form.


ABSTRACT: The shape deformation of membrane nanotubes is studied by a combination of theoretical analysis and molecular simulation. First we perform free energy analysis to demonstrate the effects of various factors on two ideal states for the pearling transition, and then we carry out dissipative particle dynamics simulations, through which various types of membrane tube deformation are found, including membrane pearling, buckling, and bulging. Different models for inducing tube deformation, including the osmotic pressure, area difference and spontaneous curvature models, are considered to investigate tubular instabilities. Combined with free energy analysis, our simulations show that the origin of the deformation of membrane tubes in different models can be classified into two categories: effective spontaneous curvature and membrane tension. We further demonstrate that for different models, a positive membrane tension is required for the pearling transition. Finally we show that different models can be coupled to effectively deform the membrane tube.


ABSTRACT: We study the effect of surface stress on the pure bending of a finite thickness plate under large deformation. The surface is assumed to be isotropic and its stress consists of a part that can be interpreted as a residual stress and a part that stiffens as the surface increases its area. Our results show that residual surface stress and surface stiffness can both increase the overall bending stiffness but through different mechanisms. For sufficiently large residual surface tension, we discover a new type of instability – the bending moment reaches a maximum at a critical curvature. Effects of surface stress on different stress components in the bulk of the plate are discussed and the possibility of self-bending due to asymmetry of the surface properties is also explored. The results of our calculations provide insights into surface stress effects in the large deformation regime and can be used as a test for implementation of finite element methods for surface elasticity.


ABSTRACT: Soft solids such as PDMS or silicone are widely needed in many advanced applications such as flexible electronics and medical engineering. The ability to control the structure and properties of the surface of soft solids provides new opportunities in these applications. In particular, mechanical loading induced elastic instability is a convenient method to control the surface morphology. The critical strain at which the crease nucleates is experimentally measured under plane strain conditions, and is found to be consistent with that
predicted by nonlinear large deformation theory of creases. Under compressive loading, we find that silicone undergoes a transition of creasing pattern from a single channeling or double channeling crease to an unchanneling crease, depending on the specimen's width and height. Finite element simulations are performed to better understand the underlying mechanism of creasing, wherein a relationship between the depth and spacing of the creases is established. It is found to be in good agreement with the experimental data obtained.


ABSTRACT: We examine the mechanics of three-layer composite films composed of an elastomeric layer sandwiched between two thin surface layers of plastic. Upon stretching and releasing such composite films, they develop a highly wrinkled surface texture. The mechanism for this texturing is that during stretching, the plastic layers yield and stretch irreversibly whereas the elastomer stretches reversibly. Thus upon releasing, the plastic layers buckle due to compressive stress imposed by the elastomer. Experiments are conducted using SEPS elastomer and 50 micron thick LLDPE plastic films. Stretching and releasing the composites to 2–5 times their original length induces buckles with wavelength on the order of 200 microns, and the wavelength decreases as the stretching increases. FEM simulations reveal that plastic deformation is involved at all stages during this process: (1) during stretching, the plastic layer yields in tension; (2) during recovery, the plastic layer first yields in-plane in compression and then buckles; (3) post-buckling, plastic hinges are formed at high-curvature regions. Homogeneous wrinkles are predicted only within a finite window of material properties: if the yield stress is too low, the plastic layers yield in-plane, without wrinkling, whereas if the yield stress is too high, non-homogeneous wrinkles are predicted. This approach to realizing highly wrinkled textures offers several advantages, most importantly the fact that high aspect ratio wrinkles (amplitude to wavelength ratios exceeding 0.4) can be realized.


ABSTRACT: Thin films that exhibit spatially heterogeneous swelling often buckle into the third dimension to minimize stress. These effects, in turn, offer a promising strategy to fabricate complex three-dimensional structures from two-dimensional sheets. Here we employ surface topography as a new means to guide buckling of swollen polymer bilayer films and thereby control the morphology of resulting three-dimensional objects. Topographic patterns are created on poly(dimethylsiloxane) (PDMS) films selectively coated with a thin layer of non-swelling parylene on different sides of the patterned films. After swelling in an organic solvent, various structures are formed, including half-pipes, helical tubules, and ribbons. We demonstrate these effects and introduce a simple geometric model that qualitatively captures the relationship between surface topography and the resulting swollen film morphologies. The model's limitations are also examined.


ABSTRACT: Wrinkling of thin films and membranes can occur due to various mechanisms such as growth and/or mismatch between the mechanical properties of the film and substrate. However, the physical origins of dynamic wrinkling in soft membranes are still not fully understood. Here we use milk skin as a tractable experimental system to investigate the physics of wrinkle formation in a thin, poroelastic film. Upon heating milk, a micron-thick hydrogel of denatured proteins and fat globules forms at the air–water interface. Over time, we observe an increase in the total length of wrinkles. By confocal imaging and profilometry, we determine that the composition and thickness of the milk skin appears to be homogeneous over the length scale of the wrinkles, excluding differences in milk skin composition as a major contributor to wrinkling. To explain the physical origins of wrinkle growth, we describe theory that considers the milk skin as a thin, poroelastic film where pressure is generated by the evaporative-driven flow of solvent across the film; this imparts in-plane stresses in the milk skin, which cause wrinkling. Viscous effects can explain the time-dependent growth of wrinkles. Our theoretical predictions of the effects of relative humidity on the total length of wrinkles over time are consistent with our experimental results. Our findings provide insight into the physics of the common phenomenon of milk skin wrinkling, and identify hydration gradients as another physical mechanism that can drive morphological instabilities in soft matter.
ABSTRACT: Optimal buckling of a tissue, e.g. a plant leaf, growing by means of exponential division of its peripheral cells, is considered in the framework of a conformal approach. It is shown that the boundary profile of a tissue is described by the 2D eikonal equation, which provides the geometric optic approximation for the wavefront propagating in a medium with an inhomogeneous refraction coefficient. A variety of optimal surfaces embedded in 3D is controlled by spatial dependence of the refraction coefficient which, in turn, is dictated by the local growth protocol.

ABSTRACT: Organic–inorganic perovskites are semiconductors used for applications in optoelectronics and photovoltaics. Micron and submicron perovskite patterns have been explored in semitransparent photovoltaic and lasing applications. In this work, we show that a polymeric medium can be used to create a patterned perovskite, by using a novel and inexpensive approach.

ABSTRACT: Localized deformation is ubiquitous in many natural and engineering materials as they approach failure, and a significant effort has been made to understand localization processes with simple continuum models. Real materials are much more commonly heterogeneous but it is unclear exactly how heterogeneity affects outcomes. In this work we study the response of an idealized heterogeneous elastic sheet on a soft foundation as it is uniaxially compressed. The patterned surface layers are created by selective ultraviolet/ozone treatment of the top surface of a polydimethylsiloxane (PDMS) sample using a TEM grid as a mask. By controlling the exposure time of UV/O₃, samples ranging from continuous thin films to sets of isolated small plates were created. We find that patterned regions noticeably localize while bulk regions appear as uniform wrinkles, and that local and global strains depend on the pattern pitch, exposure levels and the treatment protocol. Remarkably, various responses can be modeled using well-understood theory that ignores pattern details aside from the small distance between the adjacent boundaries and the local value of strain.

ABSTRACT: We study the indentation of ultrathin elastic sheets clamped to the edge of a circular hole. This classical setup has received considerable attention lately, being used by various experimental groups as a probe to measure the surface properties and stretching modulus of thin solid films. Despite the apparent simplicity of this method, the geometric nonlinearity inherent in the mechanical response of thin solid objects renders the analysis of the resulting data a nontrivial task. Importantly, the essence of this difficulty is in the geometric coupling between in-plane stress and out-of-plane deformations, and hence is present in the behaviour of Hookean solids even when the slope of the deformed membrane remains small. Here we take a systematic approach to address this problem, using the membrane limit of the Föppl–von-Kármán equations. This approach highlights some of the dangers in the use of approximate formulae in the metrology of solid films, which can introduce large errors; we suggest how such errors may be avoided in performing experiments and analyzing the resulting data.

ABSTRACT: We study the influence of one or multiple thin spots on the flow-induced instabilities of flexible shells of revolution with non-zero Gaussian curvatures. The shell's equation of motion is described by a thin doubly-curved shell theory and is coupled with perturbed flow pressure, calculated based on an inviscid flow model. We show that for shells with positive Gaussian curvatures conveying fluid, the existence of a thin spot
results in a localized flow-induced buckling response of the shell in the neighborhood of the thin spot, and significantly reduces the critical flow velocity for buckling instability. For shells with negative Gaussian curvatures, the buckling response is extended along the shell's characteristic lines and the critical flow velocity is only slightly reduced. We also show that the length scale of the localized deformation generated by a thin spot is proportional to the shell's global thickness when the stiffness of the thin spot is negligible compared with the stiffness of the rest of the shell. When two thin spots exist at a distance, their influences are independent from each other for shells with positive Gaussian curvatures, but large-scale deformations can be created due to multiple thin spots on shells with negative curvatures, depending on the thin spots' relative position.


ABSTRACT: Dielectric elastomer sheets undergo in-plane expansion when stimulated by a transverse electric field. We study experimentally how dielectric plates subjected to a non-uniform voltage distribution undergo buckling instabilities. Two different configurations involving circular plates are investigated: plates freely floating on a bath of water, and plates clamped on a frame. We describe theoretically the out-of-plane deformation of the plates within the framework of weakly non-linear plate equations. This study constitutes a first step of a route to control the 3D activation of dielectric elastomers.


ABSTRACT: A membrane of a dielectric elastomer may undergo electromechanical phase transition from the flat to wrinkled state, when the applied voltage reaches a critical value. The wrinkled region is observed to expand at the expense of the flat region during the phase transition. In this paper, we report on a dynamic pattern of wrinkles in a circular membrane of a dielectric elastomer. During phase transition, both the flat and wrinkled regions move interchangeably in the membrane. The radial prestretch is found to significantly affect electromechanical phase transition. For example, a membrane with a small prestretch can exhibit a dynamic pattern of wrinkles, which is essentially related to snap-through instability. However, a membrane with a large prestretch undergoes continuous phase transition, without exhibiting a dynamic pattern. An analytical model is developed to interpret these experimental phenomena. Finite element simulations are performed to predict the wrinkle morphology, especially the coexistence of flat and wrinkled regions. Both the theoretical calculations and finite element simulations are qualitatively consistent with the experiments. Additionally, we observe another type of electromechanical behavior involving a dynamic pattern of wrinkles with different wavelengths. The membrane first undergoes continuous transition from the flat to wrinkled state, followed by discontinuous transition from one wrinkled state to another. These results may inspire new applications for dielectric elastomers such as on-demand patterning of wrinkles for microfluidics and stretchable electronics.


ABSTRACT: Tubular vesicles represent abundant structural motifs which are observed both in experiments and in nature. We analyse them within the theory of bending elasticity and determine the equilibrium solutions at fixed volume, surface area, and segment length without imposing any specific symmetry or periodicity. We identify four different non-periodic equilibrium shapes. Depending on the precise value of the constraints or the corresponding Lagrange multipliers, these four shapes include: (i) snake-like and (ii) helical structures, (iii) tubes with a spherical body, and (iv) tubes with a discoidal body. However different in the details, all of the shapes have the same general cylindrical morphology which is either globally modulated or is a superposition of an additional structural motif and the cylinder. These results point to a great significance of the circular cylindrical shape and offer a comprehensive and general analysis of the shape of tubular vesicles.


ABSTRACT: While simple at first glance, the dense packing of sheets is a complex phenomenon that depends on material parameters and the packing protocol. We study the effect of plasticity on the crumpling of sheets of
different materials by performing isotropic compaction experiments on sheets of different sizes and elasto-plastic properties. First, we quantify the material properties using a dimensionless foldability index. Then, the compaction force required to crumple a sheet into a ball as well as the average number of layers inside the ball are measured. For each material, both quantities exhibit a power-law dependence on the diameter of the crumpled ball. We experimentally establish the power-law exponents and find that both depend nonlinearly on the foldability index. However the exponents that characterize the mechanical response and morphology of the crumpled materials are related linearly. A simple scaling argument explains this in terms of the buckling of the sheets, and recovers the relation between the crumpling force and the morphology of the crumpled structure. Our results suggest a new approach to tailor the mechanical response of the crumpled objects by carefully selecting their material properties.


ABSTRACT: Existing analyses predict that thin metal films deposited on compliant substrates are subject to a variety of surface instabilities, such as wrinkles, folds, creases, etc., that become more prominent with increased compressive residual stress. Under compressive stress, cracks have been assumed to form only when the interfacial strength is weak, allowing the film to detach from the substrate. In this work, we demonstrate that cracks also form on surfaces under compressive mismatch strain when the interface is strong. In particular, we consider metal alloy films sputter deposited under bias on elastomers with different thicknesses, curing temperatures or surface treatments. The deposition parameters created residual compressive strains and strong adhesion in the bilayers. Samples without surface treatment formed wrinkles and through-thickness cracks at 0.25–0.4% mismatch strains. Only through-thickness cracks were observed in UV treated samples. The crack spacing was found to decrease by a factor of 4 when the surface was UV treated and by a factor of 3 as the elastomer thickness decreased from 30 to 6 μm. Cracks penetrated through the elastomer, 15–30 times deeper than the film thickness, and formed in all samples with a brittle coating. A numerical model was developed to explain the formation of through-thickness cracks and wrinkles under applied compressive mismatch strains. The model suggests that cracks can initiate from the peak of wrinkles when the critical fracture strength of the coating is exceeded. For the UV treated samples, through-thickness cracks are possibly impacted by the formation of an embrittled near surface PDMS layer.


ABSTRACT: Wrinkle aspect ratio, or the amplitude divided by the wavelength, is hindered by strain localization transitions when an increasing global compressive stress is applied to synthetic material systems. However, many examples from living organisms show extremely high aspect ratios, such as gut villi and flower petals. We use three experimental approaches to demonstrate that these high aspect ratio structures can be achieved by modifying the network stress in the wrinkle substrate. We modify the wrinkle stress and effectively delay the strain localization transition, such as folding, to larger aspect ratios by using a zero-stress initial wavy substrate, creating a secondary network with post-curing, or using chemical stress relaxation materials. A wrinkle aspect ratio as high as 0.85, almost three times higher than common values of synthetic wrinkles, is achieved, and a quantitative framework is presented to provide understanding the different strategies and predictions for future investigations.


ABSTRACT: Self-folding or micro-origami technologies are actively investigated as a novel manufacturing process to fabricate three-dimensional macro/micro-structures. In this paper, we present a simple process to produce a self-folding structure with a biaxially oriented polystyrene sheet (BOPS) or Shrinky Dinks. A BOPS sheet is known to shrink to one-third of its original size in plane, when it is heated above 160 °C. A grid pattern is engraved on one side of the BOPS film with a laser engraver to decrease the thermal shrinkage of the engraved side. The thermal shrinkage of the non-engraved side remains the same and this unbalanced thermal
shrinkage causes folding of the structure as the structure shrinks at high temperature. We investigated the self-folding mechanism and characterized how the grid geometry, the grid size, and the power of the laser engraver affect the bending curvature. The developed fabrication process to locally modulate thermomechanical properties of the material by engraving the grid pattern and the demonstrated design methodology to harness the unbalanced thermal shrinkage can be applied to develop complicated self-folding macro/micro structures.


ABSTRACT: We demonstrate, using both finite element simulations and a linear stability analysis, the emergence of an electro-elastocapillary Rayleigh–plateau instability in dielectric elastomer (DE) films under 2D, plane strain conditions. When subject to an electric field, the DEs exhibit a buckling instability for small elastocapillary numbers. For larger elastocapillary numbers, the DEs instead exhibit the Rayleigh–plateau instability. The stability analysis demonstrates the critical effect of the electric field in causing the Rayleigh–plateau instability, which cannot be induced solely by surface tension in DE films. Overall, this work demonstrates the effects of geometry, boundary conditions, and multi-physical coupling on a new example of Rayleigh–plateau instability in soft solids.


ABSTRACT: Inspired by complex multi-functional leaf and petal surfaces, we introduce a mechanically directed self-assembly process to create linearly oriented micro- and nanosized surface wrinkles in an all-polymer bi-layer system based on a shape-memory polymer substrate. By systematically investigating the influence of coating thickness and substrate programming strain on wrinkle period and height, we reveal how to control the structure size from a few hundred nanometers up to several microns. As a parameter unique to shape memory polymers, we demonstrate that the temperature during the recovery process can also be utilized to tailor the structure dimensions. Furthermore, we advance the method with a second structuring step to mimic the hierarchically structured petal surfaces of tulips and daisies. The presented structuring method provides a large-scale, mold-free, and very cost-effective way for the full-polymer fabrication of micro and sub-microstructures with adjustable structure size and intrinsic irregularity.


ABSTRACT: Pull-in instability often occurs when a film of a dielectric elastomer is subjected to an electric field. In this work, we concoct a set of simple, experimentally implementable, conditions that render the dielectric elastomer film impervious to pull-in instability for all practical loading conditions. We show that a uniaxially pre-stretched film has a significantly large actuation stretch in the direction perpendicular to the pre-stretch and find that the maximal specific energy of a dielectric elastomer generator can be increased from 6.3 J g−1 to 8.3 J g−1 by avoiding the pull-in instability.


ABSTRACT: Programmable, reversible and repeatable wrinkling of shape memory polymer (SMP) thin films on elastomeric polydimethylsiloxane (PDMS) substrates is realized, by utilizing the heat responsive shape memory effect of SMPs. The dependencies of wrinkle wavelength and amplitude on program strain and SMP film thickness are shown to agree with the established nonlinear buckling theory. The wrinkling is reversible, as the wrinkled SMP thin film can be recovered to the flat state by heating up the bilayer system. The programming cycle between wrinkle and flat is repeatable, and different program strains can be used in different programming cycles to induce different surface morphologies. Enabled by the programmable, reversible and repeatable SMP film wrinkling on PDMS, smart, programmable surface adhesion with large tuning range is demonstrated.

ABSTRACT: Lipid monolayers at the air/water interface are often subject to large mechanical stresses when compressed laterally. For large enough compression they fold in the out-of-plane direction to relax stress. The repetitive folding and unfolding of lung surfactant monolayers during breathing plays a critical role in conserving monolayer material at the air/water interface lining the lung. Although the mechanisms behind the folding have been explored recently, relatively little information exists regarding the implications of folding dynamics on the long-term stability of the monolayer. We address this question by investigating the dynamical effect of folding rate in a lipid monolayer containing nano-particles, using a combination of analytic theory, simulation and experiment. We find that the presence of adsorbed particles are essential for monolayer rupture during unfolding. These particles act as linkers pinning the folds shut. The rate of folding affects reversibility as well. We construct a reversibility phase diagram spanned by the compression period and the size of the adsorbed particles showing the complex interaction of fold morphology, particle diffusion, and linker unbinding that results in reversible or irreversible folding.


ABSTRACT: Self-similar structures are capable of highly enhancing the deformability of stretchable electronics. We presented a self-assembly method based on the tunable buckling of serpentine fiber-based interconnects (FiberBIs), which are deposited using our presented helix electrohydrodynamic printing (HE-printing) technique, to fabricate self-similar structures with enhanced stretchability (up to 250%). It provides a low-cost, printing-based approach for the generation of large-scale self-similar FiberBIs. Distinct buckling behaviors and modes occur under specific conditions. To elucidate the mechanics governing this phenomenon, we present detailed experimental and theoretical studies of the buckling mechanics of serpentine microfibers on compliant substrates. Firstly, the effect of the magnitude and direction of prestrain on the buckling behavior of a fiber-on-substrate is discussed. Secondly, the critical geometry of a serpentine fiber as a key parameter for fabricating uniform self-similar fibers is also figured out. Finally, the cross-sectional geometry of the fiber as a judgment criterion for determining the in-surface or out-of-surface buckling of the fiber is established. The investigation can guide the fabrication process of large-scale self-similar structures for high-performance electronic devices with extreme stretchability.


ABSTRACT: A thin film of a critical ferrofluid mixture undergoes a sequence of transitions in a magnetic field. First the application of a field induces a critical demixing of the fluid into cylindrical droplets of the minority phase immersed in an extended majority phase. At a second critical field the cylindrical shape is destabilized and transforms into a labyrinth pattern. A third wrinkling transition occurs at even higher field if the liquid has a liquid/air interface. The wrinkling is absent if the droplet has a cover-slide on top. We explain the wrinkling by the wetting behavior of the liquid/air interface that shifts the surface region away from a critical demixing point.


ABSTRACT: Shape memory polymers (SMPs) can remember two or more distinct shapes, and thus can have a lot of potential applications. This paper presents combined experimental and theoretical studies on the wrinkling of single-crystal Si ribbons on SMPs and the temperature dependent evolution. Using the shape memory effect of heat responsive SMPs, this study provides a method to build wavy forms of single-crystal silicon thin films on top of SMP substrates. Silicon ribbons obtained from a Si-on-insulator (SOI) wafer are released and transferred onto the surface of programmed SMPs. Then such bilayer systems are recovered at different temperatures, yielding well-defined, wavy profiles of Si ribbons. The wavy profiles are shown to evolve with time, and the evolution behavior strongly depends on the recovery temperature. At relatively low recovery
temperatures, both wrinkle wavelength and amplitude increase with time as evolution progresses. Finite element analysis (FEA) accounting for the thermomechanical behavior of SMPs is conducted to study the wrinkling of Si ribbons on SMPs, which shows good agreement with experiment. Merging of wrinkles is observed in FEA, which could explain the increase of wrinkle wavelength observed in the experiment. This study can have important implications for smart stretchable electronics, wrinkling mechanics, stimuli-responsive surface engineering, and advanced manufacturing.


ABSTRACT: Polymeric thin films coated on non-wettable substrates undergo film-instabilities, which are usually manifested as surface deformation in the form of dewetting or wrinkling. The former takes place in fluidic films, whereas the latter occurs in solid films. Therefore, there have rarely been reports of systems involving simultaneous deformations of dewetting and wrinkling. In this study, we propose polymeric thin films of liquid crystalline (LC) mesogens prepared on a non-wettable Si substrate and apply a treatment of plasma irradiation to form a thin polymerized layer at the surface. The resulting compressive stress generated in the surface region drives the formation of wrinkles, while at the same time, dipolar attraction between LC molecules induces competitive cohesive dewetting. Intriguing surface structures were obtained whereby dewetting-like hole arrays are nested inside the randomly propagated wrinkles. The structural features are readily controlled by the degree of surface cross-linking, hydrophilicity of the substrates, and the LC film thickness. In particular, dewetting of LC mesogens is observed to be restricted to occur at the trough regions of wrinkles, exhibiting the typical behavior of geometrically confined dewetting. Finally, wrinkling–dewetting mixed structures are separated from the substrate in the form of free standing films to demonstrate the potential applicability as membranes.


ABSTRACT: Compressing a thin, stiff film attached to a thick, compliant substrate can lead to a number of different modes of mechanical deformation depending upon the material properties of the system. In this article we explore direct transitions from surface wrinkling to buckle delamination, and provide a theoretical framework for understanding the conditions under which such transitions take place, as well as the resulting dimensions of the wrinkling-induced delamination. A key conclusion of this work is that the width of the delamination blister formed from a wrinkled film is relatively strain-independent, suggesting that delaminations can be used in such systems to measure the adhesion energy at the film–substrate interface. In addition, we demonstrate how the length and width of delaminations can be tailored through straightforward control of the substrate and film properties in the system, illustrating how wrinkling delaminations can be used for both thin film metrology and patterning applications.


ABSTRACT: We introduce a new experimental system to study the effects of pre-stretch on the buckling patterns that emerge from the biaxial compression of elastomeric bilayer shells. Upon fabrication of the samples, releasing the pre-stretch in the substrate through deflation places the outer film in a state of biaxial compression and yields a variety of buckling patterns. We systematically explore the parameter space by varying the pre-stretch of the substrate and the ratio between the stiffness of the substrate and film. The phase diagram of the system exhibits a variety of buckling patterns: from the classic periodic wrinkle to creases, folds, and high aspect ratio ridges. Our system is capable of readily transitioning between these buckling patterns, a first for biaxial systems. We focus on the wrinkle to ridge transition. In the latter, we find that pre-stretch plays an essential role and that the ridge geometry (width, height) remains nearly constant throughout their formation process. For the localized ridged patterns, we find that the propagation of the ridge tip depends strongly on both strain and stiffness ratio, in a way that is akin to hierarchical fracture.

ABSTRACT: We propose a hybrid discrete–continuum model to study the ground state of protein shells. The model allows for shape transformation of the shell and buckling transitions as well as the competition between states with different symmetries that characterize discrete particle models with radial pair potentials. Our main results are as follows. For large Föppl–von Kármán (FvK) numbers the shells have stable isometric ground states. As the FvK number is reduced, shells undergo a buckling transition resembling that of thin-shell elasticity theory. When the width of the pair potential is reduced below a critical value, then buckling coincides with the onset of structural instability triggered by over-stretched pair potentials. Chiral shells are found to be more prone to structural instability than achiral shells. It is argued that the well-width appropriate for protein shells lies below the structural instability threshold. This means that the self-assembly of protein shells with a well-defined, stable structure is possible only if the bending energy of the shell is sufficiently low so that the FvK number of the assembled shell is above the buckling threshold.


ABSTRACT: We fabricate an elastomeric beam standing on a flexible substrate using 3D printing and soft lithography and investigate lateral buckling generated in the part of the wall when this beam is under pure bending. We also observe changes in the morphology of wrinkling along the applied strain and geometry of the wall, and then analyze it with scaling concepts. Furthermore, the degree of lateral buckling is controlled through the tip design in the ratchet structure and it is verified with finite element simulation. Based on this, a millimeter scale device with a visual difference according to the curvature is manufactured.


ABSTRACT: Thin elastic sheets bend easily and, if they are patterned with cuts, can deform in sophisticated ways. Here we show that carefully tuning the location and arrangement of cuts within thin sheets enables the design of mechanical actuators that scale down to atomically-thin 2D materials. We first show that by understanding the mechanics of a single non-propagating crack in a sheet, we can generate four fundamental forms of linear actuation: roll, pitch, yaw, and lift. Our analytical model shows that these deformations are only weakly dependent on thickness, which we confirm with experiments on centimeter-scale objects and molecular dynamics simulations of graphene and MoS$_2$ nanoscale sheets. We show how the interactions between non-propagating cracks can enable either lift or rotation, and we use a combination of experiments, theory, continuum computational analysis, and molecular dynamics simulations to provide mechanistic insights into the geometric and topological design of kirigami actuators.


ABSTRACT: A growing bacterial colony is a dense suspension of an increasing number of cells capable of individual as well as collective motion. After inoculating Pseudomonas aeruginosa over an annular area on an agar plate, we observe the growth and spread of the bacterial population, and model the process by considering the physical effects that account for the features observed. Over a course of 10–12 hours, the majority of bacteria migrate to and accumulate at the edges. We model the capillary flow induced by imbalanced evaporation flux as the cause for the accumulation, much like the well-known coffee stain phenomenon. Simultaneously, periodic buckles or protrusions occur at the inner edge. These buckles indicate that the crowding bacteria produce a jam, transforming the densely packed population at the inner edge to a solid state. The continued bacterial growth produces buckles. Subsequently, a ring of packed bacteria behind the inner edge detach from it and break into pieces, forming bacterial droplets. These droplets slowly coalesce while they continually grow and collectively surf on the agar surface in the region where the colony had previously spread over. Our study shows a clear example of how fluid dynamics and elasto-mechanics together govern the bacterial colony pattern evolution.

ABSTRACT: Wrinkling is a well-known example of instability-driven surface deformation that occurs when the accumulated compressive stress exceeds the critical value in multilayered systems. A number of studies have investigated the instability conditions and the corresponding mechanisms of wrinkling deformation. Force balance analysis of bilayer systems, in which the thickness of the capping layer is importantly considered, has offered a useful approach for the quantitative understanding of wrinkling. However, it is inappropriate for multilayer wrinkling (layer number > 3) consisting of heterogeneous materials (e.g. polymer/metal or inorganic), in which the thickness variation in the substrate is also crucial. Therefore, to accommodate the additive characteristics of multilayered systems, we thermally treated tri- or quad-layer samples of polymer/metal multilayers to generate surface wrinkles and used a cumulative energy balance analysis to consider the individual contribution of each constituent layer. Unlike the composite layer model, wherein the thickness effect of the capping layer is highly overestimated for heterogeneously stacked multilayers, our approach precisely reflects the bending energy contribution of the given multilayer system, with results that match well with experimental values. Furthermore, we demonstrate the feasibility of this approach as a metrological tool for simple and straightforward estimation of the thermomechanical properties of polymers, whereby a delicate change in the Young's modulus of a thin polymeric layer near its glass transition temperature can be successfully monitored.


ABSTRACT: Predicting the behaviour of particle-covered fluid interfaces under compression has implications in several fields. The surface-tension driven adhesion of particles to drops and bubbles is exploited for example to enhance the stability of foams and emulsion and develop new generation materials. When a particle-covered fluid interface is compressed, one can observe either smooth buckling or particle desorption from the interface. The microscopic mechanisms leading to the buckling-to-desorption transition are not fully understood. In this paper we simulate a spherical drop covered by a monolayer of spherical particles. The particle-covered interface is subject to time-dependent compressive surface stresses that mimic the slow deflation of the drop. The buckling-to-desorption transition depends in a non-trivial way on three non-dimensional parameters: the ratio \( \Pi/\gamma \) of particle-induced surface pressure and bare surface tension, the ratio \( a/R \) of particle and drop radii, and the parameter \( f \) characterising the strength of adhesion of each particle to the interface. Based on the insights from the simulations, we propose a configuration diagram describing the effect of these controlling parameters. We find that particle desorption is highly correlated with a mechanical instability that produces small-scale undulations of the monolayer of the order of the particle size that grow when the surface pressure is sufficiently large. We argue that the large local curvature associated with these small undulations can produce large normal forces, enhancing the probability of desorption.


ABSTRACT: Over the course of a life time, as a result of adaptive mechanobiological processes (e.g. ageing), or the action of external physical factors such as mechanical loading, the human skin is subjected to, and hosts complex biophysical processes. These phenomena typically operate through a complex interplay, that, ultimately, is responsible for the evolutive geometrical characteristics of the skin surface. Wrinkles are a manifestation of these effects. Although numerous theoretical models of wrinkles arising in multi-layered structures have been proposed, they typically apply to idealised geometries. In the case of skin, which can be viewed as a geometrically complex multi-layer assembly, it is pertinent to question whether the natural skin microrelief could play a significant role in conditioning the characteristics of compression-induced micro-wrinkles by acting as an array of geometrical imperfections. Here, we explore this question through the development of an anatomically-based finite strain parametric finite element model of the skin, represented as a stratum corneum layer on top of a thicker and softer substrate. Our study suggests that skin microrelief could be the dominant factor conditioning micro-wrinkle characteristics for moderate elastic modulus ratios between the
two layers. Beyond stiffness ratios of 100, other factors tend to overwrite the effects of skin microrelief. Such stiffness ratio fluctuations can be induced by changes in relative humidity or particular skin conditions and can therefore have important implications for skin tribology.


ABSTRACT: Curvature plays an important role in the morphological evolution of soft shells under stretch. Here, through a combination of experiment, theory and simulation, we investigate the behavior of a hemispherical soft shell subject to an increasing outward point force at its pole. In contrast to an inward point force inducing a polygonal pattern of buckling in the shell, we observe a four-stage morphological transition and symmetry breaking under an increasing outward point force. The shell undergoes axisymmetric deformation around its pole and then buckles into a non-axisymmetric shape with a number of shallow wrinkles emanating from the pole, followed by the emergence of crater-like deep crumples and ultimately a transformation into a wrinkled pseudocone. Our theoretical analysis and numerical simulations yield the critical conditions for the morphological transitions at each stage of deformation and reveal the underlying interplays between elastic bending and stretching energies and the curvature of the shell.


ABSTRACT: Red blood cells flowing through capillaries assume a wide variety of different shapes owing to their high deformability. Predicting the realized shapes is a complex field as they are determined by the intricate interplay between the flow conditions and the membrane mechanics. In this work we construct the shape phase diagram of a single red blood cell with a physiological viscosity ratio flowing in a microchannel. We use both experimental in vitro measurements as well as 3D numerical simulations to complement the respective other one. Numerically, we have easy control over the initial starting configuration and natural access to the full 3D shape. With this information we obtain the phase diagram as a function of initial position, starting shape and cell velocity. Experimentally, we measure the occurrence frequency of the different shapes as a function of the cell velocity to construct the experimental diagram which is in good agreement with the numerical observations. Two different major shapes are found, namely croissants and slippers. Notably, both shapes show coexistence at low (<1 mm s$^{-1}$) and high velocities (>3 mm s$^{-1}$) while in-between only croissants are stable. This pronounced bistability indicates that RBC shapes are not only determined by system parameters such as flow velocity or channel size, but also strongly depend on the initial conditions.


ABSTRACT: Few advanced mechanics of materials solutions have found broader and more enduring applications than Emil Winkler's beam on elastic foundation analysis, first published in 1867. Now, 150 years after its introduction, this concept continues to enjoy widespread use in its original application field of civil engineering, and has also had a profound effect on the field of adhesion mechanics, including for soft matter adhesion phenomena. A review of the model is presented with a focus on applications to adhesion science, highlighting classical works that utilize the model as well as recent usages that extend its scope. The special case of the behavior of plates on incompressible (e.g., elastomeric and viscous liquid) foundations is reviewed because of the significant relevance to the behavior of soft matter interlayers between one or more flexible adherends.


ABSTRACT: Two-dimensional (2-D) atomically thin graphene has exhibited overwhelming excellent properties over its bulk counterpart graphite, yet the broad applications and explorations of its unprecedented properties require a diversity of its geometric morphologies, beyond its inherently planar structures. In this study, we present a self-folding approach for converting 2-D planar free-standing graphene to 2-D and 3-D folded structures through the evaporation of its liquid solutions. This approach involves competition between
the surface energy of the liquid, and the deformation energy and van der Waals energy of graphene. An energy-based theoretical model is developed to describe the self-folding process during liquid evaporation by incorporating both graphene dimensions and surface wettability. The critical elastocapillary length by liquid evaporation is extracted and exemplified by investigating three typical graphene geometries with rectangular, circular and triangular shapes. After the complete evaporation of the liquid, the critical self-folding length of graphene that can enable a stable folded pattern by van der Waals energy is also obtained. In parallel, full-scale molecular dynamics (MD) simulations are performed to monitor the evolution of deformation energies and folded patterns with liquid evaporation. The simulation results demonstrate the formation of 2-D folded racket-like and 3-D folded cone-like patterns and show remarkable agreement with theoretical predictions in both energy variations and folded patterns. This work offers quantitative guidance for controlling the self-folding of graphene and other 2-D materials into complex structures by liquid evaporation.

ABSTRACT: A facile methodology to create a wrinkled surface with a tailored topography is presented herein. The dependency of the elasticity of poly(dimethyl)siloxane (PDMS) on the curing temperature has been exploited to obtain a substrate with an elasticity gradient. The temperature gradient across the length of PDMS is created by a novel set-up consisting of a metal and insulator connected to a heater and the highest usable (no degradation of PDMS) temperature gradient is used. The time-dependent temperature distributions along the substrate are measured and the underlying physics of the dependence of the PDMS elasticity on the curing temperature is addressed. The PDMS substrate with the elasticity gradient is first stretched and subsequently oxidized by oxygen plasma. Upon relaxation, an ordered wrinkled surface with continuously varying wavelength and amplitude along the length of PDMS is obtained. The extent of hydrophobicity recovery of this plasma oxidized PDMS with varying elasticity has been studied. The change in the wavelength and amplitude of the regular patterns on the substrate can be controlled by varying operational parameters like applied pre-strain, plasma power and the heater temperature. It has been found that the spatial distributions of the topography and the hydrophobicity collectively decide the resultant wettability of the substrate. Such surfaces with gradients in the substructure dimensions demonstrate different wetting characteristics that may lead to a wide gamut of applications including droplet movement, cell adhesion and proliferation, diffraction grating etc.

ABSTRACT: It is well known that drying drops of colloidal dispersions undergo complex morphological transitions involving buckling of a particle-packed outer shell during drying. Although capillary stresses generated during drying have been identified as the cause for buckling, the exact conditions for buckling and its relation to the particle size, rigidity, and nature of packing have not been understood. Here, we derive explicit expressions for the critical capillary pressure for buckling of droplets based on the mechanical properties of the particle network formed during drying and the conditions under which buckling can be avoided. We anticipate our results to form the basis for design of formulations for the pharmaceutical, food and ceramics industry.

ABSTRACT: Heterogeneous growth plays an important role in the shape and pattern formation of thin elastic structures ranging from the petals of blooming lilies to the cell walls of growing bacteria. Here we address the stability and regulation of such growth, which we modeled as a quasi-static time evolution of a metric, with fast elastic relaxation of the shape. We consider regulation via coupling of the growth law, defined by the time derivative of the target metric, to purely local properties of the shape, such as the local curvature and stress. For cylindrical shells, motivated by rod-like E. coli, we show that coupling to curvature alone is generically linearly unstable to small wavelength fluctuations and that additionally coupling to stress can stabilize these modes. Interestingly, within this framework, the longest wavelength fluctuations can only be stabilized with the mean curvature flow. Our approach can readily be extended to gain insights into the general classes of stable growth laws for different target geometries.

ABSTRACT: An elastic bilayer composed of a stiff film bonded to a soft substrate forms wrinkles under compression. While these uniform and periodic wrinkles initially grow in amplitude with applied strain, the onset of secondary bifurcations such as period doubling typically limit the aspect ratio (i.e., amplitude divided by wavelength) of wrinkles that can be achieved. Here, we present a simple strategy that employs a supported bilayer with comparable thicknesses of the film and substrate to achieve wrinkles with higher aspect ratio. We use both experiments and finite element simulations to reveal that at small thickness contrast, period doubling can be delayed, allowing the wrinkles to grow uniformly to high aspect ratio. In addition, we show that the periodic wrinkles can evolve through symmetry breaking and transition to a periodic pattern of ridges with even higher aspect ratio.


ABSTRACT: We study the origins of multiple mechanically stable states exhibited by an elastic shell comprising multiple conical frusta, a geometry common to reconfigurable corrugated structures such as ‘bendy straws’. This multistability is characterized by mechanical stability of axially extended and collapsed states, as well as a partially inverted ‘bent’ state that exhibits stability in any azimuthal direction. To understand the origin of this behavior, we study how geometry and internal stress affect the stability of linked conical frusta. We find that tuning geometrical parameters such as the frustum heights and cone angles can provide axial bistability, whereas stability in the bent state requires a sufficient amount of internal pre-stress, resulting from a mismatch between the natural and geometric curvatures of the shell. We provide insight into the latter effect through curvature analysis during deformation using X-ray computed tomography (CT), and with a simple mechanical model that captures the qualitative behavior of these highly reconfigurable systems.


ABSTRACT: Surface instabilities have been extensively studied for homogeneous materials or film/substrate systems but with less studies on elastic graded materials. This paper studies surface wrinkling of an elastic graded layer theoretically, numerically and experimentally. A theoretical model for the onset of surface wrinkling with a sinusoidal mode is established. The predicted critical wrinkling strain and wavelength agree well with finite element analysis (FEA) for the elastic graded layer with exponentially decaying modulus. The influence of the layer thickness as well as the material properties on the critical conditions for the onset of surface wrinkling is fully investigated. The morphology evolution of surface wrinkling from FEA indicates the transitions of the sinusoidal mode to the arch mode and then to the period-doubling mode with a co-existing crease mode and folding mode, which agree well quantitatively with experimental observations. These results are helpful to provide physical insights into the influence of material inhomogeneity on surface instabilities.


ABSTRACT: We investigate the out-of-plane shape morphing capability of single-material elastic sheets with architected cut patterns that result in arrays of tiles connected by flexible hinges. We demonstrate that a non-periodic cut pattern can cause a sheet to buckle into three-dimensional shapes, such as domes or patterns of wrinkles, when pulled at specific boundary points. These global buckling modes are observed in experiments and rationalized by an in-plane kinematic analysis that highlights the role of the geometric frustration arising from non-periodicity. The study focuses on elastic sheets, and is later extended to elastic-plastic materials to achieve shape retention. Our work illustrates a scalable route towards the fabrication of three-dimensional objects with nonzero Gaussian curvature from initially-flat sheets.

ABSTRACT: Controlled surface wrinkling is widely applied for structuring surfaces in the micro- and nano-range. The formation of cracks in the wrinkling process is however limiting applications, and developing approaches towards crack-free wrinkles is therefore vital. To understand crack-formation, we systematically characterized the thickness and mechanics of thin layers formed by O-plasma-oxidation of polydimethylsiloxane (PDMS) as a function of plasma power and pressure using Atomic Force Microscopy Quantitative Nano-mechanical Mapping (AFM-QNM). We found a nearly constant layer thickness with simultaneously changing Young’s moduli for both power and pressure screenings. We determined the respective crack densities, revealing conditions for crack-free wrinkling. Thus we could identify correlations between the intensity of plasma treatment and the cracking behavior. The primary cause for crack-suppression is a continuous elasticity gradient starting within the soft bulk PDMS, and rising up to several hundred MPa at the oxidized layer’s surface. With mechanical simulations via the Finite Elements Method (FEM) we were able to demonstrate a noticeable difference in maximal stress intensity $\sigma_{\text{max}}$ between a comparable, but theoretical single layer and a gradient interface. A threshold in tensile stress of $\sigma = 14$ MPa distinguishes between intact and cracked layers.


ABSTRACT: Soft materials that exhibit electromechanical coupling are an important element in the development of soft robotics, flexible and stretchable electronics, energy harvesters, sensor and actuators. Truly soft natural piezoelectrics essentially do not exist and typical dielectric elastomers, predicated on electrostriction and the Maxwell stress effect, exhibit only a one-way electromechanical coupling. Extensive research however has shown that soft electrets i.e. materials with embedded immobile charges and dipoles, can be artificially engineered to exhibit a rather large piezoelectric-like effect. Unfortunately, this piezoelectric effect—large as it may be—is primarily restricted to an electromechanical coupling in the longitudinal direction or what is referred colloquially as the $d_{33}$ piezoelectric coefficient. In sharp contrast, the transverse piezoelectric property (the so-called $d_{31}$ coefficient) is rather small. This distinction has profound implications since these soft electrets exhibit negligible electromechanical coupling under bending deformation. As a result, the typically engineered soft electrets are rendered substantively ill-suited for energy harvesting as well as actuation/sensing of flexure motion that plays a critical role in applications like soft robotics. In this work, we analyze nonlinear bending deformation of a soft electret structure and examine the precise conditions that may lead to a strong emergent piezoelectric response under bending. Furthermore, we show that non-uniformly distributed dipoles and charges in the soft electrets lead to an apparent electromechanical response that may be ambiguously and interchangeably interpreted as either transverse piezoelectricity or flexoelectricity. We suggest pragmatic routes to engineer a large transverse piezoelectric ($d_{31}$) and flexoelectric coefficient in soft electrets. Finally, we show that in an appropriately designed soft electret, even a uniform external electric field can induce curvature in the structure thus enabling its application as a bending actuator.


ABSTRACT: Cardiolipin is a non-bilayer phospholipid with a unique dimeric structure. It localizes to negative curvature regions in bacteria and is believed to stabilize respiratory chain complexes in the highly curved mitochondrial membrane. Cardiolipin’s localization mechanism remains unresolved, because important aspects such as the structural basis and strength for lipid curvature preferences are difficult to determine, partly due to the lack of efficient simulation methods. Here, we report a computational approach to study curvature preferences of cardiolipin by simulated membrane buckling and quantitative modeling. We combine coarse-grained molecular dynamics with simulated buckling to determine the curvature preferences in three-component bilayer membranes with varying concentrations of cardiolipin, and extract curvature-dependent concentrations...
and lipid acyl chain order parameter profiles. Cardiolipin shows a strong preference for negative curvatures, with a highly asymmetric chain order parameter profile. The concentration profiles are consistent with an elastic model for lipid curvature sensing that relates lipid segregation to local curvature via the material constants of the bilayers. These computations constitute new steps to unravel the molecular mechanism by which cardiolipin senses curvature in lipid membranes, and the method can be generalized to other lipids and membrane components as well.


ABSTRACT: We study the periodic buckling patterns that emerge when elastic shells are subjected to geometric confinement. Residual swelling provides access to range of shapes (saddles, rolled sheets, cylinders, and spherical sections) which vary in their extrinsic and intrinsic curvatures. Our experimental and numerical data show that when these moderately thick structures are radially confined, a single geometric parameter – the ratio of the total shell radius to the amount of unconstrained material – predicts the number of lobes formed. We present a model that interprets this scaling as the competition between radial and circumferential bending. Next, we show that reducing the transverse confinement of saddles causes the lobe number to decrease with a similar scaling analysis. Hence, one geometric parameter captures the wave number through a wide range of radial and transverse confinement, connecting the shell shape to the shape of the boundary that confines it. We expect these results to be relevant for an expanse of shell shapes, and thus applicable to the design of shape-shifting materials and the swelling and growth of soft structures.


ABSTRACT: Capsules often prolong the shelf-life of active ingredients, such as many types of drugs, food additives, or cosmetic substances, because they delay oxidation of these substances or prevent their reactions with molecules contained in the surrounding. If capsules are appropriately designed, they can offer an additional benefit: they allow close control over the timing and location of the release of active ingredients. To take advantage of these features, capsules must possess shells whose thickness and composition are well-defined. However, the shell thickness of capsules often varies considerably even within a single capsule, thereby hampering good control over the release kinetics of encapsulants. These variations can be reduced, and hence the degree of control over the release kinetics increased, if shells are made thin. Unfortunately, the controlled fabrication of mechanically stable microcapsules with well-defined sub-μm thick shells is difficult. Here, we introduce a method to fabricate capsules with uniform semi-permeable shells with a thickness as low as 400 nm. This is achieved using water–oil–water double emulsions with 800 nm thick shells as templates to fabricate capsules with uniform 400 nm thin shells. These shells occupy less than 2% of the capsule volume, thereby minimizing their footprint. Despite their thin shells, these capsules are mechanically robust: they withstand pressures up to 1.3 MPa without deformation and remain intact if exposed to pressures up to 2.75 MPa. Moreover, while they are permeable towards water, they retain low molecular weight encapsulants even if dried and re-dispersed. The thin shells of the capsules open up new possibilities of their use to functionalize materials with at least one dimension that is small, such as coatings, where thick shells introduce defects, or as building blocks of new types of functional materials.


ABSTRACT: We study the wrinkle patterns obtained when applying a thin polymeric film on a uniaxially prestretched soft foundation. The film is coated onto a substrate where it drags under the action of gravity, thereby introducing a continuous variation in its thickness. We first study the fluid mechanics component of the problem and derive the coating profile as a function of the curing properties of the polymeric solution. Upon polymerization, the prestretch is released and yields the formation of wrinkles, which are arranged in organized patterns, including fractals. We study a variety of scenarios depending on the relative orientation of the gradient of film thickness and the stretching direction. In particular, we characterize and rationalize the distribution of
singular events in our problem where wrinkles merge to allow a variation of the average value of the wrinkle wavelength across the sample.


ABSTRACT: To go beyond the simple model for the fold as two flexible surfaces or faces linked by a crease that behaves as an elastic hinge, we carefully shape and anneal a crease within a polymer sheet and study its mechanical response. First, we carry out an experimental study that involves recording both the shape of the fold in various loading configurations and the associated force needed to deform it. Then, an elastic model of the fold is built upon a continuous description of both the faces and the crease as a thin sheet with a non-flat reference configuration. The comparison between the model and experiments yields the local fold properties and explains the significant differences we observe between tensile and compression regimes. Furthermore, an asymptotic study of the fold deformation enables us to determine the local shape of the crease and identify the origin of its mechanical behaviour.


ABSTRACT: Crumpled sheets show slow mechanical relaxation and long lasting memory of previous mechanical states. By using uniaxial compression tests, the role of friction and ductility on the stress relaxation dynamics of crumpled systems is investigated. We find a material dependent relaxation constant that can be tuned by changing ductility and adhesive properties of the sheet. After a two-step compression protocol, nonmonotonic aging is reported for polymeric, elastomeric and metal sheets, with relaxation dynamics that are dependent on the material's properties. These findings can contribute to tailoring and programming of crumpled materials to get desirable mechanical properties.


ABSTRACT: The drying of colloidal suspensions is a very complex process leading to a sol–gel transition induced by solvent evaporation. The resulting film can even crack and delaminate. In this study, we investigate the drying process of a colloidal suspension with a highly volatile solvent and we show for initially millimeter-thick layers that the resulting pattern of delaminated plates considerably differs from what is usually observed for aqueous colloidal suspensions. Visualization using an IR camera reveals that hexagonal convection cells can develop during the drying of suspensions with a highly volatile solvent and may persist until the film consolidation. This leads to the formation of non-homogeneous films presenting surface corrugations. Thus, we highlight the importance of the hydrodynamics during the first phase of strong solvent evaporation and its consequences for the following drying steps. A criterion predicting whether or not Bénard–Marangoni instability effectively occurs will be discussed. Finally, we report a non-classical delamination mode generating fragments with convex surfaces, whereas buckle-driven delamination usually results in concave shapes.


ABSTRACT: In this work, we study the plane-strain deformations of hyperelastic plates induced by differential growth, aiming to derive some analytical formulas for 2D shape-programming of hyperelastic plates. First, we present a plate equation system with the growth functions incorporated, which is derived from the 3D governing system through a series expansion and truncation approach. By proposing a novel analytical method, the plate equation system is solved explicitly. The obtained solutions can reveal the dependence of the current
configurations of the hyperelastic plates on the differential growth fields. By solving an inverse problem, some analytical formulas are obtained, which can be used to identify the growth functions for generating arbitrary 2D geometrical shapes of the hyperelastic plates. To demonstrate the efficiency of these formulas, some representative examples are studied, which show good consistency with the numerical simulations. The obtained analytical formulas have wide potential applications in the design of intelligent soft devices.

Nontawit Cheewaruangroj (1) and John S. Biggins (1,2)
(1) Cavendish Laboratory, University of Cambridge, 19 JJ Thomson Avenue, Cambridge CB3 0HE, UK
(2) Engineering Department, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK


ABSTRACT: If a neo-Hookean elastic layer adhered to a neo-Hookean substrate grows equibiaxially, it will buckle into a topographic pattern. Here, we combine higher order perturbation theory and finite element numerics to predict the pattern formed just beyond the buckling threshold. More precisely, we construct a series of solutions corresponding to hexagonal, square and stripe patterns, and expand the elastic energy for each pattern as a Landau-like energy series in the topography amplitude. We see that, for square and stripe patterns, the elastic energy is invariant under topography inversion, making the instabilities supercritical. However, since patterns of hexagonal dents are physically different to patterns of hexagonal bumps, the hexagonal energy lacks this invariance. This lack introduces a cubic term which causes hexagonal patterns to be formed subcritically and are hence energetically favoured. Our analytic calculation of the cubic term allows us to determine that dents are favoured in incompressible systems, but bumps are favored in sufficiently compressible systems. Finally, we consider a stiff layer sandwiched between an identical substrate and superstrate pair. This system has topography inversion symmetry, so hexagons form supercritically, and square patterns are favoured. We use finite element calculations to verify our theoretical predictions for each pattern, and confirm which pattern is selected. Previous work has used a simplified elastic model (a plate & a linear elastic substrate) that possesses invariance under topography inversion, and hence incorrectly predicted square patterns. Our work demonstrates that large strain geometry is sufficient to break this symmetry and explain the hexagonal dent patterns observed in buckling experiments.

Long Ma (1), Xuepeng Liu (1,2), Ai-kah Soh (3), Linghui He (1), Changzheng Wu (4) and Yong Ni (1),
(1) CAS Key Laboratory of Mechanical Behavior and Design of Materials, Department of Modern Mechanics, University of Science and Technology of China, Hefei, P. R. China
(2) Anhui Province Key Lab of Aerospace Structural Parts Forming Technology and Equipment, Institute of Industry and Equipment Technology, Hefei University of Technology, Hefei, P. R. China
(3) School of Engineering, Monash University Malaysia, Jalan Lagoon Selatan, Bandar Sunway, Selangor Darul Ehsan, Malaysia
(4) Division of Nanomaterials & Chemistry, Hefei National Laboratory for Physical Sciences at the Microscale, University of Science and Technology of China, Hefei, P. R. China


ABSTRACT: Topological defect nucleation and boundary branching in crystal growth on a curved surface are two typical elastic instabilities driven by curvature induced stress, and have usually been discussed separately in the past. In this work they are simultaneously considered during crystal growth on a sphere. Phase diagrams with respect to sphere radius, size, edge energy and stiffness of the crystal for the equilibrium crystal morphologies are achieved by theoretical analysis and validated by Brownian dynamics simulations. The simulation results further demonstrate the detail of morphological evolution governed by these two different stress relaxation modes. Topological defect nucleation and boundary branching not only compete with each other but also coexist in a range of combinations of factors. Clarification of the interaction mechanism provides a better understanding of various curved crystal morphologies for their potential applications.
Catherine E. Wisinger (1), Leslie A. Maynard (1) and Justin R. Barone (2,3,4)
(1) Chemical Engineering, Virginia Tech Blacksburg, USA
(2) Biological Systems Engineering, Virginia Tech Blacksburg, USA
(3) Center for Soft Matter and Biological Physics, Virginia Tech Blacksburg, USA
(4) Macromolecules Innovation Institute, Virginia Tech Blacksburg, USA
ABSTRACT: Polyolefin thermoplastic elastomer (POE) bilayers of varying length (L) to width (W) ratio are formed through traditional polymer processing. Each layer is completely isotropic but the bilayers have an elastic recovery mismatch such that when stretched, one layer recovers to a different extent than the other. Upon stretching bilayers from low to moderate strains and releasing the bilayer bends (curvature, $\kappa$, $\kappa < 1/L$).
Stretching to moderate strain and releasing results in bilayer curling ($1/L < \kappa < 1/W$). Finally, stretching to high strains and releasing such that $\kappa \geq 1/W$ results in twisting into a helix for $L/W > 2\pi$ bilayers and rolling into a cylinder for $L/W < 2\pi$. Varying $W$ can change the helical pitch, $l$, of twisted bilayers. The twisted bilayer helical rise angle varies between $\theta = 60$ and $90^\circ$. Metastability, i.e., bilayers that show a combination of the two behaviors, is observed at long absolute $L$ or short absolute $W$. The bilayers are modeled using Euler–Bernoulli beam theory to show that the curvature can be predicted using the elastic recovery of the layer that recovers more.

Xiaoxiao Zhang (1), Patrick T. Mather (2), Mark J. Bowick (3) and Teng Zhang (1)
(1) Department of Mechanical and Aerospace Engineering, Syracuse University, Syracuse, USA
(2) Department of Chemical Engineering, Bucknell University, Lewisburg, USA
(3) Kavli Institute for Theoretical Physics, University of California, Santa Barbara, USA
ABSTRACT: We investigate wrinkling patterns in a tri-layer torus consisting of an expanding thin outer layer, an intermediate soft layer and an inner core with a tunable shear modulus, inspired by pattern formation in developmental biology, such as follicle pattern formation during the development of chicken embryos. We show from large-scale finite element simulations that hexagonal wrinkling patterns form for stiff cores whereas stripe wrinkling patterns develop for soft cores. Hexagons and stripes co-exist to form hybrid patterns for cores with intermediate stiffness. The governing mechanism for the pattern transition is that the stiffness of the inner core controls the degree to which the major radius of the torus expands – this has a greater effect on deformation in the long direction as compared to the short direction of the torus. This anisotropic deformation alters stress states in the outer layer which change from biaxial (preferred hexagons) to uniaxial (preferred stripes) compression as the core stiffness is reduced. As the outer layer continues to expand, stripe and hexagon patterns will evolve into zigzags and segmented labyrinths, respectively. Stripe wrinkles are observed to initiate at the inner surface of the torus while hexagon wrinkles start from the outer surface as a result of curvature-dependent stresses in the torus. We further discuss the effects of elasticities and geometries of the torus on the wrinkling patterns.

Pengfei Yang (1,2), Fei Dang (1), Xiangbiao Liao (2) and Xi Chen (2,3)
(1) International Center for Applied Mechanics, State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace, Xi’an Jiaotong University, Xi’an 710049, China
(2) Earth Engineering Center, Center for Advanced Materials for Energy and Environment, Department of Earth and Environmental Engineering, Columbia University, New York, USA
(3) School of Chemical Engineering, Northwest University, Xi’an 710069, China
ABSTRACT: This paper studies the buckling morphology transition of an elastic ring confined in an annular channel. Under uniform axial strain, the ring would first form one inward blister and then transit to an “S” shape, but does not induce more blisters due to an energy barrier caused by the annular shape of the channel. In
order to overcome the energy barrier, external perturbation is employed and a stable morphology with multiple blisters may be obtained. A theoretical framework is then established to calculate the bifurcation points of the shape transition, which agrees well with finite-element (FEM) simulation results. The diagrams of the stable buckling morphologies with respect to the geometrics of the elastic rings are presented, which may provide useful insights for practical applications, for example, the design of a peristaltic pump.

Serge Mora (1), Edward Andò (2), Jean-Marc Fromental (3), Ty Phou (3) and Yves Pomeau (4)  
(1) Laboratoire de Mécanique et de Génie Civil, Université de Montpellier and CNRS, 163 rue Auguste Broussonnet, F-34090 Montpellier, France  
(2) Laboratoire 3SR, Université Grenoble Alpes and CNRS, F-38041 Grenoble, France  
(3) Laboratoire Charles Coulomb, Université de Montpellier and CNRS, 163 rue Auguste Broussonnet, F-34090 Montpellier, France  
(4) University of Arizona, Department of Mathematics, Tucson, USA


**ABSTRACT:** Deformations of heavy elastic cylinders with their axis in the direction of earth's gravity field are investigated. The specimens, made of polyacrylamide hydrogels, are attached from their top circular cross section to a rigid plate. An equilibrium configuration results from the interplay between gravity that tends to deform the cylinders downwards under their own weight, and elasticity that resists these distortions. The corresponding steady state exhibits fascinating shapes which are measured with lab-based micro-tomography. For any given initial radius to height ratio, the deformed cylinders are no longer axially symmetric beyond a critical value of a control parameter that depends on the volume force, the height and the elastic modulus: self-similar wrinkling hierarchies develop, and dimples appear at the bottom surface of the shallowest samples. We show that these patterns are the consequences of elastic instabilities.


**ABSTRACT:** This paper explores the physical mechanisms responsible for the appearance of small blisters on the surface of temperature sensitive hydrogels as they deswell rapidly during their volume phase transition. For this, we develop a numerical model that couples the processes of hydrogel deswelling and blister growth due to the existence of a thin quasi-impermeable layer on its surface. The model points out that blister inflation originates at defects point under the gel's surface, under the effect of the increasing osmotic pressure in the gel as it undergoes its phase transition. Due to their large deformation, these blisters often experience a mechanical instability that triggers a sudden increase in their growth rate at the expense of their closest neighbors. Using a simple computational model, we then show that blisters are able to communicate via internal pressure and that these interactions are mediated by two characteristic time scales related to solvent transport within and between adjacent blisters. Our study finally indicates that these mechanisms can be controlled by temperature and the gel's cross-link density to achieve diversity of blister patterns on the gel's surface. The proposed analysis provides predictions that agree well with experimental observations of NiPAm gels which deswell in various conditions.


**ABSTRACT:** We propose and investigate a minimal mechanism that makes use of differential swelling to modify the critical buckling conditions of elastic bilayer shells, as measured by the knockdown factor. Our shells contain an engineered defect at the north pole and are made of two layers of different crosslinked polymers that exchange free molecular chains. Depending on the size of the defect and the extent of swelling, we can observe either a decreasing or increasing knockdown factor. FEM simulations are performed using a reduced model for the swelling process to aid us in rationalizing the underlying mechanism, providing a qualitative agreement with experiments. We believe that the working principle of our mechanism can be extended to bimetallic shells undergoing variations in temperature and to shells made of pH-responsive gels, where the change in knockdown factor could be changed dynamically.
Hyeyoung Son, Allison L. Chau and Chelsea S. Davis (School of Materials Engineering, Purdue University, West Lafayette, USA), “Polymer thin film adhesion utilizing the transition from surface wrinkling to delamination”, Soft Matter, Vol. 15, No. 31, pp 6375-6382, 8 July 2019. DOI: 10.1039/C9SM01052A

ABSTRACT: Understanding the adhesion of rigid thin films to compliant substrates is critical for the development and implementation of flexible electronic devices and wearable sensor technologies. Quantifying the strength of a film–substrate interface can be challenging due to the brittleness of glassy films which can greatly complicate sample preparation, handling, and testing. Here, a method for measuring the adhesion of glassy thin films to soft elastomeric substrates is explored that exploits an understanding of surface buckling instabilities, specifically the transition from wrinkling to delamination. The adhesion (given by the critical strain energy release rate ($G$)) for two model materials’ interfaces is quantified by determining the critical delamination strain for thin glassy polymer films (polystyrene (PS) and poly(methyl methacrylate) (PMMA)) from an elastomeric substrate (poly(dimethyl siloxane) (PDMS)). By accounting for edge defects that greatly reduce the critical strain for delamination, reasonable adjusted $G$ values of $21.0 \pm 5.1 \text{ mJ m}^{-2}$ and $32.2 \pm 4.9 \text{ mJ m}^{-2}$ are found for PS–PDMS and PMMA–PDMS interfaces, respectively. The utilization of this method to characterize film modulus and adhesion could be used as a facile measurement technique for more applied polymer thin film systems.

Caifen Lei (1), Qiang Li (1), Lu Yang (2), Fei Deng (1), Jianyao Li (2), Zihan Ye (1), Ying Wang (1) and Zhenkun Zhang (1)
(1) Key Laboratory of Functional Polymer Materials of Ministry of Education, Institute of Polymer Chemistry, College of Chemistry, Nankai University, 300071 Tianjin, China
(2) School of Chemical Engineering and Technology, Tianjin University, Tianjin 300072, China


ABSTRACT: Under external pressure compression, various kinds of artificial microcapsules can undergo buckling induced deformation and catastrophic rupturing failure, which needs to be understood for their diverse practical applications. For this, many theories and numerical simulations have recently emerged, leading to some intriguing but often debatable predictions and scaling laws. However, experimental testing of these predictions is very limited, due to challenges in realizing prescribed buckling pathways and in situ monitoring of the buckling procedure. Herein, we report the buckling behaviors of well-defined spherical polydopamine (PDA) capsules with tunable sizes and homogeneous nanoscale shells. Simple but controlled solvent evaporation was implemented inside a home-made optical chamber to induce buckling of PDA capsules by following a prescribed pathway toward targeted shapes that are only dictated by the inherent material properties of the capsules. In addition, the buckling speed was slowed down to the timescale of minutes, which can prevent buckling from being trapped at some metastable intermediate states as well as facilitating in situ optical monitoring of the whole buckling procedure in slow motion. In this way, several classic buckling behaviors were clearly observed, including the sudden appearance of spinodal-like dimples above critical pressures, transition of the indentation rim from the axisymmetric to polygonal shape, and evolution of multi-Indented buckling into single indented buckling following Ostwald ripening. These observations are qualitatively comparable with recent predictions from numerical results. Furthermore, some novel buckling phenomena have been reported for the first time, which might stimulate further theories and numerical simulations.

Kirsten Harth (1,2), Torsten Trittel (1), Kathrin May (1) and Ralf Stannarius (1)
(1) Institute of Physics, Otto von Guericke University, Universitätsplatz 2, D-39106 Magdeburg, Germany
(2) Universiteit Twente, Physics of Fluids and Max Planck Center for Complex Fluid Dynamics, 7500 AE Enschede, The Netherlands


ABSTRACT: We demonstrate spontaneous wrinkling as a transient dynamical pattern in thin freely floating smectic liquid-crystalline films. The peculiarity of such films is that, while behaving liquid-like with respect to flow in the film plane, they cannot quickly expand their thickness because that requires stacking of additional
smectic layers. At short time scales, they therefore behave like quasi-incompressible membranes, very different from soap films. Smectic films can develop a transient undulation instability or form bulges in response to lateral compression. Optical experiments with freely floating bubbles on parabolic flights and in ground lab experiments are reported. The characteristic wavelengths of the wrinkles are in the submillimeter range. We demonstrate the dynamic nature of the pattern formation mechanism and develop a basic model that explains the physical mechanism for the wavelength selection and wrinkle orientation.

Hareesh Godaba (1), Zhi-Qian Zhang (2), Ujjaval Gupta (1), Choon Chiang Foo (2) and Jian Zhu (1)
(1) Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore
(2) Institute of High Performance Computing, 1 Fusionopolis Way, #16-16 Connexis, Singapore

**ABSTRACT:** Instabilities in a thin sheet are ubiquitous and can be induced by various stimuli, such as a uniaxial force, liquid–vapor surface tension, etc. This paper investigates voltage-induced instabilities in a membrane of a dielectric elastomer. Instabilities including buckling, wrinkling, and crumpling are observed in the experiments. The prestretches of the dielectric elastomer are found to play a significant role in determining its instability mode. When the prestretch is small, intermediate, or large, the membrane may undergo buckling, wrinkling, or crumpling, respectively. Finite element analysis is conducted to study these instability modes, and the simulations are well consistent with the experimental observations. We hope that this investigation of mechanical and physical properties of dielectric elastomers can enhance their extensive and significant applications in soft devices and soft robots.

Stefano Luigi Oscurato, Fabio Formisano, Corrado de Lisio, Marco d'Ischia, Felice Gesuele, Pasqualino Maddalena, Paola Manini, Ludovico Migliaccio and Alessandro Pezzella (The first author is from: Department of Physics “E. Pancini”, University of Naples “Federico II” Via Cintia 4, I-80126 Naples, Italy), “Spontaneous wrinkle emergence in nascent eumelanin thin films”, Soft Matter, Vol. 15, No. 45, pp 9261-9270, 7 December 2019,

**ABSTRACT:** Self-patterning processes originated by physical stimuli have been extensively documented in thin films, whereas spontaneous wrinkling phenomena due to chemical transformation processes are, to the best of our knowledge, unprecedented. Herein we report a case of spontaneous polymerization-driven surface nano-patterning (~500 nm) that develops in smooth thin solid films of 5,6-dihydroxyindole (DHI), a major precursor of eumelanin polymers, over a time scale of 30 to 60 days in air at room temperature. The phenomenon can be observed only above a critical film thickness of ~250 nm and it is affected by exposure to ammonia vapors causing acceleration of the oxidation process. The thickness-dependent onset of wrinkling can be attributed to non-homogeneous rates of oxidation through the film causing slow swelling/expansion of the inner layers followed by fast stiffening and cross-linking in the outer layer exposed to higher oxygen levels.


**ABSTRACT:** Global changes of cell shape under mechanical or osmotic external stresses are mostly controlled by the mechanics of the cortical actin cytoskeleton underlying the cell membrane. Some aspects of this process can be recapitulated in vitro on reconstituted actin-and-membrane systems. In this paper, we investigate how the mechanical properties of a branched actin network shell, polymerized at the surface of a liposome, control membrane shape when the volume is reduced. We observe a variety of membrane shapes depending on the actin thickness. Thin shells undergo buckling, characterized by a cup-shape deformation of the membrane that coincides with the one of the actin network. Thick shells produce membrane wrinkles, but do not deform their outer layer. For intermediate micrometer-thick shells, wrinkling of the membrane is observed, and the actin layer is slightly deformed. Confronting our experimental results with a theoretical description, we determine the transition between buckling and wrinkling, which depends on the thickness of the actin shell and the size of the...
liposome. We thus unveil the generic mechanism by which biomembranes are able to accommodate their shape against mechanical compression, through thickness adaptation of their cortical cytoskeleton.


ABSTRACT: No longer just the purview of artists and enthusiasts, origami engineering has emerged as a potentially powerful tool to create three dimensional structures on disparate scales. Whether origami (and the closely related kirigami) engineering can emerge as a useful technology will depend crucially on both fundamental theoretical advances as well as the development of further fabrication tools.


ABSTRACT: Abnormal shapes of red blood cells (RBC) have been associated with various diseases. Diverse RBC shapes have also been intriguing for membrane biophysics. Here we focus on sickle shaped RBC which form due to abnormal growth of semi-rigid hemoglobin (HbS) fibers confined in RBC. Using the area difference elasticity (ADE) model for RBC and worm-like chain model for the confined HbS fibers, we explore shape deformations at equilibrium using Monte-Carlo simulations. We show that while a single HbS fiber is not rigid enough to produce sickle like deformation, a fiber bundle can do so. We also consider multiple disjoint filaments and find that confinement can generate multipolar RBC shapes and can even promote helical filament conformations which have not been discussed before. We show that the same model, when applied to microtubules confined in phospholipid vesicles, predicts vesicle tubulation. In addition we reproduce the tube collapse transition and tennis racket type vesicle shapes, as reported in experiments. We conclude that with a decrease in the surface area to volume ratio, and membrane rigidity, the vesicles prefer tubulation over sickling. The highlight of this work is several important non-axisymmetric RBC and vesicle shapes, which have never been explored in simulations.


ABSTRACT: We report a versatile approach to generate 2D dual-frequency patterns on soft substrates by superposition of 1D single-frequency wrinkles. Wave superposition is achieved by applying sequential orthogonal strains to elastomeric coupons, as opposed to the application of a (simultaneous) biaxial strain field. First, a 1D wrinkling pattern is induced by the well-known mechanical instability of a bilayer formed by oxygen plasma-oxidation of a (pre-strained) polydimethylsiloxane elastomer. The wrinkled surface formed upon strain release is then replicated to obtain a stress-free substrate, and stretched in the direction perpendicular to the first generation. Subsequent plasma exposure and mechanical relaxation (with independent process parameters) yield a prescribed second-generation wrinkling, whose profile and dependence on the first generation we examine in detail. By independently varying plasma oxidation and strain parameters in both directions, we demonstrate the formation of a wide array of topographies, including arrays of symmetric 2D checkerboard patterns with exceptional area coverage with respect to those formed by simultaneous 2D wrinkling. While the resulting topographies cannot be explained in terms of a simple orthogonal wave superposition, we show that, by accounting for the orthogonal prestrain experienced by the first wrinkling generation, the resulting 2D patterns can be readily calculated from 1D wrinkling behaviour.


ABSTRACT: We report a numerical method to control the swimming direction by exploiting buckling instability in uniflagellar bacteria and bio-inspired soft robots. Our model system is comprised of a spherical rigid head and a helical elastic flagellum. The rotation of the flagellum in low Reynolds environment generates
a propulsive force that allows the system to swim in fluid. The locomotion is an intricate interplay between the elasticity of the flagellum, the hydrodynamic loading, and the flow generated by the moving head. We use the Discrete Elastic Rods algorithm to capture the geometrically nonlinear deformation in the flagellum, Lighthill's Slender Body Theory to simulate the hydrodynamics, and Higdons model for the spherical head in motion within viscous fluid. This flagellated system follows a straight path if the angular velocity of the flagellum is below a critical threshold. Buckling ensues in the flagellum beyond this threshold angular velocity and the system takes a nonlinear trajectory. We consider the angular velocity as the control parameter and solve the inverse problem of computing the angular velocity, that varies with time, given a desired nonlinear trajectory. Our results indicate that bacteria can exploit buckling in flagellum to precisely control their swimming direction.

Seog-Jin Jeon (1,2) and Ryan C. Hayward (2)
(1) Department of Polymer Science and Engineering, Kumoh National Institute of Technology, Gumi, Gyeongbuk 39177, South Korea
(2) Department of Polymer Science and Engineering, University of Massachusetts Amherst, Amherst 01003, Massachusetts, USA

ABSTRACT: Trilayer polymer films consisting of a thermoresponsive hydrogel, poly(diethyl acrylamide) (PDEAM), sandwiched by rigid layers of a glassy polymer, poly(para-methylstyrene) (PpMS), patterned into parallel striped features are prepared and used to drive temperature-responsive reversible anisotropic expansion. Significant swelling occurs along the direction perpendicular to the stripes, while very little swelling is observed along the direction parallel to the stripes, leading to an overall swelling anisotropy of 1.17. Introducing a difference Δ in the widths of the stripes on the top to bottom surfaces causes the films to roll upon swelling, where both the magnitude and sign of the resulting curvature can be controlled by varying Δ. Using patterns of concentric circular lines (analogous to +1 defects in liquid crystalline polymers), we demonstrate the swelling-induced formation of cone-like shapes, where the buckling direction of each unit can be programmed through local variations in Δ. This trilayer concept provides a simple way to simultaneously control both the Gaussian curvature and direction of buckling in shape-morphing hydrogels, with advantages for accessing smaller length-scales compared to existing methods.


ABSTRACT: In this work, we study the peeling of a cylindrical shell attached to a smooth rigid substrate and subjected to a vertical force. A generalized peeling model based on the energy-variational approach is presented, and its numerical solutions characterize the cross-section profile and peeling force. The interfacial interactions are represented by the Lennard-Jones potential. Molecular dynamics simulations are performed for the peeling system with single-walled carbon nanotubes and gold substrates, and simulation results show good agreement with the theoretical predictions. We show that there are three stages (stable peeling stage, line-contact stage, and pull-off stage) in the entire peeling process. A spring-like behavior is observed in the stable peeling stage. With the peeling displacement increasing, the second stage has a marked feature of line contact and the peeling force arrives at a peak pull-off force. Furthermore, we show that the pull-off force strongly depends on the flexural stiffness of cylindrical shell and two Lennard-Jones parameters, but is independent of the initial radius of cylindrical shell. Our findings may help to reveal the interactions between thin-walled nanotubes and substrates.

ABSTRACT: Nanoparticle based ultra-thin membranes have been shown to have remarkable mechanical properties while also possessing novel electrical, optical or magnetic properties, which could be controlled by tailoring properties at the level of individual nanoparticles. Since in most cases the ultra-thin membranes are coupled to some substrates, the role of membrane–substrate interactions, apart from nanoparticle–nanoparticle interactions become very crucial in understanding their mechanical and thermal stability, as well as their plethora of applications. However, systematic studies in this direction have been conspicuously absent. Here we report thermal stability and the corresponding microscopic dynamics of polymer supported ultra-thin membranes comprising of self-assembled, ordered grains of polymer grafted nanoparticles having tunable mechanical properties. The initially ordered membranes show distinct pathways for temperature induced disordering depending on membrane flexibility as well as on interfacial entropic and enthalpic interactions with the underlying polymer thin film. We also observe contrasting temperature dependence of microscopic dynamics of these membranes depending on whether the graft polymer–substrate polymer interactions are predominantly entropic or enthalpic in nature. Our results suggest that apart from their varied applications, the soft nanoparticle–polymer hybrid membranes are a playground for rich physics involving subtle entropic and enthalpic effects along with the nanoparticles softness, which eventually determine their thermo-mechanical stability.


ABSTRACT: Membrane curvature effects are important in numerous cellular processes and many membrane interacting proteins induce spontaneous curvature upon membrane binding. Shiga and cholera toxins both belong to the AB family of toxins and consist of a toxic A subunit and a membrane-binding pentameric B subunit. Shiga and cholera toxins induce tubular membrane invaginations in cells and GUVs due to curvature effects and the toxins are known from MD simulations to induce curvature. Membrane invaginations have been linked to uptake of the toxins into cells. As a novel model system to experimentally characterize curvature-inducing proteins, we study the morphology induced in planar membrane patches. It was previously shown that annexins induce distinct morphologies in membrane patches including membrane rolling. In this study we show that the B subunits of Shiga and cholera toxins (STxB, CTxB) both induce roll-up of cell-sized membrane patches. Rolling starts from the free membrane edges of the patch and is completed within a few seconds. We characterize the branched roll morphology and find experimental estimates for the spontaneous curvature of the toxins based on the topology of rolls. The estimates are in agreement with previous MD simulations. We quantify the dynamics of rolling as induced by the toxins and demonstrate agreement with a theoretical model of the rolling dynamics. The model solves the equation of motion for a membrane roll and includes viscous drag and adhesion to the support. The results suggest that membrane rolling may be a general phenomenon displayed by many proteins that induce negative curvature in membranes with free edges.


ABSTRACT: We study the capillary adhesion of a spherical elastic cap on a rigid sphere of a different radius. Caps of small area accommodate the combination of flexural and in-plane strains induced by the mismatch in curvature, and fully adhere to the sphere. Conversely, wider caps delaminate and exhibit only partial contact. We determine the maximum size of the cap enabling full adhesion and describe its dependence on experimental parameters through a balance of stretching and adhesion energies. Beyond the maximum size, complex adhesion patterns such as blisters, bubbles or star shapes are observed. We rationalize these different states in configuration diagrams where stretching, bending and adhesion energies are compared through two dimensionless parameters.

Bjarke Frost Nielsen (1), Gaute Linga (2), Amalie Christensen (1,3) and Joachim Mathiesen (1)
(1) Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark
(2) PoreLab, The Njord Centre, Department of Physics, University of Oslo, P. O. Box 1048, 0316 Oslo, Norway
ABSTRACT: Hardcore/soft shell (HCSS) particles have been shown to self-assemble into a remarkably rich variety of structures under compression due to the simple interplay between the hard-core and soft-shoulder length scales in their interactions. Most studies in this area model the soft shell interaction as a square shoulder potential. Although appealing from a theoretical point of view, the potential is physically unrealistic because


ABSTRACT: The main goal of this work is the design of a coarse-grained theoretical model of minimal resolution for the study of the physical properties of icosahedral virus capsids within the linear-response regime. In this model the capsid is represented as an interacting many-body system whose composing elements are capsid subunits (capsomers), which are treated as three-dimensional rigid bodies. The total interaction potential energy is written as a sum of pairwise capsomer–capsomer interactions. Based on previous work [Gomez Llorente et al., Soft Matter, 2014, 10, 3560], a minimal and complete anisotropic binary interaction that includes a full Hessian matrix of independent force constants is proposed. In this interaction model, capsomers have rotational symmetry around an axis of order \( n > 2 \). The full coarse-grained model is applied to analyse the low-frequency normal-mode spectrum of icosahedral \( T = 1 \) capsids. The model performance is evaluated by fitting its predicted spectrum to the full-atom results for the Satellite Tobacco Necrosis Virus (STNV) capsid [Dykeman and Sankey, Phys. Rev. Lett., 2008, 100, 028101]. Two capsomer choices that are compatible with the capsid icosahedral symmetry are checked, namely pentamers (\( n = 5 \)) and trimers (\( n = 3 \)). Both subunit types provide fair fits, from which the magnitude of the coarse-grained force constants for a real virus is obtained. The model is able to uncover latent instabilities whose analysis is fully consistent with the current knowledge about the STNV capsid, which does not self-assemble in the absence of RNA and is thermally unstable. The straightforward generalisability of the model beyond the linear regime and its completeness make it a promising tool to theoretically interpret many experimental data such as those provided by the atomic force microscopy or even to better understand processes far from equilibrium such as the capsid self-assembly.

Walter R.C. Somerville (1,2), Adam D. Law (3), Marcel Rey (4,5), Nicolas Vogel (4,5), Andrew J. Archer (6) and D. Martin A. Buzza (1)

(1) G. W. Gray Centre for Advanced Materials, Department of Physics & Mathematics, University of Hull, Hull HU6 7RX, UK
(2) The MacDiarmid Institute for Advanced Materials and Nanotechnology, School of Chemical and Physical Sciences, Victoria University of Wellington, Kelburn Parade, Wellington 6012, New Zealand
(3) medPhoton GmbH, Strubergasse 16, 5020 Salzburg, Austria
(4) Institute of Particle Technology, Friedrich-Alexander University Erlangen-Nuernberg, Cauerstrasse 4, 91058 Erlangen, Germany
(5) Interdisciplinary Center for Functional Particle Systems, Friedrich-Alexander University Erlangen-Nuernberg, Ha-berstrasse 9a, 91058 Erlangen, Germany
(6) Department of Mathematical Sciences, Loughborough University, Loughborough LE11 3TU, UK


ABSTRACT: Hard-core/soft shell (HCSS) particles have been shown to self-assemble into a remarkably rich variety of structures under compression due to the simple interplay between the hard-core and soft-shoulder length scales in their interactions. Most studies in this area model the soft shell interaction as a square shoulder potential. Although appealing from a theoretical point of view, the potential is physically unrealistic because

(3) Danmarks Nationalbank, DK-1093 Copenhagen K, Denmark


ABSTRACT: Self-assembly of ordered nanometer-scale patterns is interesting in itself, but its practical value depends on the ability to predict and control pattern formation. In this paper we demonstrate theoretically and numerically that engineering of extrinsic as well as intrinsic substrate geometry may provide such a controllable ordering mechanism for block copolymers films. We develop an effective two-dimensional model of thin films of striped-phase diblock copolymers on general curved substrates. The model is obtained as an expansion in the film thickness and thus takes the third dimension into account, which crucially allows us to predict the preferred orientations even in the absence of intrinsic curvature. We determine the minimum-energy textures on several curved surfaces and arrive at a general principle for using substrate curvature as an ordering field, namely that the stripes will tend to align along directions of maximal curvature.
there is no repulsive force in the soft shell regime, unlike in experimental HCSS systems. To make the model more realistic, here we consider HCSS particles with a range of soft shell potential profiles beyond the standard square shoulder form and study the model using both minimum energy calculations and Monte Carlo simulations. We find that by tuning density and the soft shell profile, HCSS particles in the thin shell regime \( (i.e., \text{shell to core ratio } r_1/r_0 \text{ less than or equal to sqrt(3)}) \) can form a large range of structures, including hexagons, chains, squares, rhomboids and two distinct zig-zag structures. Furthermore, by tuning the density and \( r/r_1 \), we find that HCSS particles with experimentally realistic linear ramp soft shoulder repulsions can form honeycombs and quasicrystals with 10-fold and 12-fold symmetry. Our study therefore suggests the exciting possibility of fabricating these exotic 2D structures experimentally through colloidal self-assembly.


ABSTRACT: The stretch-induced structural evolution mechanism is a long-standing scientific question in the post-stretching processing of polymer films. X-ray scattering, especially a combination of small- and wide-angle X-ray scattering (SAXS/WAXS), provides a powerful method to study the hierarchical structure of polymer films. Recent advances in synchrotron radiation (SR) light sources and detection techniques allow one to measure the structural evolution of polymer films during post-stretching processing in real time with ultra-high time resolution, which benefits the understanding on this topic. This review summarizes some recent investigations on post-stretching processing of polymer films, which combine in situ X-ray scattering techniques with purposely designed tensile apparatus in terms of three aspects: uniaxial stretching, biaxial stretching and stretching with chemical reactions. Concerning the polymer bulk, traditional deformation mechanisms like stretch-induced crystallization (SIC), crystal slipping, phase transition and melting–recrystallization are discussed for the uniaxial and biaxial post-stretching of polymer films. New deformation models have been developed to focus on the structural evolution on the length scale of lamellar stacks, which consider the potential microphase separation of the interlamellar amorphous phase and microbuckling. For solution systems, the coupled effects of the mechanical work from external force and the chemical potential from possible chemical reactions are taken into account for the structural evolution during stretching in solution. Roadmaps of structural and morphological evolution in the processing parameter space (i.e., temperature, stress, strain and the concentration of additive in the bath solution) are eventually constructed for precursor films. The accumulation of a structural evolution database for post-stretching processing of polymer films can be expected to provide a helpful guide for industrial processing for high-performance polymers in the near future.

Kanako Emori (1), Yusaku Saito (1), Akio Yonezu (1), Liangliang Zhu (2), Xiangbiao Liao (2) and Xi Chen(2,3)

(1) Department of Precision Mechanics, Chuo University, 1-13-27 Kasuga, Bunkyo, Tokyo, Japan
(2) School of Chemical Engineering, Northwest University, Xi'an 710069, China
(3) Earth Engineering Center, Center for Advanced Materials for Energy and Environment, Department of Earth and Environmental Engineering, Columbia University, New York, USA


ABSTRACT: This study aims to provide a fundamental understanding of the morphological transition of film buckling-delamination in an elastomeric bilayer spherical shell system. We developed an experimental system in which surface delamination buckles emerge because of biaxial compression of the elastomeric bilayer spherical shell driven by an air-pressured (pneumatic) device. A flat PDMS plate was first isotropically expanded and shaped into a hemisphere by air pressure. Subsequently, the hemisphere substrate was covered with a thin PDMS film. By releasing the air pressure, the substrate contracts and the outer film surface were subjected to biaxial compression; this resulted in various surface patterns of film buckling-delamination. It was found that the surface morphology transitions from initial delamination sites and that the buckles propagate on the entire surface of the sphere. This pattern formation is dependent on the surface strain distribution, i.e., radial strain and circumferential strain. In order to control the surface pattern, we systematically changed the material and system parameters such as film thickness, Young's modulus, and interfacial adhesion condition. In addition,
finite element (FEM) computation was carried out to simulate the surface pattern and to elucidate the mechanism of buckling-delamination morphological transition.

Monica M. Ripp (1,2), Vincent Demery (3,4), Teng Zhang (2,5) and Joseph D. Paulsen (1,2)
(1) Department of Physics, Syracuse University, Syracuse, NY 13244, USA
(2) BioInspired Syracuse: Institute for Material and Living Systems, Syracuse University, Syracuse, NY 13244, USA
(3) Gulliver, CNRS, ESPCI Paris, PSL Research University, 10 rue Vauquelin, 75005 Paris, France
(4) Univ Lyon, ENS de Lyon, Univ Claude Bernard Lyon 1, CNRS, Laboratoire de Physique, F-69342 Lyon, France
(5) Department of Mechanical and Aerospace Engineering, Syracuse University, Syracuse, NY 13244, USA


ABSTRACT: A basic paradigm underlying the Hookean mechanics of amorphous, isotropic solids is that small deformations are proportional to the magnitude of external forces. However, slender bodies may undergo large deformations even under minute forces, leading to nonlinear responses rooted in purely geometric effects. Here we study the indentation of a polymer film on a liquid bath. Our experiments and simulations support a recently-predicted stiffening response [D. Vella and B. Davidovitch, Phys. Rev. E, 2018, 98, 013003], and we show that the system softens at large slopes, in agreement with our theory that addresses small and large deflections. We show how stiffening and softening emanate from nontrivial yet generic features of the stress and displacement fields.

References listed at the end of the paper:
B. Audoly and Y. Pomeau, Elasticity and geometry: from hair curls to the nonlinear response of shells, Oxford University Press, 2010,
B. Li, Y.-P. Cao, X.-Q. Feng and H. Gao, Soft Matter, 2012, 8, 5728 — 5745
M. Pagitz Philos. Trans. R. Soc. A, 2007, 3003 — 3017
J.Huang, PhD thesis, University of Massachusetts, Amherst, 2010.
J. Chopin, V. Démery and B. Davidovitch, J. Elasticity, 2015, 119, 137 — 189
D. Kumar, J. D. Paulsen, T. P. Russell and N. Menon, Science, 2018, 359, 775 —778
B. P. Binks Curr. Opin. Colloid Interface Sci., 2002, 7, 21 —41

Rachel Downing (1), Guilherme Volpe Bossa (2) and Sylvio May (1)
(1) Department of Physics, North Dakota State University, Fargo North Dakota 58108-6050, USA
(2) Department of Physics, São Paulo State University (UNESP), Institute of Biosciences, Humanities and Exact Sciences, São José do Rio Preto, SP, Brazil


ABSTRACT: Amphipathic peptides that partition into lipid bilayers affect the curvature elastic properties of their host. Some of these peptides are able to shift the Gaussian modulus to positive values, thus triggering an instability with respect to the formation of saddle curvatures. To characterize the generic aspects of the underlying mechanism, we employ a molecular lipid model that accounts for the interfacial tension between the polar and apolar regions of the membrane, for interactions between the lipid headgroups, and for the energy to stretch or compress the hydrocarbon chains. Peptides are modeled as cylinders that partition into the host membrane in a parallel orientation where they diminish the space available to the lipid headgroups and chains. The penetration depth into the membrane is determined by the angular size of the peptide's hydrophilic region. We demonstrate that only peptides with a small angular size of their hydrophilic region have an intrinsic tendency to render the Gaussian modulus more positive, and we identify conditions at which the Gaussian modulus adopts a positive sign upon increasing the peptide concentration. Our model allows us to also incorporate electrostatic interactions between cationic peptides and anionic lipids on the level of the linear Debye–Hückel model. We show that electrostatic interactions tend to shift the Gaussian modulus toward more positive values. Steric and electrostatic lipid–peptide interactions jointly decrease the effective interaction strength in the headgroup region of the host membrane thus suggesting a generic mechanisms of how certain amphipathic peptides are able to induce the formation of saddle curvatures.


ABSTRACT: Surfaces of soft solids can have significant surface stress, extensional modulus and bending stiffness. Previous theoretical studies have usually examined cases in which both the surface stress and bending stiffness are constant, assuming small deformation. In this work we consider a general formulation in which the surface can support large deformation and carry both surface stresses and surface bending moments. We demonstrate that the large deformation theory can be reduced to the classical linear theory (Shuttleworth equation). We obtain exact solutions for problems of an inflated cylindrical shell and bending of a plate with a finite thickness. Our analysis illustrates the different manners in which surface stiffening and surface bending stabilize these structures. We discuss how the complex surface constitutive behaviors affect the stress field of the bulk. Our calculation provides insights into effects of strain-dependent surface stress and surface bending in the large deformation regime, and can be used as a model to implement surface finite elements to study large deformation of complex structures.


ABSTRACT: KOBRA (Kirchoff Biological Rod Algorithm) is an algorithm and software package designed to perform dynamical simulations of elongated biomolecules such as those containing alpha-helices and coiled-coils. It represents these as coarsely-discretised Kirchoff rods, with linear elements that can stretch, bend and twist independently. These rods can have anisotropic and inhomogeneous parameters and bent or twisted equilibrium structures, allowing for a coarse-grained parameterisation of complex biological structures. Each
element is non-inertial and subject to thermal fluctuations. The speed and simplicity of the algorithm allows KOBRA rods to easily access timescales from nanoseconds to seconds. To demonstrate this functionality, a KOBRA rod was parameterised using data from all-atom simulations of the Ndc80 protein complex, and compared against these simulations and negative-stain EM images. The distribution of bend angles and principal components were highly correlated between KOBRA, all-atom molecular dynamics, and experimental data. The properties of a hinge region, thought to be found at an unstructured loop, were studied. A C++


ABSTRACT: Lack of stiffness often limits thin shape-shifting structures to small scales. The large in-plane transformations required to distort the metrics are indeed commonly achieved by using soft hydrogels or elastomers. We introduce here a versatile single-step method to shape-program stiff inflated structures, opening the door for numerous large scale applications, ranging from space deployable structures to emergency shelters. This technique relies on channel patterns obtained by heat-sealing superimposed flat quasi-inextensible fabric sheets. Inflating channels induces an anisotropic in-plane contraction and thus a possible change of Gaussian curvature. Seam lines, which act as a director field for the in-plane deformation, encode the shape of the deployed structure. We present three patterning methods to quantitatively and analytically program shells with non-Euclidean metrics. In addition to shapes, we describe with scaling laws the mechanical properties of the inflated structures. Large deployed structures can resist their weight, substantially broadening the palette of applications.


ABSTRACT: The role of applied fields on the structure of liquid crystals confined to shell geometries has been studied in past theoretical work, providing strategies to produce liquid crystal shells with controlled defect structure or valence. However, the predictions of such studies have not been experimentally explored yet. In this work, we study the structural transformations undergone by tetravalent nematic liquid crystal shells under a strong uniform magnetic field, using both experiments and simulations. We consider two different cases in terms of shell geometry and initial defect symmetry: (i) homogeneous shells with four \( s = +1/2 \) defects in a tetrahedral arrangement, and (ii) inhomogeneous shells with four \( s = +1/2 \) defects localized in their thinner parts. Consistently with previous theoretical results, we observe that the initial defect structure evolves into a bipolar one, in a process where the defects migrate towards the poles. Interestingly, we find that the defect trajectories and dynamics are controlled by curvature walls that connect the defects by pairs. Based on the angle between \( \mathbf{B} \), the local projection of the magnetic field on the shell surface, and \( \mathbf{n} \), a vector describing the defect orientations, we are able to predict the nature and shape of those inversion walls, and therefore, the trajectory and dynamics of the defects. This rule, based on symmetry arguments, is consistent with both experiments and simulations and applies for shells that are either homogeneous or inhomogeneous in thickness. By modifying the angle between \( \mathbf{B} \) and \( \mathbf{n} \), we are able to induce, in controlled way, complex routes towards the final bipolar state. In the case of inhomogeneous shells, the specific symmetry of the shell allowed us to observe a hybrid splay-bend Helfrich wall for the first time.

Sami C. Al-Izzi (1,2,3,4), Pierre Sens (3,4), Matthew S. Turner(5,6) and Shigeyuki Komura (7)
(1) School of Physics & EMBL-Australia node in Single Molecule Science, University of New South Wales, Sydney, Australia
(2) Department of Mathematics, University of Warwick, Coventry CV4 7AL, UK
(3) Institut Curie, PSL Research University, CNRS, Physical Chemistry Curie, Paris, France
(4) Sorbonne Université, CNRS, UMR 168, Paris, France
(5) Department of Physics & Centre for Complexity Science, University of Warwick, Coventry CV4 7AL, UK
(6) Department of Chemical Engineering, University of Kyoto, Kyoto 615-8510, Japan
(7) Department of Chemistry, Graduate School of Science, Tokyo Metropolitan University, Tokyo 192-0397, Japan
ABSTRACT: Utilising Onsager's variational formulation, we derive dynamical equations for the relaxation of a fluid membrane tube in the limit of small deformation, allowing for a contrast of solvent viscosity across the membrane and variations in surface tension due to membrane incompressibility. We compute the relaxation rates, recovering known results in the case of purely axis-symmetric perturbations and making new predictions for higher order (azimuthal) \( m \)-modes. We analyse the long and short wavelength limits of these modes by making use of various asymptotic arguments. We incorporate stochastic terms to our dynamical equations suitable to describe both passive thermal forces and non-equilibrium active forces. We derive expressions for the fluctuation amplitudes, an effective temperature associated with active fluctuations, and the power spectral density for both the thermal and active fluctuations. We discuss an experimental assay that might enable measurement of these fluctuations to infer the properties of the active noise. Finally we discuss our results in the context of active membranes more generally and give an overview of some open questions in the field.

Olga V. Konevtsova (1), Daria S. Roshal (1), Rudolf Podgornik (2,3,4,5) and Sergei B. Rochal (1)
(1) Physics Faculty, Southern Federal University, Rostov-on-Don, Russia
(2) Department of Theoretical Physics, Jožef Stefan Institute, SI-1000 Ljubljana, Slovenia
(3) Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia
(4) School of Physical Sciences and Kavli Institute for Theoretical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China
(5) CAS Key Laboratory of Soft Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

ABSTRACT: Understanding the physicochemical processes occurring in viruses during their maturation is of fundamental importance since only mature viruses can infect host cells. Here we consider the irreversible and reversible morphological changes that occur with the dodecahedral \( \varphi 6 \) procapsid during the sequential packaging of 3 RNA segments forming the viral genome. It is shown that the dodecahedral shape of all the four observed capsid states is perfectly reproduced by a sphere radially deformed by only two irreducible spherical harmonics with icosahedral symmetry and wave numbers \( l = 6 \) and \( l = 10 \). The rotation of proteins around the 3-fold axes at the Procapsid \( \rightarrow \) Intermediate 1 irreversible transformation is in fact also well described with the shear field containing only two irreducible harmonics with the same two wave numbers. The high stability of the Intermediate 1 state is discussed and the shapes of the Intermediate 2 state and Capsid (reversibly transforming back to the Intermediate 1 state) are shown to be mainly due to the isotropic pressure that the encapsidated RNA segments exert on the shell walls. The hidden symmetry of the capsid and the physicochemical features of the \textit{in vitro} genome extraction from the viral shell are also elucidated.

ABSTRACT: Solvent evaporation in unpinned droplets of colloidal suspensions leads to the formation of porous shells which buckle under the pressure differential imposed by drying. We investigate the role of aspect ratio of rod-shaped particles in suppressing such buckling instabilities. Longer, thinner rods pack into permeable shells with consequently lower Darcy's pressure and thus avoid buckling.

ABSTRACT: We study the birth and propagation of a delamination front in the peeling of a soft, weakly adhesive layer. In a controlled-displacement setting, the layer partially detaches \textit{via} a subcritical instability and
the motion continues until arrested, by jamming of the two lobes. Using numerical solutions and scaling
analysis, we quantitatively describe the equilibrium shapes and obtain constitutive sensitivities of jamming
process to material and interface properties. We conclude with a way to delay or avoid jamming altogether by
tunable interface properties.

Theresa Elder, Timothy Twohig, Harmeet Singh and Andrew B. Croll, “Adhesion of a tape loop”, Soft Matter,
ABSTRACT: In this work, we revisit experimentally and theoretically the mechanics of a tape loop. Using
primarily elastic materials (polydimethylsiloxane, PDMS, or polycarbonate, PC) and confocal microscopy, we
monitor the shape as well as the applied forces during an entire cycle of compression and retraction of a half-
loop compressed between parallel glass plates. We observe distinct differences in film shape during the cycle;
points of equal applied force or equal plate separation differ in shape upon compression or retraction. To model
the adhesion cycle in its entirety, we adapt the ‘Sticky Elastica’ of [T. J. W. Wagner et al., Soft Matter, 2013, 9,
1025–1030] to the tape loop geometry, which allows a complete analytical description of both the force balance
and the film shape. We show that under compression the system is generally not sensitive to interfacial
interactions, whereas in the limit of large separation of the confining parallel plates during retraction the system
is well described by the peel model. Ultimately, we apply this understanding to the measurement of the energy
release rate of a wide range of different cross-linker ratio PDMS elastomer half-loops in contact with glass.
Finally, we show how the model illuminates an incredibly simple adhesion measurement technique, which only
requires a ruler to perform.

Rossana Rojas Molina, Susanne Liese, Haleh Alimohamadi, Padmini Rangamani and Andreas Carlson,
2020, https://doi.org/10.1039/D0SM01028F
ABSTRACT: A wide range of proteins are known to create shape transformations of biological membranes,
where the remodelling is a coupling between the energetic costs from deforming the membrane, the recruitment
of proteins that induce a local spontaneous curvature $C$ and the diffusion of proteins along the membrane. We
propose a minimal mathematical model that accounts for these processes to describe the diffuso-kinetic
dynamics of membrane budding processes. By deploying numerical simulations we map out the membrane
shapes, the time for vesicle formation and the vesicle size as a function of the dimensionless kinetic recruitment
parameter $K$ and the proteins sensitivity to mean curvature. We derive a time for scission that follows a power
law $\sim K^{-\alpha}$, a consequence of the interplay between the spreading of proteins by diffusion and the kinetic-limited
increase of the protein density on the membrane. We also find a scaling law for the vesicle size $\sim 1/[C]$, with $[C]$ the average protein density in the vesicle, which is confirmed in the numerical simulations.
Rescaling all the membrane profiles at the time of vesicle formation highlights that the membrane adopts a self-
similar shape.

Daniel Duffy and John S. Biggins, “Defective nematogenesis: Gauss curvature in programmable shape-
responsive sheets with topological defects”, Soft Matter, Vol. 16, No. 48, pp 10935-10945, 28 December 2020,
https://doi.org/10.1039/D0SM01192D
ABSTRACT: Flat sheets encoded with patterns of contraction/elongation morph into curved surfaces. If the
surfaces bear Gauss curvature, the resulting actuation can be strong and powerful. We deploy the Gauss–Bonnet
theorem to deduce the Gauss curvature encoded in a pattern of uniform-magnitude contraction/elongation with
spatially varying direction, as is commonly implemented in patterned liquid crystal elastomers. This approach
reveals two fundamentally distinct contributions: a structural curvature which depends on the precise form of
the pattern, and a topological curvature generated by defects in the contractile direction. These curvatures grow
as different functions of the contraction/elongation magnitude, explaining the apparent contradiction between
previous calculations for simple +1 defects, and smooth defect-free patterns. We verify these structural and
topological contributions by conducting numerical shell calculations on sheets encoded with simple higher-
order contractile defects to reveal their activated morphology. Finally we calculate the Gauss curvature
generated by patterns with spatially varying magnitude and direction, which leads to additional magnitude
gradient contributions to the structural term. We anticipate this form will be useful whenever magnitude and
direction are natural variables, including in describing the contraction of a muscle along its patterned fiber direction, or a tissue growing by elongating its cells.

Soft Matter, Vol. 16, No. 48, pp 10935-10945, 28 December 2020,

**More papers published in the journal, Earthquake Engineering & Structural Dynamics** (2014 and on)

Google the string, “Earthquake Engineering & Structural Dynamics”, then click on “Earthquake Engineering & Structural Dynamics – Wiley”, click on “Browse” (dark strip at top), go to “All Issues” and choose year/volume.


**SUMMARY:** Buckling plays a fundamental role in the design of steel tanks because of the small thicknesses of the walls of this class of structures. The first part of the paper presents a review of this phenomenon for liquid-containing circular cylindrical steel tanks that are fully anchored at the base, considering the different buckling modes and especially the secondary buckling occurring in the top part of the tank. A case study based on a cylindrical tank is then introduced in order to investigate various aspects of dynamic buckling. The finite element model of the case study tank is set-up using the added mass method for fluid modelling. The influence of pre-stress states caused by hydrostatic pressure and self-weight on the natural periods of the structure is first studied and it is found that this influence is very small as far as the global behaviour of the tanks is considered, while it is important for local, shell-type, vibration modes. In the following, the efficiency and sufficiency of different ground motion intensity measures is analysed by means of cloud analysis with a set of 40 recorded accelerograms. In particular, the peak ground displacement has been found being the most efficient and sufficient intensity measure so far as the maximum relative displacement of the tank walls is concerned. Finally, incremental nonlinear time-history analyses are performed considering the case study structure under recorded earthquake ground motions in order to identify the critical buckling loads and to derive fragility curves for the buckling limit state.


**SUMMARY:** Cyclic loading tests and finite element analyses on six novel all-steel buckling-restrained braces (BRBs) are conducted using different loading patterns to investigate the core plate high-mode buckling phenomenon. The proposed BRB is composed of a core member and a pair of identical restraining members, which restrains the core member by using bolted shim spacers. The design of the proposed BRB allows the core plate to be visually inspected immediately following a major earthquake. If necessary, the pair of restraining members can be conveniently disassembled, and the damaged core plate can be replaced. Test results indicate that the proposed BRBs can sustain large cyclic strain reversals and cumulative plastic deformations in excess of 400 times the yield strain. Experimental and analytical results confirm that the high-mode buckling wavelength is related to the core plate thickness and the applied loading patterns. The larger the axial compressive strain is applied, the shorter the high-mode buckling wavelength would be developed. The buckling wavelength is about 12 times the core plate thickness when the high-mode buckling shape is fully developed. However, it reduces to about 10 times the core plate thickness when a compressive core strain reaches greater than 0.03. The high-mode buckling wavelength can be satisfactorily predicted using the proposed method or from the finite element analysis.

Xiaodong Ji, Hongzhen Kang, Xingchen Chen and Jiaru Qian, “Seismic behavior and strength capacity of steel tube-reinforced concrete composite columns”, Earthquake Engineering & Structural Dynamics, Vol. 43, No. 4, pp 487-505, 10 April 2014, [https://doi.org/10.1002/eqe.2354](https://doi.org/10.1002/eqe.2354)
SUMMARY: The steel tube–reinforced concrete (ST–RC) composite column is a novel type of composite column, which consists of a steel tube embedded in RC. In this paper, the seismic behavior of ST–RC columns is examined through a series of experiments in which 10 one-third scale column specimens were subjected to axial forces and lateral cyclic loading. The test variables include the axial force ratio applied to the columns and the amount of transverse reinforcement. All specimens failed in a flexural mode, showing stable hysteresis loops. Thanks to the steel tube and the high-strength concrete it is filled with, the ST–RC column specimens had approximately 30% lower axial force ratios and 22% higher maximum bending moments relative to the comparable RC columns when subjected to identical axial compressive loads. The amount of transverse reinforcement made only a small difference to the lateral load-carrying capacity but significantly affected the deformation and energy dissipation capacity of the ST–RC columns. The specimens that satisfied the requirements for transverse reinforcement adopted for medium ductile RC columns as specified by the Chinese Code for Seismic Design of Buildings (GB 50011–2010) and EuroCode 8 achieved an ultimate drift ratio of around 0.03 and a displacement ductility ratio of approximately 5. The design formulas used to evaluate the strength capacity of the ST–RC columns were developed on the basis of the superposition method. The predictions from the formulas showed good agreement with the test results, with errors no greater than 10%.

SUMMARY: The corner gusset plates in a steel braced frame can be subjected to forces not only from the brace but also from the effects of the frame actions. In this study, several finite element models are constructed to analyze the gusset-to-beam and gusset-to-column interface forces. It is found that the frame actions affect the gusset interface force distributions significantly. A simplified strut model to represent the gusset plate is adopted to evaluate the frame action forces. In addition, the generalized uniform force method is adopted as it provides more freedom for designers to configure the gusset plate shapes than using the uniform force method.

In this paper, a performance-based design method is proposed. The gusset interface force demands take into account the combined effect of the brace maximum axial force capacity and the peak beam shear possibly developed in the frame. The specimen design and key results of a series of full-scale three-story buckling-restrained braced frame (BRBF) hybrid tests are discussed. The gusset interface cracks observed at inter-story drift greater than 0.03 radians can be well predicted by using the proposed design method. The BRBF tests and analyses confirm that the proposed design method is reasonable. The effectiveness of varying the width of gusset edge stiffeners in reducing the gusset tip stress concentrations is also investigated. This paper concludes with recommendations for the seismic design of BRBF corner gusset plates.

SUMMARY: Buckling-restrained braces (BRBs) are widely used as ductile seismic-resistant and energy-dissipating structural members in seismic regions. Although BRBs are expected to exhibit stable hysteresis under cyclic axial loading, one of the key limit states is global flexural buckling, which can produce an undesirable response. Many prior studies have indicated the possibility of global buckling of a BRB before its core yields owing to connection failure. In this paper, BRB stability concepts are presented, including their bending-moment transfer capacity at restrainer ends for various connection stiffness values with initial out-of-plane drifts, and a unified simple equation set for ensuring BRB stability is proposed. Moreover, a series of cyclic loading tests with initial out-of-plane drifts are conducted, and the results are compared with those of the proposed equations.
SUMMARY: The insertion of fluid viscous dampers in building structures is an innovative technology that can improve significantly the seismic response. These devices could be very useful also in the retrofit of existing buildings. The effect of this typology of damping system is usually identified with an equivalent supplemental damping ratio, which depends on the maximum displacement of the structure, so that iterative procedures are required. In this paper, a simplified direct assessment method for nonlinear structures equipped with nonlinear fluid viscous dampers is proposed. The method proposed in this study is composed by two steps. The first one yields the direct estimate of the supplemental damping ratio provided by nonlinear viscous dampers in presence of a linear elastic structural response. The second step extends the procedure to structures with nonlinear behavior. Both graphical and analytical approaches have been developed. The proposed method has then been verified through several applications and comparisons with nonlinear dynamic analyses. Moreover, an investigation has been performed with regard to the influence of the relations that define the damping reduction factor and the hysteretic damping.

SUMMARY: Recent research developed and experimentally validated a self‐centering buckling‐restrained brace (SC‐BRB) that employs a restoring mechanism created using concentric tubes held flush with pretensioned shape memory alloy rods, in conjunction with a buckling‐restrained brace (BRB) that dissipates seismic energy. The present computational study investigated how the SC‐BRB can be implemented in real buildings to improve seismic performance. First, a computational brace model was developed and calibrated against experimental data, including the definition of a new cyclic material model for superelastic NiTi shape memory alloy. A parametric study were then conducted to explore the design space for SC‐BRBs. Finally, a set of prototype buildings was designed and computationally subjected to a suite of ground motions. The effect of the lateral resistance of gravity framing on self‐centering was also examined. From the component study, the SC‐BRB was found to dissipate sufficient energy even with large self‐centering ratios (as large as 4) based on criteria found in the literature for limiting peak drifts. From the prototype building study, a SC‐BRB self‐centering ratio of 0.5 was capable of reliably limiting residual drifts to negligible values, which is consistent with a dynamic form of self‐centering discussed in the literature. Because large self‐centering ratios can create significant overstrength, the most efficient SC‐BRB frame designs had a self‐centering ratio in the range of 0.5–1.5. Ambient building resistance (e.g., gravity framing) was found to reduce peak drifts, but had a negligible effect on residual drifts.

SUMMARY: The seismic behavior of plane moment‐resisting frames (MRFs) consisting of I steel beams and concrete‐filled steel tube (CFT) columns is investigated in this study. More specifically, the effect of modeling details of each individual component of CFT‐MRFs, such as the composite CFT columns, the beam‐column connections, the panel zones, and the steel I beams on their seismic behavior, is studied through comparisons against available experimental results. Then, fragility curves are constructed for three typical CFT‐MRFs, designed according to European codes, for various levels of modeling sophistication through nonlinear time‐history analyses. On the basis of these fragility curves, one can select the appropriate modeling level of sophistication that can lead to the desired seismic behavior for a given seismic intensity.

SUMMARY: This paper describes an investigation of pipe–soil interaction equations suggested by currently used pipeline seismic design codes and the applicability of these equations to segmented pipelines. The results of computer-aided analyses were compared to results obtained in full-scale experiments on a segmented ductile iron pipeline 93 mm in diameter and 15 m in length. The pipeline was installed 600 mm below the ground surface in a sandy soil compacted to two different subgrade reaction values. The type of fault considered was a reverse fault with an intersection angle of 60° with the pipeline, and the fault movement was a total of 350 mm in three same steps in the fault trace direction. The findings of this study demonstrate the necessity of considering the nature of soil behavior in pipe–soil interaction equations and the effects of connection joints on the integrated response of pipelines to fault-induced ground deformations. A new combination of equations constituting a direction-wise selection from among the equations proposed by currently used guidelines is introduced as a new series to describe pipe–soil interaction for segmented pipelines and is verified using the results of full-scale experiments.


SUMMARY: A welded end-slot buckling-restrained brace (WES-BRB) has been developed at the Taiwan National Center for Research on Earthquake Engineering (NCREE). A steel frame equipped with a WES-BRB can offer a cost-effective solution to meet interstory drift and earthquake-resistant design requirements for seismic steel buildings. According to the WES-BRB and connection design procedure proposed by NCREE, there are seven key elements of a buckling-restrained braced frame (BRBF) design that require design checking. In order to assist an engineer with the design of the WES-BRB members and connections, an innovative cloud service named Brace on Demand has been constructed at NCREE. In this study, using 581 BRBF design examples, the effectiveness of the proposed design procedures to meet all design checks is demonstrated. It is found that the most critical limit states for an initial design are joint region buckling, gusset plate buckling, and gusset-to-beam and gusset-to-column interface strength. Accordingly, the causes of improper designs and associated strategies for improving the initial designs are discussed in this paper. Recommendations on initial selections including the BRB joint size and gusset plate thickness are given. The paper provides the detailed road map for engineers to develop the spreadsheet for BRB and connection designs.


SUMMARY: Previous theoretical studies have shown that tank uplift, that is, separation of the tank base from the foundation, generally reduces the base shear and the base moment. However, there is a paucity of experimental investigations concerning the effect of uplift on the tank wall stresses, which is the principal parameter that controls the seismic design of liquid-storage tanks. This paper reports a series of shake table experiments on a polyvinyl chloride model tank containing water. A comparison of the seismic behaviour of the tank with and without anchorage is described. Stochastically generated ground motions, based on a Japanese design spectrum, and three tank aspect ratios (liquid-height/radius) are considered. Measurements were made of the stresses at the outer shell of the tank, the tank wall acceleration and the horizontal displacement at the top of the tank. While the top displacement and the tank shell acceleration increased when uplift was allowed, axial compressive stresses decreased by between 35% and 64% with tank uplift. The effect of uplift on the hoop stresses was variable depending on the aspect ratio. A comparison of experimental values with a numerical model is provided.

SUMMARY: The dynamic response of a wind turbine on a monopile is studied under horizontal and vertical earthquake excitations. The analyses are carried out using the finite element program SAP2000. The finite element model of the structure is verified against the results of shake table tests, and the earthquake response of the soil model is verified against analytical solutions of the steady-state response of homogeneous strata. The focus of the analyses in this paper is the vertical earthquake response of wind turbines including the soil-structure interaction effects. The analyses are carried out for both a non-homogeneous stratum and a deep soil using the three-step method. In addition, a procedure is implemented which allows one to perform coupled soil-structure interaction analyses by properly tuning the damping in the tower structure. The analyses show amplification of the ground surface acceleration to the top of the tower by a factor of two. These accelerations are capable of causing damage in the turbine and the tower structure, or malfunctioning of the turbine after the earthquake; therefore, vertical earthquake excitation is considered a potential critical loading in design of wind turbines even in low-to-moderate seismic areas.


SUMMARY: According to Eurocode 8, the seismic design of flat-bottom circular silos containing grain-like material is based on a rough estimate of the inertial force imposed on the structure by the ensiled content during an earthquake: 80% of the mass of the content multiplied by the peak ground acceleration. A recent analytical consideration of the horizontal shear force mobilised within the ensiled material during an earthquake proposed by some of the authors has resulted in a radically reduced estimate of this load suggesting that, in practice, the effective mass of the content is significantly less than that specified. This paper describes a series of laboratory tests that featured shaking table and a silo model, which were conducted in order to obtain some experimental data to verify the proposed theoretical formulations and to compare with the established code provisions. Several tests have been performed with different heights of ensiled material – about 0.5 mm diameter Ballotini glass – and different magnitudes of grain-wall friction. The results indicate that in all cases, the effective mass is indeed lower than the Eurocode specification, suggesting that the specification is overly conservative, and that the wall–grain friction coefficient strongly affects the overturning moment at the silo base. At peak ground accelerations up to around 0.35g the proposed analytical formulation provides an improved estimate of the inertial force imposed on such structures by their contents.


SUMMARY: A thin-profile buckling-restrained brace (thin-BRB) consists of a rectangular steel casing and a flat steel core that is parallel to a gusset plate. A thin configuration reduces the width of the restraining member and thus saves usable space in buildings. However, deformable debonding layers, which cover the steel core plate in order to mitigate the difference between the peak tensile and compressive axial forces, provide a space for the steel core to form high mode buckling waves when the thin-BRB is under compression. The wave crests squeeze the debonding layers and produce outward forces on the inner surface of the restraining member. If the restraining member is too weak in sustaining the outward forces, local bulging failure occurs and the thin-BRB loses its compression capacity immediately. In order to investigate local bulging behavior, a total of 22 thin-BRB specimens with a ratio of steel core plate to restraining steel tube depth ranging from 0.3 to 0.7 and axial yield force capacities ranging from 421kN to 3036kN were tested by applying either cyclically increasing, decreasing, or constant axial strains. The restraining steel tube widths of all the specimens were smaller than 200mm and were infilled with mortar with a compressive strength of 97MPa or 55MPa. Thirteen of the 22 thin-BRB specimens' restraining members bulged out when the compressive core strains exceeded 0.03. A seismic design method of the thin-BRB in preventing local bulging failure is proposed in this study. Test and finite element model (FEM) analysis results suggest that the outward forces can be estimated according to the BRB...
compressive strength, steel core high mode buckling wavelength, and the debonding layer thickness. In addition, the capacity of the restraining member in resisting the outward forces can be estimated by using the upper bound theory in plastic analysis. Both the FEM analysis and test results indicate that the proposed method is effective in predicting the possibility of local bulging failure. Test results indicate that the proposed design method is conservative for thin-BRB specimens with a large steel core plate to restraining steel tube depth ratio. This paper concludes with design recommendations for thin-BRBs for severe seismic services.

SUMMARY: A refined substructure technique in the frequency domain is developed, which permits consideration of the interaction effects among adjacent containers through the supporting deformable soil medium. The tank-liquid systems are represented by means of mechanical models, whereas discrete springs and dashpots stand for the soil beneath the foundations. The proposed model is employed to assess the responses of adjacent circular, cylindrical tanks for harmonic and seismic excitations over wide range of tank proportions and soil conditions. The influence of the number, spatial arrangement of the containers and their distance on the overall system's behavior is addressed. The results indicate that the cross-interaction effects can substantially alter the impulsive components of response of each individual element in a tank farm. The degree of this impact is primarily controlled by the tank proportions and the proximity of the predominant natural frequencies of the shell-liquid-soil systems and the input seismic motion. The group effects should be not a priori disregarded, unless the tanks are founded on shallow soil deposit overlying very stiff material or bedrock.

SUMMARY: One of the key limit states of buckling-restrained braces (BRBs) is global flexural buckling including the effects of the connections. The authors have previously proposed a unified explicit equation set for controlling the out-of-plane stability of BRBs based on bending-moment transfer capacity at the restrainer ends. The proposed equation set is capable of estimating BRB stability for various connection stiffnesses, including initial out-of-plane drift effects. However, it is only valid for symmetrical end conditions, limiting application to the single diagonal configuration. In the chevron configuration, the out-of-plane stiffness in the two ends differs because of the rotation of the attached beam. In this study, the equation set is extended to BRBs with asymmetric end conditions, such as the chevron configuration. Cyclic loading tests of the chevron configuration with initial out-of-plane drifts are conducted, and the results are compared with the proposed equation set, which is formulated as a function of the normalized stiffness of the attached beam.

References listed at the end of the paper:

SUMMARY: The global growth in wind energy suggests that wind farms will increasingly be deployed in seismically active regions, with large arrays of similarly designed structures potentially at risk of simultaneous failure under a major earthquake. Wind turbine support towers are often constructed as thin-walled metal shell structures, well known for their imperfection sensitivity, and are susceptible to sudden buckling failure under compressive axial loading. This study presents a comprehensive analysis of the seismic response of a 1.5-MW wind turbine steel support tower modelled as a near-cylindrical shell structure with realistic axisymmetric weld depression imperfections. A selection of 20 representative earthquake ground motion records, 10 ‘near-fault’ and 10 ‘far-field’, was applied and the aggregate seismic response explored using lateral drifts and total plastic energy dissipation during the earthquake as structural demand parameters. The tower was found to exhibit high stiffness, although global collapse may occur soon after the elastic limit is exceeded through the development of a highly unstable plastic hinge under seismic excitations. Realistic imperfections were found to have a significant effect on the intensities of ground accelerations at which damage initiates and on the failure location, but only a small effect on the vibration properties and the response prior to damage. Including vertical accelerations similarly had a limited effect on the elastic response, but potentially shifts the location of the plastic hinge to a more slender and, therefore, weaker part of the tower. The aggregate response was found to be


15 Architectural Institute of Japan: Recommendations for stability design of steel structures, Sec. 3.5 Buckling-restrained braces, 2011, 74–79.


SUMMARY: Permanent fault displacements (PFDs) because of fault ruptures emerging at the surface are critical for seismic design and risk assessment of continuous pipelines. They impose significant compressive and tensile strains to the pipe cross-section at pipe-fault crossings. The complexity of fault rupture, inaccurate mapping of fault location and uncertainties in fault-pipe crossing geometries require probabilistic approaches for assessing the PFD hazard and mitigating pipeline failure risk against PFD. However, the probabilistic approaches are currently waived in seismic design of pipelines. Bearing on these facts, this paper first assesses the probabilistic PFD hazard by using Monte Carlo-based stochastic simulations whose theory and implementation are given in detail. The computed hazard is then used in the probabilistic risk assessment approach to calculate the failure probability of continuous pipelines under different PFD levels as well as pipe cross-section properties. Our probabilistic pipeline risk computations consider uncertainties arising from complex fault rupture and geomorphology that result in inaccurate mapping of fault location and fault-pipe crossings. The results presented in this paper suggest the re-evaluation of design provisions in current pipeline design guidelines to reduce the seismic risk of these geographically distributed structural systems.


SUMMARY: The cured-in-place-pipe (CIPP) liner technology involves installation of flexible polymeric composite liners coated with thermosetting resin to the inner surfaces of existing buried pipelines. This innovative technology provides an efficient, economic, and environmentally friendly alternative for rehabilitation of structurally compromised underground pipelines without expensive and disruptive excavation. However, the lack of analytical/numerical procedures to quantify the seismic performance of CIPP liner reinforced pipelines remains a barrier to the seismic design and rehabilitation of underground pipelines. This paper first develops an experimentally validated hysteretic model of ductile iron push-on joints, reinforced with one particular type of CIPP liner under repeated axial loading. A numerical procedure is then proposed to systematically assess the seismic performance and fragility of straight buried pipelines incorporating push-on joints and subjected to transient ground deformations. The numerical results indicate that CIPP liner-reinforced pipelines exhibit favorable robust seismic performance with limited joint damage under high-intensity transient ground deformations.


SUMMARY: Conventional damage prediction methods for lifeline structures are primarily based on peak ground motion measurements. However, line structures such as lifelines suffer damage that is mainly induced by the strain of the ground and therefore are likely to be vulnerable to sharp spatial changes in the ground motion. In this study, we propose a measure for evaluating the damage incurred by underground water supply pipelines based on the spatial gradient of the peak ground velocity (PGV), in an attempt to quantify the effects of the geospatial variabilities in the ground motion on pipeline damage. We investigated the spatial distribution of the damage caused to water pipelines during the Niigata-ken Chuetsu earthquake on October 10, 2004 (Japan Meteorological Agency magnitude (Mw) of 6.8) and the Kobe earthquake on January 17, 1995 (Mw 7.3) and compared the surveyed damage with the PGV distribution as well as with the gradients of the PGV calculated around the damage areas. For the Kobe earthquake, we used the PGV distribution obtained by the strong-motion simulation performed by Matsushima and Kawase. In case of the Chuetsu earthquake, we estimated the ground motion using a broadband-frequency-based strong-ground-motion simulation method based on a multiasperity source model. In both cases, we calculated the gradients of the PGV along the geographical

SUMMARY: This paper proposes a dynamic centrifuge model test method for the accurate simulation of the behaviours of a liquid storage tank with different types of foundations during earthquakes. The method can be used to determine the actual stress conditions of a prototype storage-tank structure. It was used in the present study to investigate the soil-foundation-structure interactions of a simplified storage tank under two different earthquake motions, which were simulated using a shaking table installed in a centrifuge basket. Three different types of foundations were considered, namely, a shallow foundation, a slab on the surface of the ground connected to piles and a slab with disconnected piles. The test results were organised to compare the ground surface and foundation motions, the slab of foundation and top of structure motions and the horizontal and vertical motions of the slab, respectively. These were used to establish the complex dynamic behaviours of tank models with different foundations. The effects of soil–foundation–structure interaction with three foundation conditions and two different earthquake motions are focused and some important factors, that should be considered for future designs are also discussed in this research.


SUMMARY: A performance-based earthquake engineering approach is developed for the seismic risk assessment of fixed-roof atmospheric steel liquid storage tanks. The proposed method is based on a surrogate single-mass model that consists of elastic beam-column elements and nonlinear springs. Appropriate component and system-level damage states are defined, following the identification of commonly observed modes of failure that may occur during an earthquake. Incremental dynamic analysis and simplified cloud are offered as potential approaches to derive the distribution of response parameters given the seismic intensity. A parametric investigation that engages the aforementioned analysis methods is conducted on 3 tanks of varying geometry, considering both anchored and unanchored support conditions. Special attention is paid to the elephant's foot buckling formation, by offering extensive information on its capacity and demand representation within the seismic risk assessment process. Seismic fragility curves are initially extracted for the component-level damage states, to compare the effect of each analysis approach on the estimated performance. The subsequent generation of system-level fragility curves reveals the issue of nonsequential damage states, whereby significant damage may abruptly appear without precursory lighter damage states.


ABSTRACT: Axially loaded members might experience compressive forces above their static buckling capacity because of dynamic buckling under rapid shortening. Although the subject is studied in the context of engineering mechanics, it has not been thoroughly investigated in the field of earthquake engineering. Such dynamic overshoots in the compressive capacity can also be observed for braces of concentrically braced frames (CBFs) during earthquakes. Consequently, a comprehensive investigation is conducted in this study regarding the effects of dynamic buckling of braces on the seismic behavior of steel CBFs. After providing a theoretical background, recent dynamic experiments on braces and CBFs are simulated and discussed to investigate the occurrence of dynamic overshoot during these tests. Eight archetype CBFs are then designed, modeled, and subjected to a large set of ground motions to provide a quantified insight on the frequency and anticipated level of dynamic overshoot in the compressive capacity of braces during earthquakes. Results of a total of 1600 nonlinear time history analyses revealed that dynamic overshoots occur frequently in braces and
affect the behavior of CBFs notably. Considerable increases are recorded in forces transmitted to other members of CBFs as a consequence of such dynamic overshoots. Importance of incorporating these dynamic overshoots in the capacity design procedure of columns, beams, and gusset plates is highlighted. Furthermore, results of a parametric study are presented and summarized in the form of a simple formula that can be used as a guide for estimating the level of dynamic overshoot.

SUMMARY: Buried pipelines are often constructed in seismic and other geohazard areas, where severe ground deformations may induce severe strains in the pipeline. Calculation of those strains is essential for assessing pipeline integrity, and therefore, the development of efficient models accounting for soil-pipe interaction is required. The present paper is aiming at developing efficient tools for calculating ground-induced deformation on buried pipelines, often triggered by earthquake action, in the form of fault rupture, liquefaction-induced lateral spreading, soil subsidence, or landslide. Soil-pipe interaction is investigated by using advanced numerical tools, which employ solid elements for the soil, shell elements for the pipe, and account for soil-pipe interaction, supported by large-scale experiments. Soil-pipe interaction in axial and transverse directions is evaluated first, using results from special-purpose experiments and finite element simulations. The comparison between experimental and numerical results offers valuable information on key material parameters, necessary for accurate simulation of soil-pipe interaction. Furthermore, reference is made to relevant provisions of design recommendations. Using the finite element models, calibrated from these experiments, pipeline performance at seismic-fault crossings is analyzed, emphasizing on soil-pipe interaction effects in the axial direction. The second part refers to full-scale experiments, performed on a unique testing device. These experiments are modeled with the finite element tools to verify their efficiency in simulating soil-pipe response under landslide or strike-slip fault movement. The large-scale experimental results compare very well with the numerical predictions, verifying the capability of the finite element models for accurate prediction of pipeline response under permanent earthquake-induced ground deformations.

SUMMARY: A series of scalar and vector intensity measures is examined to determine their suitability within the seismic risk assessment of liquid storage tanks. Using a surrogate modelling approach on a squat tank that is examined under both anchored and unanchored support conditions, incremental dynamic analysis is adopted to generate the distributions of response parameters conditioned on each of the candidate intensity measures. Efficiency and sufficiency metrics are used in order to perform the intensity measure evaluation for individual failure modes, while a comparison in terms of mean annual frequency of exceedance is performed with respect to a damage state that is mutually governed by the impulsive and convective modes of the tank. The results reveal combinations of spectral acceleration ordinates as adequate predictors, among which the average spectral acceleration is singled out as the optimal solution. The sole exception is found for the sloshing-controlled modes of failure, where mainly the convective period spectral acceleration is deemed adequate to represent the associated response due to their underlying linear relationship. A computationally efficient method in terms of site hazard analysis is finally proposed to serve in place of the vector-valued intensity measures, providing a good match for the unanchored tank considered and a more conservative one for the corresponding anchored system.

SUMMARY: This paper introduces a novel seismic isolation system based on metamaterial concepts for the reduction of ground motion-induced vibrations in fuel storage tanks. In recent years, the advance of seismic metamaterials has led to various new concepts for the attenuation of seismic waves. Of particular interest for the present work is the concept of locally resonant materials, which are able to attenuate seismic waves at
wavelengths much greater than the dimensions of their unit cells. Based on this concept, we propose a finite locally resonant Metafoundation, the so-called Metafoundation, which is able to shield fuel storage tanks from earthquakes. To crystallize the ideas, the Metafoundation is designed according to the Italian standards with conservatism and optimized under the consideration of its interaction with both superstructure and ground. To accomplish this, we developed two optimization procedures that are able to compute the response of the coupled foundation-tank system subjected to site-specific ground motion spectra. They are carried out in the frequency domain, and both the optimal damping and the frequency parameters of the Metafoundation-embedded resonators are evaluated. As case studies for the superstructure, we consider one slender and one broad tank characterized by different geometries and eigenproperties. Furthermore, the expected site-specific ground motion is taken into account with filtered Gaussian white noise processes modeled with a modified Kanai-Tajimi filter. Both the effectiveness of the optimization procedures and the resulting systems are evaluated through time history analyses with two sets of natural accelerograms corresponding to operating basis and safe shutdown earthquakes, respectively.


ABSTRACT: The coupled steel plate shear wall (C-SPSW) configuration has been investigated by researchers as a means of improving the overturning stiffness and architectural flexibility of SPSW structures. While C-SPSWs have been shown to exhibit excellent seismic performance, the fabrication cost associated with the high number of moment-resisting connections used in such systems is a potential detraction to their use as an economical solution. Past research has shown that the hysteresis response of SPSWs with simple frame connections is significantly pinched, and as such, most seismic codes prohibit their use in high seismic areas. However, when used in the C-SPSW configuration, a dual system is formed in which the coupling beams not only improve resistance to overturning but also provide substantial lateral strength and energy dissipation capacity. This paper presents an exploration of the potential to improve the economy of C-SPSWs by using the simple boundary frame connections. First, employing the principles of plastic analysis, an attempt is made to quantify the contribution of the coupling beams to the overall lateral load resistance of the system. Then, to evaluate the seismic performance of such C-SPSW systems and allow for the comparison with that of the C-SPSWs with rigid frames, several prototypes are designed and analyzed using a series of nonlinear response history and pushover analyses. The results indicated that the C-SPSWs with simple boundary frames exhibited satisfactory seismic performance comparable with that of the C-SPSWs with rigid frames under both the 10/50 and 2/50 hazard levels, while allowing for reduced fabrication costs.


ABSTRACT: The bidirectional response of a portion of a reinforced concrete (RC) waffle-flat plate (WFP) structure subjected to far-field ground motions is studied through shake table tests. The test specimen is a scaled portion of a prototype structure designed under current building codes and located in a region of moderate seismicity of the Mediterranean area. The specimen was subjected to a sequence of tests of increasing acceleration amplitude that respectively represented very frequent, frequent, design, and very rare earthquakes at the site. The test structure performed well (basically in the elastic domain) under very frequent and frequent earthquakes, approached the boundary between the performance levels of life safety and near collapse under the design earthquake, and collapsed under the very rare earthquake. Damage concentrated at column bases and at the transverse beams of the exterior plate-to-column connection. Columns dissipated about 10% of the total energy that contributes to damage, and the rest was dissipated by the exterior plate-column connection. The total energy input on the structure until collapse under the bidirectional seismic action was very close to the value obtained in previous studies on a similar specimen tested under unidirectional ground motions. The capacity curve estimated from the experimental base shear vs top displacement relationship suggests it is best to use a behavior factor of at most q = 2 when designing WFP structures with the reduced-spectrum force-based approach.

SUMMARY: The characterization of the dynamic behavior of an arch dam, and its evolution throughout the structure's lifetime, provides important data for the safety control process. Forced vibration tests remain a reliable technique for this purpose. The Baixo Sabor dam is a 123 m high arch dam recently built in Portugal. Forced vibration tests were performed before and after the reservoir filling. Two techniques for forced vibration test are compared, discrete frequency scanning, the standard methodology, and continuous frequency scanning (sine sweep), a new proposed methodology, which allowed faster results without loss of precision. For the interpretation of test results two numerical models of the dam-reservoir-foundation system were built, and calibrated with the experimental data. A good match of numerical and experimental results was obtained for the six lowest frequencies and corresponding mode shapes.


ABSTRACT: An efficient component model has been developed that captures strength and stiffness deterioration of steel hollow structural section (HSS) columns. The proposed model consists of two fiber-based segments at a member's ends along with an elastic segment in between. The fibers exhibit nonlinear uniaxial stress–strain behavior, which is explicitly defined by uniaxial monotonic tensile and cyclic round coupon tests. The postbuckling behavior of an HSS column is traced through a proposed uniaxial effective stress–strain constitutive formulation, which includes a softening branch in compression and an energy-based deterioration rule to trace the influence of cyclic deterioration in the inelastic cyclic straining. These may be inferred by uniaxial stub-column tests. The component model captures the coupling between the column axial force and flexural demands. Consistent model parameters for a number of steel materials used in the steel construction in North America and Japan are proposed along with the associated model calibration process. The efficiency of the proposed model in predicting the hysteretic behavior of HSS columns is demonstrated by comparisons with physical steel column tests subjected to various loading histories, including representative ones of ratcheting prior to earthquake-induced collapse. The proposed model is implemented in an open-source finite element software for nonlinear response history analysis of frame structures. The effectiveness of the proposed model in simulating dynamic instability of steel frame buildings is demonstrated through nonlinear response simulations of a four-story steel frame building, which was tested at full-scale through collapse. Limitations as well as suggestions for future work are discussed.

Earthquake Engineering & Structural Dynamics, Vol. 50, No. 1. pp 1702-1720, January 2021, (no papers)

More papers published in the journal, Shock and Vibration (2014 and on)
Google the string, “Shock and Vibration”, then click on “Shock and Vibration – An Open Access Journal – Hindawi”, click on “Table of Contents” (green strip near top), click on Table of Contents for Year 201x and scan titles. (Better: click on “Search”, then type the journal name (Shock and Vibration) and Volume (20xx))


ABSTRACT: The paper proposes a three-dimensional elastic analysis of the free vibration problem of one-layered spherical, cylindrical, and flat panels. The exact solution is developed for the differential equations of equilibrium written in orthogonal curvilinear coordinates for the free vibrations of simply supported structures. These equations consider an exact geometry for shells without simplifications. The main novelty is the possibility of a general formulation for different geometries. The equations written in general orthogonal
curvilinear coordinates allow the analysis of spherical shell panels and they automatically degenerate into cylindrical shell panel, cylindrical closed shell, and plate cases. Results are proposed for isotropic and orthotropic structures. An exhaustive overview is given of the vibration modes for a number of thickness ratios, imposed wave numbers, geometries, embedded materials, and angles of orthotropy. These results can also be used as reference solutions to validate two-dimensional models for plates and shells in both analytical and numerical form (e.g., closed solutions, finite element method, differential quadrature method, and global collocation method).

References listed at the end of the paper:

46 E. Carrera, S. Brischetto, and P. Nali, Plates and Shells for Smart Structures: Classical and Advanced Theories for Modeling and Analysis, John Wiley & Sons, New Delhi, India, 2011.


ABSTRACT: This study presents a technique that uses a model reduction method for the dynamic response analysis of a beam structure to a moving load, which can be modeled either as a moving point force or as a moving body. The nature of the dedicated condensation method tailored to address the moving load case is that the master degrees of freedom are reselected, and the coefficient matrices of the condensed model are recalculated as the load travels from one element to another. Although this process increases computational burden, the overall computational time is still greatly reduced because of the small scale of motion equations. To illustrate and validate the methodology, the technique is initially applied to a simply supported beam subjected to a single-point load moving along the beam. Subsequently, the technique is applied to a practical model for wheel-rail interaction dynamic analysis in railway engineering. Numerical examples show that the
condensation model can solve the moving load problem faster than an analytical model or its full finite element model. The proposed model also exhibits high computational accuracy.

References listed at the end of the paper:


ABSTRACT: The modal parameters of a structure that is estimated from ambient vibration measurements are always subject to bias and variance errors. Accordingly the concept of the stabilization diagram is introduced to help users identify the correct model. One of the most important problems using this diagram is the appearance of spurious modes that should be discriminated to simplify modes selections. This study presents a new stabilization criterion obtained through a novel numerical implementation of the stabilization diagram and the discussion of model validation employing the power spectral density. As an application, an aircraft skeleton is used.

References listed at the end of the paper:

ABSTRACT: The major purpose of this paper is the development of wave dispersion curves calculation in multilayered composite-metal plates. At first, equations of motion and characteristic equations for the free waves on a single-layered orthotropic plate are presented. Since direction of wave propagation in composite materials is effective on equations of motion and dispersion curves, two different cases are considered: propagation of wave along an axis of material symmetry and along off-axes of material symmetry. Then, presented equations are extended for a multilayered orthotropic composite-metal plate using the transfer matrix method in which a global transfer matrix may be extracted which relates stresses and displacements on the top layer to those on the bottom one. By satisfying appropriate boundary conditions on the outer boundaries, wave characteristic equations and then dispersion curves are obtained. Moreover, presented equations may be applied to other materials such as monoclinic, transversely isotropic, cubic, and isotropic materials. To verify the solution procedure, a number of numerical illustrations for a single-layered orthotropic and double-layered orthotropic-metal are presented.

References listed at the end of the paper:

R. Ansari (1), A. Momen (1), S. Rouhi (2) and S. Ajori (1)
(1) Department of Mechanical Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran
(2) Young Researchers Club, Islamic Azad University, Langroud Branch, P.O. Box 44715-1333, Langroud, Guilan, Iran


ABSTRACT: The vibrational behavior of single-walled carbon nanocones is studied using molecular structural method and molecular dynamics simulations. In molecular structural approach, point mass and beam elements are employed to model the carbon atoms and the connecting covalent bonds, respectively. Single-walled carbon nanocones with different apex angles are considered. Besides, the vibrational behavior of nanocones under various types of boundary conditions is studied. Predicted natural frequencies are compared with the existing results in the literature and also with the ones obtained by molecular dynamics simulations. It is found that decreasing apex angle and the length of carbon nanocone results in an increase in the natural frequency. Comparing the vibrational behavior of single-walled carbon nanocones under different boundary conditions shows that the effect of end condition on the natural frequency is more prominent for nanocones with smaller apex angles.

References listed at the end of the paper:
ABSTRACT: A new method for the synthesis of structures with prescribed target natural frequencies and mode shapes is presented. The introduction of a modal Rayleigh quotient approximation based on the target mode shapes is the means to propose a structural synthesis problem whose solution is free from eigenvector sensitivity analysis. The frequencies and mode shapes can be adjusted as close as possible to the desired target values, while minimizing the total mass. Several examples corroborate the efficacy of the proposed method.

References listed at the end of the paper:


ABSTRACT: Three-dimensional fully coupled simulation is conducted to analyze the dynamic response of sandwich panels comprising equal thicknesses face sheets sandwiching a corrugated core when subjected to localized impulse created by the detonation of cylindrical explosive. A large number of computational cases have been calculated to comprehensively investigate the performance of sandwich panels under near-field air blast loading. Results show that the deformation/failure modes of panels depend strongly on stand-off distance. The beneficial FSI effect can be enhanced by decreasing the thickness of front face sheet. The core configuration has a negligible influence on the peak reflected pressure, but it has an effect on the deflection of a panel. It is found that the benefits of a sandwich panel over an equivalent weight solid plate to withstand near-field air blast loading are more evident at lower stand-off distance.

References listed at the end of the paper:

ABSTRACT: An analysis method is proposed for the vibration analysis of the Mindlin rectangular plates with general elastically restrained edges, in which the vibration displacements and the cross-sectional rotations of the mid-plane are expressed as the linear combination of a double Fourier cosine series and four one-dimensional Fourier series. The use of these supplementary functions is to solve the possible discontinuities with first derivatives at each edge. So this method can be applied to get the exact solution for vibration of plates with general elastic boundary conditions. The matrix eigenvalue equation which is equivalent to governing differential equations of the plate can be derived through using the boundary conditions and the governing equations based on Mindlin plate theory. The natural frequencies can be got through solving the matrix equation. Finally the numerical results are presented to validate the accuracy of the method.

References listed at the end of the paper:


ABSTRACT: A review of past and recent developments in multiaxial excitation of linear and nonlinear structures is presented. The objective is to review some of the basic approaches used in the analytical and experimental methods for kinematic and dynamic analysis of flexible mechanical systems, and to identify future directions in this research area. In addition, comparison between uniaxial and multiaxial excitations and their impact on a structure’s life-cycles is provided. The importance of understanding failure mechanisms in complex structures has led to the development of a vast range of theoretical, numerical, and experimental techniques to address complex dynamical effects. Therefore, it is imperative to identify the failure mechanisms of structures...
through experimental and virtual failure assessment based on correctly identified dynamic loads. For that reason, techniques for mapping the dynamic loads to fatigue were provided. Future research areas in structural dynamics due to multiaxial excitation are identified as (i) effect of dynamic couplings, (ii) modal interaction, (iii) modal identification and experimental methods for flexible structures, and (iv) computational models for large deformation in response to multiaxial excitation.

References listed at the end of the paper:

ABSTRACT: This paper presents dynamic methodologies able to obtain concept models of automotive beams and joints, which compare favourably with the existing literature methods, in terms of accuracy, easiness of implementation, and computational loads. For the concept beams, the proposed method is based on a dynamic finite element (FE) approach, which estimates the stiffness characteristics of equivalent 1D beam elements using the natural frequencies, computed by a modal analysis of the detailed 3D FE model of the structure. Concept beams are then connected to each other by a concept joint, which is obtained through a dynamic reduction technique that makes use of its vibration normal modes. The joint reduction is improved through the application of a new interface beam-to-joint element, able to interpolate accurately the nodal displacements of the outer contour of the section, to obtain displacements and rotations of the central connection node. The proposed approach is validated through an application case that is typical in vehicle body engineering: the analysis of a structure formed by three spot-welded thin-walled beams, connected by a joint.

References listed at the end of the paper:


ABSTRACT: The present study investigates the vibration and sound radiation by panels exited by turbulent flow and by random noise. Composite and aluminum panels are analyzed through a developed analytical framework. The main objective of this study is to identify the difference between the vibroacoustic behaviour of these two types of panels. This topic is of particular importance, given the growing interest in applying composite materials for the construction of aircraft structures, in parts where aluminum panels were traditionally being used. An original mathematical framework is presented for the prediction of noise and vibration for composite panels. Results show the effect of panel size, thickness of core, and thickness of face layers on the predictions. Smaller composite panels generally produced lower levels of sound and vibration than longer and wider composite panels. Compared with isotropic panels, the composite panels analyzed generated lower noise levels, although it was observed that noise level was amplified at certain frequencies. References listed at the end of the paper:


Joana Rocha (Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, ON, Canada K1S 5B6), “Sound radiation and vibration of composite panels excited by turbulent flow: Analytical prediction and analysis”, Shock and Vibration, Volume 2014, Article ID 316481, 18 pages, http://dx.doi.org/10.1155/2014/316481
ABSTRACT: This study addresses new formulation for active vibration control of plates by optimal locations of attached piezotransducers. Free vibrations are solved by Rayleigh-Ritz and transient by assumed modes methods. Optimal orientations of patches are determined by spatial controllability/observability, as well as residual modes to reduce spillover. These criteria are used to achieve optimal fitness function defined for genetic algorithm to find optimal locations. To control vibrations, negative velocity feedback control is designed. Results indicate that, by locating piezopatches at optimal positions, depreciation rate increases and amplitudes of vibrations reduce effectively. The effect of number of piezodevices is analyzed.

References listed at the end of the paper:


ABSTRACT: When calculating the vibration or sound power of a vibration source, it is necessary to know the point mobility of the supporting structure. A new method is presented for the calculation of point mobility of a thin circular plate with concentrated masses in this paper. Transverse vibration mode functions are
worked out by utilizing the structural circumferential periodicity of the inertia excitation produced by the concentrated masses. The numerical vibratory results, taking the clamped case as an instance, are compared to the published ones to validate the method for ensuring the correctness of mobility solution. Point mobility matrix, including the driving and transfer point mobility, of the titled structure is computed based on the transverse vibration solution. After that, effect of the concentrated masses on the mechanical point mobility characteristics is analyzed.

References listed at the end of the paper:
9 D. Sciulli, Dynamics and control for vibration isolation design [Ph.D. dissertation], Virginia Polytechnic Institute and State University, 1997.

Ting Zhang, Hong Guang Li, Guo Ping Cai and Fu Cai Li, “Experimental verifications of vibration suppression for a smart cantilever beam with a modified velocity feedback controller”, Shock and Vibration, Volume 2014, Article ID 172570, 9 pages, http://dx.doi.org/10.1155/2014/172570

ABSTRACT: This paper presents various experimental verifications for the theoretical analysis results of vibration suppression to a smart flexible beam bonded with a piezoelectric actuator by a velocity feedback controller and an extended state observer (ESO). During the state feedback control (SFC) design process for the smart flexible beam with the pole placement theory, in the state feedback gain matrix, the velocity feedback gain is much more than the displacement feedback gain. For the difference between the velocity feedback gain and the displacement feedback gain, a modified velocity feedback controller is applied based on a dynamical
model with the Hamilton principle to the smart beam. In addition, the feedback velocity is attained with the extended state observer and the displacement is acquired by the foil gauge on the root of the smart flexible beam. The control voltage is calculated by the designed velocity feedback gain multiplied by the feedback velocity. Through some experiment verifications for simulation results, it is indicated that the suppressed amplitude of free vibration is up to 62.13% while the attenuated magnitude of its velocity is up to 61.31%. Therefore, it is demonstrated that the modified velocity feedback control with the extended state observer is feasible to reduce free vibration.

References listed at the end of the paper:

ABSTRACT: Structural frames with masonry infill panels make up a significant portion of the buildings constructed in earthquake-prone areas prior to the developing of the seismic design standards. In this paper, the effects of masonry panels on the vibration response of an infilled steel-frame building are investigated. Various ambient and steady state forced vibration tests are carried out to realize the dynamic characteristics of the system. 3D finite element models of the building with and without infill panels are provided based on marcomodeling theorem. A set of analytical approximate formulas are also derived to estimate the vibrational period. The natural frequencies of the building are computed using numerical, analytical, and experimental methods. The results show that neglecting the effect of infill panels leads to considerable error. Moreover, it is shown that there is good agreement among the results obtained by the three methods considering the effect of infill panels.

References listed at the end of the paper:


ABSTRACT: Based on strain gradient elasticity theory, a finite element procedure is proposed for computation of natural frequencies for the microbeams of constant width and linear varying depth. Weak form formulation of the equation of motion is obtained first as in common classical finite element procedure in terms of various kinds of boundary conditions. Gradient elastic shape functions are used for interpolating deflection inside a finite element. Stiffness and mass matrices are then calculated to solve the microbeam eigen value problem. A solution for natural frequencies is obtained using characteristic equation of microbeam in gradient elasticity. The results are given in a series of figures and compared with their classical counterparts. The effect of various slope values on the natural frequencies are examined in some numerical examples. Comparison with the classical elasticity theory is also performed to verify the present study.

References listed at the end of the paper:


Shun-Fa Hwang, Chao-Wen Chen, Sung-Chin Chung and Yaw-Shyan Tsay, “Finite element simulation of the vibration provided by sandwich rigid panel with a resilient material in between under heavyweight impact,” Shock and Vibration, Volume 2014, Article ID 507830, 9 pages, \url{http://dx.doi.org/10.1155/2014/507830}

**ABSTRACT:** The purpose of the present work is to use an explicit finite element code to model the impact behavior of a heavyweight impact source like rubber ball and to predict the floor impact vibration of resilient materials, which are used in the floor coverings construction for sound insulation. To simulate the impact force of rubber balls, the hyperviscoelastic rubber model is applied. Then, this rubber model is used in the simulation for the impact vibration of resilient materials. The results indicate that the hyperviscoelastic rubber model could precisely simulate the impact force of rubber balls, as its two parameters are properly chosen according to the desired impact force. Also, the present model could capture the impact and vibration behavior of the considered materials and reasonably evaluate the insulation effect of resilient materials.

**References listed at the end of the paper:**


18. C. I. Lu, Predicting the influence of the access floor concerning impact sound insulation using FEM [M.S. thesis], National Cheng-Kung University, Tainan, Taiwan, 2007.


24. 2011, \url{http://forum.simwe.com/}.

R. Ansari, M.A. Ashrafi and S. Hosseinzadeh (Department of Mechanical Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran), “Vibration characteristics of piezoelectric microbeams based on the modified

ABSTRACT: The vibration behavior of piezoelectric microbeams is studied on the basis of the modified couple stress theory. The governing equations of motion and boundary conditions for the Euler-Bernoulli and Timoshenko beam models are derived using Hamilton’s principle. By the exact solution of the governing equations, an expression for natural frequencies of microbeams with simply supported boundary conditions is obtained. Numerical results for both beam models are presented and the effects of piezoelectricity and length scale parameter are illustrated. It is found that the influences of piezoelectricity and size effects are more prominent when the length of microbeams decreases. A comparison between two beam models also reveals that the Euler-Bernoulli beam model tends to overestimate the natural frequencies of microbeams as compared to its Timoshenko counterpart.

References listed at the end of the paper:
ABSTRACT: One of the interesting fields that attracted many researchers in recent years is the smart structures. The piezomaterials, because of their ability in converting both mechanical stress and electricity to each other, are very applicable in this field. However, most of the works available used various inexact two-dimensional theories with certain types of simplification, which are inaccurate in some applications such as thick shells while, in some applications due to request of large displacement/stress, thick piezoelectric panel is needed and two-dimensional theories have not enough accuracy. This study investigates the dynamic steady state response and natural frequency of a piezoelectric circular cylindrical panel using exact three-dimensional solutions based on this decomposition technique. In addition, the formulation is written for both simply supported and clamped boundary conditions. Then the natural frequencies, mode shapes, and dynamic steady state response of the circular cylindrical panel in frequency domain are validated with commercial finite element software (ABAQUS) to show the validity of the mathematical formulation and the results will be compared, finally.

References listed at the end of the paper:


ABSTRACT: An analytical framework is developed for the vibration analysis of annular sector plates with general elastic restraints along each edge of plates. Regardless of boundary conditions, the displacement solution is invariably expressed as a new form of trigonometric expansion with accelerated convergence. The expansion coefficients are treated as the generalized coordinates and determined using the Rayleigh–Ritz technique. This work allows a capability of modeling annular sector plates under a variety of boundary conditions and changing the boundary conditions as easily as modifying the material properties or dimensions of the plates. Of equal importance, the proposed approach is universally applicable to annular sector plates of any inclusion angles up to 2π. The reliability and accuracy of the current method are adequately validated through numerical examples.

References listed at the end of the paper:

ABSTRACT: For a few decades, various methods to suppress the vibrations of structures have been proposed and exploited. These include passive methods using constrained layer damping (CLD) and active methods using smart materials. However, applying these methods to large structures may not be practical because of weight, material, and actuator constraints. The objective of the present study is to propose and exploit a new method to suppress the vibration of a large and heavy beam structure with a minimum increase in mass or volume of material. Traditional tuned mass dampers (TMD) are very effective for attenuating structural vibrations; however, they often add substantial mass. Eddy current damping is relatively simple and has excellent performance but is force limited. The proposed method is to apply relatively light-weight TMD to attenuate the vibration of a large beam structure and increase its performance by applying eddy current damping to a TMD. The results show that the present method is simple but effective in suppressing the vibration of a large beam structure without a substantial weight increase.

References listed at the end of the paper:
The equations of motion, governing the free transverse vibrations of orthotropic thin trapezoidal plates, are derived with boundary condition CSCS. Frequency corresponding to the first two modes of vibration is calculated for the orthotropic thin trapezoidal plate having CSCS edges for different values of thermal gradient, taper constant, and aspect ratio. The proposed method is applied to solve orthotropic thin trapezoidal plate of variable thickness with C-S-C-S boundary conditions. Results are shown by figures for different values of thermal gradient, taper constant, and aspect ratio for the first two modes of vibrations.

References listed at the end of the paper:

ABSTRACT: A B-spline wavelet on interval (BSWI) finite element is developed for curved beams, and the static and free vibration behaviors of curved beam (arch) are investigated in this paper. Instead of the traditional polynomial interpolation, scaling functions at a certain scale have been adopted to form the shape functions and construct wavelet-based elements. Different from the process of the direct wavelet addition in the other wavelet numerical methods, the element displacement field represented by the coefficients of wavelets expansions is transformed from wavelet space to physical space by aid of the corresponding transformation matrix. Furthermore, compared with the commonly used Daubechies wavelet, BSWI has explicit expressions and excellent approximation properties, which guarantee satisfactory results. Numerical examples are performed to demonstrate the accuracy and efficiency with respect to previously published formulations for curved beams.

References listed at the end of the paper:


ABSTRACT: This study presents a technique that uses a model reduction method for the dynamic response analysis of a beam structure to a moving load, which can be modeled either as a moving point force or as a moving body. The nature of the dedicated condensation method tailored to address the moving load case is that the master degrees of freedom are reselected, and the coefficient matrices of the condensed model are recalculated as the load travels from one element to another. Although this process increases computational burden, the overall computational time is still greatly reduced because of the small scale of motion equations. To illustrate and validate the methodology, the technique is initially applied to a simply supported beam and then to a practical structure, with the results demonstrating that the condensation model can solve the moving load problem faster than an analytical model or its full finite element model. The proposed model also exhibits high computational accuracy.

References listed at the end of the paper:

ABSTRACT: Critical velocities are investigated for an infinite Timoshenko beam resting on a Winkler-type elastic foundation subjected to a harmonic moving load. The determination of critical velocities ultimately comes down to discrimination of the existence of multiple real roots of an algebraic equation with real coefficients of the 4th degree, which can be solved by employing Descartes sign method and complete discrimination system for polynomials. Numerical calculations for the European high-speed rail show that there are at most four critical velocities for an infinite Timoshenko beam, which is very different from those gained by others. Furthermore, the shear wave velocity must be the critical velocity, but the longitudinal wave velocity is not possible under certain conditions. Further numerical simulations indicate that all critical velocities are limited to be less than the longitudinal wave velocity no matter how large the foundation stiffness is or how high the loading frequency is. Additionally, our study suggests that the maximum value of one group velocity of waves in Timoshenko beam should be one “dangerous” velocity for the moving load in launching process, which has never been referred to in previous work.

References listed at the end of the paper:


ABSTRACT: An analytical method based on the wave theory is proposed to calculate the pressure at the interfaces of coated plate subjected to underwater weak shock wave. The method is carried out to give analytical results by summing up the pressure increment, which can be calculated analytically, in time sequence. The results are in very good agreement with the finite element (FE) predictions for the coating case and Taylor’s results for the noncoating case, which validate the method that is suitable for underwater weak shock problem. On the other hand, Taylor’s results for the coating case are invalid, which indicates a potential application field for the method. The extension of the analytical method to q-layer systems and dissipation case is also outlined.

References listed at the end of the paper:
18 T. P. Brasek, Effect of Surface Coating on One-Dimensional System Subjected to Unit Step Pressure Wave, Naval postgraduate School, Monterey, Calif, USA, 1994.

ABSTRACT: We study a capacitive MEMS switch composed of two clamped-clamped exible microbeams. We first develop a mathematical model for the MEMS switch where the upper microbeam represents the ground transmission line and the lower one represents the central transmission line. An electrostatic force is applied between the two microbeams to yield the switch to its ON and OFF states. We derive the equations of motion of the system and associated boundary conditions and solve the static and dynamic problems using the differential quadratic method. We show that using only nine grid points gives relatively accurate results when compared to those obtained using FEM. We also examine the transient behavior of the microswitch and obtain results indicating that subsequent reduction in actuation voltage, switching time, and power consumption are expected along with relatively good RF performances. ANSYS HFSS simulator is used in this paper to extract the RF characteristics of the microswitch. HFSS simulation results show that the insertion loss is as low as $-0.31 \, \text{dB}$ and that the return loss is better than $-12.41 \, \text{dB}$ at 10 GHz in the ON state. At the OFF state, the isolation is lower than $-23 \, \text{dB}$ in the range of 10 to 50 GHz.

References listed at the end of the paper:


ABSTRACT: This paper presents an adaptive-predictive vibration control system using extended Kalman filtering for the joint estimation of system states and model parameters. A fixed-free cantilever beam equipped with piezoceramic actuators serves as a test platform to validate the proposed control strategy. Deflection readings taken at the end of the beam have been used to reconstruct the position and velocity information for a second-order state-space model. In addition to the states, the dynamic system has been augmented by the unknown model parameters: stiffness, damping constant, and a voltage/force conversion constant, characterizing the actuating effect of the piezoceramic transducers. The states and parameters of this augmented system have been estimated in real time, using the hybrid extended Kalman filter. The estimated model parameters have been applied to define the continuous state-space model of the vibrating system, which in turn is discretized for the predictive controller. The model predictive control algorithm generates state predictions and dual-mode quadratic cost prediction matrices based on the updated discrete state-space models. The resulting cost function is then minimized using quadratic programming to find the sequence of optimal but constrained control inputs. The proposed active vibration control system is implemented and evaluated experimentally to investigate the viability of the control method.

References listed at the end of the paper:

49 M. Corless, Linear Systems and Control: A First Course, Course notes for AAE 564, Purdue University, West Lafayette, Ind, USA, 2008.
ABSTRACT: The maximizing of sound transmission loss (TL) across a functionally graded material (FGM) cylindrical shell has been conducted using a genetic algorithm (GA). To prevent the softening effect from occurring due to optimization, the objective function is modified based on the first resonant frequency. Optimization is performed over the frequency range 1000–4000 Hz, where the ear is the most sensitive. The weighting constants are chosen here to correspond to an A-weighting scale. Since the weight of the shell structure is an important concern in most applications, the weight of the optimized structure is constrained. Several traditional materials are used and the result shows that optimized shells with aluminum-nickel and aluminum-steel FGM are the most effective at maximizing TL at both stiffness and mass control region, while they have minimum weight.

References listed at the end of the paper:
References listed at the end of the paper:

ABSTRACT: This paper presents selected results and aspects of the multidisciplinary and interdisciplinary research oriented for the experimental and numerical study of the structural dynamics of a bend-twist coupled full scale section of a wind turbine blade structure. The main goal of the conducted research is to validate finite element model of the modified wind turbine blade section mounted in the flexible support structure accordingly to the experimental results. Bend-twist coupling was implemented by adding angled unidirectional layers on the suction and pressure side of the blade. Dynamic test and simulations were performed on a section of a full scale wind turbine blade provided by Vestas Wind Systems A/S. The numerical results are compared to the experimental measurements and the discrepancies are assessed by natural frequency difference and modal assurance criterion. Based on sensitivity analysis, set of model parameters was selected for the model updating process. Design of experiment and response surface method was implemented to find values of model parameters yielding results closest to the experimental. The updated finite element model is producing results more consistent with the measurement outcomes.

References listed at the end of the paper:

W. Gafsi, F. Najar, S. Choura and S. El-Borgi, “Confinement of vibrations in variable-geometry nonlinear flexible beam”, Shock and Vibration, Volume 2014, Article ID 687340, 7 pages,

http://dx.doi.org/10.1155/2014/687340

ABSTRACT: In this paper, we propose a novel strategy for controlling a flexible nonlinear beam with the confinement of vibrations. We focus principally on design issues related to the passive control of the beam by proper selection of its geometrical and physical parameters. Due to large deflections within the regions where the vibrations are to be confined, we admit a nonlinear model that describes with precision the beam dynamics. In order to design a set of physical and geometrical parameters of the beam, we first formulate an inverse

ABSTRACT: Noncollocated control of flexible structures results in nonminimum-phase systems because the separation between the actuator and the sensor creates an input-output delay. The delay can deteriorate stability of closed-loop systems. This paper presents a simple approach to improve the delay-margin of the noncollocated vibration control of piezo-actuated flexible beams using a fractional-order controller. Results of real life experiments illustrate efficiency of the controller and show that the fractional-order controller has better stability robustness than the integer-order controller.

References listed at the end of the paper:
1 C. C. Fuller, Active Control of Vibration, Academic Press, 1996.
ABSTRACT: On the basis of modified couple stress theory, the postbuckling behavior of the Euler-Bernoulli microscale FG beams is investigated by means of an exact solution method. The modified couple stress theory as a nonclassical continuum theory is capable of interpreting the size dependencies which become more significant at micro/nanoscales. The Von-Karman type nonlinear strain-displacement relationships are employed. The thermal effects are also incorporated into formulation. The governing equation of motion and the corresponding boundary conditions are derived using Hamilton’s principle. The material properties are assumed to be graded in the thickness direction according to the power-law distribution. A closed-form solution is obtained for the postbuckling deformation which is beyond the critical buckling load. To study the vibrations taking place in the vicinity of a buckled equilibrium position, the linear vibration problem is exactly solved around the first three buckled configurations. The natural frequencies of the lowest vibration modes around each of the first three buckled configurations are obtained. The influences of power-law exponent, boundary condition, length scale parameter, and thermal environment changes on the static deflection and free vibration frequencies are studied. A comparison is also made between the present results and those obtained via the classical beam theories.

References listed at the end of the paper:


ABSTRACT: This paper studies nonlinear vibration mechanism of hard coating thin plate based on macroscopic vibration theory and proposes finite element iteration method (FEIM) to theoretically calculate its nature frequency and vibration response. First of all, strain dependent mechanical property of hard coating is briefly introduced and polynomial method is adopted to characterize the storage and loss modulus of coating material. Then, the principle formulas of inherent and dynamic response characteristics of the hard coating composite plate are derived. And consequently specific analysis procedure is proposed by combining ANSYS APDL and self-designed MATLAB program. Finally, a composite plate coated with MgO + Al2O3 is taken as a study object and both nonlinear vibration test and analysis are conducted on the plate specimen with considering strain dependent mechanical parameters of hard coating. Through comparing the resulting frequency and response results, the practicability and reliability of FEIM have been verified and the corresponding analysis results can provide an important reference for further study on nonlinear vibration mechanism of hard coating composite structure.

References listed at the end of the paper:
6 J. E. Hansel, The influence of thickness on the complex modulus of air plasma sprayed ceramic blend coatings [M.S. thesis], Wright State University, Dayton, Ohio, USA, 2008.
ABSTRACT: Lamb wave based structural health monitoring shows a lot of potential for damage detection of composite structures. However, currently there is no agreement upon optimal network arrangement or detection algorithm. The objective of this research is to develop a sparse network that can be expanded to detect damage over a large area. To achieve this, a novel technique based on damage progression history has been developed. This technique gives an amplification factor to data along actuator-sensor paths that show a steady reduction in transmitted power as induced damage progresses and is implemented with the reconstruction algorithm for probabilistic inspection of damage (RAPID) technique. Two damage metrics are used with the algorithm and a comparison is made to the more commonly used signal difference coefficient (SDC) metric. Best case results show that damage is detected within 12 mm. The algorithm is also run on a more sparse network with no damage detection, therefore indicating that the selected arrangement is the most sparse arrangement with this configuration.

References listed at the end of the paper:
ABSTRACT: This paper studies the vibrational behavior and far-field sound radiation of a submerged stiffened conical shell at low frequencies. The solution for the dynamic response of the conical shell is presented in the form of a power series. A smeared approach is used to model the ring stiffeners. Fluid loading is taken into account by dividing the conical shell into narrow strips which are considered to be local cylindrical shells. The far-field sound pressure is solved by the Element Radiation Superposition Method. Excitations in two directions are considered to simulate the loading on the surface of the conical shell. These excitations are applied along the generator and normal to the surface of the conical shell. The contributions from the individual circumferential modes on the structural responses of the conical shell are studied. The effects of the external fluid loading and stiffeners are discussed. The results from the analytical models are validated by numerical results from a fully coupled finite element/boundary element model.

References listed at the end of the paper:

walled carbon nanotube (SWCNT) system containing a fluid with a Pasternak layer in

ABSTRACT: Two improved analytical methods of calculations for natural frequencies and mode shapes of a uniform cantilever beam carrying a tip-mass under base excitation are presented based on forced vibration theory and the method of separation of variables, respectively. The cantilever model is simplified in detail by replacing the tip-mass with an equivalent inertial force and inertial moment acting at the free end of the cantilever based on D’Alembert’s principle. The concentrated equivalent inertial force and inertial moment are further represented as distributed loads using Dirac Delta Function. In this case, some typical natural frequencies and mode shapes of the cantilever model are calculated by the improved and unimproved analytical methods. The comparing results show that, after improvement, these two methods are in extremely good agreement with each other even the offset distance between the gravity center of the tip-mass and the attachment point is large. As further verification, the transient and steady displacement responses of the cantilever system under a sine base excitation are presented in which two improved methods are separately utilized. Finally, an experimental cantilever system is fabricated and the theoretical displacement responses are validated by the experimental measurements successfully.

References listed at the end of the paper:


Mehrdad Nasirshoaibi (1), Nader Mohammadi (1) and Masih Nasirshoaibi (2)
(1) Department of Mechanical Engineering, Islamic Azad University, Parand Branch, Tehran 3761396361, Iran
(2) Department of Mechanical Engineering, Islamic Azad University, Semnan Branch, Semnan 8965151567, Iran

Forced transverse vibration of a closed double single-walled carbon nanotube system containing a fluid with effect of compressive axial load”, Shock and Vibration, Volume 2015, Article ID 435284, 11 pages,
http://dx.doi.org/10.1155/2015/435284

ABSTRACT: Based on the Rayleigh beam theory, the forced transverse vibrations of a closed double single-walled carbon nanotube (SWCNT) system containing a fluid with a Pasternak layer in-between are investigated. It is assumed that the two single-walled carbon nanotubes of the system are continuously joined by a Pasternak
layer and both sides of SWCNTs containing a fluid are closed. The dynamic responses of the system caused by arbitrarily distributed continuous loads are obtained. The effect of compressive axial load on the forced vibrations of the double single-walled carbon nanotube system is discussed for one case of particular excitation loading. The properties of the forced transverse vibrations of the system are found to be significantly dependent on the compressive axial load. The steady-state vibration amplitudes of the SWCNT decrease with increasing of length of SWCNT. Vibrations caused by the harmonic exciting forces are discussed, and conditions of resonance and dynamic vibration absorption are formulated. The SWCNT-type dynamic absorber is a new concept of a dynamic vibration absorber (DVA), which can be applied to suppress excessive vibrations of corresponding SWCNT systems.

References listed at the end of the paper:


ABSTRACT: The energy density governing equation to analyze the high-frequency dynamic behavior of plates in thermal environments is derived in this paper, in which the thermal effects are considered to change the membrane stress state and temperature dependent material properties of plates. Then the thermal effects on the energy reflection and transmission coefficients are dealt with hereof. Based on the above, an EFEM (energy finite element method) based approximate approach for the energy analysis of coupled plates under nonuniform thermal environments is proposed. The approach could be conducted by three steps: (1) thermal analysis, (2) thermal stress analysis, and (3) forming element matrixes, joint matrixes, and the whole EFEM formulation for the energy analysis. The same mesh model is used for all the three steps. The comparison between EFEM results and classical modal superposition method results of simply supported plates in various uniform thermal environments and coupled plates in nonuniform thermal environments demonstrated that the derived energy governing equation and the proposed approach described well the smooth time- and locally space-averaged
References listed at the end of the paper:


ABSTRACT: A topology optimization method is proposed to minimize the resonant response of plates with constrained layer damping (CLD) treatment under specified broadband harmonic excitations. The topology optimization problem is formulated and the square of displacement resonant response in frequency domain at the specified point is considered as the objective function. Two sensitivity analysis methods are investigated and discussed. The derivative of modal damp ratio is not considered in the conventional sensitivity analysis method. An improved sensitivity analysis method considering the derivative of modal damp ratio is developed to improve the computational accuracy of the sensitivity. The evolutionary structural optimization (ESO) method is used to search the optimal layout of CLD material on plates. Numerical examples and experimental results show that the optimal layout of CLD treatment on the plate from the proposed topology optimization using the conventional sensitivity analysis or the improved sensitivity analysis can reduce the displacement resonant response. However, the optimization method using the improved sensitivity analysis can produce a higher modal damping ratio than that using the conventional sensitivity analysis and develop a smaller displacement resonant response.

References listed at the end of the paper:

ABSTRACT: The particle damping technology is a passive vibration control technique. The particle dampers (PDs) as one of the passive damping devices has found wide use in the field of aeronautical engineering, mechanical engineering, and civil engineering because it has several advantages compared with the forms of viscous damping, for example, structure simplicity, low cost, robust properties, and being effective over a wide range of frequencies. In this paper, a novelty simulation method based on multiphase flow theory (MFT) is developed to evaluate the particle damping characteristics using FEM combining DEM with COMSOL Multiphysics. First, the effects of the collisions and friction between the particles are interpreted as an equivalent nonlinear viscous damping based on MFT of gas particle. Next, the contribution of PDs is estimated as equivalent spring-damper system. Then a cantilever rectangular plate treated with PDs is introduced in a finite element model of structure system. Finally frequency response functions (FRFs) of the plate without and with particle dampers are predicted to study characteristics of the particle damping plates under forced vibration. Meanwhile, an experimental verification is performed. Simulation results are in good agreement with experimental data. It is concluded that the simulation method in this paper is valid.

References listed at the end of the paper:

Jianjun He and Xiangzi Chen (School of Automobile and Mechanical Engineering, Changsha University of Science and Technology, Changsha 410004, China), “Integrated topology optimization of structure/vibration control for piezoelectric cylindrical shell based on the genetic algorithm”, Shock and Vibration, Volume 2015, Article ID 456147, 10 pages, http://dx.doi.org/10.1155/2015/456147

ABSTRACT: A hybrid optimization strategy for integrated topological optimization design of piezoelectric cylindrical flat shell structure is proposed. The method combines the genetic algorithm (GA) and linear-quadratic-regulator (LQR) theory to optimize the performance of coupling structure/control system. The GA is used to choose the optimal structure topology and number and placements of actuators and control parameters; meanwhile, the LQR is used to design control system to suppress vibration of optimal structure under sinusoidal excitation, which is based on the couple-mode space control. In addition, the mathematical morphology operators are used for repairs of disconnected structure topology. The results of numerical simulation and computations show that the proposed method is effective and feasible, with good performance for the optimal and coupling piezoelectric cylindrical shell structure/control system.

References listed at the end of the paper:
ABSTRACT: We present a node-based free-form optimization method for designing forms of thin-walled structures in order to control vibration displacements or mode at a prescribed frequency. A squared displacement error norm is introduced at the prescribed surface as the objective functional to control the vibration displacements to target values in a frequency response problem. It is assumed that the thin-walled structure is varied in the normal direction to the surface and the thickness is constant. A nonparametric shape optimization problem is formulated, and the shape gradient function is theoretically derived using the material derivative method and the adjoint variable method. The shape gradient function obtained is applied to the surface of the thin-walled structure as a fictitious traction force to vary the form. With this free-form optimization method, an optimum thin-walled structure with a smooth free-form surface can be obtained without any shape parameterization. The calculated results show the effectiveness of the proposed method for the optimal free-form design of thin-walled structures with vibration mode control.

References listed at the end of the paper:
ABSTRACT: A kind of high-aspect-ratio shape memory alloy (SMA) composite wing is proposed to reduce the wing’s fluttering. The nonlinear dynamic characteristics and optimal control of the SMA composite wings subjected to in-plane stochastic excitation are investigated where the great bending under the flight loads is considered. The stochastic stability of the system is analyzed, and the system’s response is obtained. The conditions of stochastic Hopf bifurcation are determined, and the probability density of the first-passage time is obtained. Finally, the optimal control strategy is proposed. Numerical simulation shows that the stability of the system varies with bifurcation parameters, and stochastic Hopf bifurcation appears in the process; the reliability of the system is improved through optimal control, and the first-passage time is delayed. Finally, the effects of the control strategy are proved by experiments. The results of this paper are helpful for engineering applications of SMA.

References listed at the end of the paper:


ABSTRACT: The weighted sum of spatial gradients (WSSG) control minimization parameter is developed for use in active structural acoustic control (ASAC) on a clamped flat rectangular plate. The WSSG minimization parameter is measured using four accelerometers grouped closely together on the test structure. In previous work, WSSG was developed on a simply supported flat rectangular plate and showed promise as a control metric. The displacement on the clamped plate has been modeled using an approximate analytical solution assuming shape functions corresponding to clamped-clamped beams. From the analytical formulation, weights, which were found to be the reciprocal of the wave number squared, have been derived to produce a uniform WSSG field across the plate. In active control simulations, this quantity has been shown to provide better global control of acoustic radiation than volume velocity. Analysis is presented which shows that comparable control, regardless of the sensor location, can be achieved using WSSG. Experimental results are presented which demonstrate that WSSG works effectively in practice, with results similar to the simulations. The results show that minimization of WSSG can be used as an effective control objective on clamped rectangular plates to achieve attenuation of acoustic radiation.

References listed at the end of the paper:


ABSTRACT: Prediction of bending wave transmission across systems of coupled plates which incorporate periodic ribbed plates is considered using Statistical Energy Analysis (SEA) in the low- and mid-frequency ranges and Advanced SEA (ASEA) in the high-frequency range. This paper investigates the crossover from prediction with SEA to ASEA through comparison with Finite Element Methods. Results from L-junctions confirm that this crossover occurs near the frequency band containing the fundamental bending mode of the individual bays on the ribbed plate when ribs are parallel to the junction line. Below this frequency band, SEA models treating each periodic ribbed plate as a single subsystem were shown to be appropriate. Above this frequency band, large reductions occur in the vibration level when propagation takes place across successive bays on ribbed plates when the ribs are parallel to the junction. This is due to spatial filtering; hence it is necessary to use ASEA which can incorporate indirect coupling associated with this transmission mechanism. A system of three coupled plates was also modelled which introduced flanking transmission. The results show that a wide frequency range can be covered by using both SEA and ASEA for systems of coupled plates where some or all of the plates are periodic ribbed plates.

References listed at the end of the paper:


ABSTRACT: To determine the force mechanism for the steel plate shear wall with slits, the pushover analysis method was used in this study. An estimated equation for the lateral bearing capacity which considered the effect of edge stiffener was proposed. A simplified elastic-plastic analytical model for the stiffened steel slit wall composed of beam elements was presented, where the effects of edge stiffeners were taken into account. The wall-frame analysis model was established, and the geometric parameters were defined. Pushover analysis of two specimens was carried out, and the analysis was validated by comparing the results from the experiment, the shell element model, and a simplified model. The simplified model provided a good prediction of the lateral stiffness and the strength of the steel slit wall, with less than 10% error compared with the experimental results. The mutual effects of the bearing wall and the frame were also predicted correctly. In the end, the seismic performance evaluation of a steel slit wall-frame structure was presented. The results showed that the steel slit wall could prevent the beams and columns from being damaged by an earthquake and that the steel slit wall was an efficient energy dissipation component.

References listed at the end of the paper:

18 W. W. Shen, Elastic simplified model studies of steel plate shear wall with slits [M.S. thesis], Xi’an University of Architecture and Technology, Xi’an, China, 2009, (Chinese).
22 H. Y. Chen, Experimental studies and theoretical analysis of steel plate shear wall with slits [M.S. thesis], Tianjin University, Tianjin, China, 2008 (Chinese).

ABSTRACT: Shock absorption characteristics of combined aluminium honeycomb structures were studied experimentally. In the experiments, a testing platform was design to compare the shock absorption level of different honeycomb specimens quantitatively. The shock response curves of six test points mounted on the platform were recorded with acceleration sensors when the buffer was impacted by a bullet driven by high pressure gas. The maximum acceleration values in time domain and in specifically spectral domain were obtained based on spectral analysis. Comparing the data of combined aluminium honeycomb buffer and single aluminium honeycomb buffer, conclusion can be obtained that shock absorbing characteristic of combined aluminium honeycomb buffer is better. Furthermore, compression properties of three kinds of buffers were tested under quasi-static state. The energy absorption parameters were calculated. The results show suitable combined aluminium honeycomb buffer can smooth the stress and lower the energy applied to the testing platform.

References listed at the end of the paper:
ABSTRACT: The effect of fatigue damage (FD) on the energy absorption properties of honeycomb paperboard is investigated by fatigue compression experiments. The constitutive relations of honeycomb paperboard have been changed after the fatigue damage. The results show that FD has effect on plateau stress and energy absorption capacity of honeycomb paperboard after fatigue cycles but has no significant effect on densification strain. Energy absorption diagram based on the effect of FD is constructed for honeycomb paperboard, which could be used for optimization design of packaging materials.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: A steel-poly(methyl methacrylate) (steel-PMMA) beam was fabricated to investigate the vibration properties of a one-dimensional phononic crystal structure. The experimental system included an excitation signal, a signal acquisition system, and a data analysis and processing system. When an excitation signal was exerted on one end of the beam, the signals of six response points were collected with acceleration sensors. Subsequent signal analysis showed that the beam was attenuated in certain frequency ranges. The lumped mass method was then used to calculate the bandgap of the phononic crystal beam to analyze the vibration properties of a beam made of two different materials. The finite element method was also employed to simulate the vibration of the phononic crystal beam, and the simulation results were consistent with theoretical calculations. The existence of the bandgap was confirmed experimentally and theoretically, which allows for the potential applications of phononic crystals, including wave guiding and filtering, in integrated structures.

Harri Hakula and Mikael Laaksonen (Department of Mathematics and Systems Analysis, School of Science, Aalto University, P.O. Box 11100, 00076 Aalto, Finland), “Hybrid stochastic finite element method for mechanical vibration problems”, Shock and Vibration, Volume 2015, Article ID 812069, 13 pages, http://dx.doi.org/10.1155/2015/812069

ABSTRACT: We present and analyze a new hybrid stochastic finite element method for solving eigenmodes of structures with random geometry and random elastic modulus. The fundamental assumption is that the smallest eigenpair is well defined over the whole stochastic parameter space. The geometric uncertainty is resolved using collocation and random material models using Galerkin method at each collocation point. The response statistics, expectation and variance of the smallest eigenmode, are computed in numerical experiments. The hybrid approach is superior to alternatives in practical cases where the number of random parameters used to describe geometric uncertainty is much smaller than that of the material models.

References listed at the end of the paper:


for some internal resonances there.

The energy exchange mechanism between interacting nonlinear modes has been analyzed. It has been shown that when the linear parts of nonlinear equations of motion occur to be coupled. A new approach proposed in this analysis.

The internal resonances two.

ABSTRACT: In the previous analysis, the dynamic behavior of a nonlinear plate embedded into a fractional derivative viscoelastic medium has been studied by the method of multiple time scales under the conditions of the internal resonances two-to-one and one-to-one, as well as the internal combinational resonances for the case when the linear parts of nonlinear equations of motion occur to be coupled. A new approach proposed in this paper allows one to uncouple the linear parts of equations of motion of the plate, while the same method, the method of multiple time scales, has been utilized for solving nonlinear equations. The influence of viscosity on the energy exchange mechanism between interacting nonlinear modes has been analyzed. It has been shown that for some internal resonances there exist such particular cases when it is possible to obtain two first integrals.
namely, the energy integral and the stream function, which allows one to reduce the problem to the calculation of elliptic integrals. The new approach enables one to solve the problems of vibrations of thin bodies more efficiently.

References listed at the end of the paper:

ABSTRACT: It is of great importance to evaluate the hull structural vibrations response of large ships in extreme seas. Studies of hydroelastic response of an ultra large ship have been conducted with comparative verification between experimental and numerical methods in order to estimate the wave loads response considering hull vibration and water impact. A segmented self-propelling model with steel backbone system was elaborately designed and the experiments were performed in a tank. Time domain numerical simulations of the ship were carried out by using three-dimensional nonlinear hydroelasticity theory. The results from the computational analyses have been correlated with those from model tests.

References listed at the end of the paper:
11 H. Li, 3-D hydroelasticity analysis method for wave loads of ships [Ph.D. dissertation], Harbin Engineering University, 2009.


ABSTRACT: A dynamic model of composite shaft with variable cross section is presented. Free vibration equations of the variable cross section thin-walled composite shaft considering the effect of shear deformation are established based on a refined variational asymptotic method and Hamilton’s principle. The numerical
This study proposes a novel substructural identification method based on the Bernoulli-Euler beam theory with a single variable optimization scheme to estimate the flexural rigidity of a beam-like structure such as a bridge deck, which is one of the major structural integrity indices of a structure. In ordinary bridges, the boundary condition of a superstructure can be significantly altered by aging and environmental variations, and the actual boundary conditions are generally unknown or difficult to be estimated correctly. To efficiently bypass the problems related to boundary conditions, a substructural identification method is proposed to evaluate the flexural rigidity regardless of the actual boundary conditions by isolating an identification region within the internal substructure. The proposed method is very simple and effective as it utilizes the single variable optimization based on the transfer function formulated utilizing Bernoulli Euler beam theory for the inverse analysis to obtain the flexural rigidity. This novel method is also rigorously investigated by applying it for estimating the flexural rigidity of a simply supported beam model with different boundary conditions, a concrete plate-girder bridge model with different length of an internal substructure, a cantilever-type wind turbine tower structure with different type of excitation, and a steel box-girder bridge model with internal structural damages.

References listed at the end of the paper:

References listed at the end of the paper:

measured in defined. The results show that the mathematical model can predict accurately the flutter instability zones of the spinning disk. The eigenvalues of the system are computed numerically, and the flutter instability zones are identified. The governing linear equations of transverse vibrations of the disk lock into that flutter zone. Sometimes, the system cannot pass a flutter zone, and transverse vibrations of the disk lock into that flutter zone when a backward travelling wave of a mode meets a reflected wave of a different mode.

**ABSTRACT:** "Guided splined disks" are defined as flat thin disks in which the inner radius of the disk is splined and matches a splined arbor that provides the driving torque for rotating the disk. Lateral constraint for the disk is provided by space fixed guide pads. Experimental lateral displacement of run-up tests of such a system is presented, and the flutter instability zones are identified. The results indicate that flutter instability occurs at speeds when a backward travelling wave of a mode meets a reflected wave of a different mode. Sometimes, the system cannot pass a flutter zone, and transverse vibrations of the disk lock into that flutter instability zone. The governing linear equations of transverse motion of such a spinning disk, with assumed free inner and outer boundary conditions, are derived. A lateral constraint is introduced and modeled as a linear spring. Rigid body translational and tilting degrees of freedom are included in the analysis of the total motion of the spinning disk. The eigenvalues of the system are computed numerically, and the flutter instability zones are defined. The results show that the mathematical model can predict accurately the flutter instability zones measured in the experimental tests.

References listed at the end of the paper:
Sha Zhang, Wen-Ming Zhang, Zhi-Ke Peng and Guang Meng (State Key Laboratory of Mechanical System and Vibration, School of Mechanical Engineering, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, China), “Dynamic characteristics of electrostatically actuated shape optimized variable geometry microbeam”, Shock and Vibration, Volume 2015, Article ID 867171, 15 pages, http://dx.doi.org/10.1155/2015/867171

ABSTRACT: We mainly analyze the dynamic characteristics of electrostatically actuated shape optimized variable geometry microbeam. A nonlinear dynamic model considering midplane stretching, electrostatic force, and electrical field fringing effects is developed. Firstly, we study the static responses of the optimized microbeams under DC polarization voltage. The generalized differential quadrature method (GDQM) is used. Secondly, the dynamic responses of the shape optimized microbeams driven by DC and AC voltages are investigated using GDQM in conjunction with Levenberg-Marquardt optimization method. The results show that the more gradual change in width, the larger the resonant frequency and the maximum amplitude at resonance. Then we further discuss in detail how do the maximum width, midsection width, and curvature of the width function affect the frequency response of the microbeams. We find that the amplitude and resonant frequency of the dynamic response are not monotonically increasing as the curvature of the width function increases and there exists a critical curvature. This analysis will be helpful in the optimal design of MEMS actuators. Finally, for more consideration, different residual stress, squeeze-film damping, and fringing effect models are introduced into the governing equation of motion and we compare the corresponding dynamic response.

References listed at the end of the paper:

This paper aims to evaluate the impact interaction between the abutment and the girder subjected to nonuniform seismic excitation. An impact model based on tests is presented by taking material properties of the backfill of the abutment into consideration. The conditional simulation is performed to investigate the spatial variation of earthquake ground motions. A two-span continuous steel box girder bridge is taken as the example to analyze and assess the pounding interaction between the abutment and the girder. The detailed
nonlinear finite element (FE) model is established and the steel girder and the reinforced concrete piers are modeled by nonlinear fiber elements. The pounding element of the abutment is simulated by using a trilinear compression gap element. The elastic-perfectly plastic element is used to model the nonlinear rubber bearings. The comparisons of the pounding forces, the shear forces of the nonlinear bearings, the moments of reinforced concrete piers, and the axial pounding stresses of the steel girder are studied. The made observations indicate that the nonuniform excitation for multisupport bridge is imperative in the analysis and evaluation of the pounding effects of the bridges.

References listed at the end of the paper:

18. California Department of Transportation (CLATRANS), Seismic Design Criteria, Version 1.6, California Department of Transportation (CLATRANS), Sacramento, Calif, USA, 2010.
ABSTRACT: This paper focuses on the nonlinear dynamics modeling and parameter identification of an Aluminum Honeycomb Panel (AHP) with multiple bolted joints. Finite element method using eight-node solid elements is exploited to model the panel and the bolted connection interface as a homogeneous, isotropic plate and as a thin layer of nonlinear elastic-plastic material, respectively. The material properties of a thin layer are defined by a bilinear elastic plastic model, which can describe the energy dissipation and softening phenomena in the bolted joints under nonlinear states. Experimental tests at low and high excitation levels are performed to reveal the dynamic characteristics of the bolted structure. In particular, the linear material parameters of the panel are identified via experimental tests at low excitation levels, whereas the nonlinear material parameters of the thin layer are updated by using the genetic algorithm to minimize the residual error between the measured and the simulation data at a high excitation level. It is demonstrated by comparing the frequency responses of the updated FEM and the experimental system that the thin layer of bilinear elastic-plastic material is very effective for modeling the nonlinear joint interface of the assembled structure with multiple bolts.

References listed at the end of the paper:


ABSTRACT: The nonlinear free and forced vibration of the composite beams embedded with shape memory alloy (SMA) fibers are investigated based on first-order shear deformation beam theory and the von Kármán type nonlinear strain-displacement equation. A thermomechanical constitutive equation of SMA proposed by Brinson is used to calculate the recovery stress of the constrained SMA fibers. The equations of motion are derived by using Hamilton’s principle. The approximate solution is obtained for vibration analysis of the composite beams based on the Galerkin approach. The parametric study is carried out to display the effect of the actuation temperature, the volume fraction, the initial strain of SMA fibers, and the length-to-thickness ratio. The shear deformation is shown to have a significant contribution to nonlinear vibration behavior of the composite beams with SMA fibers.

References listed at the end of the paper:

1 J. Zou, The constitutive relation of shape memory alloy and the analysis by the finite element method of shape memory alloy reinforced composite laminated plates [Ph.D. thesis], Huazhong University of Science and Technology, WuHan, China, 1999.

ABSTRACT: Design optimization of dynamic properties, for example, modal frequencies, can be of much importance when structures are exposed to the shock and/or vibration environments. A modal strain based method is proposed for fast design of natural frequencies of plate-like structures. The basic theory of modal strains of thin plates is reviewed. The capability of determining the highly sensitive elements by means of modal strain analysis is theoretically demonstrated. Finite element models were constructed in numerical simulations. Firstly, the application of the proposed method is conducted on a central-massed flat plate which was topologically optimized by the Reference. The results of modal strain analysis at the first mode have good agreement with the results from the topology optimization. Furthermore, some features of the strain mode shapes (SMSs) of the flat plate are investigated. Finally, the SMSs are applied to the optimization of a stiffened plate. Attention is focused on the distributions of the SMSs of the stiffeners, which also shows good agreement with the results from the topology optimization in the previous study. Several higher orders of SMSs are extracted, which can visualize the most sensitive elements to the corresponding modal frequency. In summary, both the theory and simulations validate the correctness and convenience of applying SMSs to dynamic design of plate-like structures.

References listed at the end of the paper:
The dynamic analysis of flexible delaminated layered beams is revisited. Exploiting Boolean vectors, a novel assembly scheme is developed which can be used to enforce the continuity requirements at the edges of delamination region, leading to a delamination stiffness term. The proposed assembly technique can be used to form various beam configurations with through-width delaminations, irrespective of the formulation used to model each beam segment. The proposed assembly system and the Galerkin Finite Element Method (FEM) formulation are subsequently used to investigate the natural frequencies and modes of 2- and 3-layer beam configurations. Using the Euler-Bernoulli bending beam theory and free mode delamination, the governing differential equations are exploited and two beam finite elements are developed. The free bending vibration of three illustrative example problems, characterized by delamination zones of variable length, is investigated. The intact and defective beam natural frequencies and modes obtained from the proposed assembly/FEM beam formulations are presented along with the analytical results and those available in the literature.

References listed at the end of the paper:
21 A. R. Ghorbanzad, Free vibration analysis of layered beams with delamination damage—an ANSYS-based FEM investigation [M.S. thesis], Department of Aerospace Engineering, Ryerson University, Toronto, Canada, 2012.

ABSTRACT: An analytical procedure for free vibration analysis of circular cylindrical shells with arbitrary boundary conditions is developed with the employment of the method of reverberation-ray matrix. Based on the Flügge thin shell theory, the equations of motion are solved and exact solutions of the traveling wave form along the axial direction and the standing wave form along the circumferential direction are obtained. With such a unidirectional traveling wave form solution, the method of reverberation-ray matrix is introduced to derive a unified and compact form of equation for natural frequencies of circular cylindrical shells with arbitrary boundary conditions. The exact frequency parameters obtained in this paper are validated by comparing with those given by other researchers. The effects of the elastic restraints on the frequency parameters are examined in detail and some novel and useful conclusions are achieved.

References listed at the end of the paper:

ABSTRACT: This paper presents a modified harmonic balance solution method incorporated with Vieta’s substitution technique for nonlinear multimode damped beam vibration. The aim of the modification in the solution procedures is to develop the analytic formulations, which are used to calculate the vibration amplitudes of a nonlinear multimode damped beam without the need of nonlinear equation solver for the nonlinear algebraic equations generated in the harmonic balance processes. The result obtained from the proposed method shows reasonable agreement with that from a previous numerical integration method. In general, the results can show the convergence and prove the accuracy of the proposed method.

References listed at the end of the paper:
ABSTRACT: Two kinds of hexagonal aluminum honeycombs are tested to study their out-of-plane crushing behavior. In the tests, honeycomb samples, including single hexagonal aluminum honeycomb (SAH) samples and two stack-up combined hexagonal aluminum honeycombs (CHAH) samples, are compressed at a fixed quasistatic loading rate. The results show that the inserting process of CHAH can erase the initial peak stress that occurred in SAH. Meanwhile, energy-absorbing property of combined honeycomb samples is more beneficial than the one of single honeycomb sample with the same thickness if the two types of honeycomb samples are completely crushed. Then, the applicability of the existing theoretical model for single hexagonal honeycomb is discussed, and an area equivalent method is proposed to calculate the crushing stress for nearly regular hexagonal honeycombs. Furthermore, a semiempirical formula is proposed to calculate the inserting plateau stress of two stack-up CHAH, in which structural parameters and mechanics properties of base material are concerned. The results show that the predicted stresses of three kinds of two stack-up combined honeycombs are in good agreement with the experimental data. Based on this study, stress-displacement curve of aluminum honeycombs can be designed in detail, which is very beneficial to optimize the energy-absorbing structures in engineering fields.

References listed at the end of the paper:
Lin Mu and Guiping Zhao (State Key Laboratory of Mechanical Structure Strength and Vibration, School of Aerospace, Xi’an Jiaotong University, Xi’an 710049, China), “Fundamental frequency analysis of sandwich beams with functionally graded face and metallic foam core”, Shock and Vibration, Article ID 3287645, Vol. 2016, http://dx.doi.org/10.1155/2016/3287645

ABSTRACT: This study is interested in assessing a way to analyze fundamental frequency of sandwich beams with functionally graded face sheet and homogeneous core. The face sheet, which is an exponentially graded material (EGM) varying smoothly in the thickness direction only, is composed of a mixture of metal and ceramic. The core which is made of foam metal is homogeneous. The classical plate theory (CPT) is used to analyze the face sheet and a higher-order theory (HOT) is used to analyze the core of sandwich beams, in which both the transverse normal and shear strains of the core are considered. The extended Galerkin method is used to solve the governing equations to obtain the vibration equations of the sandwich beams suitable for numerical analysis. The fundamental frequency obtained by the theoretical model is validated by using the finite element code ABAQUS and comparison with earlier works. The influences of material and geometric properties on the fundamental frequency of the sandwich beams are analyzed.

References listed at the end of the paper:


ABSTRACT: This paper presents a free vibration analysis of three-dimensional coupled beams with arbitrary coupling angle using an improved Fourier method. The displacement and rotation of the coupled beams are represented by the improved Fourier series which consisted of Fourier cosine series and closed-form auxiliary functions. The coupling and boundary conditions are accomplished by setting coupling and boundary springs and assigning corresponding stiffness values to the springs. Modal parameters are determined through the application of Rayleigh-Ritz procedure to the system energy formulation. The accuracy and convergence of the present method are demonstrated by finite element method (FEM) result. Investigation on vibration of the propulsion shafting structure shows the extensive applicability of present method. The studies on the vibration suppression devices are also reported.

References listed at the end of the paper:


ABSTRACT: Nonlinear vibration of a fluid-conveying pipe subjected to a transverse external harmonic excitation is investigated in the case with two-to-one internal resonance. The excitation amplitude is in the same magnitude of the transverse displacement. The fluid in the pipes flows in the speed larger than the critical speed so that the straight configuration becomes an unstable equilibrium and two curved configurations bifurcate as stable equilibriums. The motion measured from each of curved equilibrium configurations is governed by a nonlinear integro–partial–differential equation with variable coefficients. The Galerkin method is employed to
discretize the governing equation into a gyroscopic system consisting of a set of coupled nonlinear ordinary differential equations. The method of multiple scales is applied to analyze approximately the gyroscopic system. A set of first-order ordinary differential equations governing the modulations of the amplitude and the phase are derived via the method. In the supercritical regime, the subharmonic, superharmonic, and combination resonances are examined in the presence of the $2:1$ internal resonance. The steady-state responses and their stabilities are determined. The various jump phenomena in the amplitude-frequency response curves are demonstrated. The effects of the viscosity, the excitation amplitude, the nonlinearity, and the flow speed are observed. The analytical results are supported by the numerical integration.

References listed at the end of the paper:
ABSTRACT: For the applicability of dynamic similitude models of thin walled structures, such as engine blades, turbine discs, and cylindrical shells, the dynamic similitude design of typical thin walled structures is investigated. The governing equation of typical thin walled structures is firstly unified, which guides to establishing dynamic scaling laws of typical thin walled structures. Based on the governing equation, geometrically complete scaling law of the typical thin walled structure is derived. In order to determine accurate distorted scaling laws of typical thin walled structures, three principles are proposed and theoretically proved by combining the sensitivity analysis and governing equation. Taking the thin walled annular plate as an example, geometrically complete and distorted scaling laws can be obtained based on the principles of determining dynamic scaling laws. Furthermore, the previous five orders’ accurate distorted scaling laws of thin walled annular plates are presented and numerically validated. Finally, the effectiveness of the similitude design method is validated by experimental annular plates.

References listed at the end of the paper:


ABSTRACT: Based on the theory of Donnell and Kirchhoff hypothesis and by using the complex constant model of viscoelastic materials, the vibration equations of five-layered constrained damping plate are established. The transfer matrix method (TMM) is improved and used to solve equations. The improved TMM is more effective to solve complex structural vibration. The influence of layer numbers, thickness of each layer, and arrangement of materials on vibration behavior are discussed. It is proved that multilayered plates can more effectively reduce natural frequency and obtain higher structural loss factor. The loss factor increases with the number of whole layers. Symmetrical structure can obtain higher structural loss factor than one-direction structure. Uniform arrangement of viscoelastic materials and constrained materials can obtain higher structural loss factor than nonuniform arrangement. There is different optimum frequency with different material thickness, and the optimum frequency is not dependent from layer numbers.

References listed at the end of the paper:


http://dx.doi.org/10.1155/2016/8705031

ABSTRACT: A steel mesh can improve the tensile strength and stability of a polyethylene (PE) pipe in a water supply pipeline system. However, it can also cause more severe water hammer hazard due to increasing wave speed. In order to analyze the influence of the steel mesh on the shock wave speed and transient response processes, an improved wave speed formula is proposed by incorporating the equivalent elastic modulus. A field measurement validates the wave speed formula. Moreover, the transient wave propagation and extreme pressures are simulated and compared by the method of characteristics (MOC) for reinforced PE pipes with various steel-mesh densities. Results show that a steel mesh can significantly increase the shock wave speed in a PE pipe and thus can cause severe peak pressure and hydraulic surges in a water supply pipeline system. The proposed wave speed formula can more reasonably evaluate the wave speed and improve the transient simulation of steel-mesh-reinforced PE pipes.

References listed at the end of the paper:


**ABSTRACT:** Shape reconstruction of aerospace plate structure is an important issue for safe operation of aerospace vehicles. One way to achieve such reconstruction is by constructing smart fiber Bragg grating (FBG) plate structure with discrete distributed FBG sensor arrays using reconstruction algorithms in which error analysis of reconstruction algorithm is a key link. Considering that traditional error analysis methods can only deal with static data, a new dynamic data error analysis method is proposed based on LMS algorithm for shape reconstruction of smart FBG plate structure. Firstly, smart FBG structure and orthogonal curved network based reconstruction method is introduced. Then, a dynamic error analysis model is proposed for dynamic reconstruction error analysis. Thirdly, the parameter identification is done for the proposed dynamic error analysis model based on least mean square (LMS) algorithm. Finally, an experimental verification platform is constructed and experimental dynamic reconstruction analysis is done. Experimental results show that the dynamic characteristics of the reconstruction performance for plate structure can be obtained accurately based on the proposed dynamic error analysis method. The proposed method can also be used for other data acquisition systems and data processing systems as a general error analysis method.

References listed at the end of the paper:
ABSTRACT: The aim of this paper is to apply the elastic wave motion theory and the classical one-dimensional cavitation theory to analyze the response of a typical double-bottom structure subjected to underwater blast. The section-varying bar theory and the general acoustic impedance are introduced to get the simplified analytical models. The double-bottom structure is idealized by the basic unit of three substructures which include the simple panel, the panel with stiffener (T-shaped), and the panel associated with girder (I-shaped). According to the simplified models, the analytical models for the corresponding substructures are set up. By taking the cavitation effect into account, the process of fluid-structure interaction can be thoroughly understood, as well as the stress wave propagation. Good agreement between the analytical solution and the finite element prediction is achieved. On the other hand, the Taylor predictions for the panel associated with girder (I-shaped) including the effects of cavitation are invalid, indicating a potential field for the analytical method. The validated analytical models are used to determine the sensitivity of structure response to dimensionless geometric parameters, alpha, beta, and gamma. Based on the dynamic response of the substructures, we establish the approximate analytical models which are able to predict the response of double-bottom structure to underwater explosion.

References listed at the end of the paper:
ABSTRACT: A new model for the free transverse vibration of axially functionally graded (FG) tapered Euler-Bernoulli beams is developed through the spline finite point method by investigating the effects of the variation of cross-sectional and material properties along the longitudinal directions. In the proposed method, the beam is discretized with a set of uniformly scattered spline nodes along the beam axis instead of meshes, and the displacement field is approximated by the particularly constructed cubic B-spline interpolation functions with good adaptability for various boundary conditions. Unlike traditional discretization and modeling methods, the global structural stiffness and mass matrices for beams of the proposed model are directly generated after spline discretization without needing element meshes, generation, and assembling. The proposed method shows the distinguished features of high modeling efficiency, low computational cost, and convenience for boundary condition treatment. The performance of the proposed method is verified through numerical examples available in the published literature. All results demonstrate that the proposed method can analyze the free vibration of axially FG tapered Euler-Bernoulli beams with various boundary conditions. Moreover, high accuracy and efficiency can be achieved.

References listed at the end of the paper:

ABSTRACT: Radial vibration of the circular plate is presented using wave propagation approach and classical method containing Bessel solution and Hankel solution for calculating the natural frequency theoretically. In cylindrical coordinate system, in order to obtain natural frequency, propagation and reflection matrices are deduced at the boundaries of free-free, fixed-fixed, and fixed-free using wave propagation approach. Furthermore, radial phononic crystal is constructed by connecting two materials periodically for the analysis of band phenomenon. Also, Finite Element Simulation (FEM) is adopted to verify the theoretical results. Finally, the radial and piezoelectric effects on the band are also discussed.

References listed at the end of the paper:


YongHee Ryu, WooYoung Jung and BuSeog Ju, “Vibration effects of nonclassically damped building-piping systems subjected to extreme loads,” Shock and Vibration, Volume 2016, Article ID 6189326, 9 pages

http://dx.doi.org/10.1155/2016/6189326

ABSTRACT: Piping leakage can occur at T-joint, elbows, valves, or nozzles in nuclear power plants and nonnuclear power plants such as petrochemical plants when subjected to extreme loads and such leakage of piping systems can also lead to fire or explosion. For example, leakage of sodium, toxic gases, or nitrogen in hospitals can cause man-made hazards. The primary objective of this research is to understand the vibration effects due to classical/nonclassical damping with building-piping systems under extreme loads. The current
evaluation employed finite-element analysis to calculate the effects of the responses of classically and nonclassically damped building-piping systems. Classical and nonclassical damping matrices for a coupled primary-secondary system were developed based on the Rayleigh equation. A total of 10 selected ground motions were applied to single degree of freedom (SDOF) primary-SDOF secondary (2-DOF coupled) systems in which the ratios of the natural frequencies between the primary and secondary systems ranged between 0.9 and 1.1. It revealed that the vibration effect of nonclassical damping was significant where the natural frequencies of the two systems were nearly tuned. For piping-material nonlinearity, the effects of nonclassical damping on the result forces of piping systems were not significantly different from those of classical damping.

References listed at the end of the paper:


ABSTRACT: Lightweight sandwich structures with highly porous 2D cores or 3D (three-dimensional) periodic cores can effectively withstand underwater explosion load. In most of the previous studies of sandwich structure antiblast dynamics, the underwater explosion (UNDEX) bubble phase was neglected. As the UNDEX bubble load is one of the severest damage sources that may lead to structure large plastic deformation and crevasses failure, the failure mechanisms of sandwich structures might not be accurate if only shock wave is considered. In this paper, detailed 3D finite element (FE) numerical models of UNDEX bubble-LCSP (lightweight corrugated sandwich plates) interaction are developed by using MSC.Dytran. Upon the validated FE model, the bubble shape, impact pressure, and fluid field velocities for different stand-off distances are studied. Based on numerical results, the failure modes of LCSP and the whole damage process are obtained. It is demonstrated that the UNDEX bubble collapse jet local load plays a more significant role than the UNDEX shock wave load especially in near-field underwater explosion.

References listed at the end of the paper:


Ting Zhang, Ying Pan and Lijie Cao (College of Mechanical Engineering, Shanghai University of Engineering Science, Shanghai 201620, China), “Dynamical model for an interharmonic property of a piezoelectric bimorph cantilever beam with self-sensing function”, Shock and Vibration, Volume 2016, Article ID 606095, 9 pages
ABSTRACT: A piezoelectric bimorph cantilevered beam is analyzed dynamically by a longitudinal and transverse coupling theory. When a sinusoidal voltage is applied on the actuating layer of the bimorph, the output voltage of the sensing layer appears as interharmonic component signal. The interharmonic frequency is noninteger harmonic frequency of the applied voltage. A dynamic model is proposed to describe the interharmonic property of the piezoelectric bimorph beam. Through some simulations and experiments, the theoretical model is verified effectively to express the nonlinear characteristic. Furthermore, when the piezoelectric bimorph resonance happens, some interharmonic response at low frequency will modulate with the resonance response.

References listed at the end of the paper:


ABSTRACT: The vortex-induced vibration is one of the most important factors to make the engineering failure in wind engineering. This paper focuses on the suppression method of vortex-induced vibration that occurs on a circular cylinder fitted with vortex generators, based on the wind tunnel experiment. The effect of the vortex generators is presented with comparisons including the bare cylinder. The experimental results reveal that the vortex generators can efficiently suppress vortex-induced vibration of the circular cylinder. Vortex generator control can make the boundary layer profile fuller and hence more resistant to separation. The selections of skew angles and the angular position have a significant influence on the vortex generator control effect. By correlation analysis, it can be concluded that the vortex generators can inhibit the communication between the two shear layers and produce streamwise vortices to generate a disturbance in the spanwise direction.
Qiansheng Tang, Chaofeng Li and Bangchun Wen (School of Mechanical Engineering & Automation, Northeastern University, Shenyang 110819, China), “Analysis on forced vibration of thin-wall cylindrical shell with nonlinear boundary condition”, Shock and Vibration, Volume 2016, Article ID 8978932, 22 pages http://dx.doi.org/10.1155/2016/8978932

ABSTRACT: Forced vibration of thin-wall cylindrical shell under nonlinear boundary condition was discussed in this paper. The nonlinear boundary was modeled as supported clearance in one end of shell and the restraint was assumed as linearly elastic in the radial direction. Based on Sanders’ shell theory, Lagrange equation was utilized to derive the nonlinear governing equations of cylindrical shell. The displacements in three directions were represented by beam functions and trigonometric functions. In the study of nonlinear dynamic responses of thin-wall cylindrical shell with supported clearance under external loads, the Newmark method is used to obtain time history, frequency spectrum plot, phase portraits, Poincare section, bifurcation diagrams, and three-dimensional spectrum plot with different parameters. The effects of external loads, supported clearance, and support stiffness on nonlinear dynamics behaviors of cylindrical shell with nonlinear boundary condition were discussed.

References listed at the end of the paper:

ABSTRACT: In order to study the vibration problem of liquid-solid coupling of rectangular liquid-storage structure with horizontal elastic baffle, ignoring the influence of surface gravity wave, two different velocity potential functions corresponding to the liquid above and below the elastic baffle are assumed; based on the theory of mathematical equation and energy method, the formulas of basic frequency of liquid-solid coupling vibration system are derived, the baffle joined to the tank wall with 3 kinds of boundary conditions, namely, four edges simply supported, two opposite edges clamped and two opposite edges simply supported, and four edges clamped; the influence rules of baffle length-width ratio, the ratio of baffle height to liquid level, baffle elastic modulus, baffle density, baffle thickness, and liquid density on the coupling vibration performance are studied. The results show that the frequency of the clamped boundary is minimum; the influences of baffle length-width ratio and relative height on the basic frequency are much greater than that of the other system parameters; the relation between baffle length-width ratio and the frequency is exponential, while baffle relative height has a parabola relation with the frequency; the larger the baffle length-width ratio, the closer the baffle to the liquid level; the coupling frequency will be reduced more obviously.

References listed at the end of the paper:
References listed at the end of the paper:


**ABSTRACT:** Comparison study on free vibration of circular cylindrical shells between thin and moderately thick shell theories when using the exact dynamic stiffness method (DSM) formulation is presented. Firstly, both the thin and moderately thick dynamic stiffness formulations are examined. Based on the strain and kinetic energy, the vibration governing equations are expressed in the Hamilton form for both thin and moderately thick circular cylindrical shells. The dynamic stiffness is assembled in a similar way as that in classic skeletal theory. With the employment of the Wittrick-Williams algorithm, natural frequencies of circular cylindrical shells can be obtained. A FORTRAN code is written and used to compute the modal characteristics. Numerical examples are presented, verifying the proposed computational framework. Since the DSM is an exact approach, the advantages of high accuracy, no-missing frequencies, and good adaptability to various geometries and boundary conditions are demonstrated. Comprehensive parametric studies on the thickness to radius ratio (h/r) and the length to radius ratio (L/r) are performed. Applicable ranges of h/r are found for both thin and moderately thick DSM formulations, and influences of L/r on frequencies are also investigated. The following conclusions are reached: frequencies of moderately thick shells can be considered as alternatives to those of thin shells with high accuracy where h/r is small and L/r is large, without any observation of shear locking.

**References listed at the end of the paper:**

Thin-walled parts primarily comprise the entire piece of rough machining, and the material removal rate can surpass 95%. Numerous components with thin-walled structures are preferred in the aerospace industry for their light weight, high strength, and other advantages. In aerospace thin-walled workpiece machining processes and practical applications, they are excited by the vibration. The preload changing the modal stiffness of the part is found and this change causes continuous changes in the natural frequency. Researching on the influence of pretightening force on dynamic characteristics of thin-walled components is highly significant for controlling vibration. In this study, the typical aviation thin-walled part is the research object. Finite element numerical simulation and experimental verification are employed to analyze the dynamic characteristics of 7075 aluminum alloy thin-walled plates under different preloads for exploring the relationship between natural frequency and preload. The relationship is validated by comparative results. Both the simulation and experimental results show that the natural frequencies of plates increase following the augmentation of the preload. Thus, this research introduces the method where vibration of aerospace thin-walled parts is reduced by preload. For practical engineering application, a program showing the relationship between natural frequency and preload is written using Visual Basic language.

References listed at the end of the paper:
ABSTRACT: Applicability of the vibration correlation technique (VCT) for nondestructive evaluation of the axial buckling load is considered. Thin-walled cylindrical shells with and without circular cutouts have been produced by adhesive overlap bonding from a sheet of aluminium alloy. Both mid-surface and bond-line imperfections of initial shell geometry have been characterized by a laser scanner. Vibration response of shells under axial compression has been monitored to experimentally determine the variation of the first eigenfrequency as a function of applied load. It is demonstrated that VCT provides reliable estimate of buckling load when structure has been loaded up to at least 60% of the critical load. This applies to uncut structures where global failure mode is governing collapse of the structure. By contrast, a local buckling in the vicinity of a cutout could not be predicted by VCT means. Nevertheless, it has been demonstrated that certain reinforcement around cutout may enable the global failure mode and corresponding reliability of VCT estimation.

References listed at the end of the paper:


ABSTRACT: Lamb waves have shown promising advantages for damage identification in thin-walled structures. Multiple modes of Lamb wave provide diverse sensitivities to different types of damage. To sufficiently utilize damage-related wave features, damage indices were developed by using hybrid Lamb wave modes from Hilbert-Huang spectra. Damage indices were defined as surface integrals of Hilbert-Huang spectra on featured regions determined by time and frequency windowing. The time windowing was performed according to individual propagation velocity of different Lamb wave mode, while the frequency windowing was performed according to the frequency of excitation. By summing damage indices for all transmitter-receiver pairs, pixels were calculated to reconstruct a damage map to characterize the degree of damage at each location on structure. Both numerical and experimental validations were conducted to identify a nonpenetrating damage. The results demonstrated that the proposed damage indices using hybrid Lamb wave modes are more sensitive and robust than the one using single Lamb wave mode.

References listed at the end of the paper:


ABSTRACT: This paper presents free and forced vibration analysis of airtight cylindrical vessels consisting of elliptical, paraboloidal, and cylindrical shells by using Jacobi-Ritz Method. In this research, the theoretical model for vibration analysis is formulated by Flügge’s thin shell theory and the solution is obtained by Rayleigh-Ritz method. The vessel structure is divided into shell components (i.e., ellipsoid, parabolic, and cylinder) and their segments, and each displacement field of shell segments is represented by the Jacobi polynomials and the standard Fourth order series. The continuous conditions at the interface are modeled by using the spring stiffness technique. The reliability and the accuracy of the present method are verified by comparing the results of the proposed method with the results of the previous literature and the finite element method (FEM). Moreover, some numerical results for free and forced vibration of elliptical-cylindrical-elliptical vessel (ECE vessel) and paraboloidal-cylindrical-elliptical vessel (PCE vessel) are presented.

References listed at the end of the paper:
Masoud Biglarkhani (1) and Keyvan Sadeghi (2)
(1) Department of Civil Engineering, Hormozgan University, Bandar Abbas, Iran
(2) Department of Mechanical Engineering, Buein Zahra Technical University, Qazvin, Iran


ABSTRACT: Incremental explosive analysis (IEA) is addressed as an applicable method for performance-based assessment of stiffened and unstiffened cylindrical shells subjected to underwater explosion (UNDEX) loading. In fact, this method is inspired by the incremental dynamic analysis (IDA) which is a known parametric analysis method in the field of earthquake engineering. This paper aims to introduce the application of IEA approach in UNDEX in order to estimate different limit states and deterministic assessment of cylindrical shells, considering the uncertainty of loading conditions. The local, bay, and general buckling modes are defined as limit states for performance calculation. Different standoff distances and depth parameters combining several loading conditions are considered. The explosive loading intensity is specified and scaled in several levels to force the structure through the entire range of its behavior. The results are plotted in terms of a damage measure (DM) versus selected intensity measure (IM). The statistical treatment of the obtained multi-IEA curves is performed to summarize the results in a predictive mode. Finally, the fragility curves as damage probability indicators of shells in UNDEX loading are extracted. Results show that the IEA is a promising method for performance-based assessment of cylindrical shells subjected to UNDEX loading.

References listed at the end of the paper:
32 A. Shipping, Guide for b...
noise reduction per unit thickness decreases with the increase of laying thickness, while noise reduction per unit area increases.

References listed at the end of the paper:
4 K. Idrisi, Heterogeneous (HG) Blankets for Improved Aircraft Interior Noise Reduction, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA, 2005.


ABSTRACT: Dynamic Finite Element formulation is a powerful technique that combines the accuracy of the exact analysis with wide applicability of the finite element method. The infinite dimensionality of the exact solution space of plate equation has been a major challenge for development of such elements for the dynamic analysis of flexible two-dimensional structures. In this research, a framework for such extension based on subset solutions is proposed. An example element is then developed and implemented in MATLAB® software for numerical testing, verification, and validation purposes. Although the presented formulation is not exact, the element exhibits good convergence characteristics and can be further enriched using the proposed framework.

References listed at the end of the paper:

ABSTRACT: An efficient modified Fourier series-based sampling surface approach is proposed for the analytical evaluation of the vibration characteristics of thick curved beams subjected to general restraints. The theoretical models of the beams are formulated by the theory of elasticity in two dimensions, which allows arbitrary thickness configurations to be tackled. As an innovation of this work, the approach is based upon the sampling surface method combined with the use of modified Fourier series approximation. In particular, the transverse beam domain is discretized by a set of sampling surfaces with unequal spaces, and the displacement components in beam domain coinciding with these surfaces are mathematically described as a set of modified Fourier series in which certain supplementary functions are included to remove all the relevant discontinuities with the displacements and their derivatives at the boundaries to form a mathematically complete set and guarantee the results convergent to the exact solutions. The final results are numerically solved using a modified variational principle by means of Lagrange multipliers and penalty method for the sake of arbitrary boundary conditions. The influences of transverse normal and shear deformation on the vibration characteristics with respect to the geometrical dimension and boundary conditions are systematically evaluated.


ABSTRACT: A parameter optimal design method for a tank with an inerter system is proposed in this study based on the requirements of tank vibration control to improve the effectiveness and efficiency of vibration control. Moreover, a response indicator and a cost control indicator are selected based on the control targets for liquid storage tanks for simultaneously minimizing the dynamic response and controlling costs. These indicators are reformulated through a random vibration analysis under virtual excitation. The problem is then transformed from a multiobjective optimization problem to a single-objective nonlinear problem using the epsilon-constraint method, which is consistent with the demand-based method. White noise excitation can be used to design the tank with the inerter system under seismic excitation to simplify the calculation. Subsequently, a MATLAB-based calculation program is compiled, and several optimization cases are examined under different excitation conditions. The effectiveness of the demand-based method is proven through a time history analysis. The results show that specific vibration control requirements can be met at the lowest cost with a simultaneous reduction in base shears and overturning base moments.

References listed at the end of the paper:


ABSTRACT: The free vibration analysis of moderately thick functionally graded (FG) sector plates resting on two-parameter elastic foundation with general boundary conditions is presented via Fourier-Ritz method, which is composed of the modified Fourier series approach and the Ritz procedure. The material properties are assumed to vary continuously along the thickness according to the power-law distribution. The bilayered and single-layered functionally graded sector plates are obtained as the special cases of sandwich plates. The first-order shear deformation theory (FSDT) is adopted to construct the theoretical model. Under current framework, regardless of boundary conditions, each displacement and each rotation of plates is represented by the modified Fourier series consisting of a standard Fourier cosine series and several closed-form auxiliary functions introduced to ensure and accelerate the convergence of the series representation. Then, the accurate solutions are obtained by using the Ritz procedure based on the energy function of sector plates. The present method shows good convergence, reliability, and accuracy by comprehensive investigation with some selected classical boundary conditions. Numerous new vibration results for moderately thick FG sandwich sector plates are
provided. The effects of the elastic restraint parameters and so forth on free vibration characteristic of sector plates are presented.

References listed at the end of the paper:


ABSTRACT: The free vibration analysis of the functionally graded (FG) double curved shallow shell structures with general boundary conditions is investigated by an improved Fourier series method (IFSM). The material properties of FG structures are assumed to vary continuously in the thickness direction, according to the four graded parameters of the volume distribution function. Under the current framework, the displacement and rotation functions are set to a spectral form, including a double Fourier cosine series and two supplementary functions. These supplements can effectively eliminate the discontinuity and jumping phenomena of the displacement function along the edges. The formulation is based on the first-order shear deformation theory (FSDT) and Rayleigh–Ritz technique. This method can be universally applied to the free vibration analysis of the shallow shell, because it only needs to change the relevant parameters instead of modifying the basic functions or adapting solution procedures. The proposed method shows excellent convergence and accuracy, which has been compared with the results of the existing literatures. Numerous new results for free vibration analysis of FG shallow shells with various boundary conditions, geometric parameter, material parameters, gradient parameters, and volume distribution functions are investigated, which may serve as the benchmark solution for future researches.

References listed at the end of the paper:


ABSTRACT: It is important to study the properties and mechanics of egg drop impacts in order to reduce egg loss during processing and logistics and to provide a basis for the protective packaging of egg products. In this paper, we present the results of our study of the effects of the structural parameters on the mechanical properties of an egg using a finite element model of the egg. Based on Fluid–Solid coupling theory, a finite element model of an egg was constructed using ADINA, a finite element calculation and analysis software package. To simplify the model, the internal fluid of the egg was considered to be a homogeneous substance. The egg drop impact was simulated by the coupling solution, and the feasibility of the model was verified by comparison with the experimental results of a drop test. In summary, the modeling scheme was shown to be feasible and the simulation results provide a theoretical basis for the optimum design of egg packaging and egg processing equipment.

References listed at the end of the paper:
2 Y. Ren, Research on Biomechanics of Eggs Based on Shape Characteristics, Huazhong Agriculture University, Wuhan, China, 2007.
5 Z. Cui, Egg Static Load Characteristics Analysis and Study on Finite Elemen, Jiangsu University, Zhenjiang, China, 2009.
16 America Society of Agricultural Engineer. Compression Test of Food Materials of Convex Shape. ASAE Standarde, 2003: 596-603.

ABSTRACT: An improved Fourier series method (IFSM) is applied to study the free and forced vibration characteristics of the moderately thick laminated composite rectangular plates on the elastic Winkler or Pasternak foundations which have elastic uniform supports and multipoints supports. The formulation is based on the first-order shear deformation theory (FSDT) and combined with artificial virtual spring technology and the plate-foundation interaction by establishing the two-parameter foundation model. Under the framework of this paper, the displacement and rotation functions are expressed as a double Fourier cosine series and two supplementary functions which have no relations to boundary conditions. The Rayleigh–Ritz technique is applied to solve all the series expansion coefficients. The accuracy of the results obtained by the present method is validated by being compared with the results of literatures and Finite Element Method (FEM). In this paper, some results are obtained by analyzing the varying parameters, such as different boundary conditions, the number of layers and points, the spring stiffness parameters, and foundation parameters, which can provide a benchmark for the future research.

References listed at the end of the paper:
This research has experimentally investigated the influence on vibration characteristics of thin cantilever cylindrical shell (TCS) with hard coating under cantilever boundary condition. Firstly, the theoretical model of TCS with hard coating is established to calculate its natural frequencies and modal shapes so as to roughly understand vibration characteristic of TCS when it is coated with hard coating material. Then, by considering its nonlinear stiffness and damping influences, an experiment system is established to accurately measure vibration parameters of the shell, and the corresponding test methods and identification techniques are also proposed. Finally, based on the measured data, the influences on natural frequencies, modal shapes, damping ratios, and vibration responses of TCS with hard coating are analyzed and discussed in detail. It can be found that hard coating can play an important role in vibration reduction of TCS, and for the most modes of TCS, hard coating will result in the decrease of natural frequencies, but the decreased level is not very big, and its damping effects on the higher frequency range of the shell are weak and ineffective. Therefore, in order to make better use of this coating material, we must carefully choose the concerned antivibration frequency range of the shell; otherwise it may lead to some negative effects.

References listed at the end of the paper:


31 F. Ivancie, The Effect of a Hard Coating on the Damping and Fatigue Life of Titanium, Air Force Institute of Technology, Ohio, USA.
ABSTRACT: The resonator is the key element of the Coriolis Vibratory Gyroscope (CVG). The vibrational characteristics of the resonator, including the resonant frequency, vibrational amplitude, and Q factor, have a great influence on CVG’s performance. Among them, the vibrational amplitude mainly affects the scale factor and the signal-to-noise ratio, and the Q factor directly determines the precision and drift characteristics of the gyroscope. In this paper, a finite element model of a cylindrical shell resonator actuated by piezoelectric electrodes with different thicknesses is built to investigate the vibrational characteristics. The simulation results indicate that the resonant frequency barely changes with the electrode thickness, whereas the vibrational amplitude is inversely proportional to the electrode thickness under the same driving voltage. Experiments were performed with four resonators and piezoelectric electrodes of four sizes, and results were consistent with simulations. The resonant frequencies of four resonators changed within 0.36% after attaching the piezoelectric electrodes. Meanwhile, with the same driving voltage, it was shown that the vibrational amplitude decreased with the increase of electrode thickness. Moreover, thinner electrodes resulted in better Q factor and therefore better performance. This study may provide useful reference on electrode design of the CVGs.

References listed at the end of the paper:
20 Y. Tao, Study on key technologies of cupped wave [pdf thesis], National University of Defense Technology, Changsha, China, 2011.
ABSTRACT: Cylindrical explosive loading has an important application in explosive working, researching on weapon damage, and explosive-driving load. This study uses experimental and numerical methods to study the response of long and thin tubes when subjected to cylindrical explosive loading. The flake-like charge and multipoint initiation technique were adopted to load cylindrical explosive waves. Experimental results showed that the method could produce uniform deformation in certain parts of the long tube, but partial spall injuries occurred after the explosion. The macroscopic and microscopic deformation of tubes were analyzed. Numerical simulations were conducted to investigate the detailed response of the tube subjected to a cylindrical explosive wave. The results indicate that the collision of explosive waves brought inconsistencies in pressure and velocity. The pressure and velocity in the collision region were significantly higher than those of other parts, which caused the collision region to be easily damaged.

References listed at the end of the paper:

ABSTRACT: This paper presents the first known vibration characteristic of rectangular thick plates on Pasternak foundation with arbitrary boundary conditions on the basis of the three-dimensional elasticity theory. The arbitrary boundary conditions are obtained by laying out three types of linear springs on all edges. The modified Fourier series are chosen as the basis functions of the admissible function of the thick plates to eliminate all the relevant discontinuities of the displacements and their derivatives at the edges. The exact solution is obtained based on the Rayleigh–Ritz procedure by the energy functions of the thick plate. The excellent accuracy and reliability of current solutions are demonstrated by numerical examples and comparisons with the results available in the literature. In addition, the influence of the foundation coefficients as well as the boundary restraint parameters is also analyzed, which can serve as the benchmark data for the future research technique.

References listed at the end of the paper:
27 E. Winkler, Die Lehre von der Elastizität und Festigkeit, 1867.

ABSTRACT: Sandwich structures are able to provide enhanced strength, stiffness, and lightweight characteristics, thus contributing to an improved overall structural response. To this sandwich configuration one may associate through-thickness graded core material properties and homogeneous or graded properties nanocomposite skins. These tailormade possibilities may provide alternative design solutions to specific problem requisites. This work aims to address these possibilities, considering to this purpose a package of three beam layerwise models based on different shear deformation theories, implemented through Krigeing-based finite elements. The viscoelastic behaviour of the sandwich core is modelled using the complex method and the dynamic problem is solved in the frequency domain. A set of case studies illustrates the performance of the models.

References listed at the end of the paper:
ABSTRACT: This paper studies low-frequency sound transmission loss (STL) of an infinite orthogonally rib-stiffened sandwich structure flexibly connected with periodic subwavelength arrays of finite shunted piezoelectric patches. A complete theoretical model is proposed by three steps. First, the panels and piezoelectric patches on both sides are equivalent to two homogeneous facesheets by effective medium method. Second, we take into account all inertia terms of the rib-stiffeners to establish the governing equations by space harmonic method, separating the amplitude coefficients of the equivalent facesheets through virtual work principle. Third, the expression of STL is reduced. Based on the two prerequisites of subwavelength assumption and convergence criterion, the accuracy and validity of the model are verified by finite element simulations, cited experiments, and theoretical values. In the end, parameters affecting the STL performance of the structure are studied. All of these results show that the sandwich structure can improve the low-frequency STL effectively and broaden the sound insulation bandwidth.

References listed at the end of the paper:

43 1999.


ABSTRACT: A novel electric Gibbs function was proposed for the piezoelectric microbeams (PMBs) by employing a modified couple stress theory. Based on the new Gibbs function and the Euler-Bernoulli beam theory, the governing equations which incorporate the effects of couple stress, flexoelectricity, and
piezoelectricity were derived for the mechanics of PMBs. The analysis of the effective bending rigidity shows the effects of size and flexoelectricity can greaten the stiffness of PMBs so that the natural frequency increases significantly compared with the Euler-Bernoulli beam, and then the mechanical and electrical properties of PMBs are enhanced compared to the classical beam. This study can guide the design of microscale piezoelectric/flexoelectric structures which may find potential applications in the microelectromechanical systems (MEMS).

References listed at the end of the paper:
ABSTRACT: Nonstationary random vibration analysis of an infinitely long beam resting on a Kelvin foundation subjected to moving random loads is studied in this paper. Based on the pseudo excitation method (PEM) combined with the Fourier transform (FT), a closed-form solution of the power spectral responses of the nonstationary random vibration of the system is derived in the frequency-wavenumber domain. On the numerical integration scheme a fast Fourier transform is developed for moving load problems through a parameter substitution, which is found to be superior to Simpson’s rule. The results obtained by using the PEM-FT method are verified using Monte Carlo method and good agreement between these two sets of results is achieved. Special attention is paid to investigation of the effects of the moving load velocity, a few key system parameters, and coherence of loads on the random vibration responses. The relationship between the critical speed and resonance is also explored.

References listed at the end of the paper:

ABSTRACT: The similarity of each scale model is verified based on the theory of similarity, deriving the similarity law of internal explosions in a single-layer spherical lattice shell structure via dimensional theory, calculated based on models with scaling coefficients of 1, 0.8, 0.6, 0.4, 0.2, and 0.1. The results show that the shock wave propagation characteristics, the distribution of the overpressure on the inner surface, the maximum dynamic response position, and the position at which the earliest explosion venting occurs are all similar to those of the original model. With the decrease of scaling coefficients, the overpressure peak value of the shock waves of each scale model, and the specific action time of the positive pressure zone, as well as specific impulse are increasingly deviated from the original model values; when the scaling coefficient is 0.1, the maximum relative error between the overpressure peak value at the measurement point and the specific action time of the positive pressure zone as well as the specific impulse and the original model value is 4.9%. Thus, it is feasible to forecast the internal explosion effect of the original structure size model by using the experiment results of the scale model with scaling coefficient lambda gte 0.1.

References listed at the end of the paper:

Underwater shock loading experiment device is the equipment which simulates underwater explosive shock wave through experiment. Underwater shock loading experiment device was used to conduct high-speed underwater impact on aluminium foam panel and its damage modes were studied in this paper. 3D dynamic DIC test system was used to collect and analyze real-time deformation of target board. After the experiment was completed, a numerical simulation of the series of experiment was conducted through ABAQUS finite element simulation and then a comparative analysis of the experiment was implemented. To comprehensively study damage modes of aluminium foam panel subjected to underwater shock loading, damage modes of aluminium foam panel at different shock speeds were studied. Results indicated that when a certain impact speed which could damage aluminium foam panel was reached, if the impact speed was low, aluminium foam panel would generate shear fracture at constrained boundary of flange; if the impact speed was high, aluminium foam panel would firstly generate fracture at the center and then generate shear fracture at constrained boundary of flange, and central fracture would generate three cracks.

References listed at the end of the paper:


ABSTRACT: The free vibration behaviors of functionally graded rings were investigated theoretically. The material graded in the thickness direction according to the power law rule and the rings were assumed to be in plane stress and plane strain states. Based on the first-order shear deformation theory and the kinetic relation of von Kármán type, the frequency equation for free vibration of functionally graded ring was derived. The derived results were verified by those in literatures which reveals that the present theory can be appropriate to predict the free vibration characteristics for quite thick rings with the radius-to-thickness ratio from 60 down to 2.09. Comparison between the plane stress case and the plane strain case indicates a slight difference. Meanwhile, the effects of the structural dimensional parameters and the material inhomogeneous parameter are examined. It is interesting that the value of the logarithmic form of vibration frequency is inversely proportional to the logarithmic form of the radius-to-thickness ratio or the mean radius.
References listed at the end of the paper:


ABSTRACT: Nonlinear principal parametric resonance and stability are investigated for rotating circular plate subjected to parametric excitation resulting from the time-varying speed in the magnetic field. According to the conductive rotating thin circular plate in magnetic field, the magnetoelastic parametric vibration equations of a conductive rotating thin circular plate are deduced by the use of Hamilton principle with the expressions of kinetic energy and strain energy. The axisymmetric parameter vibration differential equation of the variable-velocity rotating circular plate is obtained through the application of Galerkin integral method. Then, the method of multiple scales is applied to derive the nonlinear principal parametric resonance amplitude-frequency equation. The stability and the critical condition of stability of the plate are discussed. The influences of detuning parameter, rotation rate, and magnetic induction intensity are investigated on the principal parametric resonance behavior. The result shows that stable and unstable solutions exist when detuning parameter is negative, and the resonance amplitude can be weakened by changing the magnetic induction intensity.

References listed at the end of the paper:


References listed at the end of the paper:


ABSTRACT: In order to obtain the dispersion rule of fragments about the asymmetric shell subjected to internal blast loading, two different cross section structures, concave-shaped and convex-shaped, were carried out by experimental and numerical methods. The simulation results well coincided with the experimental results, and the spatial distribution and fragment velocity were obtained. The optimal curvatures for the different concave structures changed from 4r to 6r (r represents the charge radius), as the central angle of concave structure changed from 90° to 120°. However, the optimal curvature changed weakly when the central angle of concave structure was larger than 120°. In addition, a formula which can rapidly predict the projection angle range was fitted for the convex structure. The conclusions can provide a reference for concave-shaped and convex-shaped structures to achieve a higher effectiveness of fragments.

References listed at the end of the paper:

1 R. W. Gurney, The Initial Velocities of Fragments from Bombs, Shells and Grenades, BRL Report No. 405, 1943.


ABSTRACT: A new differential transformation method is developed in this paper and is applied for free vibration problem of pipes conveying fluid. The natural frequencies, critical flow velocities, and vibration mode functions of such pipes with several typical boundary conditions are obtained and compared with the results predicted by Galerkin method and finite element method (FEM) and with other results archived. The results show that the present method is of high precision and can serve as an analytical method for the vibration of pipes conveying fluid.

References listed at the end of the paper:


ABSTRACT: To investigate the dynamic behavior of laminated plates with nonlinear elastic restraints, a varied constraint force model and a systematic numerical procedure are presented in this work. Several kinds of typical relationships of force-displacement for spring are established to simulate the nonlinear elastic restraints. In addition, considering the restraining moments of flexible pads, the pads are modeled by translational and rotational springs. The displacement-dependent constraint forces are added to the right-hand side of equations of motion and treated as additional applied loads. These loads can be explicitly defined, via an independent set of nonlinear load functions. The time histories of transverse displacements at typical points of the laminated plate are obtained through the transient analysis. Numerical examples show that the present method can effectively treat the geometrically nonlinear transient response of plates with nonlinear elastic restraints.

References listed at the end of the paper:

ABSTRACT: In the present paper, the problem on impact of a viscoelastic sphere against a viscoelastic plate is considered with due account for the extension of plate’s middle surface and local bearing of sphere and plate’s materials via the Hertz theory. The standard linear solid models with conventional derivatives and with fractional-order derivatives are used as viscoelastic models, respectively, outside and within the contact domain. As a result of impact, transient waves (surfaces of strong discontinuity) are generated in the plate, behind the wave fronts of which up to the boundaries of the contact domain the solution is constructed in terms of one-term ray expansions due to short-time duration of the impact process. The motion of the contact zone occurs under the action of extension forces acting in the plate’s middle surface, transverse force, and the Hertzian contact force. The suggested approach allows one to find the time-dependence of the impactor’s indentation into the target and the Hertzian contact force.

References listed at the end of the paper:
ABSTRACT: The modal analysis method (MAM) is very useful for obtaining the dynamic responses of a structure in analytical closed forms. In order to use the MAM, accurate information is needed on the natural frequencies, mode shapes, and orthogonality of the mode shapes a priori. A thorough literature survey reveals that the necessary information reported in the existing literature is sometimes very limited or incomplete, even for simple beam models such as Timoshenko beams. Thus, we present complete information on the natural
frequencies, three types of mode shapes, and the orthogonality of the mode shapes for simply supported Timoshenko beams. Based on this information, we use the MAM to derive the forced vibration responses of a simply supported Timoshenko beam subjected to arbitrary initial conditions and to stationary or moving loads (a point transverse force and a point bending moment) in analytical closed form. We then conduct numerical studies to investigate the effects of each type of mode shape on the long-term dynamic responses (vibrations), the short-term dynamic responses (waves), and the deformed shapes of an example Timoshenko beam subjected to stationary or moving point loads.

References listed at the end of the paper:
Min Wang (1), Mingshou Zhong (1), Yuan Long (1), Kai Ding (2), Xingbo Xie (1) and Liu Ying(1)
(1) Academy of Field Engineering, Army Engineering University of PLA, Nanjing, Jiangsu 210007, China
(2) Science and Technology on Near-Surface Detection Laboratory, Wuxi, Jiangsu 214035, China


ABSTRACT: With the combination of model experiment and numerical simulation, we explore the effect of collapse height, weight, and pipe-soil stiffness ratio on dynamic strain of shallow buried metal pipe under the collapse impact load. By analyzing the strain at different measuring points of the buried pipeline, the strain law of the buried pipeline under the collapse impact load is obtained. Based on the range analysis and variance significance analysis, it was found that the pipe-soil stiffness ratio has a more significant impact on the dynamic strain of the buried pipeline under impact compared to the collapse height and the weight. Then, the numerical simulation method was used to further analyze the effect of pipe-soil stiffness ratio on the dynamic response of buried pipelines; the following conclusions are drawn: As the stiffness ratio of pipe-soil increases, the plastic stress and strain of the buried pipeline will decrease, and influence of the pipeline by the collapse impact is slighter.

References listed at the end of the paper:
8 Z.-J. Sun, Analysis of Mechanical Properties of Buried Pipelines under Ground Surcharge Load, Zhejiang University, HangZhou, China, 2014.
References listed at the end of the paper:


ABSTRACT: Based on the bolted flange connection structure between stages of the missiles, four experimental specimens are simplified and manufactured, and the transverse impact failure experiments of the drop hammer are designed and carried out in this study. During the experiments, a new signal sensor is designed to collect the data of the bolts force, and the response data such as the bolts force, the slotted displacement of the connecting interface, and the impact force are collected in the loading process. The sequential failure mechanism of the structure under transverse impact load is analyzed and demonstrated according to the experimental results and the measured data. Additionally, a finite element model to simulate the failure process of the connection structure has been established, and the precision of the model has been verified and validated according to the experimental results. Moreover, the comparison between the results of the experiments and the simulation shows that the precision of this model is reliable in the engineering.

References listed at the end of the paper:
Wei Qu, Huaijiang Zhang, Wei Li, Wenqian Sun, Lina Zhao and Haihui Ning (School of Mechanical and Electrical Engineering, Central South University, Changsha 410083, China), “Influence of support stiffness on dynamic characteristics of the hydraulic pipe subjected to basic vibration”, Shock and Vibration, Article ID 4035725, Vol. 2018, https://doi.org/10.1155/2018/4035725

ABSTRACT: The basic vibration generated during the tunneling process of hard rock tunnel results in the change of the support stiffness of the hydraulic pipe, which causes the problem of reduction of pipe transmission efficiency. A transverse motion equation of the hydraulic pipe was established by correlating with Hamilton’s principle under basic vibration. In consideration of the fluid-structure interaction (FSI), the support was simplified as an equivalent and a spring. The bidirectional fluid-solid coupling analysis method was used to investigate dynamic characteristics of the pipeline under different support stiffness conditions. The finite element method (FEM) and the experimental analysis are applied to verify the proposed methodology. The numerical results show that the maximum displacement of the pipe decreases with the increase of the support stiffness; the maximum stress of the pipe decreases first and then increases with the increase of the support stiffness; the amplitude of the fluid pressure fluctuation at the outlet of the pipe increases with the increase of the support stiffness. But the fluid pressure fluctuation with the higher stiffness is first stable, which can indicate that the support stiffness can increase the damping of the pipe system. This study can get a significant access to the structural design of the pipeline under basic vibration.

References listed at the end of the paper:

ABSTRACT: Based on the positive scheme method, the thermal load of the jet flow in an inner composite-material direction pipe is obtained, and the thermoelasticity coupling transient response is investigated. The positive scheme method with second-order accuracy is extended for solving the axisymmetric Euler equations, and the supersonic axisymmetric jet flow over a missile afterbody containing jet exhaust is simulated. The correctness of the development for the positive scheme method is verified. With the developed positive scheme method used to simulate the jet flow in the inner direction pipe, the thermal load is obtained. The thermoelasticity coupling finite element model of the composite-material direction pipe is established, and the stress response under dynamic pressure, unsteady temperature, and coupling state is obtained. Results show that, at the beginning of engine ignition, the effect of dynamic pressure and temperature field on the coupling stress is basically the same, and after that, the contribution of the temperature field to the coupling stress increases, and the thermal stress is the main factor affecting the strength of the composite-material direction pipe.

References listed at the end of the paper:
ABSTRACT: The Galerkin method is proposed to reveal the dynamic response of pipe conveying fluid (PCF), with lateral moving supports on both ends of the pipe. Firstly, the dynamic equation is derived by the Newtonian method after calculating the acceleration of the fluid element via the dynamics approach. Secondly, the discrete form of the dynamic equation is formulated by the Galerkin method. Thirdly, the numerical analysis of the system is carried out through the fourth-order Runge–Kutta method, and the effectiveness of the proposed method is validated by comparison with the analytical results obtained by the mode superposition method. In the example analysis, the responses of the lateral deflection and bending moment are investigated for the pinned-pinned, clamped-pinned, and clamped-clamped PCF. The effects of fluid velocity and the moving frequencies of supports are discussed. Especially, the deflection responses are analyzed under extreme condition; i.e., the moving frequency of a support is identical to the natural frequency of PCF.

References listed at the end of the paper:

ABSTRACT: Vibration analysis and optimization of a rectangular plate with a flanging hyperellipse cutout is investigated in this paper, numerically. In the analysis, finite element method (FEM) is applied to perform parametric studies on various plates in different boundary conditions, addressing the influence of different cutout parameters (area, shape, flanging height, position, and rotation) on the first- and second-order natural frequencies of the rectangular plate and providing references for the optimum design. Then, maximization of frequency or the difference of two consecutive frequencies of the rectangular plate is carried out using Multi-island Genetic Algorithm, aiming to achieve the best dynamic characteristics. The results show that different cutout parameters have great influence on vibration performance of the plate, the existing of the flanging increases the out-of-plane stiffness of the plate. Additionally, the nature frequency of the plate has been improved obviously for different models with the optimal design of the cutout.

References listed at the end of the paper:
ABSTRACT: The experimental investigations on the square tubes with various stand-off distances and wall thickness were helpful to understand the dynamic response of metal shell under single and double explosion. Therefore, the effect of stand-off distance, wall thickness, and amounts of explosion on the deformation and damage of the square tubes and the regular pattern of the fracture development was analyzed by dimensions of local plastic deformation, volume of the depression area, and crack type. The result reveals that the deformation and fracture mode of steel square tubes gradually transform from local deformation to rupture with the decrease of wall thickness and stand-off distance. Besides, the failure degrees of square tubes under a double explosion were relatively higher than those of square tubes under a single explosion. In addition, the experiment indicates that the side corners of the square tube are very vulnerable, and they are damaged easily by the stress concentration and shear effect. The conclusion provides an important scientific basis for the structural design of square-tube structures and calculation of engineering protection.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: The inverse Finite Element Method (iFEM) is applied to reconstruct the displacement field of a shell structure which undergoes large deformations using discreet strain measurements as the prescribed data. The iFEM computations are carried out using an incremental procedure where at each load step, the incremental strains are used to evaluate the incremental displacements which in turn update the geometry of the deformed structure. The efficacy of the proposed approach to predict large displacements is examined using two case studies involving a cantilevered wing-shaped plate and a clamped plate. The incremental iFEM procedure is demonstrated to be sufficiently accurate in terms of reproducing the correct nonlinear character of the load-displacement curve even when a reduced number of strain sensors is used. Therefore, this approach may have important implications for real-time monitoring of aerospace structures that undergo large displacements. References listed at the end of the paper:


References listed at the end of the paper:


To study the seismic behavior of a single-layer reticulated dome subjected to severe earthquakes, a series of shaking table tests were conducted for this paper. Seismic responses including the acceleration, displacement, and strains gathered at the members and nodes were discussed. The dynamic characteristics, including structure frequencies and damping ratio, were obtained through the results under the input excitation of white noise and the fast sine sweeping with different amplitudes. Various isolation devices usually installed in the upper portion of the structures have been widely used to reduce the dynamic responses for more than three decades. However, these isolation devices deal mostly with either horizontal isolation or vertical isolation, which is not applicable for synchronous isolation in both horizontal and vertical isolation. Therefore, an innovative isolated support for three-dimensional isolation was invented. In order to understand the earthquake-isolation effects of a single-layer reticulated dome with the isolated support, a series of shaking table tests were conducted. The dynamic behavior of the structure was then investigated and discussed using the acceleration and displacement responses of the tested structures with or without the isolated supports. The experimental results show that the isolated support invented in this study had a remarkable earthquake-isolation action in both horizontal and vertical isolation.
References listed at the end of the paper:


ABSTRACT: Free vibration analysis of beams with single delamination undergoing bending-torsion coupling is made, using traditional finite element technique. The Galerkin weighted residual method is applied to convert the coupled differential equations of motion into to a discrete problem, where, in addition to the conventional mass and stiffness matrices, a delamination stiffness matrix, representing the extra stiffening effects at the delamination tips, is introduced. The linear eigenvalue problem resulting from the discretization along the length of the beam is solved to determine the frequencies and modes of free vibration. Both “free mode” and “constrained mode” delamination models are considered in formulation, and it is shown that the continuity (both kinematic and force) conditions at the beam span-wise locations corresponding to the extremities of the delaminated region, in particular, play a great role in “free mode” model formulation. Current trends in the literature are examined, and insight into different types of modeling techniques and constraint types are introduced. In addition, the data previously available in the literature and those obtained from a finite element-
based commercial software are utilized to validate the presented modeling scheme and to verify the correctness of natural frequencies of the systems analyzed here. The paper ends with general discussions and conclusions on the presented theories and modeling approaches.

References listed at the end of the paper:

ABSTRACT: A frequency-domain spectral element method (SEM) is proposed for the vibration analysis of thin plate structures subjected to a moving point force. The thin plate structures may consist of multiple rectangular thin plates with arbitrary boundary conditions that form multispans thin plate structures, such as bridges. The time-domain point force moving on a thin rectangular plate with arbitrary trajectory is transformed into a series of stationary point forces in the frequency domain. The vibration responses induced by the moving point force are then obtained by superposing all vibration responses excited by each stationary point force. For the vibration response of a specific stationary point force, the plate subjected to the specific stationary point force is represented by four spectral finite plate elements, which were developed in the authors’ previous work. The SEM-based vibration analysis technique is first presented for single-span thin plate structures and then extended to the multispans thin plate structures. The high accuracy and computational efficiency of the proposed SEM-based vibration analysis technique are verified by comparison with other well-known solution methods, such as the exact theory, integral transform method, finite element method, and the commercial finite element analysis package ANSYS.

References listed at the end of the paper:
31 W. C. Reynolds, Solution of Partial Differential Equations, Department of Mechanical Engineering, Stanford University, CA, USA, 1981.


ABSTRACT: To investigate the mechanical properties of embedded honeycomb plates with high efficiency and accuracy, a new multilayered equivalent finite element method (FEM) model is proposed. A series of FEM numerical studies (modal analysis, static analysis, and shock spectrum analysis) are performed. The goal is to compare the errors produced by the multilayered equivalent method and by existing equivalent approaches. The obtained results indicate that the proposed model shows good agreement with the original plate. Moreover, based on the new model, a parametric study correlating the microstructure parameters (embedded depth/cell size) to modal frequency is proposed, and a multiparameter equation for frequency and embedded depth/cell size is established to serve as a basis for structural optimization design.

References listed at the end of the paper:

ABSTRACT: To provide a theoretical basis for metal honeycombs used for buffering and crashworthy structures, this study investigated the out-of-plane crushing of metal hexagonal honeycombs with various cell specifications. The mathematical models of mean crushing stress and peak crushing stress for metal hexagonal honeycombs were predicted on the basis of simplified super element theory. The experimental study was carried out to check the accuracy of mathematical models and verify the effectiveness of the proposed approach. The presented theoretical models were compared with the results obtained from experiments on nine types of honeycombs under quasi-static compression loading in the out-of-plane direction. Excellent correlation has been observed between the theoretical and experimental results.

References listed at the end of the paper:
Considering the disastrous consequences of the oil tank failure, it is of great importance to ensure the safety of the large-scale oil tank under earthquakes. This study sheds light on investigating the dynamic response of a 100,000 m³ cylindrical oil storage tank under seismic excitations: The influence of core height and face plate thickness on the response of honeycomb sandwich panels subjected to blast loading. Materials and Design, vol. 31, no. 4, pp. 1887–1899, 2010.


ABSTRACT: Considering the disastrous consequences of the oil tank failure, it is of great importance to ensure the safety of the large-scale oil tank under earthquakes. This study sheds light on investigating the dynamic effects of various cellular structures on the energy absorption and crashworthiness of cylindrical metal honeycombs. The finite element method (FEM) is employed to simulate the dynamic responses of these structures under impact loading. The effects of core height, material, and face plate thickness on the energy absorption and crashworthiness of metal honeycombs are analyzed comprehensively. The results indicate that the honeycomb structure with a lower core height and thicker face plates exhibits better energy absorption and crashworthiness performance. This study provides valuable insights for the design and optimization of honeycomb structures in the field of oil storage facilities.
response of a prototype 100,000 m³ cylindrical oil-storage tank under various seismic excitations. The foundation of the tank is also considered in this study so that the obtained results are closer to the reality. Shaking table tests are conducted using a 1/20 scale liquid-tank-foundation system under various seismic excitations. The test results reveal that the dynamic responses such as accelerations and the deformation of the test specimen in the major and minor vibration directions do not differ significantly. Finite element models are constructed for the test specimen and the prototype tank and are validated through comparing the simulation results with the test data. The simulation results suggest that it might be necessary to stiffen the locations on the tank wall where the thickness of the tank wall changes because the stresses at such locations may be close or even exceed the yield strength of the structural steel under severe earthquakes.

References listed at the end of the paper:

7 Eurocode 8, Design of Structures for Earthquake Resistance–Part 4: Silos, Tanks and Pipelines, European Committee for Standardization (ECS), Brussels, Belgium, 2006.
ABSTRACT: The deformation and damage mechanism of shell structures under near-field explosion loads has been of great significance in the theoretical study of impact dynamics and may serve as a dependable theoretic basis for the antiexplosion design of shell structures. In this paper, the plastic zone and crevasse size of clamped square plates under near-field explosion loads were discussed based on the plastic hinge law and energy theory. The crevasse size of a plate moving at motion modes I and II under medium load was obtained according to the ultimate plastic strain criterion. Furthermore, the plastic zone under a high load was determined in terms of the movement law of a plastic hinge line. When the applied load ended, the crevasse sizes of the plates at motion modes III and IV were deduced on the basis of the principle of energy conservation. Finally, numerical simulation was used to analyze the deformation and damage mechanism of the shell structures under near-field explosion loads. The theory and method proposed in this paper are verified using ANSYS software and compared with the experimental results. This study verifies the validity of the proposed approach for analysis of the deformation and damage of a clamped square plate under near-field explosion loads.

References listed at the end of the paper:


ABSTRACT: The free flexural vibration of thin rectangular plates is revisited. A new, quasi-exact solution to the governing differential equation is formed by following a unique method of decomposing the governing equation into two beam-like expressions. Using the proposed quasi-exact solution, a Dynamic Coefficient Matrix (DCM) method is formed and used to investigate the free lateral vibration of a rectangular thin plate, subjected to various boundary conditions. Exploiting a special code written on MATLAB, the flexural natural frequencies of the plate are found by sweeping the frequency domain in search of specific frequencies that yield a zero determinant. Results are validated extensively both by the limited exact results available in the open literature and by numerical studies using ANSYS and in-house conventional FEM programs using both 12- and 16-DOF plate elements. The accuracy of all methods for lateral free vibration analysis is assessed and critically examined through benchmark solutions. It is envisioned that the proposed quasi-exact solution and the DCM method will allow engineers to more conveniently investigate the vibration behaviour of two-dimensional structural components during the preliminary design stages, before a detailed design begins.

References listed at the end of the paper:
2 C. L. M. H. Navier, Bulletin des sciences de la societe philomatique de Paris,
References listed at the end of the paper:


ABSTRACT: A series solution for the transverse vibration of Mindlin rectangular plates with elastic point supports around the edges is studied. The series solution for the problem is obtained using improved Fourier series method, in which the vibration displacements and the cross-sectional rotations of the midplane are represented by a double Fourier cosine series and four supplementary functions. The supplementary functions are expressed as the combination of trigonometric functions and a single cosine series expansion and are introduced to remove the potential discontinuities associated with the original admissible functions along the edges when they are viewed as periodic functions defined over the entire x-y plane. This series solution is approximately accurate in the sense that it explicitly satisfies, to any specified accuracy, both the governing equations and the boundary conditions. The convergence, accuracy, stability, and efficiency of the proposed method have been examined through a series of numerical examples. Some numerical examples about the nondimensional frequency and mode shapes of Mindlin rectangular plates with different point-supported edge conditions are given.


ABSTRACT: This paper is concerned with temperature effects on the modeling and vibration characteristics of Euler-Bernoulli beams with symmetric and nonsymmetric boundary conditions. It is assumed that in the considered model the temperature increases/decreases instantly, and the temperature variation is uniformly distributed along the length and the cross-section. By using the extended Hamilton’s principle, the mathematical model which takes into account thermal and mechanical loadings, represented by partial differential equations (PDEs), is established. The PDEs of the planar motion are discretized to a set of second-order ordinary differential equations by using the Galerkin method. As to three different boundary conditions, eigenvalue analyses are performed to obtain the close-form eigenvalue solutions. First four natural frequencies with thermal effects are investigated. By using the Lindstedt-Poincaré method and multiple scales method, the approximate solutions of the nonlinear free and forced vibrations (primary, super, and subharmonic resonances) are obtained. The influences of temperature variations on response amplitudes, the localisation of the resonance zones, and the stability of the steady-state solutions are investigated, through examining frequency response curves and excitation response curves. Numerical results show that response amplitudes, the number and the stability of nontrivial solutions, and the hardening-spring characteristics are all closely related to temperature changes. As to temperature effects on vibration behaviors of structures, different boundary conditions should be paid more attention.


ABSTRACT: This paper presents an accurate solution method for the static and vibration analysis of functionally graded Reissner-Mindlin plate with general boundary conditions on the basis of the improved Fourier series method. In the theoretical formulations, the governing equations and the general elastic boundary equations are obtained by using Hamilton’s principle. The components of admissible displacement functions are expanded as an improved Fourier series form which contains a 2D Fourier cosine series and auxiliary function in the form of 1D series. The major role of the auxiliary function is to remove the potential discontinuities of the displacement function and its derivatives at the edges and ensure and accelerate the convergence of the series representation. The characteristic equations are easily obtained via substituting admissible displacement
functions into governing equations and the general elastic boundary equations. Several examples are made to show the excellent accuracy and convergence of the current solutions. The results of this paper may serve as benchmark data for future research in related field.

References listed at the end of the paper:


study the effects of the fiber orientation, modulus ratio significantly affects the vibration of the shell structure. Additionally, parametric investigations are carried out to vary with different circumferential mode orders and vibrational power flow input and its propagation. It is found that characteristics of the vibrational power flow in the coupled system and the transmission of the power flow carried by different internal forces (moments) of the shell in the axial direction are established. Numerical computations are implemented to investigate the effects of arbitrary boundary conditions so as to maximize the structural overall LFS insulation. The basic ideas of this approach are as follows: (1) the sound transmission loss (TL) analysis of a plate with arbitrary boundary conditions is conducted by the coupled FEM-BEM method; (2) the single-number rating method (such as low frequency sound transmission class) is used to assess the plate’s overall LFS insulation; and (3) the genetic algorithm (GA) is employed for searching the optimal solutions of the multiple-parameter optimization problem. The proposed approach is subsequently illustrated by numerical studies. The results show the effectiveness of consideration of the effects of boundary condition in the plate’s LFS insulation optimization and demonstrate the feasibility and effectiveness of this approach as a structure design tool.


ABSTRACT: The Lindstedt-Poincaré method is applied to a nonuniform Euler-Bernoulli beam model for the free transverse vibrations of the system. The nonuniformities in the system include spatially varying and piecewise continuous bending stiffness and mass per unit length. The expression for the natural frequencies is obtained up to second-order and the expression for the mode shapes is obtained up to first-order. The explicit dependence of the natural frequencies and mode shapes on reference values for the bending stiffness and the mass per unit length of the system is determined. Multiple methods for choosing these reference values are presented and are compared using numerical examples.


ABSTRACT: A combined approach based on finite element method, boundary element method, and genetic algorithm (FEM-BEM-GA) is proposed for optimizing the low frequency sound (LFS) insulation performance of plate structures. This approach can identify the optimal structural parameters (especially concerning the effects of arbitrary boundary conditions) so as to maximize the structural overall LFS insulation. The basic ideas of this approach are as follows: (1) the sound transmission loss (TL) analysis of a plate with arbitrary boundary conditions is conducted by the coupled FEM-BEM method; (2) the single-number rating method (such as low frequency sound transmission class) is used to assess the plate’s overall LFS insulation; and (3) the genetic algorithm (GA) is employed for searching the optimal solutions of the multiple-parameter optimization problem. The proposed approach is subsequently illustrated by numerical studies. The results show the effectiveness of consideration of the effects of boundary condition in the plate’s LFS insulation optimization and demonstrate the feasibility and effectiveness of this approach as a structure design tool.


ABSTRACT: The characteristics of vibrational power flow in an infinite laminated composite cylindrical shell filled with fluid excited by a circumferential line cosine harmonic force are investigated using wave propagation approach. The harmonic motions of the shell and the fluid filled in the shell are described by Love shell theory and acoustic wave equation, respectively. Under the driving force, the vibrational power flow input into the coupled system and the transmission of the power flow carried by different internal forces (moments) of the shell in the axial direction are established. Numerical computations are implemented to investigate the vibrational power flow input and its propagation. It is found that characteristics of the vibrational power flow vary with different circumferential mode orders and frequencies, and the presence of fluid in the shell significantly affects the vibration of the shell structure. Additionally, parametric investigations are carried out to study the effects of the fiber orientation, modulus ratio E11/E22, and thickness-to-radius parameter h/R on input
power into the coupled system and propagation power along the shell axial direction. This work will provide some guidance for the vibration control of the laminated composite cylindrical shell.

References listed at the end of the paper:
ABSTRACT: Generalized differential quadrature (GDQ) method is used to analyze the vibration of sandwich beams with different boundary conditions. The equations of motion of the sandwich beam are derived using higher-order sandwich panel theory (HSAPT). Seven partial differential equations of motions are obtained through the use of Hamilton’s principle. The GDQ method is utilized to solve the equations of motion. Experiments are conducted to validate the proposed theory. The results from the analytical model are also compared to those from the literature and finite element method (FEM). Parametric studies are conducted to investigate the effects of different parameters on the natural frequency and response of the sandwich beam under various boundary conditions.

References listed at the end of the paper:


ABSTRACT: A modeling method is proposed for the vibration characteristics of rectangular plates with cutouts having variable size. Different from the existing modeling method by considering the cutout as an extremely thin part of the plate, the energy principles in conjunction with Rayleigh-Ritz solution technique are employed for the modeling of the structure. Under this theoretical framework, the effect of the cutout is taken into account by subtracting the energies of the cutout domains from the total energies of the whole plate with arbitrary boundary conditions. The displacement of the rectangular plate with nonuniform physic parameters is expressed as the combination of a two-dimensional trigonometric cosine series and supplementary terms introduced to ensure the uniform convergence of the solution over the entire solution domain including the cutouts boundary. The effectiveness and reliability of the eigenmodes of the rectangular plate with cutouts are checked against the results obtained by the finite element method (FEM). The cutout number, position, and size are varied to illustrate the effect of the cutouts on the vibration characteristics of the rectangular plate with cutouts.

References listed at the end of the paper:

ABSTRACT: The panel structures of flight vehicles at supersonic or hypersonic speeds are subjected to combined thermal, acoustic, and aerodynamic loads. Because of the combined thermal and acoustic loads, the panel structure may exhibit nonlinear random vibration responses, such as the snap-through phenomenon and random vibrations. These unique dynamic behaviors of the panel structure under combined thermal and acoustic loads can result in serious damage or fatigue failure of the panel structures of high-speed flight vehicles. This study investigates the nonlinear random responses of thin and thick panels under combined thermal and acoustic loads. The panels are modeled based on the first-order shear deformation theory (FSDT) to account for transverse shear deformations. The von-Karman nonlinear strain–displacement relationship is used for geometric nonlinearity in the out-of-plane direction of the panel. The thermal load distribution is assumed to be constant in the thickness direction of the panel. The random acoustic load is represented as stationary White–Gaussian random pressure with zero mean and uniform magnitude over the panels. Static and dynamic equations are derived using the principle of virtual work and the nonlinear finite element method. A thermal postbuckling analysis is conducted using the Newton–Raphson method, and the dynamic nonlinear equations are solved using the Newmark–β time integration method. In the present numerical analyses, the snap-through responses for both the thin and thick panels are investigated, and the results indicate that the loading conditions that cause snap-through are different for thin and thick panels.

References listed at the end of the paper:
6 Y. Lu, Random vibration analysis of higher-order nonlinear beams and composite plates with Applications of ARMA models [Ph.D. thesis], Virginia Polytechnic Institute and State University, Blacksburg, Va, USA, 2008.


ABSTRACT: Explosive vessels are vulnerable to shock wave impacts during operation processing. It is necessary to explore the vessel’s vibration characteristics. In this paper, acceleration sensors were adopted to collect vibration acceleration signals at the inner and outer surfaces of the composite double-layer explosive
vessel under explosive loading. Then, the effective vibration velocity curve can be obtained by fitting polynomials to eliminate the acceleration integral trend. Thereafter, Hilbert-Huang Transform (HHT) was applied to analyze the time-frequency distribution of vibration velocity signals. The results showed that the special “steel plate–buffer interlayer–steel plate” structure can effectively attenuate the explosion vibration effect, and the frequency distribution range of vibration signal at the inner surface was wider than that at the outer surface, and furthermore the main vibration frequency was close to the natural frequency at the inner surface. Meanwhile, vibration amplitude and the main vibration frequency decreased obviously compared with the outer surface, and the vibration time of 0–200 Hz low-order frequency was shortened. The above researches closely linked the energy distribution with frequency of vibration signals and provided valuable reference for safer protection and vibration reduction design of explosive vessel.


ABSTRACT: Free vibration of rings is presented via wave approach theoretically. Firstly, based on the solutions of out-of-plane vibration, propagation, reflection, and coordination matrices are derived for the case of a fixed boundary at inner surface and a free boundary at outer surface. Then, assembling these matrices, characteristic equation of natural frequency is obtained. Wave approach is employed to study the free vibration of these ring structures. Natural frequencies calculated by wave approach are compared with those obtained by classical method and Finite Element Method (FEM). Afterwards natural frequencies of four type boundaries are calculated. Transverse vibration transmissibility of rings propagating from outer to inner and from inner to outer is investigated. Finally, the effects of structural and material parameters on free vibration are discussed in detail.

References listed at the end of the paper:

ABSTRACT: Comparative experiments were conducted with two different structures to study the mechanism of aluminum foam sandwich attenuating blast shock wave. The sandwich structure is composed of “steel–aluminum foam–steel,” and the mild steel structure is composed of “steel–steel.” In the experiment, the polyvinylidene fluoride transducers were used to directly test the load of stress wave between different interfaces of sandwich and mild steel structures. The strain of back sheet was simultaneously measured using high-precision strain gauge. The accuracy of the test results was verified by Hench’s formula. Experimental results show that the wave attenuation rate on the mild steel structure is only 11.3%, whereas the wave attenuation rate on the sandwich structure can exceed 90%. The interface effect is clearly a more crucial factor in the wave attenuation. The peak value of back sheet strain in the mild steel structure is much higher than the sandwich structure. The apparent overall “X” crushing band is produced in the aluminum foam core, and scanning electron microscope (SEM) observation clearly shows the collapse of the cell wall. Experiments on the sandwich structure with different aluminum foam densities indicate that increasing the relative density results in increased attenuation capability of the aluminum foam and decreased attenuation capability of the sandwich structure. Experiments on the sandwich structure with different aluminum foam thickness indicate that increasing the thickness results in increased attenuation capability of the aluminum foam and the sandwich structure.

References listed at the end of the paper:
vibration investigation in the future. In addition, the effects of sector angles and ratio of inside to outside radii
results of frequency parameters with mode shapes are shown and may be used as benchmark results for the
obtained from the finite element analysis as well as open available literature. On this basis
refinement schemes (the h
Arnoldi Method. Several numerical examples of sector, annular, and circular plates are performed, and three
can be deriv
the exact geometry of sector, annular, and
circular plates, but also provide higher continuity of basis function and its derivatives. The governing equations
variable field. The NURBS basic functions can not only preserve the exact geometry of sector, annular, and
2018/4314761, Vol. 2018,
ABSTRACT: The in-plane free vibration of sector, annular, and circular plates is investigated by isogeometric
finite element approach on the basis of nonuniform rational B-spline (NURBS) basis functions. Under the
current framework, both the displacement field and geometry of the sector, annular, and circular plates are
modeled by NURBS basis functions to bridge the gap between the design of geometry and the analysis of
variable field. The NURBS basic functions can not only preserve the exact geometry of sector, annular, and
circular plates, but also provide higher continuity of basis function and its derivatives. The governing equations
can be derived by employing the principle of virtual work and the desired solutions are obtained by using the
Arnoldi Method. Several numerical examples of sector, annular, and circular plates are performed, and three
refinement schemes (the h-, p-, and k-refinement strategies) are applied to demonstrate the convergence. Then
the effectiveness and accuracy of the proposed approach are validated through comparisons with results
obtained from the finite element analysis as well as open available literature. On this basis, some new numerical
results of frequency parameters with mode shapes are shown and may be used as benchmark results for the
vibration investigation in the future. In addition, the effects of sector angles and ratio of inside to outside radii


References listed at the end of the paper:
ABSTRACT: For a few decades, various methods of suppressing structural vibration have been proposed. The present study proposes and exploits an effective method of suppressing the vibration of cantilever plates similar to the solar panels of a satellite. Magnetically tuned mass dampers (mTMDs) are a tuned mass damper (TMD) with eddy current damping (ECD). We introduce the mTMD concept for the multimode vibration suppression of the cantilever plate. The design parameters of the mTMD are determined based on the parametric study of the theoretical four-degree-of-freedom model, which was derived for a cantilever plate with TMDs. Two TMDs are optimized for the first bending mode and first torsion mode of the plate, and they are verified analytically.
and experimentally. To increase the damping performance of the TMDs, ECD is introduced. Its damping ratios are estimated analytically and verified experimentally.

References listed at the end of the paper:


ABSTRACT: Problems related to the transverse vibration of a rotating tapered cantilever beam with hollow circular cross-section are addressed, in which the inner radius of cross-section is constant and the outer radius changes linearly along the beam axis. First, considering the geometry parameters of the varying cross-sectional beam, rotary inertia, and the secondary coupling deformation term, the differential equation of motion for the transverse vibration of rotating taper beam with solid and hollow circular cross-section is derived by Hamilton variational principle, which includes some complex variable coefficient terms. Next, dimensionless
parameters and variables are introduced for the differential equation and boundary conditions, and the differential quadrature method (DQM) is employed to solve this differential equation with variable coefficients. Combining with discretization equations for the differential equation and boundary conditions, an eigen-equation of the system including some dimensionless parameters is formulated in implicit algebraic form, so it is easy to simulate the dynamical behaviors of rotating tapered beams. Finally, for rotating solid tapered beams, comparisons with previously reported results demonstrate that the results obtained by the present method are in close agreement; for rotating tapered hollow beams, the effects of the hub dimensionless angular speed, ratios of hub radius to beam length, the slenderness ratio, the ratio of inner radius to the root radius, and taper ratio of cross-section on the first three-order dimensionless natural frequencies are more further depicted.


ABSTRACT: Energy finite element analysis (EFEA) has unique advantages in solving high-frequency dynamic responses of orthotropic structures, due to its ability to obtain detailed local response information. In order to accurately predict high-frequency vibration response of the stiffened orthotropic plate, EFEA theory on the propagation of bending wave in the orthotropic structure and the energy transfer coefficient which express the energy transfer at the stiffener was investigated. Based on the EFEA theory presented, high-frequency dynamic responses of a stiffened orthotropic plates were predicted. Furthermore, tests were done for the same problem, and differences between prediction and test were discussed. Finally, the future works were pointed out.

References listed at the end of the paper:


ABSTRACT: Paper honeycomb sandwich panel is an environment-sensitive material. Its cushioning property is closely related to its structural factors, the temperature and humidity, random shocks, and vibration events in the logistics environment. In order to visually characterize the cushioning property of paper honeycomb sandwich panel in different logistics conditions, the energy absorption equation of per unit volume of paper honeycomb sandwich panel was constructed by piecewise function. The three-dimensional (3D) energy absorption diagram of paper honeycomb sandwich panel was constructed by connecting the inflexion of energy absorption curve. It takes into account the temperature, humidity, strain rate, and characteristics of the honeycomb structure. On the one hand, this diagram breaks through the limitation of the static compression curve of paper honeycomb sandwich panel, which depends on the test specimen and is applicable only to the standard condition. On the other hand, it breaks through the limitation of the conventional 2D energy absorption diagram which has less information. Elastic modulus was used to normalize the plateau stress and energy absorption per unit volume. This makes the 3D energy absorption diagram universal for different material sandwich panels. It provides a new theoretical basis for packaging optimized design.

References listed at the end of the paper:
ABSTRACT: Structures composed of functionally graded materials (FGM) can satisfy many rigorous requisitions in engineering application. In this paper, the nonlinear dynamics of a simply supported FGM conical panel with different forms of initial imperfections are investigated. The conical panel is subjected to the simple harmonic excitation along the radial direction and the parametric excitation in the meridian direction. The small initial geometric imperfection of the conical panel is expressed by the form of the Cosine functions. According to a power-law distribution, the effective material properties are assumed to be graded along the thickness direction. Based on the first-order shear deformation theory and von Karman type nonlinear geometric relationship, the nonlinear equations of motion are established by using the Hamilton principle. The nonlinear partial differential governing equations are truncated by Galerkin method to obtain the ordinary differential equations along the radial displacement. The effects of imperfection types, half-wave numbers of the imperfection, amplitudes of the imperfection, and damping on the dynamic behaviors are studied by numerical simulation. Maximum Lyapunov exponents, bifurcation diagrams, time histories, phase portraits, and Poincare maps are obtained to show the dynamic responses of the system.

References listed at the end of the paper:

19 W. Xiong, Energy absorption model research of paper honeycomb sandwich structure based on temperature and relative humidity [Master, thesis], Zhejiang Sci-Tech University, China, 2011.
20 Z. F. Xu, Energy absorption model research of paper honeycomb sandwich structure based on strain rate [Master, thesis], Xi’an University of Technology, China, 2011.


ABSTRACT: A survey of recent developments in the dynamic analysis of sandwich panels with face sheet-to-core debonding is presented. The finite element method within the ABAQUS™ code is utilized. The emphasis is directed to the procedures used to elaborate linear and nonlinear models and to predict dynamic response of the sandwich panels. Recently developed models are presented, which can be applied for structural health monitoring algorithms of real-scale sandwich panels. First, various popular theories of intact sandwich panels are briefly mentioned and a model is proposed to effectively analyse the modal dynamics of debonded and damaged (due to impact) sandwich panels. The influences of debonding size, form, and location and number of such damage incidents on the modal characteristics of sandwich panels are shown. For nonlinear analysis, models based on implicit and explicit time integration schemes are presented and dynamic responses gained with those models are discussed. Finally, questions related to debonding progression at the face sheet-core interface when dynamic loading continues with time are briefly highlighted.

References listed at the end of the paper:
2249, Leuven, Belgium, 2011.


ABSTRACT: A simple yet accurate solution procedure based on the improved Fourier series method (IFSM) is applied to the vibration characteristics analysis of a cylindrical shell-circular plate (S-P) coupled structure subjected to various boundary conditions. By applying four types of coupling springs with arbitrary stiffness at the junction of the coupled structure, the mechanical coupling effects are completely considered. Each of the plate and shell displacement functions is expressed as the superposition of a two-dimensional Fourier series and several supplementary functions. The unknown series-expansion coefficients are treated as the generalized coordinates and determined using the familiar Rayleigh-Ritz procedure. Using the IFSM, a unified solution for the S-P coupled structure with symmetrical and asymmetrical boundary conditions can be derived directly.
without the need to change either the equations of motion or the expressions of the displacements. This solution can be verified by comparing the current results with those calculated by the finite-element method (FEM). The effects of several significant factors, including the restraint stiffness, the coupling stiffness, and the situation of coupling, are presented. The forced vibration behaviors of the S-P coupled structure are also illustrated.

References listed at the end of the paper:


ABSTRACT: The Dynamic Finite Element (DFE) formulation is a superconvergent, semianalytical method used to perform vibration analysis of structural components during the early stages of design. It was presented as an alternative to analytical and numerical methods that exhibit various drawbacks, which limit their applicability during the preliminary design stages. The DFE method, originally developed by the second author, has been exploited heavily to study the modal behaviour of beams in the past. Results from these studies have shown that the DFE method is capable of arriving at highly accurate results with a coarse mesh, thus, making it an ideal choice for preliminary stage modal analysis and design of structural components. However, the DFE method has not yet been extended to study the vibration behaviour of plates. Thus, the aim of this study is to develop a set of frequency-dependent, trigonometric shape functions for a 4-noded, 4-DOF per node element as a basis for developing a DFE method for thin rectangular plates. To this end, the authors exploit a distinct quasi-exact solution to the plate governing equation and this solution is then used to derive the new, trigonometric basis and shape functions, based on which the DFE method would be developed.

References listed at the end of the paper:
ABSTRACT: This study employs experiments and numerical simulation to analyze the dynamic response of steel beams under huge-mass impact. The experiments were simulated using LSDYNA. The numerical simulation is in good agreement with experimental results, thus indicating that the LTB phenomenon is the real tendency of steel beams under impact. Meanwhile, the study shows that LS-DYNA can readily predict the LTB of steel beams. A numerical simulation on the dynamic response of H-shaped cross-section steel beams under huge-mass impact is conducted to determine the LTB behavior. The phenomenon of dynamic LTB is illustrated by displacement, strain, and deformation of H-shaped steel beams. Thereafter, a parametric study is conducted to investigate the effects of initial impact velocity and momentum on LTB. The LTB of H-shaped cross-section steel beams under transverse impact is primarily dependent on the level of impact kinetic energy, whereas impact momentum has a minor effect on LTB mode.

References listed at the end of the paper:

Mingyue Shao, Jimei Wu, Yan Wang and Qijumin Wu (First author is from: School of Mechanical and Precision Instrument Engineering, Xi’an University of Technology, Xi’an 710048, China), “Nonlinear parametric vibration and chaotic behaviors of an axially accelerating moving membrane”, Shock and Vibration, Article ID 6294814, Volume 2019, https://doi.org/10.1155/2019/6294814

ABSTRACT: Nonlinear vibration characteristics of a moving membrane with variable velocity have been examined. The velocity is presumed as harmonic change that takes place over uniform average speed, and the nonlinear vibration equation of the axially moving membrane is inferred according to the D’Alembert principle and the von Kármán nonlinear thin plate theory. The Galerkin method is employed for discretizing the vibration partial differential equations. However, the solutions concerning to differential equations are determined through the 4th order Runge–Kutta technique. The results of mean velocity, velocity variation amplitude, and aspect ratio on nonlinear vibration of moving membranes are emphasized. The phase-plane diagrams, time histories, bifurcation graphs, and Poincaré maps are obtained; besides that, the stability regions and chaotic regions of membranes are also obtained. This paper gives a theoretical foundation for enhancing the dynamic behavior and stability of moving membranes.

References listed at the end of the paper:


Masoud Derakhshani and Thomas A. Berfield (Mechanical Engineering Department, University of Louisville, Louisville, KY 40292, USA), “Snap-through and mechanical strain analysis of a MEMS bistable vibration energy harvester”, Shock and Vibration, Article ID 6743676, Volume 2019, https://doi.org/10.1155/2019/6743676

ABSTRACT: Vibration-based energy harvesting via microelectromechanical system- (MEMS-) scale devices presents numerous challenges due to difficulties in maximizing power output at low driving frequencies. This work investigates the performance of a uniquely designed microscale bistable vibration energy harvester featuring a central buckled beam coated with a piezoelectric layer. In this design, the central beam is pinned at its midpoint by using a torsional rod, which in turn is connected to two cantilever arms designed to induce bistable motion of the central buckled beam. The ability to induce switching between stable states is a critical strategy for boosting power output of MEMS. This study presents the formulation of a model to analyze the static and dynamic behaviors of the coupled structure, with a focus on the evolution of elongation strain within the piezoelectric layer. Cases of various initial buckling stress levels, driving frequencies, and driving amplitudes were considered to identify regimes of viable energy harvesting. Results showed that bistable-state switching, or snap-through motion of the buckled beam, produced a significant increase in power production potential over a range of driving frequencies. These results indicate that optimal vibration scavenging requires an approach that balances the initial buckling stress level with the expected range of driving frequencies for a particular environment.

References listed at the end of the paper:
[12] F. Cottone et al., “Piezoelectric buckled beams for random vibration energy harvesting,” Smart Materials and Structures, vol. 21,
no. 3, article 035021, 2012.


Desmond Adair, Askar Ibrayev, Alima Tazabekova and Jong R. Kim (First author is from: Department of Mechanical & Aerospace Engineering, Nazarbayev University, Astana 010000, Kazakhstan), “Free vibrations with large amplitude of axially loaded Euler–Bernoulli beams for various end restraints resting on a Winkler one-parameter foundation using the Adomian modified decomposition method”, Shock and Vibration, Article ID 3405075, Volume 2019, https://doi.org/10.1155/2019/3405075

ABSTRACT: Analytical solutions describing free transverse vibrations with large amplitude of axially loaded Euler–Bernoulli beams for various end restraints resting on a Winkler one-parameter foundation are obtained using the Adomian modified decomposition method (AMDM). The AMDM allows the governing equation to become a recursive algebraic equation, and, after some additional simple mathematical operations, the equations can be cast as an eigenvector problem whose solution results in the calculation of natural frequencies and corresponding closed-form series solution of the mode shapes. Important to the use of the Adomian modified decomposition method is the treatment of the nonlinear Fredholm integral coefficient, which forms part of the governing equation. In addition to the calculation of natural frequencies and mode shapes, investigations are made of the effects on the free vibrations of the Winkler parameter and of increasing the axial loading.

References listed at the end of the paper:


ABSTRACT: The multilayer plate has a great potential for automotive and aerospace applications. However, the complexity in structure and calculation of the response impede the practical applications of multilayer plates. To solve this problem, this work proposes a new plate finite element and a simplified finite element (FE) model for multilayer plates. The proposed new plate finite element consists of the shear and extension strains in all layers. The multilayer structure with the proposed new plate finite element is regarded as a reference to calculate the reference value of the transverse response. The simplified FE model of multilayer plates is proposed based on the equivalent bending stiffness by curve fitting of the reference value of the transverse response. Numerical study shows that this approach can be used to set up the simplified FE model of multilayer plates.

References listed at the end of the paper:
References listed at the end of the paper:  
2017.


Wuchao Zhao, Jiang Qian and Pengzhao Jia (State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University, Shanghai 200092, China), “Peak response prediction for RC beams under impact loading”, Shock and Vibration, Article ID 6813693, Volume 2019

ABSTRACT: In this paper, a novel and simple method for predicting the peak response of RC beams subjected to impact loading is proposed. The theoretical basis for calculating the peak impact force originates from the contact law, the principle of conservation of energy, the impulse-momentum theorem, and the wave theory. Additionally, the conventional beam theory, in conjunction with the well-known layered-section approach, is utilized to obtain the force-deflection relationship of the RC beam. Subsequently, by taking into account the strain rate effect, the maximum midspan deflection of RC beams under impact loading is determined based on the conservation of energy approach. A comparison with 143 impact tests has shown that the proposed method is able to estimate the maximum midspan deflection of RC beams under impact loading with high accuracy. The prediction of the peak impact force is shown to be slightly overestimated, which however can be used in the anti-impact design to preclude the shear failure near the impact point.

Hongjun Zhang, Cuangsong Chen, Linfang Qian and Jia Ma (School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing City 210094, China), “FE-meshfree QUAD4 element with modified radial point interpolation function for structural dynamic analysis”, Shock and Vibration, Article ID 3269276 Volume 2019

ABSTRACT: The partition-of-unity method based on FE-Meshfree QUAD4 element synthesizes the respective advantages of meshfree and finite element methods by exploiting composite shape functions to obtain high-order global approximations. This method yields high accuracy and convergence rate without necessitating extra nodes or DOFs. In this study, the FE-Meshfree method is extended to the free and forced vibration analysis of two-dimensional solids. A modified radial point interpolation function without any supporting tuning parameters is applied to construct the composite shape functions. The governing equations of elastodynamic problem are transformed into a standard weak formulation and then discretized into time-
dependent equations which are solved via Bathe time integration scheme to conduct the forced vibration analysis. Several numerical test problems are solved and compared against previously published numerical solutions. Results show that the proposed FE-Meshfree QUAD4 element owns greater tolerance for mesh distortion and provides more accurate solutions.

References listed at the end of the paper:


ABSTRACT: Tapered thin-walled structures have been widely used in wind turbine and rotor blade. In this paper, a spectral finite element model is developed to investigate tapered thin-walled beam structures, in which torsion related warping effect is included. First, a set of fully coupled governing equations are derived using Hamilton’s principle to account for axial, bending, and torsion motion. Then, the differential transform method (DTM) is applied to obtain the semianalytical solutions in order to formulate the spectral finite element. Finally, numerical simulations are conducted for tapered thin-walled wind turbine rotor blades and validated by the ANSYS. Modal frequency results agree well with the ANSYS predictions, in which approximate 30,000 shell elements were used. In the SFEM, one single spectral finite element is needed to perform such calculations because the interpolation functions are deduced from the exact semianalytical solutions. Coupled axial-bending-torsion mode shapes are obtained as well. In summary, the proposed spectral finite element model is able to accurately and efficiently perform the modal analysis for tapered thin-walled rotor blades. These modal frequency and mode shape results are important to carry out design and performance evaluation of the tapered thin-walled structures.


References listed at the end of the paper:

ABSTRACT: The present paper analyzes the vibration issue of thin-walled beams under combined initial axial load and end moment in two cases with different boundary conditions, specifically the simply supported-end and the laterally fixed-end boundary conditions. The analytical expressions for the first natural frequencies of thin-walled beams were derived by two methods that are a method based on the existence of the roots theorem of differential equation systems and the Rayleigh method. In particular, the stability boundary of a beam can be determined directly from its first natural frequency expression. The analytical results are in good agreement with those from the finite element analysis software ANSYS Mechanical APDL. The research results obtained here are useful for those creating tooth blade designs of innovative frame saw machines.

References listed at the end of the paper:


ABSTRACT: The free vibration characteristic of spherical cap with general edge constraints is studied by means of a unified method. The energy method and Kirchhoff hypothesis are adopted to derive the formulas. The displacement functions are improved based on the domain decomposition method, in which the unified Jacobi polynomials are introduced to represent the displacement function component along circumferential direction. The displacement function component along axial direction is still the Fourier series. In addition, the spring stiffness method forms a unified format to deal with various complex boundary conditions and the continuity conditions at two adjacent segments. Then, the final solutions can be obtained based on the Ritz method. To prove the validity of this method, the results of the same condition are compared with FEM, published literatures, and experiment. The results show that the present method has the advantages of fast...
convergence, high solution accuracy, simple boundary simulation, etc. In addition, some numerical results of uniform and stepped spherical caps with various geometric parameters and edge conditions are reported.

References listed at the end of the paper:

ABSTRACT: Based on the Ritz method, this paper focused on the free vibration of functionally graded (FG) spherical torus with uniform variable thickness along axial direction under different boundary conditions. The first-order shear deformation theory (FSDT) is employed to formulate the analytical model. The method involves partitioning of the spherical torus structure into proper shell segments in order to satisfy the computing requirement of high-order vibration responses according to the domain decomposition method. The two adjacent segments are connected by using the penalty method, where penalty parameters are defined by the artificial springs; the continuity condition and different boundary conditions can be obtained by assigning the appropriate values of springs. The displacement functions’ components are double mixed series, in which Fourier series and unified Jacobi polynomials, respectively, represent displacement function along circumferential direction and axial direction. Then the Ritz method is used to obtain final solutions. The numerical results obtained by the proposed method show great agreement with previously published literatures and those from the finite element program ABAQUS. The effects of boundary conditions and geometric parameters on the vibration responses of the structure are also presented. The most novelty of this paper is to generalize the selection of admissible displacement functions by using Jacobi polynomial. 

References listed at the end of the paper:


Yuan Cao, Rui Zhong, Dong Shao, Qingshan Wang, and Xianlei Guan (Authors 1 and 3 are from: Naval Research Academy, Beijing 100161, China), “Dynamic Analysis of Rectangular Plate Stiffened by Any Number of Beams with Different Lengths and Orientations”, Shock and Vibration, Article ID 2364515 Vol. 2019, https://doi.org/10.1155/2019/2364515

ABSTRACT: The present work is concerned with dynamic characteristics of beam-stiffened rectangular plate by an improved Fourier series method (IFSM), including mobility characteristics, structural intensity, and transient response. The artificial coupling spring technology is introduced to establish the clamped or elastic connections at the interface between the plate and beams. According to IFSM, the displacement field of the plate and the stiffening beams are expressed as a combination of the Fourier cosine series and its auxiliary functions. Then, the Rayleigh–Ritz method is applied to solve the unknown Fourier coefficients, which determines the dynamic characteristics of the coupled structure. The Newmark method is adopted to obtain the transient response of the coupled structure, where the Rayleigh damping is taken into consideration. The rapid convergence of the current method is shown, and good agreement between the predicted results and FEM results is also revealed. On this basis, the effects of the factors related to the stiffening beam (including the length, orientations, and arrangement spacing of beams) and elastic parameters, as well as damping coefficients on the dynamic characteristics of the stiffened plate are investigated.

References listed at the end of the paper:

ABSTRACT: Free vibration of rectangular plates with three kinds of porosity distributions and different boundary constraints has been performed by means of a semi-analytical method. The distribution of porous varies along the thickness of the plate, in which the mechanical properties are defined by open-cell metal foam. Regardless of boundary conditions, displacement admissible functions are represented by combination of standard cosine Fourier series and auxiliary sine series. The kinetic energy and potential energy of plates are also expressed on the basis of first-order shear deformation theory (FSDT) and displacement admissible functions. Finally, the coefficients in the Fourier series which determine natural frequencies and modal shape are derived by means of the Rayleigh–Ritz method. Convergence and dependability of the current method are verified by comparing with the results of FEM and related literatures. In addition, some new results considering geometry parameters under classical and elastic boundary constraints are listed. The effects of geometry parameters, material parameters, and boundary constraints have been discussed in detail.

References listed at the end of the paper:


ABSTRACT: In previous numerical models developed for the impact dynamic responses of reticulated domes, mostly BEAM 161 elements and piecewise linear plastic material model have been employed and spherical joints have been simplified as intersection points of beams, which is called the B-P method. The B-P method can be employed in studying the dynamic responses of reticulated shells under low- to moderate-speed impacts with no obvious temperature effect. However, the analysis of the dynamic responses of reticulated shells under moderate- and high-speed impacts of missiles and other aircraft using this method had errors because it could not take into account the temperature effect. To accurately describe the mechanical responses of reticulated shells under aircraft impacts, the Johnson–Cook material model considering temperature effect with corresponding SHELL 163 element was selected for determining the members of the numerical model and the shell element was used to establish the spherical joints of reticulated shells; the whole process was called the S-J modeling method. This modeling method was capable of considering the effects of high strain rates, high temperatures, large strains, stress state change, and loading history. S-J and B-P methods were used to model the reticulated shell structures. Comparing the numerical analysis results of the drop hammer impact of the two developed methods with experimental results verified the accuracy of the S-J modeling method. In addition, based on the results obtained from the S-J modeling method and LS-DYNA finite element analysis software, a numerical model was established for small aircraft impact reticulated shells and the failure modes and dynamic responses of reticulated shell structures under aircraft impacts were studied. In terms of energy analysis, it was found that the effects of roof plates, spherical joints, and temperature softening could not be ignored in such studies.

References listed at the end of the paper:
- L. Lin, Refined Study on Impact Response and Failure of Reticulated Shells, Harbin Institute of Technology, Harbin, China, 2015.
ABSTRACT: Large steel storage tanks designed with long-span structures, employed for storing oil and fuel, have been widely used in many countries over the past twenty years. Most of these tanks are thin-walled cylindrical shells. Owing to the high risk of gas explosions and the resulting deaths, injuries, and economic losses, more thorough damage analyses of these large structures should be conducted. This study examines the structural response of a simplified steel storage tank under a blast impact, as calculated by the LS-DYNA software package. The numerical results are then compared with a scale-model experiment. On that basis, the simplified storage tank prototype, which has a $15 \times 10^3$ m$^3$ capacity, is analyzed using numerical simulation. In this study, we address issues around the variation in structural responses—particularly of the failure mode, resultant displacement, structural energy, and dynamic strain under the impact. In addition, we also discuss the effects of varying the internal liquid level, constraint conditions, and blast intensity.

References listed at the end of the paper:


ABSTRACT: In practical engineering, pipeline vibration is often not caused by a single factor but by a combination of many factors. A fluid-structure coupling method is proposed in this paper and used to study the vibration of the compressor pipeline under the interaction of pipeline structure and airflow in it. The method is based on structured grids, so that the displacements of grid nodes can be calculated accurately at each time step. The results of transient calculation show that when the given inlet mass flow rate is constant and there is no other disturbance, the pressure fluctuation and the vibration of pipeline structure will occur by using fluid-structure coupling, and the vibration frequencies are consistent with the third- and fifth-order structural natural frequencies. Moreover, the higher the pressure in the pipe, the greater the fluid-structure coupling vibration. In addition, the fluid-structure coupling vibration not only occurs in the studied pipeline but also propagates to distant downstream pipeline. Comparing the above results with experimental results, it is found that the results of fluid-structure coupling calculation are in agreement with the actual situation, which shows that the method is reasonable and reliable and can be applied to engineering.

References listed at the end of the paper:

ABSTRACT: A semianalytical three-dimensional (3D) elasticity solution for the vibration of the orthotropic plate is presented under arbitrary boundary conditions. Three-dimensional (3D) elasticity theory provides the theoretical support for the energy function of orthotropic plates. The orthotropic plates which have the arbitrary boundary condition are realized by the way of arranging three sets of linear springs at the edges. With the aim of eliminating the nonsmooth phenomenon at the edges, the admissible displacement function of an orthotropic plate is expressed with a modified Fourier series solution. Under this framework, a change that occurs on the boundary conditions only needs to modify the boundary parameters of the orthotropic plate, without the need for new derivation, thus greatly saving the modeling time. The convergence and accuracy of the proposed method are better than those of the published literature. Lastly, the new vibration results and parametric research of thick orthotropic plates as well as the geometric parameter are also presented.

References listed at the end of the paper:


Jing Dong, Junhai Zhao, Dongfang Zhang, and Yingping Li (School of Civil Engineering, Chang’an University, Xi’an, Shaanxi 710061, China), “Research on Dynamic Response of Concrete-Filled Steel Tube Columns Confined with FRP under Blast Loading”, Shock and Vibration, Article ID 8692310 Vol. 2019, https://doi.org/10.1155/2019/8692310

ABSTRACT: Recently, a concrete-filled steel tube confined with fiber-reinforced polymer (FRP) has become a hot research issue as a new type of structure. These studies mainly focus on its static performance and seismic and impact behaviour, with little research on its blast resistance performance. In this study, the dynamic response of concrete-filled steel tube columns confined with FRP under blast loading was investigated. Numerical analysis was implemented using multimaterial ALE method in the finite element analysis program LS-DYNA. The proposed numerical model was validated by the SDOF result and available experimental data. And the effects of the number of FRP layers, concrete strength, and cross section were also discussed in detail based on the proposed numerical model. The results indicate that the constraints of FRP effectively enhance the blast resistance of the column, and the vulnerable parts mainly occur at the middle and two ends of the column. The blast resistance of the column can be enhanced by increasing the number of FRP layers or concrete strength. These results could provide a certain basis for blast resistance design of concrete-filled steel tubes confined with FRP.

References listed at the end of the paper:


UFC 3-340-02, Structures to Resist the Effects of Accidental Explosions, United States Department of the Army, Washington, DC, USA, 2008.


ABSTRACT: Antisloshing baffles are widely used in many engineering fields, including aerospace, ocean engineering, and nuclear engineering. The semianalytical scheme is proposed to explore the effect of the single flexible baffle on the coupled responses in the rigid cylindrical tank partially filled with ideal liquid undergoing the pitching excitation. The function series for the velocity potential, the dynamic deflection of the flexible baffle, and the surface wave height are given by introducing the time-dependent generalized coordinates. The Stokes–Joukowski potentials which are contained in the liquid velocity potential can be solved analytically. According to the dynamic and kinematic equations for the free surface and the coupled vibration equation for the flexible baffle, the coupled dynamic response equations are obtained. The additional damping terms are introduced to account for the sloshing damping. The semianalytical method is validated by the comparison study with the numerical results. Parameter studies are conducted to investigate the effects of the parameters of the flexible baffle on the coupled responses of the system.

References listed at the end of the paper:


INTRODUCTION: Continuous systems, such as beams, membranes, plates, shells, and other structural/mechanical components, represent fundamental elements of mechanical systems in any field of engineering: Aerospace, Aeronautics, Automation, Automotive, Civil, Nuclear, Petroleum, and Railways. The modern designer is required to optimize structural elements to improve the performance-to-cost ratio, produce lightweight machines, and improve the efficiency. Such optimizations easily lead to a magnification of vibration/dynamic problems such as resonances, instabilities, and nonlinear behaviors. Therefore, the development of new methods of analysis, testing, and monitoring is greatly welcome. This special issue focuses on sharing recent advances and developments of theories, algorithms, and applications that involve the dynamics and vibrations of continuous systems.

The contributions to this special issue include innovative theoretical studies, advanced numerical simulations, and new experimental approaches to investigate and better understand complex dynamic phenomena; more specifically, methods and theories for beams, membranes, plates, and shells; numerical approaches for structural elements; fluid-structure interaction; nonlinear acoustics; identification, diagnosis, friction models, and vehicle dynamics.

Seventeen contributions have been received from all over the world: Canada, China, Kazakhstan, Italy, Macau, Spain, and USA. This shows the generalized interest on the topic. The following short description of the special issue content is organized by grouping the contributions in coherent subtopics.

Fuzhen Pang, Cong Gao, Jie Cui, Yi Ren, Haichao Li, and Hongcheng Wang (All except the third author are from: College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China), “A Semianalytical Approach for Free Vibration Characteristics of Functionally Graded Spherical Shell Based on First-Order Shear Deformation Theory”, Shock and Vibration, Article ID 7352901 Vol. 2019, https://doi.org/10.1155/2019/7352901

ABSTRACT: This paper describes a unified solution to investigate free vibration solutions of functionally graded (FG) spherical shell with general boundary restraints. The analytical model is established based on the first-order shear deformation theory, and the material varies uniformly along the thickness of FG spherical shell which is divided into several sections along the meridian direction. The displacement functions along circumferential and axial direction are, respectively, composed by Fourier series and Jacobi polynomial regardless of boundary restraints. The boundary restraints of FG spherical shell can be easily simulated according to penalty method of spring stiffness technique, and the vibration solutions are obtained by Rayleigh–Ritz method. To verify the reliability and accuracy of the present solutions, the convergence and numerical verification have been conducted about different boundary parameters, Jacobi parameter, etc. The results obtained by the present method closely agree with those obtained from the published literatures, experiments, and finite element method (FEM). The impacts of geometric dimensions and boundary conditions on the vibration characteristics of FG spherical shell structure are also presented.

References listed at the end of the paper:


This paper describes an experimental study on the pure bending mechanical behavior of a pressurized pipe and adoption of a measured moment-curvature relationship under different working conditions in numerical simulations for transient pipe-whip prediction. To describe the effects of pipe contents and internal pressure, the governing equations were derived based on large deformation theory. Bending moment and axial force were uncoupled in the constitutive equation, and an experiment-based relationship between moment and curvature was adopted. The numerical simulations show that the present model can simulate the mechanical processes of elasticity, plastic hardening, and softening behavior in the initial, middle, and late stages of whole response, respectively. In addition, it was shown that kinks may occur at several positions along an empty cantilever pipe due to the collapse of sections under intense dynamic loading. However, this behavior did not occur for the full pressurized pipe, indicating that the contents and internal pressure are able to effectively impede the partial flattening of the pipe section, improving its critical curvature and changing its plastic dynamic response behavior.

References listed at the end of the paper:


Feng Liu, Yuchao Yang, and Yuelei Wu (Shandong University of Science and Technology, Shandong Provincial Key Laboratory of Civil Engineering Disaster Prevention and Mitigation, Qingdao 266510, China), “The Characteristic Transient Response of a Pressurized Cantilever Pipe SubJECTED to Transverse Impact at Its Tip”, Shock and Vibration, Article ID 4030379 Vol. 2019, https://doi.org/10.1155/2019/4030379

ABSTRACT: This paper describes an experimental study on the pure bending mechanical behavior of a pressurized pipe and adoption of a measured moment-curvature relationship under different working conditions in numerical simulations for transient pipe-whip prediction. To describe the effects of pipe contents and internal pressure, the governing equations were derived based on large deformation theory. Bending moment and axial force were uncoupled in the constitutive equation, and an experiment-based relationship between moment and curvature was adopted. The numerical simulations show that the present model can simulate the mechanical processes of elasticity, plastic hardening, and softening behavior in the initial, middle, and late stages of whole response, respectively. In addition, it was shown that kinks may occur at several positions along an empty cantilever pipe due to the collapse of sections under intense dynamic loading. However, this behavior did not occur for the full pressurized pipe, indicating that the contents and internal pressure are able to effectively impede the partial flattening of the pipe section, improving its critical curvature and changing its plastic dynamic response behavior.

ABSTRACT: This paper presents an investigation on the dynamical properties of single-walled carbon nanotubes (SWCNTs), and nonlinear modal interaction and energy exchange are analysed in detail. Resonance interactions between two conjugate circumferential flexural modes (CFMs) are investigated. The nanotubes are analysed through a continuous shell model, and a thin shell theory is used to model the dynamics of the system; free-free boundary conditions are considered. The Rayleigh–Ritz method is applied to approximate linear eigenfunctions of the partial differential equations that govern the shell dynamics. An energy approach, based on Lagrange equations and series expansion of the displacements, is considered to reduce the initial partial differential equations to a set of nonlinear ordinary differential equations of motion. The model is validated in linear field (natural frequencies) by means of comparisons with literature. A convergence analysis is carried out in order to obtain the smallest modal expansion able to simulate the nonlinear regimes. The time evolution of the nonlinear energy distribution over the SWCNT surface is studied. The nonlinear dynamics of the system is analysed by means of phase portraits. The resonance interaction and energy transfer between the conjugate CFMs are investigated. A travelling wave moving along the circumferential direction of the SWCNT is observed.

References listed at the end of the paper:


ABSTRACT: Auxetic mechanical metamaterials that exhibit a negative Poisson’s ratio (NPR) can be artificially designed to exhibit a unique range of physical and mechanical properties. Novel sandwich structures composed of uniform and gradient auxetic double arrowhead honeycomb (DAH) cores were investigated in terms of their vibration and sound transmission performance stimulated by nonhomogeneous metamaterials with nonperiodic cell geometries. The spectral element method (SEM) was employed to accurately evaluate the natural
frequencies and dynamic responses with a limited number of elements at high frequencies. The results indicated that the vibrating mode shapes and deformations of the DAH sandwich models were strongly affected by the patterned gradient metamaterials. In addition, the sound transmission performance of the considered DAH sandwich models was investigated regarding the sound transmission loss (STL) from 1 Hz to 1500 Hz under a normal incident planar wave, and this performance was compared with that for hexagonal honeycomb sandwich panels. A programmable structural-acoustic optimization was implemented to maximize the STL while maintaining a constant weight and high strength. The results showed that the uniform DAH sandwich models with larger NPRs generally exhibited better vibration and acoustic attenuation behaviors and that the optimized gradient increasing NPR models yielded higher STL values than the optimized gradient decreasing NPR models for two specified frequency cases, with improvements of 6.52 dB and 2.52 dB and a higher bending stiffness but a lower overall STL. Thus, sandwich panels consisting of auxetic DAHs can achieve desirable vibroacoustic performance with a higher bending stiffness than conventional hexagonal honeycomb sandwich structures, and the design of gradient DAHs can be extended to obtain optimized vibration and noise-control capabilities.

References listed at the end of the paper:
nucleation of new holes inside the material domain, and the final design is insensitive to initial designs. The optimized result is demonstrated that the modal strain energy method. The finite element model for the composite plate is described as a combination of several desired modal loss factors for a single modal show that the proposed method has the possibility of solving by


ABSTRACT: Sensitivity analysis and response surface methods were employed to optimize the structural modal of SUV doors. A finite element numerical simulation model was established and was calibrated by restraint modal tests. To screen out highly sensitive panels, a sensitivity analysis for the thickness of door panels was proposed based on the fifth-order modal frequency of the door. Data points were obtained by a faceted central composite design with the design variables from the thickness of the highly sensitive panels, and a second-order explicit response surface function of the fifth-order modal frequency of the vehicle door was established. An optimization model was established according to the response surface method. The final results demonstrate that the modal-frequency matching of the door and body in white was optimized after changing the thicknesses, with a 5.74% material reduction.


ABSTRACT: Application of level set method to optimize the topology of free damping treatments on plates is investigated. The objective function is defined as a combination of several desired modal loss factors solved by the finite element-modal strain energy method. The finite element model for the composite plate is described as combining the level set function. A clamped rectangle composite plate is numerically and experimentally analyzed. The optimized results for a single modal show that the proposed method has the possibility of nucleation of new holes inside the material domain, and the final design is insensitive to initial designs. The
damping treatments are guided towards the areas with high modal strain energy. For the multimodal case, the optimized result matches the normalized modal strain energy of the base plate, which would provide a simple implementation way for industrial application. Experimental results show good agreements with the proposed method. The experimental results are in good agreement with the optimization results. It is very promising to see that the optimized result for each modal has almost the same damping effect as that of the full coverage case, and the result for multimodal gets moderate damping at each modal.

References listed at the end of the paper:


ABSTRACT: Free vibration of conical shells of variable thickness is analysed under shear deformation theory with simply supported and clamped free boundary conditions by applying collocation with spline approximation. Sinusoidal thickness variation of layers is assumed in axial direction. Displacements and rotational functions are approximated by Bickley-type splines of order three and a generalized eigenvalue problem is obtained. This problem is solved numerically for an eigenfrequency parameter and an associated eigenvector of spline coefficients. The vibration of composite conical shells consisting of three layers and five layers where each layer is made up of different materials is analysed. Parametric studies are made for analysing the frequencies of the shell with respect to the coefficients of thickness variations, length ratio, cone angle, circumferential node number, and different ply angles with different combinations of the materials. The results are presented in terms of tables and graphs.

References listed at the end of the paper:


ABSTRACT: Numerical studies on the vibration and acoustic characteristics of a simply supported double-panel partition under the thermal environment are presented by the modal superposition approach and temperature field theory. Many factors are considered in this theoretical research, including acoustic refraction, dynamic response of the panel under thermal and acoustic load, vibroacoustic coupling characteristic analysis, and the variation of material properties. To access the accuracy and feasibility of the theoretical model, a finite element method is proposed to calculate the natural frequencies and mode shapes. The results show that the vibration and acoustic responses change obviously with the change of thermal stress and material properties. The rise of the graded thermal environment and thermal load decreases the natural frequencies and moves response peaks to the low-frequency range. The first valley of sound transmission loss is well consistent with the mode frequency. Finally, the relation between the average sound insulation and the thickness ratio is analyzed.

References listed at the end of the paper:

ABSTRACT: In this research, an exact dynamic stiffness model for spatial plate built-up structures under comprehensive combinations of boundary conditions is newly proposed. Dynamic stiffness formulations for plate elements with 16 different types of supported opposite edges and arbitrarily supported boundary conditions along other edges are developed, which makes the dynamic stiffness method (DSM) more applicable to engineering problems compared to existing works. The Wittrick–Williams algorithm of the DSM is applied with the explicit expressions of the J count for plate elements under all above support conditions. In return, there is no need to refine the element in the DSM, and thus, it becomes immensely efficient. Moreover, the present theory is applied for exact free vibration analysis within the whole frequency range of three built-up structures which are commonly encountered in engineering. The results show that the DSM gives exact results with as much as 100-fold computational efficiency advantage over the commercial finite element method. Besides, benchmark results are also provided.

References listed at the end of the paper:


Xi Zhang (1), Qiming Wang (2), Yousan Wang (3), and Qing Li (1)
(1) School of Mechanics and Civil Engineering, China University of Mining and Technology, Beijing, China
(2) China Aerospace Construction Group Co., Ltd., Beijing, China
(3) State Forestry Planning and Design Institute of Forest Products Industry, Beijing 100009, China

ABSTRACT: The large-span floor system being lightweight with low frequency and low damping is prone to suffer severe vibration under human excitations. In this research, the vibration performance of an innovative large-span U-shaped steel-concrete composite hollow waffle (CHW) slab was studied based on field testing and theoretical analysis. First, the modal properties of CHW slab including mode shapes, frequencies, and damping ratio were captured by on-site tests and validated by the finite element method, indicating the CHW slab is a low-frequency floor system with a low damping ratio. Second, the vibration responses of CHW slab under heel-drop and jumping excitations were studied considering the impacts of spatial position, tester number, and activity types. Third, the CHW slab shows excellent vibration serviceability proved by the frequency, accelerations, and human perceptions threshold with the current codes. Meanwhile, the paper gives appropriate threshold values for the CHW slab under impulsive excitation. Finally, the natural frequency formula for the CHW slab derived by the Rayleigh–Ritz energy method agrees well with the measurements.


ABSTRACT: In this research, an exact dynamic stiffness model for spatial plate built-up structures under comprehensive combinations of different boundary conditions is newly proposed. Dynamic stiffness formulations for plate elements with 16 different types of supported opposite edges and arbitrarily supported boundary conditions along other edges are developed, which makes the dynamic stiffness method (DSM) more applicable to engineering problems compared to existing works. The Wittrick–Williams algorithm of the DSM is applied with the explicit expressions of the J count for plate elements under all above support conditions. In return, there is no need to refine the element in the DSM, and thus, it becomes immensely efficient. Moreover, the present theory is applied for exact free vibration analysis within the whole frequency range of three built-up structures which are commonly encountered in engineering. The results show that the DSM gives exact results with as much as 100-fold computational efficiency advantage over the commercial finite element method. Besides, benchmark results are also provided.

References listed at the end of the paper:


ABSTRACT: Membrane materials are widely used in construction engineering with small mass and high flexibility, which presents strong geometric nonlinearity in vibration. In this paper, an improved multiscale perturbation method is used to solve the aerostatics stability of membrane roofs on closed and open structures by quantifying the effect of geometric nonlinearity on the single-mode aeroelastic instability wind velocity. Results show that the critical wind velocities of two models are smaller when the geometrical nonlinearity of the membrane material is neglected. In addition, under normal wind load, the influence of geometrical nonlinearity of the membrane on the aerodynamic stability of the roof can be neglected. However, under strong wind load, when the roof deformation reaches 3% of the span, the influence of geometric nonlinearity should be considered and the influence increases with the decrease of transverse and downwind span of the membrane roof. The results obtained in this paper have an important theoretical reference value for the design membrane structures.

References listed at the end of the paper:


ABSTRACT: This paper focuses on the derivation of the aerodynamic force for the cantilever plate in subsonic flow. For the first time, a new analytical expression of the quasi-steady aerodynamic force related to the velocity and the deformation for the high-aspect-ratio cantilever plate in subsonic flow is derived by utilizing the subsonic thin airfoil theory and Kutta-Joukowski theory. Results show that aerodynamic force distribution obtained theoretically is consistent with that calculated by ANSYS FLUENT. Based on the first-order shear deformation and von Karman nonlinear geometric relationship, nonlinear partial differential dynamical equations of the high-aspect-ratio plate subjected to the aerodynamic force are established by using Hamilton’s principle. Galerkin approach is applied to discretize the governing equations to ordinary differential equations. Numerical simulation is utilized to investigate the relation between the critical flutter velocity and some parameters of the system. Results show that when the inflow velocity reaches the critical value, limit cycle oscillation occurs. The aspect ratio, the thickness, and the air damping have significant impact on the critical flutter velocity of the thin plate.

References listed at the end of the paper:


ABSTRACT: A computational method is developed to study the dynamics of lightweight deployable structures during the motion process without regard to damping. Theory and implementation strategy of the developed method are given in this study. As a case study, the motion process of a bar-joint structure and a ring array scissor-type structure was simulated under external dynamic loading. In order to verify the effectiveness of the method, the simulation results are compared with the results predicted by the authenticated multibody system dynamics and simulation program. It shows that the method is effective to dynamic analysis of deployable structures no matter the structures are rigid or elastic. Displacement, velocity, and acceleration for the entire deployable structures during the motion process can be computed, as well as strain if the deployable structure is elastic.

References listed at the end of the paper:


ABSTRACT: According to the advantages of high tensile resistance and high shear strength of composite steel plate, a new antiexplosion protection method of composite steel plate lining structure is put forward. The numerical model of explosion impact of subway tunnel with composite steel plate lining structure was established by dynamic analysis software. The transient dynamic response of lining structure with the composite steel plate was simulated when explosion occurred. The research results show that the influence of explosive quantity on each point of composite steel plate lining structure is different and the change of acceleration near the centre of the detonation source is generally greater than the multiple of the increase of explosive quantity. The increase of velocity and displacement is basically consistent with the quantity of explosive. The influence of axial stress on the lining structure is the least, and the influence of the lining structure is greater in the y-direction than in the x-direction. The research results can provide the plan and basis for the emergency response of the subway tunnel.

References listed at the end of the paper:

- Y. Cui, Dynamic Response and Damage Assessment of Duplex Hollow CFST Column Subjected to Blast Loading, Changan University, Xi’an, China, 2013.
- S. H. Qu, Structural Response and Damage and Ground Vibration of Subway Station under Internal Explosion, Tianjin University, Tianjin, China, 2008.
ABSTRACT: A bidirectional functionally graded Sandwich (BFGSW) beam model made from three distinct materials is proposed and its dynamic behavior due to nonuniform motion of a moving point load is investigated for the first time. The beam consists of three layers, a homogeneous core, and two functionally graded face sheets with material properties varying in both the thickness and longitudinal directions by power gradation laws. Based on the first-order shear deformation beam theory, a finite beam element is derived and employed in computing dynamic response of the beam. The element which used the shear correction factor is simple with the stiffness and mass matrices evaluated analytically. The numerical result reveals that the material distribution plays an important role in the dynamic response of the beam, and the beam can be designed to meet the desired dynamic magnification factor by appropriately choosing the material grading indexes. A parametric study is carried out to highlight the effects of the material distribution, the beam layer thickness and aspect ratios, and the moving load speed on the dynamic characteristics. The influence of acceleration and deceleration of the moving load on the dynamic behavior of the beam is also examined and highlighted.

References listed at the end of the paper:

- W. W. Zhang, Study of Impulse Response and Shield Technology of Subway Station under Terrorist Explosion load, Shandong University of Science and Technology, Qingdao, China, 2010.


ABSTRACT: In this paper, the parametric dynamics of bidirectional functionally graded (BDFG) beams subjected to a time-dependent axial force are studied. The material properties of beam which vary along both thickness and axial directions follow the power law, and four different distribution patterns are considered. The coupled nonlinear partial differential equations describing the longitudinal-transverse displacements and the
shear deformation are derived using Hamilton’s principle based on Timoshenko beam theory. The Galerkin scheme is employed to discrete the continuous model resulting in a multiple degree-of-freedom system, namely, the reduced order model. The nonlinear parametric response of the beam is obtained by solving the discrete system numerically, and the frequency- and force-response curves are constructed by tracing the period motion using the pseudoarc-length continuation technique. Numerical results are presented to examine the effects of system parameters, e.g., gradient parameters, magnitude and frequency of external excitation, and damping coefficients. Cyclic-fold bifurcation and branch points of the period motion are spotted in parametric resonance of the BDFG beam. Results show that the asymmetrical material distribution in thickness direction of beam leads to the asymmetry of dynamic responses. Moreover, the gradient of material in axial direction has more significant effect on the dynamic features of BDFG beam than that in the thickness direction.

References listed at the end of the paper:


ABSTRACT: Flutter is an important form of wind turbine blade failure. Based on damping analysis, synthetically considering aeroelastic vibration instability of the blade and using the parameter fitting method, the aeroelastic flutter model of the pretwisted blade is built, with the simulation and emulation of flap and lead-lag directions flutter of the 2D dangerous cross section realized. Through the construction of two controllers, modular combinatorial sliding mode controller and sliding mode controller based on LMI for parameterized
design suppress blade aeroelastic flutter. The results show that a better control effect can be achieved on the premise of the design of the precise parameters of the controller: the proposed sliding mode control algorithm based on LMI can effectively act on the aeroelastic system of the blade, significantly reduce the vibration frequency, and make the aeroelastic system converge to an acceptable static difference in a short time, which proves the effectiveness of sliding mode control in suppressing high-frequency vibration under high wind speed.

References listed at the end of the paper:

ABSTRACT: The design and the manufacture of the oil and gas pipelines are being improved over the years in response to the observed damages and related disastrous effects. The improvements are possible, thanks to the increasing knowledge about pipeline performances in specific contexts. The seismic hazard on buried pipelines has always been of major concern, and the earthquake-induced soil liquefaction effects are among the most important issues to be accounted for in the design. Experiences based on case histories, experimental modelling, and numerical simulations represent the source of understanding of the involved mechanisms, the affecting parameters, and the structure response. Recently, all these aspects are becoming more accurate, thanks to the use of monitoring systems. The protection of pipelines from the seismic hazard is a crucial and challenging issue. This paper provides an overview of the research that has been conducted over the years in the specific framework of soil liquefaction phenomenon. Case histories on pipeline performances, commonly adopted analytical methods, and results of model tests and numerical simulations are summarized with main focus on the level of knowledge achieved up to date and the existing limitations that represent open issues for further development of the research. This study represents a useful background to be adopted from academics and practitioners in order to enhance the methods of analyses of the pipelines, thus improving their performances in the applications of the oil and gas industry.

References listed at the end of the paper:
- M. Kitaura and M. Miyajima, “Quantitative evaluation of damage to buried pipelines induced by soil liquefaction,” in Proceedings of the 9th World Conference on Earthquake Engineering, pp. 11–16, Japan Association for Earthquake Disaster Prevention, Tokyo, Japan, 1988.
· M. J. O’Rourke and X. Liu, Failure Criterion for Buried Pipe Subject to Longitudinal Pgd: Benchmark Case History, US National Center for Earthquake Engineering Research (NCEER), Buffalo, NY, USA, 1994.
· M. J. O’Rourke and X. Liu, Response of Buried Pipelines Subject to Earthquake Effects, University at Buffalo, Buffalo, NY, USA, 1999.


ABSTRACT: This paper investigates the dynamic behavior of a cantilevered microtube conveying fluid, undergoing large motions and subjected to motion-limiting constraints. Based on the modified couple stress theory and the von Kármán relationship, the strain energy of the microtube can be deduced and then the governing equation of motion is derived by using the Hamilton principle. The Galerkin method is applied to produce a set of ordinary differential equations. The effect of the internal material length scale parameter on the critical flow velocity is investigated. By using the projection method, the Hopf bifurcation is demonstrated. The results show that size effect on the vibration properties is significant.

References listed at the end of the paper:
displacement boundary conditions, the modal functions that satisfy the boundary conditions of the rectangular deformation of plates, and Hamilton's principle, the nonlinear dynamic equations of a rectangular, orthotropic composite laminated plate subjected to the transverse harmonic excitation are established. According to the displacement boundary conditions, the modal functions that satisfy the boundary conditions of the rectangular
plate are selected. The two-degree-of-freedom ordinary differential equations that describe the vibration of the rectangular plate are obtained by the Galerkin method. The multiscale method is used to obtain an approximate solution to the resonance problem. Both the amplitude-frequency equation and the average equations in the Cartesian coordinate form are obtained. The amplitude-frequency curves, bifurcation diagrams, phase diagrams, and time history diagrams of the rectangular plate under different parameters are obtained numerically. The influence of relevant parameters, such as excitation amplitude, tuning parameter, and damping coefficient, on the nonlinear dynamic response of the system is analyzed.

References listed at the end of the paper:

ABSTRACT: The paper presents the extension of an edge-based smoothed finite element method using three-node triangular elements for dynamic analysis of the functionally graded porous (FGP) plates subjected to moving loads resting on the elastic foundation taking into mass (EFTIM). In this study, the edge-based smoothed technique is integrated with the mixed interpolation of the tensorial component technique for the three-node triangular element (MITC3) to give so-called ES-MITC3, which helps improve significantly the accuracy for the standard MITC3 element. The EFTIM model is formed by adding a mass parameter of foundation into the Winkler–Pasternak foundation model. Two parameters of the FGP materials, the power-law index (k) and the maximum porosity distributions (Omega), take forms of cosine functions. Some numerical results of the proposed method are compared with those of published works to verify the accuracy and reliability. Furthermore, the effects of geometric parameters and materials on forced vibration of the FGP plates resting on the EFTIM are also studied in detail.

References listed at the end of the paper:

· E. Winkler, Die Lehre von der Elastizität und Festigkeit, Dominicus, Prague, Czech Republic, 1867.
· P. L. Pasternak, On a New Method of Analysis of an Elastic Foundation by Means of Two Foundation Constants, Gosudarstvennoe Izdatelstvo Literatury po Stroitelnosti i Arkhitekture, Moscow, Russia, 1954, in Russian.
ABSTRACT: Since microplates are extensively used in MEMS devices such as microbumps, micromirrors, and microphones, this work aims to study nonlinear vibration of an electrically actuated microplate whose four edges are clamped. Based on the modified couple stress theory (MCST) and strain equivalent assumption, size effect and damage are taken into consideration in the present model. The dynamic governing partial differential equations of the microplate system were obtained using Hamilton’s principle and solved using the harmonic balance method after they are transformed into ordinary differential equation with regard to time. Size effect and damage effect on nonlinear free vibration of the microplate under DC voltage are discussed using frequency–response curve. In the forced vibration analysis, the frequency-response curves were also employed for the purpose of highlighting the influence of different physical parameters such as external excitation, damping coefficient, material length scale parameter, and damage variable when the system is under AC voltage. The results presented in this study may be helpful and useful for the dynamic stability of a electrically actuated microplate system.

References listed at the end of the paper:


Abtract: In this paper, a gradient stable node-based smoothed discrete shear gap method (GS-DSG) using 3-node triangular elements is presented for Reissner–Mindlin plates in elastic-static, free vibration, and buckling analyses fields. By applying the smoothed Galerkin weak form, the discretized system equations are obtained. In order to carry out the smoothing operation and numerical integration, the smoothing domain associated with each node is defined. The modified smoothed strain with gradient information is derived from the Hu–Washizu three-field variational principle, resulting in the stabilization terms in the system equations. The stabilized discrete shear gap method is also applied to avoid transverse shear-locking problem. Several numerical examples are provided to illustrate the accuracy and effectiveness. The results demonstrate that the presented method is free of shear locking and can overcome the temporal instability issues, simultaneously obtaining excellent solutions.

References listed at the end of the paper:


References listed at the end of the paper:

ABSTRACT: In the previous investigations of the vibroacoustic characteristics of a submerged cylindrical shell in a flow field, the fluid viscosity was usually ignored. In this paper, the effect of fluid viscosity on the characteristics of vibration power flow in an infinite circular cylindrical shell immersed in a viscous acoustic medium is studied. Flügge’s thin shell theory for an isotropic, elastic, and thin cylindrical shell is employed to obtain the motion equations of the structure under circumferential-distributed line force. Together with the wave equations for the viscous flow field as well as continuity conditions at the interface, the vibroacoustic equation of motion in the coupled system is derived. Numerical analysis based on the additional-damping numerical integral method and ten-point Gaussian integral method is conducted to solve the vibroacoustic coupling equation with varying levels of viscosity. Then, the variation of the input power flow against the nondimensional axial wave number in the coupled system with different circumferential mode numbers is discussed in detail. It is found that the influence of fluid viscosity on the vibroacoustic coupled system is mainly concentrated in the low-frequency band, which is shown as the increase of the crest number and amplitude of the input power flow curves.

ABSTRACT: The shock wave propagation of the explosion in a pipe with holes was studied by a high-speed schlieren experimental system. In the experiments, schlieren images in the explosion were recorded by a high-speed camera from parallel and perpendicular orientations, respectively, and the pressure in the air was measured by an overpressure test system. In parallel orientation, it is observed that the steel pipe blocks the propagation of blast gases, but it allows the propagation of shock waves with a symmetrical shape. In perpendicular orientation, oblique shock wave fronts were observed, indicating the propagation of explosion detonation along the charge. Shock wave velocity in the hole direction is larger than that in the nonhole direction, indicating the function of holes in controlling blast energy, that is, leading blast energy to hole direction. Furthermore, the function of holes is verified by overpressure measurements in which peak overpressure in the hole direction is 0.87 KPa, 2.8 times larger than that in the nonhole direction. Finally, the variation of pressure around the explosion in a pipe with holes was analyzed by numerical simulation, qualitatively agreeing with high-speed schlieren experiments.
ABSTRACT: Large Liquefied Natural Gas (LNG) tanks are prone to damage during strong earthquakes, and accurate seismic analysis must be performed during the design phase to prevent secondary disasters. However, the seismic analysis of large LNG tanks is associated with high computational requirements, which cannot be satisfied by the calculation efficiency of traditional analytical techniques such as the Coupled Eulerian–Lagrangian (CEL) method. Thus, this paper aims to employ a less computationally demanding algorithm, the Smoothed Particle Hydrodynamics-Finite Element Method (SPH-FEM) algorithm, to simulate large LNG tanks. The seismic response of a 160,000 m³ LNG prestressed storage tank is evaluated with different liquid depths using the SPH-FEM algorithm, and simulation results are obtained with excellent efficiency and accuracy. In addition, large von Mises stress at the base of the tank indicates that strong earthquakes can severely jeopardize the structural integrity of large LNG tanks. Therefore, the SPH-FEM algorithm provides a feasible approach for the analysis of large liquid tanks in seismic engineering applications.

References listed at the end of the paper:
- L. Wu, Comparative Research Analysis of the Effect of Earthquake on LNG Tank, Harbin Engineering University, Harbin, China, 2013.
- J. Sun, L. Cui, X. Li, Z. Wang, W. Liu, and Y. Lv, “Design theory and method of LNG isolation,”References list(72,125),(725,842)
ABSTRACT: Based on the Flügge theory and orthotropic theory, the acoustic vibration coupling model of ring-stiffened cylindrical shell is established by using the wave propagation method and virtual source method. And the effects of water immersion on both sides, free surface, and hydrostatic pressure on the cylindrical shell are considered in the coupling model. Muller three-point iterative method is used to solve the coupling frequency. The calculation results of degradation theory are compared with COMSOL’s calculation results and experimental results, respectively, which verifies the reliability of the theoretical method. Finally, the influence of fluid load, ring rib parameters, boundary conditions, hydrostatic pressure, and free surface on the coupled vibration of ring-stiffened cylindrical shell is analyzed by an example.

References listed at the end of the paper:


results show that the maximum overload that the charge was subject to during the launch and penetration speed projectile penetrating reinforced concrete target, the acceleration curve of the charge and the projectile body were obtained. The reasonable assumptions an buffering force generated by the thin wall at both ends of the charge. In this study, the mathematical expressions were first gained about the axial stress analysis. During the experiment on the high-speed mass block through additive assumptions and stress analysis. During the experiment on the high-speed projectile penetrating reinforced concrete target, the acceleration curve of the charge and the projectile body were obtained. The results show that the maximum overload that the charge was subjected to during the launch and penetration.

ABSTRACT: When a projectile penetrates a target at high speed, the charge loaded inside the projectile usually bears a high overload, which will consequently severely affect its performance. In order to reduce the overload of the charge during the penetration process, the structure of the projectile was improved by adding two buffers at both ends of the charge. In this study, the mathematical expressions were first gained about the axial buffering force generated by the thin-walled metal tube, aluminum foam, and the composite structure of aluminum foam-filled thin-walled metal tube when they were impacted by the high-speed mass block through reasonable assumptions and stress analysis. During the experiment on the high-speed projectile penetrating reinforced concrete target, the acceleration curve of the charge and the projectile body were obtained. The results show that the maximum overload that the charge was subjected to during the launch and penetration...
process was significantly reduced, and the change in overload, which the charge was subjected to during the penetration process, was also less obvious.

References listed at the end of the paper:


ABSTRACT: This paper presents microstructural topology optimization of viscoelastic materials for the plates with constrained layer damping (CLD) treatments. The design objective is to maximize modal loss factor of macrostructures, which is obtained by using the Modal Strain Energy (MSE) method. The microstructure of the viscoelastic damping layer is composed of 3D periodic unit cells. The effective elastic properties of the unit cell are obtained through the strain energy-based method. The density-based topology optimization is adopted to find optimal microstructures of viscoelastic materials. The design sensitivities of modal loss factor with respect to the design variables are analyzed and the design variables are updated by Method of Moving Asymptotes (MMA). Numerical examples are given to demonstrate the validity of the proposed optimization method. The effectiveness of the optimal design method is illustrated by comparing a solid and an optimized cellular viscoelastic material as applied to the plates with CLD treatments.

References listed at the end of the paper:

ABSTRACT: The dynamic large deflection response of RC beams under low-speed impact loading at their midspan is investigated in this paper. Two simple methods such as extended Hamilton’s principle and equivalent static hypothesis are used to establish the theoretical models for both simply supported and fully clamped RC beams; analytical formulas for the maximum midspan deflection-input impact energy are obtained. The “equal area” method based on the deflection history of beams is only used during these derivations to determine the plastic bending moment and the stress distribution of the structure. Then, finite element simulations are carried out to verify the validity of the proposed predictions. It is shown that the maximum deflections for both simply supported and fully clamped beams are almost proportional with respect to the input impact energy, which agrees well with both simulations and other experimental results. Also, the boundary condition has more effect on the deflection response of the RC beams which is relatively longer.

References listed at the end of the paper:


X. Lei, Design Guidance for Strengthening Concrete Structures Using Fibre Composite Material, Concrete Society, Camberley, UK, 2012.


ABSTRACT: This paper presents the use of laser vibrometer measurements to detect and locate damage in a metal plate. An algorithm based on local spatial filters was selected, and for the purpose of comparison, the fault location was also determined based on the wavelet analysis of mode shapes. The research was carried out first on the created finite element model of aluminum plate, where two kinds of damage of increasing size and temperature change were simulated. After obtaining positive results, a laboratory experiment was carried out, which consisted of measuring the vibration of the aluminum plate with the laser vibrometer in undamaged condition, at increased temperatures, and with various damage scenarios. The conclusions of the laboratory experiment confirm the damage detection capabilities of the methods but question their damage localization potential.

References listed at the end of the paper:


ABSTRACT: Mechanical vibrations have been an important sustainable energy source, and piezoelectric cantilevers operating at the resonant frequency are regarded as one of the effective mechanisms for converting vibration energy to electricity. This paper focuses on model and experimental investigations of multiple attached masses on tuning a piezoelectric cantilever resonant frequency. A discrete model is developed to estimate the resonant frequencies’ change of a cantilever caused by multiple masses’ distribution on it. A mechanism consisted of a piezoelectric cantilever with a 0.3 g and a 0.6 g movable mass along it, respectively, is used to verify the accuracy of the proposed model experimentally. And another mechanism including a piezoelectric cantilever with two 0.3 g attached masses on it is also measured in the designed experiment to verify the discrete model. Meanwhile, the results from the second mechanism were compared with the results from the first one in which the single attached mass is 0.6 g. Two mechanisms have wildly different frequency bandwidths and sensitivities although the total weight of attached masses is the same, 0.6 g. The model and experimental results showed that frequency bandwidth and sensitivity of a piezoelectric cantilever beam can be adjusted effectively by changing the weight, location, and quantity of attached masses.

References listed at the end of the paper:
ABSTRACT: Steel water storage tanks (WSTs) are among the important components of water treatment industry facilities that are expected to remain functional and applicable after strong earthquakes. In this study, the seismic vulnerability of base-isolated steel WST is investigated. A three-dimensional finite element stick model of the targeted tank is created using OpenSees. This model is capable of reproducing convective, impulsive, and rigid responses of fluid-tank systems. Time-history responses of convective displacement, bearing displacement, and base shear force for base-isolated tank subjected to a typical ground motion are compared. Furthermore, time-history analysis based on a suite of 80 ground motions is conducted. The seismic demand models for various responses are established and the most efficient intensity measure (IM) is determined based on the dispersion and coefficient of determination. Seismic fragility curves for different responses are derived for all three damage states using cloud analysis. The results from this study reveal that (i) the convective displacement is significantly greater than bearing displacement; (ii) peak ground displacement (PGD) is the most efficient and sufficient IM for the targeted tank; and (iii) the characteristic of isolation bearing significantly influences the seismic fragilities of convective displacement and bearing displacement and has a little impact on base shear force, which makes the selection of the proper characteristic parameters for isolation bearing very essential. The analysis technique and procedure mentioned above as well as derived insights are of significance to general liquid storage tank system configuration.

References listed at the end of the paper:

The operational process of spans, there is not only a pure vibration of Vietnam but also in many other underprivileged countries around the world. Obtained results show that, during operational testing and numerical simulations, the stiffness decline of spans during monitoring the health conditions of bridges through a periodic measurement technique. This helps to reduce costs when carrying out testing and numerical simulations. Therefore, it is important to evaluate the stiffness decline of spans during their operation period. In addition, a new measurement method has been introduced to replace the traditional method of monitoring the health conditions of bridges through a periodic measurement technique. This helps to reduce costs when carrying out testing bridges. Besides, the proposed approach can be widely applied not only in Vietnam but also in many other underprivileged countries around the world. Obtained results show that, during the operational process of spans, there is not only a pure vibration evaluation such as bending vibration and


ABSTRACT: We propose a novel representative power spectrum density as a specific characteristic for showing responses of spans during a long operational period. The idea behind this method is to use the representative power spectrum density as a powerful tool to evaluate the stiffness decline of spans during their operation period. In addition, a new measurement method has been introduced to replace the traditional method of monitoring the health conditions of bridges through a periodic measurement technique. This helps to reduce costs when carrying out testing bridges. Besides, the proposed approach can be widely applied not only in Vietnam but also in many other underprivileged countries around the world. Obtained results show that, during the operational process of spans, there is not only a pure vibration evaluation such as bending vibration and
torsion vibration tests but also a combination of various vibration types including bending-torsion vibration or high-level vibrations like first-mode bending and first-mode torsion. Depending on each type of structure and material properties, different types of vibrations will appear more or less during the operational process of spans under a random moving load. Furthermore, the representative power spectrum density is also suitable for evaluating and determining many different fundamental vibrations through the same measurement time as well as various measurement times.

References listed at the end of the paper:

- Ministry of Planning and Investment of Viet Nam, Master Plan on Key Economic Zones of Viet Nam, Ministry of Planning and Investment of Viet Nam, Ho Chi Minh City, Vietnam, 2006.
- N. K. Ngo, Proposals for Method Adding Measuring Data and Preliminary Bridge Classification Procedures, Ho Chi Minh City Department of Transport, Ho Chi Minh City, Vietnam, 2011.

ABSTRACT: Stand-off free layer damping is a vibration reduction method based on the traditional free layer damping. In this paper, a stand-off free layer damping cantilever beam is prepared with the steel plate as the base layer, rigid polyurethane (PU) foam as the stand-off layer, and rubber as the damping layer, and the motion equation of the cantilever beam is derived. The dynamic mechanical properties of damping rubber and PU foam are tested and analyzed. Through hammering tests, we have studied the effect of the density and thickness of the PU foam layer on the amplitude-frequency curves, modal frequencies, and loss factors of the cantilever beams. The results show that the rubber damping material is a major font of energy dissipation of the cantilever beam, and PU foam acts mainly to expand the deformation of the damping layer and plays a role in energy consumption. By increasing the density and thickness of PU foam within a certain range, the vibration peaks of the first five modes of the cantilever beam decreases gradually, the loss factors rise, and the damping performance is improved. Meanwhile, increased density and thickness enhances the overall stiffness of the beam, making the modal frequencies get higher.

References listed at the end of the paper:

- N. K. Ngo and T. T. Truong, Mechanical Application, Publisher of Ho Chi Minh City National University, Ho Chi Minh City, Vietnam, 2003.


D. Dai, Vibration and Noise Reduction Technology, Xi’an Jiaotong University Press, Xi’an, China, 1986.
ABSTRACT: Concrete-filled steel tubular (CFST) columns are widely used in engineering structures, and they have many different cross section types. Among these, normal solid sections and concrete-filled double-skin steel tubular sections are often used. Although many studies have been conducted on CFST columns with these two section types, no studies have been conducted on their damage assessment under blast loading. In this study, experimental analysis and a numerical simulation method were integrated to evaluate the responses and assess the damage of two concrete-filled steel tubular (CFST) columns with different cross sections subjected to near-field blast loading. The results showed that for a scaled distance of 0.14 m/kg, plastic bending deformation occurred on the surfaces of the two CFST columns facing the explosive. The antiexplosion performance of the normal solid-section (NSS) CFST column was better than that of the concrete-filled double-skin steel tubular (CFDST) column. The explosion centre was set at the same height as the middle of column, and the distributions of the peak pressure values of the two columns were similar: the peak pressures at the middle points of the columns were the greatest, and the peak pressures at the bottom were higher than those at the top. With the analysis of the duration of the positive pressure, the damage at the middle was the most severe when subjected to blast loading. Using pressure-impulse damage theory and the validated numerical simulations, two pressure-impulse damage evaluation curves for NSS and CFDST columns were established separately by analysing the experimental and simulation data. Finally, based on the two pressure-impulse damage evaluation curves, the two pressure-impulse damage criteria for these two different fixed-end CFST columns were defined based on the deflection of the surfaces facing the explosives. Furthermore, the mathematical formulae for these two different column types were established to generate pressure-impulse diagrams. With the established formulae, the damage of the CFST columns with these two cross section types can be evaluated. Damage to other similar CFST columns with different cross section types due to near-field blast loading can also be evaluated by this method.

References listed at the end of the paper:


Abstract: Transverse vibration of rectangular composite plates with multiple distributed composite patches is analyzed in this paper. Because of the geometric discrepancy between the plate and patch, analytical solutions are usually hard to achieve. The present model is formulated by using the Rayleigh–Ritz method and adopting various types of modal shape functions of uniform beam as admissible functions for different boundary conditions. The total system energies are calculated by adding the energies of the substrate plate and the energies of the patches. By imposing the displacement-matching condition at the patch domains, the coordinate systems of the substrate plate and patches are coupled. By means of the present method, it is very convenient and efficient to build the system governing equations and solve the eigenvalue problem. For the composite patches, they are also assumed to be symmetrically layered and have the same layer stacking sequence with the substrate laminate. The effects of layer stacking sequence, modulus ratio, aspect ratio, and boundary conditions on the natural frequencies are investigated and discussed. The results are also compared with the existed benchmark solutions and FEM solutions for validation. The numerical results demonstrate that the proposed
approach is computationally very efficient and accurate and can be used as a tool to solve transverse vibration problems of composite plate with multiple composite patches.

References listed at the end of the paper:


ABSTRACT: In this paper, the Ritz method is adopted to investigate the vibration characteristics of isotropic moderately thick annular spherical shell with general boundary conditions. The energy expressions of the annular spherical shell were established based on the first-order shear deformation theory (FSDT). The spring stiffness method is introduced to guarantee continuity and simulate various boundary conditions on the basis of the domain decomposition method. Under the current framework, the displacement admissible function along axial direction and circumferential direction of the shell structure are, respectively, expanded as the unified Jacobi polynomials and Fourier series. The final solutions can be obtained according to the Ritz method. The validity of the proposed method is proved by comparing the results of the same condition with those obtained by the finite element method (FEM) and published literatures. The results show that the current method has fast convergence and delightful accuracy through the comparative study. On this basis, the vibration characteristics of isotropic moderately thick annular spherical shell are further studied by a series of numerical examples.

References listed at the end of the paper:


More papers published in the journal, Mathematical Problems in Engineering (2014 and on)

Google the string, “Mathematical Problems in Engineering”, then click on “Mathematical Problems in Engineering – An Open Access Journal – Hindawi”, click on “Table of Contents” (green strip near top), click on Table of Contents for Year 201x and scan titles. (Better: click on “Search”, then type the journal name (Mathematical Problems in Engineering) and Volume (20xx))


ABSTRACT: A cell-based smoothed finite element method with discrete shear gap technique is employed to study the static bending, free vibration, and mechanical and thermal buckling behaviour of functionally graded material (FGM) plates. The plate kinematics is based on the first-order shear deformation theory and the shear locking is suppressed by the discrete shear gap method. The shear correction factors are evaluated by employing the energy equivalence principle. The material property is assumed to be temperature dependent and graded only in the thickness direction. The effective properties are computed by using the Mori-Tanaka homogenization method. The accuracy of the present formulation is validated against available solutions. A systematic parametric study is carried out to examine the influence of the gradient index, the plate aspect ratio, skewness of the plate, and the boundary conditions on the global response of the FGM plates. The effect of a centrally located circular cutout on the global response is also studied.

References listed at the end of the paper:


ABSTRACT: When subjected to the dynamic load, the behavior of the structures is complex and makes it difficult to describe the process of the deformation. In the paper, an analytical model is presented to analyze the plastic deformation of the steel circular tubes. The aim of the research is to calculate the deflection and the plastic deformation angle of the tubes. A series of assumptions are made to achieve the objective. During the research, we build a mathematical model for simply supported thin-walled metal tubes with finite length. At a specified distance above the tube, a TNT charge explodes and generates a plastic shock wave. The wave can be seen as uniformly distributed over the upper semicircle of the cross-section. The simplified Tresca yield domain can be used to describe the plastic flow of the circular tube. The yield domain together with the plastic flow law and other assumptions can finally lead to the solving of the deflection. In the end, tubes with different dimensions subjected to blast wave induced by the TNT charge are observed in experiments. Comparison shows that the numerical results agree well with experiment observations.

References listed at the end of the paper:


Hua Xu (1,2), Tianbin Li (2), Jingsong Xu (1) and Yingjun Wang (3)

(1) Key Laboratory of Transportation Tunnel Engineering, Ministry of Education, School of Civil Engineering, Southwest Jiaotong University, Chengdu, Sichuan 610031, China
(2) State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu, Sichuan 610059, China
(3) Department of Structural Engineering, University of California-San Diego, La Jolla, CA 92093, USA

ABSTRACT: Dynamic stress concentration in tunnels and underground structures during earthquakes often leads to serious structural damage. A series solution of wave equation for dynamic response of underground circular lining tunnels subjected to incident plane P waves is presented by Fourier-Bessel series expansion method in this paper. The deformation and stress fields of the whole medium of surrounding rock and tunnel were obtained by solving the equations of seismic wave propagation in an elastic half space. Based on the assumption of a large circular arc, a series of solutions for dynamic stress were deduced by using a wave function expansion approach for a circular lining tunnel in an elastic half space rock medium subjected to incident plane P waves. Then, the dynamic response of the circular lining tunnel was obtained by solving a series of algebraic equations after imposing its boundary conditions for displacement and stress of the circular lining tunnel. The effects of different factors on circular lining rock tunnels, including incident frequency, incident angle, buried depth, rock conditions, and lining stiffness, were derived and several application examples are presented. The results may provide a good reference for studies on the dynamic response and aseismic design of tunnels and underground structures.

References listed at the end of the paper:
ABSTRACT: The composition of hydroxyapatite (HA) as the ceramic phase and titanium (Ti) as the metallic phase in HA/Ti functionally graded materials (FGMs) shows an excellent combination of high biocompatibility and high mechanical properties in a structure. Because the gradation of these properties is one of the factors that affects the response of the functionally graded (FG) plates, this paper is presented to show the domination of the grading parameter on the displacement and stress distribution of the plates. A three-dimensional (3D) thermomechanical model of a 20-node brick quadratic element is used in the simulation of the thermoelastic behaviors of HA/Ti FG plates subjected to constant and functional thermal, mechanical, and thermomechanical loadings. The convergence properties of the present results are examined thoroughly in order to assess the accuracy of the theory applied and to compare them with the established research results. Instead of the grading parameter, this study reveals that the loading field distribution can be another factor that reflects the thermoelastic properties of the HA/Ti FG plates. The FG structure is found to be able to withstand the thermal stresses while preserving the high toughness properties and thus shows its ability to operate at high temperature.

ABSTRACT: Dynamic instability of beams in complex structures caused by unsteady wind load has occurred more frequently. However, studies on the parametric resonance of beams are generally limited to harmonic loads, while arbitrary dynamic load is rarely involved. The critical frequency equation for simply supported Euler beams with uniform section under arbitrary axial dynamic forces is firstly derived in this paper based on the Mathieu-Hill equation. Dynamic instability regions with high precision are then calculated by a presented eigenvalue method. Further, the dynamically unstable state of beams under the wind force with any mean or fluctuating component is determined by load normalization, and the wind-induced parametric resonant response is computed by the Runge-Kutta approach. Finally, a measured wind load time-history is input into the dynamic system to indicate that the proposed methods are effective. This study presents a new method to determine the wind-induced dynamic stability of Euler beams. The beam would become dynamically unstable provided that
the parametric point, denoting the relation between load properties and structural frequency, is located in the instability region, no matter whether the wind load component is large or not.

References listed at the end of the paper:


ABSTRACT: Variational principles are established for the partially composite Timoshenko beam using the semi-inverse method. The principles are derived directly from governing differential equations for bending and vibration of the beam considered. It is concluded that the semi-inverse method is a powerful tool for searching for variational principles directly from the governing equations. Comparison between our results and the results reported in literature is given.
References listed at the end of the paper:


ABSTRACT: A model for 3D laminated composite beams, that is, beams that can vibrate in space and experience longitudinal and torsional deformations, is derived. The model is based on Timoshenko’s theory for bending and assumes that, under torsion, the cross section rotates as a rigid body but can deform longitudinally due to warping. The warping function, which is essential for correct torsional deformations, is computed preliminarily by the finite element method. Geometrical nonlinearity is taken into account by considering Green’s strain tensor. The equation of motion is derived by the principle of virtual work and discretized by the p-version finite element method. The laminates are assumed to be of orthotropic materials. The influence of the angle of orientation of the laminates on the natural frequencies and on the nonlinear modes of vibration is presented. It is shown that, due to asymmetric laminates, there exist bending-longitudinal and bending-torsional coupling in linear analysis. Dynamic responses in time domain are presented and couplings between transverse displacements and torsion are investigated.

References listed at the end of the paper:
Jiafu Liu, Siyuan Rong, Fan Shen and Naigang Cui, “Dynamics and Control of a Flexible Solar Sail”, Mathematical Problems in Engineering, Volume 2014, Article ID 868419, 25 pages,
http://dx.doi.org/10.1155/2014/868419

ABSTRACT: Solar sail can merely make use of solar radiation pressure (SRP) force as the thrust for space missions. The attitude dynamics is obtained for the highly flexible solar sail with control vanes, sliding masses, and a gimbaled control boom. The vibration equations are derived considering the geometric nonlinearity of the sail structure subjected to the forces generated by the control vanes, solar radiation pressure (SRP), and sliding masses. Then the dynamic models for attitude/vibration controller design and dynamic simulation are obtained, respectively. The linear quadratic regulator (LQR) based and optimal proportional-integral (PI) based controllers are designed for the coupled attitude/vibration models with constant disturbance torques caused by the center-of-mass (cm)/center-of-pressure (cp) offset, respectively. It can be concluded from the theoretical
analysis and simulation results that the optimal PI based controller performs better than the LQR based controller from the view of eliminating the steady-state errors. The responses with and without the geometrical nonlinearity are performed, and the differences are observed and analyzed. And some suggestions are also presented.

References listed at the end of the paper:
REFERENCES


Zihua Zhang, Junhua Li and Ping Zhuge (College of Civil Engineering and Environment, Ningbo University, Ningbo 315211, China), “Failure Analysis of Large-Scale Wind Power Structure under Simulated Typhoon”, Mathematical Problems in Engineering, Volume 2014, Article ID 486524, 10 pages, http://dx.doi.org/10.1155/2014/486524

ABSTRACT: Recently, a number of wind power structures in tropical cyclone zones are damaged by typhoon. In order to study the failure mechanisms and failure modes of wind power structure subjected to typhoon, the typhoon wind field in Dongtai wind farm is simulated based on the classical autoregressive (AR) model and a regional power-spectrum-density (PSD) model, and the simulated spectrum is verified to be in good agreement with the target spectrum. An integrated finite element (FE) model of wind power structure, composed of rotor, nacelle, tower, pile cap, and PHC piles, is established. Modal analysis reveals that pile stiffness decreases the structure’s natural frequencies, especially for high order frequencies. Structural responses under the simulated typhoon are calculated by dynamic analysis. Results show that tower buckling is the most prone failure mode of the structure. The horizontal displacement of the hub and the axial force of the most unfavorable piles are both under the limit. This study provides a way to the antityphoon design of large-scale wind power structures.

References listed at the end of the paper:


ABSTRACT: Distortional buckling is one of the most important buckling modes of the steel-concrete composite girder under negative moment. In this study, the equivalent lateral and torsional restraints of the bottom flange of a steel-concrete composite girder under negative moments due to variable axial forces are thoroughly investigated. The results show that there is a coupling effect between the applied forces and the lateral and torsional restraint of the bottom flange. Based on the calculation formula of lateral and torsional restraints, the critical buckling stress of I-steel-concrete composite girders and steel-concrete composite box girders under variable axial force is obtained. The critical bending moment of the steel-concrete composite girders can be further calculated. Compared to the traditional calculation methods of elastic foundation beam, the paper introduces an improved method, which considers coupling effect of the external loads and the foundation spring constraints of the bottom flange. Fifteen examples of the steel-concrete composite girders in different conditions are calculated. The calculation results show a good match between the hand calculation and the ANSYS finite element method, which validated that the analytic calculation method proposed in this paper is practical.

References listed at the end of the paper:

ABSTRACT: This paper presents the nonlinear free vibration analysis of axisymmetric polar orthotropic circular membrane, based on the large deflection theory of membrane and the principle of virtual displacement. We have derived the governing equations of nonlinear free vibration of circular membrane and solved them by the Galerkin method and the Bessel function to obtain the generally exact formula of nonlinear vibration frequency of circular membrane with outer edges fixed. The formula could be degraded into the solution from small deflection vibration; thus, its correctness has been verified. Finally, the paper gives the computational examples and comparative analysis with the other solution. The frequency is enlarged with the increase of the initial displacement, and the larger the initial displacement is, the larger the effect on the frequency is, and vice versa. When the initial displacement approaches zero, the result is consistent with that obtained on the basis of the small deflection theory. Results obtained from this paper provide the accurate theory for the measurement of the pretension of polar orthotropic composite materials by frequency method and some theoretical basis for the research of the dynamic response of membrane structure.

References listed at the end of the paper:
ABSTRACT: This paper presents an efficient and accurate numerical technique for analysis of two-dimensional frames accounted for both geometric nonlinearity and nonlinear elastic material behavior. An adaptive remeshing scheme is utilized to optimally discretize a structure into a set of elements where the total displacement can be decomposed into the rigid body movement and one possessing small rotations. This, therefore, allows the force-deformation relationship for the latter part to be established based on small-rotation-based kinematics. Nonlinear elastic material model is integrated into such relation via the prescribed nonlinear moment-curvature relationship. The global force-displacement relation for each element can be derived subsequently using corotational formulations. A final system of nonlinear algebraic equations along with its associated gradient matrix for the whole structure is obtained by a standard assembly procedure and then solved numerically by Newton-Raphson algorithm. A selected set of results is then reported to demonstrate and discuss the computational performance including the accuracy and convergence of the proposed technique.

References listed at the end of the paper:


ABSTRACT: We present a meshfree approach to model dynamic fracture in thin structures. Material failure is modeled based on a stress-based criterion and viscoplastic is used to describe the material behavior in the bulk material. Material fracture is simply modeled by breaking bonds between neighboring particles. The method is applied to fracture of cylindrical thin structures under explosive loading. The loading is modeled by a pressure-time history. Comparisons between the computational results and experimental data illustrate the validity and robustness of the proposed method.

References listed at the end of the paper:

ABSTRACT: The mesh-free method is employed to implement the numerical simulation of the bending behavior of beams with the size effect. On the basis of the classical Bernoulli-Euler beam theory, two higher-order strain components are introduced in the beam model. The intrinsic bulk length and the directional surface length components are introduced into the constitutive relationship to describe the size effect, and the variation of the total potential is provided. The moving least square approximation is used to construct the shape function and its second- and third-order derivatives, and the choice of the scaling factor is discussed in detail. A mesh-free scheme is built to implement numerical simulation, in which the higher-order strains are directly approximated with the nodal components due to the higher-order continuity of the shape function. The convergence of method is illustrated in virtue of an example of the simply supported beam, and the effect of the intrinsic bulk length and the directional surface length components are studied.

References listed at the end of the paper:

Ai-rong Liu, Yong-hui Huang, Qi-cai Yu and Rui Rao (Guangzhou University-Tamkang University Joint Research Center for Engineering Structure Prevention and Control, Guangzhou University, Guangzhou 510006, China), “An Analytical Solution for Lateral Buckling Critical Load Calculation of Leaning-Type Arch Bridge”, Mathematical Problems in Engineering, Volume 2014, Article ID 578473, 14 pages, http://dx.doi.org/10.1155/2014/578473

ABSTRACT: An analytical solution for lateral buckling critical load of leaning-type arch bridge was presented in this paper. New tangential and radial buckling models of the transverse brace between the main and stable arch ribs are established. Based on the Ritz method, the analytical solution for lateral buckling critical load of the leaning-type arch bridge with different central angles of main arch ribs and leaning arch ribs under different boundary conditions is derived for the first time. Comparison between the analytical results and the FEM calculated results shows that the analytical solution presented in this paper is sufficiently accurate. The parametric analysis results show that the lateral buckling critical load of the arch bridge with fixed boundary conditions is about 1.14 to 1.16 times as large as that of the arch bridge with hinged boundary condition. The lateral buckling critical load increases by approximately 31.5% to 41.2% when stable arch ribs are added, and the critical load increases as the inclined angle of stable arch rib increases. The differences in the center angles of the main arch rib and the stable arch rib have little effect on the lateral buckling critical load.

References listed at the end of the paper:
ABSTRACT: This study, with experiments and comparisons, aims to analyze the difference of stainless (SUS316L) microtubes in the flaring forming among dies with various semicone angles (35°, 40°, 45°, 50°, and 55°). The flow rule by Prandtl-Reuss combined with the finite element deformation theory and updated Lagrangian formulation (ULF) is applied to establish the finite element analysis equation for an incremental elastoplastic deformation to simulate the microtube flaring process. The broad rmin algorithm is utilized in the forming process for the elastoplastic state and die contact. The simulation data allow acquiring the deformation traceability, the relationship between punch load and punch stroke, the distribution of stress and strain, the distribution of the thinnest thickness resulted from dies with different semicone angles, and the distribution of flaring radius caused by dies with distinct semicone angles in the forming process. The experimental result presents similar results to the relationship between punch load and punch stroke and the simulation of the coefficient of friction $\mu = 0.05$, revealing the analysis being suitable for the analysis of microtube cone angle flaring process. The analysis and experimental results show that the thinnest thickness of the microtube increases with increasing semicone angles of dies and the maximal flaring radius of microtubes increases with increasing semicone angles of dies.

References listed at the end of the paper:


Yuqiao Zheng (1), Rongzhen Zhao (2) and Hong Liu (1)

(1) Key Laboratory of Digital Manufacturing Technology and Application, The Ministry of Education, Lanzhou University of Technology, Lanzhou 730050, China
(2) School of Mechanical and Electronic Engineering, Lanzhou University of Technology, Lanzhou 730050, China


ABSTRACT: This paper presents a recently developed numerical multidisciplinary optimization method for design of wind turbine blade. The objective was the highest possible blade weight under specified atmospheric conditions, determined by the design giving girder layer and location parameter. Wind turbine blade on box-section beams girder is calculated by ply thickness, main girder and trailing edge. In this study, a realistic 30 m
blade from a 1.2 MW wind turbine model of blade girder parameters is established. The optimization evolves a structure which transforms along the length of the blade, changing from a design with spar caps at the maximum thickness and a trailing edge mass to a design with spar caps toward the tip. In addition, the cross-section structural properties and the modal characteristics of a 62 m rotor blade were predicted by the developed beam finite element. In summary, these findings indicate that the conventional structural layout of a wind turbine blade is suboptimal under the static load conditions, suggesting an opportunity to reduce blade weight and cost.

References listed at the end of the paper:
6 M. Zhiyong, Large Wind Power Blade Structure Design Method Research, north China Electric Power University, Beijing, China, 2011.


ABSTRACT: From the viewpoint of practical application, based on the unsteady analytical model for transverse fluid elastic instability of tube array proposed by Yetisir and the linear attenuation function introduced by Li Ming, a new explicit model based on nonsteady state “streamtube” hypothesis is proposed and solved using complex number method. In the model, numerical integral is avoided and inappropriate aspects in Li Ming model are modified. Using the model, the fluid elastic instability analysis of a single flexible tube is made. The stability graphs for four typical types of tube array are plotted and contrasted with experimental results. It is found that the current explicit model is effective in the analysis of transverse fluid elastic instability of tube bundle. References listed at the end of the paper:

ABSTRACT: For successful structural health monitoring and structural integrity evaluation of a laminated composite structure, it is important to study the effects of delamination on the propagations of the guided waves in a delaminated composite beam by using an accurate and computationally efficient method. Thus, we developed a “frequency-domain” spectral element model for the symmetric composite beams. First-order-shear-deformation-theory (FSDT) based Timoshenko beam theory and Mindlin-Herrmann rod theory are adopted for the flexural (bending) waves and axial (extensional) waves, respectively. A spectral element model is derived from the governing equations of motion by using the variation method in the frequency domain. After validating the accuracy of the proposed spectral element model, the model is used to investigate the effects of delamination on the propagation of guided waves in examples of composite beams.

References listed at the end of the paper:

ABSTRACT: The structural optimization method of steel cantilever used in concrete box girder bridge widening is illustrated in this paper. The structural optimization method of steel cantilever incorporates the conceptual layout design of steel cantilever beam based on the topological theory and the determination of the optimal location of the transverse external prestressed tendons which connect the steel cantilever and the box girder. The optimal design theory and the analysis process are illustrated. The mechanical model for the prestressed steel cantilever is built and the analytical expression of the optimal position of the transverse external tendon is deduced. At last the effectiveness of this method is demonstrated by the design of steel cantilevers which are used to widen an existing bridge.


ABSTRACT: Analytical particular solutions of the polyharmonic multiquadrics are derived for both the Reissner and Mindlin thick-plate models in a unified formulation. In the derivation, the three coupled second-order partial differential equations are converted into a product operator of biharmonic and Helmholtz operators using the Hörmander operator decomposition technique. Then a method is introduced to eliminate the Helmholtz operator, which enables the utilization of the polyharmonic multiquadrics. Then, the analytical particular solutions of displacements, shear forces, and bending or twisting moments corresponding to the polyharmonic multiquadrics are all explicitly derived. Numerical examples are carried out to validate these particular solutions. The results obtained by the present method are more accurate than those by the traditional multiquadrics and splines.

References listed at the end of the article:
This paper presents a Bayesian approach for localizing acoustic emission (AE) source in plate-like structures with consideration of uncertainties from modeling error and measurement noise. A PZT sensor network is deployed to monitor and acquire AE wave signals released by possible damage. By using continuous wavelet transform (CWT), the time-of-flight (TOF) information of the AE wave signals is extracted and measured. With a theoretical TOF model, a Bayesian parameter identification procedure is developed to obtain the AE source location and the wave velocity at a specific frequency simultaneously and meanwhile quantify their uncertainties. It is based on Bayes’ theorem that the posterior distributions of the parameters about the AE source location and the wave velocity are obtained by relating their priors and the likelihood of the measured time difference data. A Markov chain Monte Carlo (MCMC) algorithm is employed to draw samples to approximate the posteriors. Also, a data fusion scheme is performed to fuse results identified at multiple frequencies to increase accuracy and reduce uncertainty of the final localization results. Experimental studies on
a stiffened aluminum panel with simulated AE events by pensile lead breaks (PLBs) are conducted to validate the proposed Bayesian AE source localization approach.

References listed at the end of the paper:

ABSTRACT: An element-free Galerkin method for the solution of free vibration of symmetrically laminated folded plate structures is introduced. Employing the mature meshfree folded plate model proposed by the author, a folded laminated plate is simulated as a composite structure of symmetric laminates that lie in different planes. Based on the first-order shear deformation theory (FSDT) and the moving least-squares (MLS) approximation, the stiffness and mass matrices of the laminates are derived and supposed to obtain the stiffness and mass matrices of the entire folded laminated plate. The equation governing the free vibration behaviors of the folded laminated plate is thus established. Because of the meshfree characteristics of the proposed method, no mesh is involved to determine the stiffness and mass matrices of the laminates. Therefore, the troublesome remeshing can be avoided completely from the study of such problems as the large deformation of folded laminated plates. The calculation of several numerical examples shows that the solutions given by the proposed method are very close to those given by ANSYS, using shell elements, which proves the validity of the proposed method.

References listed at the end of the paper:


ABSTRACT: Plates and shells are main components of modern engineering structures, whose buckling analysis has been focused by researchers. In this investigation, rectangular thin plates with loaded edges simply supported can be discretized by semi-analytical finite strip technology. Then the control equations of the strip elements of the buckling plate will be rewritten as the transfer equations by transfer matrix method. A new approach, namely semi-analytical Finite Strip Transfer Matrix Method, is developed for the buckling analysis of plates. This method requires no global stiffness matrix of the system, reduces the system matrix order, and improves the computational efficiency. Comparing with some theoretical results and FEM’s results of two illustrations (the plates and the ribbed plates) under six boundary conditions, the method is proved to be reliable and effective.

References listed at the end of the paper:

Li-Ke Yao, Bin He, Yu Zhang and Wei Zhou (Mechanics Department, Nanjing Tech University, Nanjing, China), “Semi-Analytical Finite Strip Transfer Matrix Method for Buckling Analysis of Rectangular Thin Plates”, Mathematical Problems in Engineering, Volume 2015, Article ID 485686, 11 pages, http://dx.doi.org/10.1155/2015/485686


ABSTRACT: The dynamic failure criterion of single-layer spherical lattice shells has been an important research subject. The paper examines dynamic failures of single-layer spherical lattice shells and proposes the structure dynamic failure criterion based on the kinetic energy. The failure criterion was demonstrated through the dynamic failure test on a single-layer spherical lattice shell. Then, simulation analysis was carried out through two cases with material damage taken into account. The proposed failure criterion can accurately identify failure moments caused either by strength fracture or by stability fracture.

References listed at the end of the paper:
3 G.-B. Nie, Research on Spatial Hysteric Experiment and Constitutive Equation for Element of Reticulated Shells, Harbin Institute of Technology, 2008.
ABSTRACT: Since 1960s, how to develop high-performance plate bending finite elements based on different plate theories has attracted a great deal of attention from finite element researchers, and numerous models have been successfully constructed. Among these elements, the most popular models are usually formulated by two theoretical bases: the Kirchhoff plate theory and the Mindlin-Reissner plate theory. Due to the advantages that only Co continuity is required and the effect of transverse shear strain can be included, the latter one seems more rational and has obtained more attention. Through abundant works, different types of Mindlin-Reissner plate models emerged in many literatures and have been applied to solve various engineering problems. However, it also brings FEM users a puzzle of how to choose a “right” one. The main purpose of this paper is to present an overview of the development history of the Mindlin-Reissner plate elements, exhibiting the state-of-art in this research field. At the end of the paper, a promising method for developing “shape-free” plate elements is recommended.

References listed at the end of the paper:


ABSTRACT: We analyse the buckling process of composite plates with through-the-width delamination and straight crack front applying uniaxial compression. We are focusing on the mixed mode buckling case, where the non-uniform distribution of the in-plane forces controls the occurrence of the buckling of the delaminated layers. For the analysis, semi-discrete finite elements will be derived based on the Lévy-type method. The method of harmonic balance is used for taking into account the force distribution that is generally non uniform in-plane.

References listed at the end of the paper:


ABSTRACT: We analyse the buckling process of composite plates with through-the-width delamination and straight crack front applying uniaxial compression. We are focusing on the mixed mode buckling case, where the non-uniform distribution of the in-plane forces controls the occurrence of the buckling of the delaminated layers. For the analysis, semi-discrete finite elements will be derived based on the Lévy-type method. The method of harmonic balance is used for taking into account the force distribution that is generally non uniform in-plane.

References listed at the end of the paper:


56 S. W. Tsai, Theory of Composites Design, Think Composites, Dayton, Ohio, USA, 1992.
obtained using recursive differentiation method (RDM). Elastic restraints for rotation and translation are

ABSTRACT: Analytical solutions have been developed for nonlinear boundary problems. In this paper, the shifting function method is applied to develop the static deflection of in-plane curved Timoshenko beams with nonlinear boundary conditions. Three coupled governing differential equations are derived via the Hamilton’s principle. The mathematical modeling of the curved beam system can be decomposed into a complete sixth-order ordinary differential characteristic equation and the associated boundary conditions. It is shown that the proposed method is valid and performs well for problems with strong nonlinearity.

References listed at the end of the paper:


S. Abohadima, M. Taha and M.A.M. Abedeen (Department of Engineering Mathematics and Physics, Faculty of Engineering, Cairo University, Giza 12211, Egypt), “General Analysis of Timoshenko Beams on Elastic Foundation”, Mathematical Problems in Engineering, Volume 2015, Article ID 182523, 11 pages, 
http://dx.doi.org/10.1155/2015/182523

ABSTRACT: General analytical solutions for stability, free and forced vibration of an axially loaded Timoshenko beam resting on a two-parameter foundation subjected to nonuniform lateral excitation are obtained using recursive differentiation method (RDM). Elastic restraints for rotation and translation are
assumed at the beam ends to investigate the effect of support weakening on the beam behavior. However, the effects of rotational inertia and shear stress induced from the axial load are considered. The obtained solutions are verified first and then used to investigate the significance of different parameters on the beam behavior. In addition, solutions of forced vibration are analyzed to highlight the effects of excitation nonhomogeneity on the beam behavior.

References listed at the end of the paper:

**ABSTRACT:** isotropic impact load, which involves building Green’s function of this problem by using the appropriate boundary conditions of thick-walled spherical shell. This method can be used to analyze displacement distribution and dynamic stress distribution of the thick-walled spherical shell. The advantages of this method are able (1) to avoid the superposition process of quasi-static solution and free vibration solution during decomposition of dynamic general solution of dynamics, (2) to well adapt for various initial conditions, and (3) to conveniently analyze the dynamic stress distribution using numerical calculation. Finally, a special case is performed to verify that the proposed Green’s function method is able to accurately analyze the dynamic stress distribution of thick-walled spherical shell under an isotropic impact load.

References listed at the end of the paper:


**ABSTRACT:** Al-Li alloy and aluminum honeycomb panel (AHP) are both excellent materials for aeronautical structures. In this paper, a plate-type aeronautical structure (PAS), which is a base mounting structure for 172 kg functional devices, is selected for comparative analysis with different materials. To compare system-level performance under multidisciplinary constraints, mathematical models for optimization are established and then structural optimization is carried out using Altair OptiStruct. For AHP, its honeycomb core is regarded as orthotropic material and its mechanical properties are calculated by Allen’s model in order to establish finite element model (FEM). The heights of facing sheet and honeycomb core are selected as design variables for size optimization. For Al-Li alloy plate, topology optimization is carried out to obtain its most efficient load path; and then a reconstruction process is executed for practical manufacturing consideration; to obtain its final configuration, accurate size optimization is also used for reconstructed model of Al-Li alloy plate. Finally, the optimized mass and performance of two PASs are compared. Results show that AHP is slightly superior to Al-Li alloy.

References listed at the end of the paper:
The paper describes application of innovative, inflatable thin-walled structures for absorption of the impact loading and thoroughly investigates their crash characteristics. The proposed concept assumes inflation of thin-walled structures with compressed gas of appropriately adjusted pressure in order to improve their basic mechanical properties, enhance energy dissipation capabilities, and increase corresponding durability to impact loading. In the first part of the paper the influence of compressed gas on mechanical characteristics of aluminium beverage can is analysed experimentally and by the corresponding numerical simulations. The following section proposes and numerically verifies three diverse engineering applications of inflatable thin-walled structures for impact absorption. Finally, the last part introduces the concept of adaptive inflatable barrier and briefly presents three simple strategies of pressure control. Both the performed basic experiment and the conducted numerical simulations show the advantageous influence of compressed gas and prove the feasibility of using inflatable thin-walled structures for impact absorption.

References listed at the end of the paper:

19 X. Zhang, Conceptual study of adaptive energy absorbers [Ph.D. thesis], The Hong Kong University of Science and Technology, 2009.
23 J. Holnicki-Szulc and R. Chmielewski, Polish Patent, P-357761.

Suihan Sui, Ling Chen, Cheng Li and Xinpei Liu (School of Urban Rail Transportation, Soochow University, Suzhou 215006, China), “Transverse Vibration of Axially Moving Functionally Graded Materials Based on

ABSTRACT: This work provides a detailed theoretical and numerical study of the inverse problem of identifying flexural rigidity in Kirchhoff plate models. From a mathematical standpoint, this inverse problem requires estimating a variable coefficient in a fourth-order boundary value problem. This inverse problem and

References listed at the end of the paper:
related estimation problems associated with general plates and shell models have been investigated by numerous researchers through an optimization framework using the output least-squares (OLSs) formulation. OLS yields a nonconvex framework and hence it is suitable for investigating only the local behavior of the solution. In this work, we propose a new convex framework for the inverse problem of identifying a variable parameter in a fourth-order inverse problem. Existence results, optimality conditions, and discretization issues are discussed in detail. The discrete inverse problem is solved by using a continuous Newton method. Numerical results show the feasibility of the proposed framework.

References listed at the end of the paper:
ABSTRACT: Several engineering problems are confronted with elastic tubes. In the current work, homothetic quasi-analytical geometrical ring models, ellipse, stadium, and peanut, are formulated allowing a computationally low cost ring shape estimation as a function of a single parameter, that is, the pinching degree. The dynamics of main geometrical parameters due to the model choice is discussed. Next, the ring models are applied to each cross section of a circular elastic tube compressed between two parallel bars for pinching efforts between 40% and 95%. The characteristic error yields less than 4% of the tubes diameter when the stadium model was used.

References listed at the end of the paper:


ABSTRACT: An experimental investigation on deformation shape of a cylindrical shell with internal medium subjected to lateral contact explosion was carried out briefly. Deformation shapes at different covered width of lateral explosive were recovered experimentally. Based on the experimental results, a corresponding analytical approach has been undertaken with rigid plastic hinge theory. In the analytical model, the cylindrical shell is divided into end-to-end rigid square bars. Deformation process of the cylindrical shell is described by using the translations and rotations of all rigid square bars. Expressions of the spring force, buckling moment, and deflection angle between adjacent rigid square bars are conducted theoretically. Given the structure parameters of the cylinder and the type of the lateral explosive charge, deformation processes and shapes are reported and discussed using the analytical approach. A good agreement has been obtained between calculated and experimental results, and thus the analytical approach can be considered as a valuable tool in understanding the deformation mechanism and predicting the deformation shapes of the cylindrical shell with internal medium subjected to lateral contact explosion. Finally, parametric studies are carried out to analyze the effects of
deformation shape, including the covered width of the lateral explosive, explosive charge material, and distribution of initial velocity.

References listed at the end of the paper:

Qi Cao (1), Haibo Jiang (2) and Haohan Wang (2)
(1) State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, Dalian 116024, China
(2) School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou 510006, China

“Shear Behavior of Corrugated Steel Webs in H Shape Bridge Girders”, Mathematical Problems in Engineering, Volume 2015, Article ID 796786, 15 pages, http://dx.doi.org/10.1155/2015/796786

ABSTRACT: In bridge engineering, girders with corrugated steel webs have shown good mechanical properties. With the promotion of composite bridge with corrugated steel webs, in particular steel-concrete composite girder bridge with corrugated steel webs, it is necessary to study the shear performance and buckling of the corrugated webs. In this research, by conducting experiment incorporated with finite element analysis, the stability of H shape beam welded with corrugated webs was tested and three failure modes were observed. Structural data including load-deflection, load-strain, and shear capacity of tested beam specimens were collected and compared with FEM analytical results by ANSYS software. The effects of web thickness, corrugation, and stiffening on shear capacity of corrugated webs were further discussed.

References listed at the end of the paper:


ABSTRACT: This work investigates the influence of Young’s modulus, shells thickness, and geometrical imperfection uncertainties on the parametric instability loads of simply supported axially excited cylindrical shells. The Donnell nonlinear shallow shell theory is used for the displacement field of the cylindrical shell and the parameters under investigation are considered as uncertain parameters with a known probability density function in the equilibrium equation. The uncertainties are discretized as Hermite-Chaos polynomials together with the Galerkin stochastic procedure that discretizes the stochastic equation in a set of deterministic equations of motion. Then, a general expression for the transversal displacement is obtained by a perturbation procedure which identifies all nonlinear modes that couple with the linear modes. So, a particular solution is selected which ensures the convergence of the response up to very large deflections. Applying the standard Galerkin method, a discrete system in time domain that considers the uncertainties is obtained and solved by fourth-order Runge-Kutta method. Several numerical strategies are used to study the nonlinear behavior of the shell considering the uncertainties in the parameters. Special attention is given to the influence of the uncertainties on the parametric instability and time response, showing that the Hermite-Chaos polynomial is a good numerical tool.

References listed at the end of the paper:
analyses of three cylindrical shell problems with different shapes, loadings, and boundary conditions. The verification and characteristics of the proposed element are investigated through the implementation of the exact mapping of curved shell configuration with a constant curvature with respect to any direction in the plane. The element displacement approximation is established by the integrals of Legendre polynomials and allows the first order shear deformation and considers anisotropic materials due to fiber orientation. The element displacement approximation is established by the integrals of Legendre polynomials and allows the first order shear deformation and considers anisotropic materials due to fiber orientation. The element displacement approximation is established by the integrals of Legendre polynomials and allows the first order shear deformation and considers anisotropic materials due to fiber orientation. The element displacement approximation is established by the integrals of Legendre polynomials and allows the first order shear deformation and considers anisotropic materials due to fiber orientation. The element displacement approximation is established by the integrals of Legendre polynomials and allows the first order shear deformation and considers anisotropic materials due to fiber orientation. The element displacement approximation is established by the integrals of Legendre polynomials and allows the first order shear deformation and considers anisotropic materials due to fiber orientation.

ABSTRACT: We introduce higher-order cylindrical shell element based on ESL (equiv-
References listed at the end of the paper:
ABSTRACT: The height at which an unloaded column will fail under its own weight was calculated for first time by Galileo for cylindrical columns. Galileo questioned himself if there exists a shape function for the cross section of the column with which it can attain a greater height than the cylindrical column. The problem is not solved since then, although the definition of the so named “constant maximum strength” solids seems to give an affirmative answer to Galileo’s question, in the form of shapes which seem to attain infinite height, even when loaded with a useful load at the top. The main contribution of this work is to show that Galileo’s problem is (i) an important problem for structural design theory of buildings and other structures, (ii) not solved by the time being in any sense, and (iii) an interesting problem for mathematicians involved in related but very different problems (as Euler’s tallest column). A contemporary formulation of the problem is included as a result of a research on the subject.

References listed at the end of the paper:

ABSTRACT: We study a dynamic fourth-order Euler-Bernoulli partial differential equation having a constant elastic modulus and area moment of inertia, a variable lineal mass density \( g(x) \), and the applied load denoted by \( f(u) \), a function of transverse displacement \( u(t,x) \). The complete Lie group classification is obtained for different forms of the variable lineal mass density \( g(x) \) and applied load \( f(u) \). The equivalence transformations are constructed to simplify the determining equations for the symmetries. The principal algebra is one-dimensional and it extends to two- and three-dimensional algebras for an arbitrary applied load, general power-law, exponential, and log type of applied loads for different forms of \( g(x) \). For the linear applied load case, we obtain an infinite-dimensional Lie algebra. We recover the Lie symmetry classification results discussed in the literature when \( g(x) \) is constant with variable applied load \( f(u) \). For the general power-law and exponential case the group invariant solutions are derived. The similarity transformations reduce the fourth-order partial differential equation to a fourth-order ordinary differential equation. For the power-law applied load case a compatible initial-boundary value problem for the clamped and free end beam cases is formulated. We deduce the fourth-order ordinary differential equation with appropriate initial and boundary conditions.

References listed at the end of the paper:

Yan-Qi Yin, Bo Zhang, Yue-ming Li and Wei-Zhen Lu, “Effect of Dead Load on Dynamic Characteristics of Rotating Timoshenko Beams”, Mathematical Problems in Engineering, Volume 2015, Article ID 582192, 10 pages, http://dx.doi.org/10.1155/2015/582192

ABSTRACT: The dynamic characteristics of a rotating cantilever Timoshenko beam under dead load are investigated in this paper. Considering the predeformation caused by dead load and centrifugal force, governing equation of rotating cantilever Timoshenko beam is derived based on Hamilton’s principle, and the influence of the load on natural vibration is revealed. A suit of modal experimental apparatus for cantilever beam is designed and used to test the natural frequencies under the dead load, and the natural frequencies under rotation condition are calculated with a commercial finite element code. Both the experimental result and numerical result are utilized to compare with the present theoretical result, and the results obtained by present modeling method show a good agreement with those obtained from the experiment and finite element method. It is found that the natural frequencies of cantilever beam increase with both the dead load and the rotating speed.

References listed at the end of the paper:

ABSTRACT: The sound radiation from elastically restrained plates covered by a decoupling layer is studied using the Spectrogeometric Method (SGM), which is a meshless and parametric modeling technique. By adopting the Rayleigh-Ritz procedure and the Rayleigh integral, a vibroacoustic coupling system is established. This model studies the situation when the plate is immersed in heavy fluid, such as water, in which the strong coupling between the structure and sound field should be fully considered. The influence of the boundary conditions on the radiated sound power and sound reduction provided by the decoupling layer based on the locally reacting model is studied. The nonuniform distributed decoupling layer is also studied to analyze the sound reduction effect. The sound intensity on the outer surface of the decoupling layer is investigated and tends to be uniform along the plate scale with increasing thickness of the decoupling layer.

References listed at the end of the paper:


ABSTRACT: This paper deals with stability analysis of clamped rectangular orthotropic thin plates subjected to uniformly distributed shear load around the edges. Due to the nature of this problem, it is impossible to present mathematically exact analytical solution for the governing differential equations. Consequently, all existing studies in the literature have been performed by means of different numerical approaches. Here, a closed-form approach is presented for simple and fast prediction of the critical buckling load of clamped narrow rectangular orthotropic thin plates. Next, a practical modification factor is proposed to extend the validity of the obtained results for a wide range of plate aspect ratios. To demonstrate the efficiency and reliability of the proposed closed-form formulas, an accurate computational code is developed based on the classical plate theory (CPT) by means of differential quadrature method (DQM) for comparison purposes. Moreover, several finite element (FE) simulations are performed via ANSYS software. It is shown that simplicity, high accuracy, and rapid prediction of the critical load for different values of the plate aspect ratio and for a wide range of effective geometric and mechanical parameters are the main advantages of the proposed closed-form formulas over other existing studies in the literature for the same problem.

References listed at the end of the paper:


ABSTRACT: Three generalizations of the Timoshenko beam model according to the linear theory of micropolar elasticity or its special cases, that is, the couple stress theory or the modified couple stress theory, recently developed in the literature, are investigated and compared. The analysis is carried out in a variational setting, making use of Hamilton’s principle. It is shown that both the Timoshenko and the (possibly modified) couple stress models are based on a microstructural kinematics which is governed by kinosthenic (ignorable) terms in the Lagrangian. Despite their difference, all models bring in a beam-plane theory only one microstructural material parameter. Besides, the micropolar model formally reduces to the couple stress model upon introducing the proper constraint on the microstructure kinematics, although the material parameter is generally different. Line loading on the microstructure results in a nonconservative force potential. Finally, the Hamiltonian form of the micropolar beam model is derived and the canonical equations are presented along with their general solution. The latter exhibits a general oscillatory pattern for the microstructure rotation and stress, whose behavior matches the numerical findings.

References listed at the end of the paper:
Xiaowei Gao, Yunfei Liu and Jun Lv (School of Aeronautics and Astronautics, State Key Laboratory of Structural Analysis for Industrial Equipment, Dalian University of Technology, Dalian 116024, China), “A New Method Applied to the Quadrilateral Membrane Element with Vertex Rigid Rotational Freedom”, Mathematical Problems in Engineering, Volume 2016, Article ID 1045438, 13 pages, http://dx.doi.org/10.1155/2016/1045438

ABSTRACT: In order to improve the performance of the membrane element with vertex rigid rotational freedom, a new method to establish the local Cartesian coordinate system and calculate the derivatives of the shape functions with respect to the local coordinates is introduced in this paper. The membrane elements with vertex rigid rotational freedom such as GQ12 and GQ12M based on this new method can achieve higher precision results than traditional methods. The numerical results demonstrate that the elements GQ12 and GQ12M with this new method can provide better membrane elements for flat shell elements. Furthermore, this new method presented in this paper offers a new approach for other membrane elements used in flat shell element to improve the computing accuracy.

References listed at the end of the paper:
ABSTRACT: The theory of the elastic shells is one of the most important parts of the theory of solid mechanics. The elastic shell can be described with its middle surface; that is, the three-dimensional elastic shell with equal thickness comprises a series of overlying surfaces like middle surface. In this paper, the differential geometric relations between elastic shell and its middle surface are provided under the curvilinear coordinate systems, which are very important for forming two-dimensional linear and nonlinear elastic shell models. Concretely, the metric tensors, the determinant of metric matrix field, the Christoffel symbols, and Riemann tensors on the three-dimensional elasticity are expressed by those on the two-dimensional middle surface, which are featured by the asymptotic expressions with respect to the variable in the direction of thickness of the shell. Thus, the novelty of this work is that we can further split three-dimensional mechanics equations into two-dimensional variation problems. Finally, two kinds of special shells, hemispherical shell and semicylindrical shell, are provided as the examples.

References listed at the end of the paper:
3 B. E. Pobedrya, Lectures on Tensor Analysis, MGU, Moscow, Russia, 1986 (Russian).
ABSTRACT: An RBF-based meshless method is presented for the analysis of thin plates undergoing large deflection. The method is based on collocation with the multiquadric radial basis function (MQ-RBF). In the proposed method, the resulting coupled nonlinear equations are solved using an incremental-iterative procedure. The accuracy and efficiency of the method are verified through several numerical examples. The inclusion of the free edge boundary condition proves that this method is accurate and efficient in handling such complex boundary value problems.

References listed at the end of the paper:
ABSTRACT: A corotational finite element formulation for large displacement analysis of planar functionally graded sandwich (FGSW) beam and frame structures is presented. The beams and frames are assumed to be formed from a metallic soft core and two symmetric functionally graded skin layers. The Euler-Bernoulli beam theory and von Kármán nonlinear strain-displacement relationship are adopted for the local strain. Exact solution of nonlinear equilibrium equations for a beam segment is employed to interpolate the displacement field for avoiding the membrane locking. An incremental-iterative procedure is used in combination with the arc-length control method to compute the equilibrium paths. Numerical examples show that the proposed formulation is capable of evaluating accurately the large displacement response with just several elements. A parametric study is carried out to highlight the effect of the material distribution, the core thickness to height ratio on the large displacement behaviour of the FGSW beam, and frame structures.

References listed at the end of the paper:


ABSTRACT: This paper reports on approaches to estimate the critical buckling loads of thin-walled T-sections with closed-form solutions. We first develop a model using energy conservation approach under the assumption that there is no correlation between the restraint coefficient and buckling half-wavelength. Secondly, we propose a numerical approach to estimate the critical buckling conditions under the more realistic torsional stiffener constraint condition. A dimensionless parameter correlated with constraint conditions is introduced through finite element (FE) analysis and data fitting technique in the numerical approach. The critical buckling coefficient and loads can be expressed as explicit functions of the dimensionless parameter. The proposed numerical approach demonstrates higher accuracy than the approach under noncorrelation assumption. Due to the explicit expression of critical buckling loads, the numerical approach presented here can be easily used in the design, analysis, and precision manufacture of T-section webs.

References listed at the end of the paper:


Wen-ku Shi, Cheng Liu, Zhi-yong Chen, Wei He and Qing-hua Zu (State Key Laboratory of Automotive Simulation and Control, Jilin University, Changchun 130025, China), “Efficient Method for Calculating the Composite Stiffness of Parabolic Leaf Springs with Variable Stiffness for Vehicle Rear Suspension”, Mathematical Problems in Engineering, Volume 2016, Article ID 5169018, 12 pages.

ABSTRACT: The composite stiffness of parabolic leaf springs with variable stiffness is difficult to calculate using traditional integral equations. Numerical integration or FEA may be used but will require computer-aided software and long calculation times. An efficient method for calculating the composite stiffness of parabolic
leaf springs with variable stiffness is developed and evaluated to reduce the complexity of calculation and shorten the calculation time. A simplified model for double-leaf springs with variable stiffness is built, and a composite stiffness calculation method for the model is derived using displacement superposition and material deformation continuity. The proposed method can be applied on triple-leaf and multileaf springs. The accuracy of the calculation method is verified by the rig test and FEA analysis. Finally, several parameters that should be considered during the design process of springs are discussed. The rig test and FEA analytical results indicate that the calculated results are acceptable. The proposed method can provide guidance for the design and production of parabolic leaf springs with variable stiffness. The composite stiffness of the leaf spring can be calculated quickly and accurately when the basic parameters of the leaf spring are known.

References listed at the end of the paper:


ABSTRACT: The purpose of this paper is to determine a critical load for a nonuniform circular steel tube under eccentrically axial load. The circular tube has variable cross section at flattened ends with existing holes used for connection between members. Three different cases of eccentricities are studied with the drilled holes either on the same side or on the opposite side of column axis. The critical load is calculated from the differential equation of deflection curve which is solved by the power series and Runge-Kutta method. In addition, the loading tests were performed on a total of 180 specimens with different diameters, slenderness, and connection. The calculated results are compared and shown in a good agreement with those obtained from the experimental results. The results also show that the critical load decreases rapidly even at a small value of eccentricity and thus may have a significant effect on the load-carrying capacity.

References listed at the end of the paper:
Chaofeng Li, Qianshen Tang and Bangchun Wen (School of Mechanical Engineering & Automation, Northeastern University, Shenyang, Liaoning 110819, China), “Nonlinear Dynamic Behavior Analysis of Pressure Thin-Wall Pipe Segment with Supported Clearance at Both Ends,” Mathematical Problems in Engineering, Volume 2016, Article ID 5432516, 22 pages, http://dx.doi.org/10.1155/2016/5432516

ABSTRACT: An analysis of nonlinear behaviors of pressure thin-wall pipe segment with supported clearance at both ends was presented in this paper. The model of pressure thin-wall pipe segment with supported clearance was established by assuming the restraint condition as the work of springs in the deformation directions. Based on Sanders shell theory, Galerkin method was utilized to discretize the energy equations, external excitation, and nonlinear restraint forces. And the nonlinear governing equations of motion were derived by using Lagrange equation. The displacements in three directions were represented by the characteristic orthogonal polynomial series and trigonometric functions. The effects of supporting stiffness and supported clearance on dynamic behavior of pipe wall were discussed. The results show that the existence of supported clearance may lead to the changing of stiffness of the pipe vibration system and the dynamic behaviors of the pipe system show nonlinearity and become more complex; for example, the amplitude-frequency curve of the foundation frequency showed hard nonlinear phenomenon. The chaos and bifurcation may emerge at some region of the values of stiffness and clearance, which means that the responses of the pressure thin-wall pipe segment would be more complex, including periodic motion, times periodic motion, and quasiperiodic or chaotic motions.

References listed at the end of the paper:


References listed at the end of the paper:


Joseph Nkongho Anyi (1,2,3), Robert Nzengwa (1,3), Jean Chills Amba (3) and Claude Calery Abbe Ngayihi (1,3)

(1) Department of Mechanical Engineering, National Advanced School Polytechnics, University of Yaoundé I, P.O. Box 8390, Yaoundé, Cameroon
(2) Department of Mechanical Engineering, Higher Technical Teachers Training College, University of Buea, P.O. Box 249 Buea Road, Kumba, Cameroon
(3) Laboratory E3M, Faculty of Industrial Engineering, University of Douala, P.O. Box 2107, Douala, Cameroon


ABSTRACT: We have developed a curved finite element for a cylindrical thick shell based on the thick shell equations established in 1999 by Nzengwa and Tagne (N-T). The displacement field of the shell is interpolated from nodal displacements only and strains assumption. Numerical results on a cylindrical thin shell are compared with those of other well-known benchmarks with satisfaction. Convergence is rapidly obtained with very few elements. A scaling was processed on the cylindrical thin shell by increasing the ratio (half the thickness over the smallest radius in absolute value) and comparing results with those obtained with the classical Kirchhoff-Love thin shell theory; it appears that results diverge at (math) because of the significant energy contribution of the change of the third fundamental form found in N-T model. This limit value of the thickness ratio which characterizes the limit between thin and thick cylindrical shells differs from the ratio 0.4 proposed by Leissa and 0.5 proposed by Narita and Leissa.

References listed at the end of the paper:
and nonuniform beams. Firstly, one-step beam with moment of inertia and mass per unit length varying as (math) and (math) was studied. By using appropriate transformations, the differential equation for flexural free
vibration of one-step beam with variable cross section is reduced to a four-order differential equation with constant coefficients. According to different types of roots for the characteristic equation of four-order differential equation with constant coefficients, two kinds of modal shape functions are obtained, and the general solutions for flexural free vibration of one-step beam with variable cross section are presented. An exact approach to solve the natural frequencies and modal shapes of multistep beam with variable cross section is presented by using transfer matrix method, the exact general solutions of one-step beam, and iterative method. Numerical examples reveal that the calculated frequencies and modal shapes are in good agreement with the finite element method (FEM), which demonstrates the solutions of present method are exact ones.

References listed at the end of the paper:

Lihua Huang, Bin Li and Yuefang Wang, “Computation Analysis of Buckling Loads of Thin-Walled Members with Open Sections”, Mathematical Problems in Engineering, Volume 2016, Article ID 8320469, 9 pages, http://dx.doi.org/10.1155/2016/8320469

ABSTRACT: The computational methods for solving buckling loads of thin-walled members with open sections are not unique when different concerns are emphasized. In this paper, the buckling loads of thin-walled members in linear-elastic, geometrically nonlinear-elastic, and nonlinear-inelastic behaviors are investigated from the views of mathematical formulation, experiment, and numerical solution. The differential equations and their solutions of linear-elastic and geometrically nonlinear-elastic buckling of thin-walled members with various constraints are derived. Taking structural angle as an example, numerical analysis of elastic and inelastic buckling is carried out via ANSYS. Elastic analyses for linearized buckling and nonlinear buckling are realized using finite elements of beam and shell and are compared with the theoretical results. The effect of modeling of constraints on numerical results is studied when shell element is applied. The factors that influence
References listed at the end of the paper:
11 J. Chen, Buckling Behavior of Single Cold-Formed Angle under Axial Load, Xi’an University of Architecture and Technology, Xi’an, China, 2004.
13 X. X. Hong, The Stability of the Cold-Formed 60° Equilateral Single Angle under Compression, Chang’ an University, Xi’an, China, 2008.


ABSTRACT: According to the flexural and torsional characteristics of curved thin-walled box girder with the effect of initial curvature, 7 basic displacements of curved box girder are determined. And then the strain-displacement calculation correlations were established. Under the curvilinear coordinate system, a three-noded curved girder finite element which has 7 degrees of freedom per node for the vibration characteristic and dynamic response analysis of curved box girder is constructed. The shape functions are used as the interpolation functions of variable curvature and variable height to accommodate to the variation of curvature and section height. A MATLAB numerical analysis program has been implemented.

References listed at the end of the paper:


ABSTRACT: We propose a new spectral element model for finite rectangular plate elements with arbitrary boundary conditions. The new spectral element model is developed by modifying the boundary splitting method used in our previous study so that the four corner nodes of a finite rectangular plate element become active. Thus, the new spectral element model can be applied to any finite rectangular plate element with arbitrary boundary conditions, while the spectral element model introduced in the our previous study is valid only for finite rectangular plate elements with four fixed corner nodes. The new spectral element model can be used as a generic finite element model because it can be assembled in any plate direction. The accuracy and computational efficiency of the new spectral element model are validated by a comparison with exact solutions, solutions obtained by the standard finite element method, and solutions from the commercial finite element analysis package ANSYS.

References listed at the end of the paper:
ABSTRACT: This major goal of this paper is to address the derivation of the frequency equation of flexural vibrating cantilever beam considering the bending moment generated by an additional mass at the free end of beam, not just the shear force. It is a transcendental equation with two unambiguous physical meaning parameters. And the influence of the two parameters on the characteristics of frequency and shape mode was made. The results show that the inertial moment of the mass has the significant effect on the natural frequency and the shape mode. And it is more reasonable using this frequency equation to analyze vibration and measure modulus.

References listed at the end of the paper:


ABSTRACT: This research proposed a new family of finite elements for spherical thick shell based on Nzengwa–Tagne’s model proposed in 1999. The model referred to hereafter as N-T model contains the classical Kirchhoff-Love (K-L) kinematic with additional terms related to the third fundamental form governing strain energy. Transverse shear stresses are computed and Co finite element is proposed for numerical implementation. However, using straight line triangular elements does not guarantee a correct computation of stress across common edges of adjacent elements because of gradient jumps. The gradient recovery method
known as Polynomial Preserving Recovery (PPR) is used for local interpolation and applied on a hemisphere under diametrically opposite charges. A good agreement of convergence results is observed; numerical results are compared to other results obtained with the classical K-L thin shell theory. Moreover, simulation on increasing values of the ratio of the shell shows impact of the N-T model especially on transverse stresses because of the significant energy contribution due to the third fundamental form tensor present in the kinematics of this model. The analysis of the thickness ratio shows difference between the classical K-L theory and N-T model when the ratio is greater than 0.099.

References listed at the end of the paper:


ABSTRACT: Buckling of nonprismatic single columns with arbitrary boundary conditions resting on a nonuniform elastic foundation may be considered as the most generalized treatment of the subject. The buckling
differential equation for such columns is extremely difficult to solve analytically. Thus, the authors propose a numerical approach by discretizing the column into a finite number of segments. Each segment has constants (modulus of elasticity), (moment of inertia), and (subgrade stiffness). Next, an exact analytical solution is derived for each prismatic segment resting on uniform elastic foundation. These segments are then assembled in a matrix from which the critical buckling load is obtained. The derived formulation accounts for different end boundary conditions. Validation is performed by benchmarking the present results against analytical solutions found in the literature, showing excellent agreement. After validation, more examples are solved to illustrate the power and flexibility of the proposed method. Overall, the proposed method provides reasonable results, and the examples solved demonstrate the versatility of the developed approach and some of its many possible applications.

References listed at the end of the paper:


Yuqiao Zheng (1,2), Yongyong Cao (1,2), Chengcheng Zhang (1,2) and Zhe He (1,2)
(1) Key Laboratory of Digital Manufacturing Technology and Application, The Ministry of Education, Lanzhou University of Technology, Lanzhou 730050, China
(2) College of Mechano-Electronic Engineering, Lanzhou University of Technology, Lanzhou 730050, China


ABSTRACT: This paper presents a structural optimization design of the realistic large scale wind turbine blade. The mathematical simulations have been compared with experimental data found in the literature. All complicated loads were applied on the blade when it was working, which impacts directly on mixed vibration of the wind rotor, tower, and other components, and this vibration can dramatically affect the service life and performance of wind turbine. The optimized mathematical model of the blade was established in the interaction between aerodynamic and structural conditions. The modal results show that the first six modes are flapwise dominant. Meanwhile, the mechanism relationship was investigated between the blade tip deformation and the load distribution. Finally, resonance cannot occur in the optimized blade, as compared to the natural frequency of the blade. It verified that the optimized model is more appropriate to describe the structure. Additionally, it provided a reference for the structural design of a large wind turbine blade.

References listed at the end of the paper:
ABSTRACT: At the collapse zone, the effects of the thickness of the consolidation grouting layer and the water pressure on the steel lining are vital to the stability of steel-lined pressure diversion tunnels. In this paper, a joint element and the load-sharing ratio of the consolidation layer are introduced to investigate the joint load-bearing characteristics of the steel lining and the consolidation layer and to determine a suitable consolidation layer thickness; a coupling method for simulating the hydromechanical interaction of the reinforced concrete lining is adopted to investigate the effect of internal water exosmosis on the seepage field at the collapse zone and to determine the external water pressure on the steel lining. In the case of a steel-lined pressure diversion tunnel, a numerical simulation is implemented to analyse the effect of the thickness of the consolidation layer and the distribution of the seepage field under the influence of internal water exosmosis. The results show that a 10 m thick consolidation layer and the adopted antiseepage measures ensure the stability of the steel lining at the collapse zone under internal and external water pressure. These research results provide a reference for the design of treatment measures for large-scale collapses in steel-lined pressure tunnels.

References listed at the end of the paper:

ABSTRACT: A minimum weight design is developed for a composite laminated tube considering the number of plies as one of the design variables. The objective function is found to be complex, and more than one optimal design point may exist with different numbers of plies. Existing methods based on evolutionary algorithms tend to become trapped around a local optimum and can find no more than one optimal result per calculation. Aiming at the characteristics of the objective function, an improved evolutionary algorithm (INDE for short) is established based on niching technology. The formula for calculating the distance between individuals in the niching technology is improved to satisfy the minimum weight design for the composite laminated tube. As a result, the improved niching evolutionary algorithm offers better global search ability and can find more than one optimal result per calculation for different numbers of plies.

References listed at the end of the paper:

and (ii) for the symmetrical curved tapered beam there is also a good agreement between the results of this study and that of a uniform tapered beam. Bending, torsional, and rotary inertia effects are considered with respect to no additional mass and the mass location are examined. Results are given in tabular form. It is concluded that (i) for the uniform tapered beam there is a good agreement between the results of this study and that of literature and (ii) for the symmetrical curved tapered beam there is also a good agreement between the results of this study.
study and that of a finite element model by using MSC.Marc. Results of out-of-plane free vibration of symmetrically tapered beams for specified boundary conditions are addressed.

References listed at the end of the paper:


ABSTRACT: A simply supported plate fluttering in hypersonic flow is investigated considering both the airflow and structural nonlinearities. Third-order piston theory is used for nonlinear aerodynamic loading, and von Karman plate theory is used for modeling the nonlinear strain-displacement relation. The Galerkin method is applied to project the partial differential governing equations (PDEs) into a set of ordinary differential equations (ODEs) in time, which is then solved by numerical integration method. In observation of limit cycle oscillations (LCO) and evolution of dynamic behaviors, nonlinear aerodynamic loading produces a smaller positive deflection peak and more complex bifurcation diagrams compared with linear aerodynamics. Moreover, a LCO obtained with the linear aerodynamics is mostly a nonsimple harmonic motion but when the aerodynamic nonlinearity is considered more complex motions are obtained, which is important in the evaluation of fatigue life. The parameters of Mach number, dynamic pressure, and in-plane thermal stresses all affect the aerodynamic nonlinearity. For a specific Mach number, there is a critical dynamic pressure beyond which the aerodynamic nonlinearity has to be considered. For a higher temperature, a lower critical dynamic pressure is required. Each nonlinear aerodynamic term in the full third-order piston theory is evaluated, based on which the nonlinear aerodynamic formulation has been simplified.

References listed at the end of the paper:
REFERENCES listed at the end of the paper:

22 Cosmos/M27, Structural Research and Analysis Corp. (SARC), 2002.
29 W. F. Zhang, Plate-Beam Theory And Analytical Solutions for Flexural-Torsional Buckling of Steel Beams, Research Report, Northeast Petroleum University, Daqing, China, 2015.
37 M. Ojalvo, Thin-Walled Bars with Open Profiles, The Olive Press, Columbus, Ohio, 1990.
48 G. J. Hancock, The behaviour of structures composed of thin-walled members [Ph.D. thesis], University of Sydney, Sydney, Australia, 1975.
ABSTRACT: As von Mises yield criterion and associated flow rule (AFR) are widely applied in metal forming field, a semitotal deformation consistent relationship between the stress and plastic strain components and the rule of dimensional changes of metal forming processes in a plane-stress state are obtained on the basis of them in this paper. The deduced consistent relationship may be easily used in forming interval of the workpiece. And the rule of dimensional changes can be understood through three plastic strain incremental circles on which the critical points can be easily determined on the same basis. Analysis of stress and plastic strain evolution of aluminum warm deep drawing process is conducted, and the advantage of nonisothermal warm forming process is revealed, indicating that this method has the potential in practical large deformation applications.

References listed at the end of the paper:


ABSTRACT: (The abstract has too much math in it.)

References listed at the end of the paper:

ABSTRACT: This paper is devoted to develop a new 8-node higher-order hybrid stress element (QH8) for free vibration and buckling analysis based on the Mindlin/Reissner plate theory. In particular, a simple explicit expression of a refine method with an adjustable constant is introduced to improve the accuracy of the analysis. A combined mass matrix for natural frequency analysis and a combined geometric stiffness matrix for buckling analysis are obtained using the refined method. It is noted that numerical examples are presented to show the validity and efficiency of the present element for free vibration and buckling analysis of plates. Furthermore, satisfactory accuracy for thin and moderately thick plates is obtained and it is free from shear locking for thin plate analysis and can pass the nonzero shear stress patch test.

References listed at the end of the paper:


ABSTRACT: Fiber Bragg Grating (FBG) sensors have been increasingly used in the field of Structural Health Monitoring (SHM) in recent years. In this paper, we proposed an impact localization algorithm based on the Empirical Mode Decomposition (EMD) and Particle Swarm Optimization–Support Vector Machine (PSO-SVM) to achieve better localization accuracy for the FBG-embedded plate. In our method, EMD is used to extract the features of FBG signals, and PSO-SVM is then applied to automatically train a classification model for the impact localization. Meanwhile, an impact monitoring system for the FBG-embedded composites has been established to actually validate our algorithm. Moreover, the relationship between the localization accuracy and the distance from impact to the nearest sensor has also been studied. Results suggest that the localization accuracy keeps increasing and is satisfactory, ranging from 93.89% to 97.14%, on our experimental conditions with the decrease of the distance. This article reports an effective and easy-implementing method for FBG signal processing in SHM systems of the composites.

References listed at the end of the article:

Deformation Prediction of Plate Line Rolling Forming Based on Inherent Strain Method

Changcheng Hu (1), Yao Zhao (1,2) and Guoyuan Tang (1)
(1) School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
(2) Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration (CISSE), Shanghai 200240, China

ABSTRACT: Inherent strain method has been widely used as a forecasting and computing method for welding deformation of large complicated structures and further applied to the research of line heating forming. Mechanical forming is a common ship-hull plate forming method, for which deformation prediction still depends mainly on elastoplastic finite element method. This paper researched the application of inherent strain method to plate line rolling forming, a common mechanical forming method, and then compared the results of inherent strain method and elastoplastic finite element method, proving the applicability of inherent strain method, providing a method for fast, accurate forecasting of distortion in plate line rolling and formation of automation equipment.

References listed at the end of the paper:

ABSTRACT: This study describes a slender reinforced concrete shear wall experimental test under in-plane cyclic lateral load, and the development of an analytical model which uses the fiber method approach to consider hysteretic nonlinear constitutive material models behavior. The shear wall tested had bending behavior, since the amount of longitudinal reinforcing bars produced weak bending capacity compared to the shear strength. The analytical model tries to represent global and local behavior of the wall, and its calibration is based on reaching experimental parameters like area enclosed and secant stiffness on every loop. After the analytical model was calibrated, the relation between some performance points and damage states observed during the test is studied.

References listed at the end of the paper:


12 ACI 318S-14, Requisitos de reglamento para el Concreto Estructural y Comentario, American Concrete Institute.

13 FEMA 306, Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings.


ABSTRACT: This paper examined and discussed a Meshless Wavelet Galerkin Method (MWGM) formulation for a first-order shear deformable beam, the properties of the MWGM, the differences between the MWGM and EFG, and programming methods for the MWGM. The first-order shear deformable beam (FSDB) consists of a pair of second-order elliptic differential equations. The weak forms of two differential equations are deduced using Hat wavelet series. The exact integration and reduced integration were used to analyze the problems. Some indeterminate beam problems are considered. Condition numbers of the stiffness matrix were analyzed with exact integration and reduced integration for two cases of these problems. Consequently, the results were converged on the analytic solutions. The shear-locking phenomenon also occurred in the MWGM as it occurs in the conventional FEM. The stiffness matrix calculated from the reduced integration causes a similar numerical error to the stiffness matrix calculated from the exact integration in the MWGM. The MWGM showed desirable results in the examples.

References listed at the end of the paper:


ABSTRACT: Presently, there exists an important need for lighter and more resistant structures, with reduced manufacturing costs. Laminated polymers are materials which respond to these new demands. Main difficulties of the design process of a composite laminate include the necessity to design both the geometry of the element and the material configuration itself and, therefore, the possibilities of creating composite materials are almost unlimited. Many techniques, ranging from linear programming or finite elements to computational intelligence,
have been used to solve this type of problems. The aim of this work is to show that more effective and dynamic methods to solve this type of problems are obtained by using certain techniques based on systematic exploitation of knowledge of the problem, together with the combination of metaheuristics based on population as well as on local search. With this objective, a memetic algorithm has been designed and compared with the main heuristics used in the design of laminated polymers in different scenarios. All solutions obtained have been validated by the ANSYS software package.

References listed at the end of the paper:


ABSTRACT: The bending solutions of rectangular thick plate with all edges clamped and supported were investigated in this study. The basic governing equations used for analysis are based on Mindlin’s higher-order shear deformation plate theory. Using a new function, the three coupled governing equations have been modified to independent partial differential equations that can be solved separately. These equations are coded in terms of deflection of the plate and the mentioned functions. By solving these decoupled equations, the analytic solutions of rectangular thick plate with all edges clamped and supported have been derived. The proposed method eliminates the complicated derivation for calculating coefficients and addresses the solution to problems directly. Moreover, numerical comparison shows the correctness and accuracy of the results.

References listed at the end of the paper:


ABSTRACT: A higher-order finite beam element for free and forced vibration analysis of functionally graded Timoshenko beams in thermal environment is formulated by using hierarchical functions to interpolate the kinematic variables. The shear strain is constrained to constant to improve the efficiency of the element. The effect of environmental temperature is taken into account in the element derivation by considering that the material properties are temperature-dependent and the temperature is nonlinear distribution in the beam thickness. The accuracy of the derived formulation is confirmed by comparing the results obtained in the present work with the published data. Numerical investigations show that the formulated element is efficient, and it is capable of giving accurate vibration characteristics by a small number of elements. A parametric study is carried out to highlight the effect of the material inhomogeneity, temperature rise, and loading parameter on the dynamic behaviour of the beams. The influence of the aspect ratio on the dynamic behaviour of the beam is also examined and highlighted.

ABSTRACT: Dynamic behavior of axially functionally graded (FG) pipes conveying fluid was investigated numerically by using the generalized integral transform technique (GITT). The transverse vibration equation was integral transformed into a coupled system of second-order differential equations in the temporal variable. The Mathematica’s built-in function, NDsolve, was employed to numerically solve the resulting transformed ODE system. Excellent convergence of the proposed eigenfunction expansions was demonstrated for
calculating the transverse displacement at various points of axially FG pipes conveying fluid. The proposed approach was verified by comparing the obtained results with the available solutions reported in the literature. Moreover, parametric studies were performed to analyze the effects of Young’s modulus variation, material distribution, and flow velocity on the dynamic behavior of axially FG pipes conveying fluid.

References listed at the end of the paper:

ABSTRACT: Wind effects on structures obtained by field measurements are often found to be nonstationary, but related researches shared by the wind-engineering community are still limited. In this paper, empirical mode decomposition (EMD) is applied to the nonstationary wind pressure time-history samples measured on an actual 167-meter high large cooling tower. It is found that the residue and some intrinsic mode functions (IMFs) of low frequencies produced by EMD are responsible for the samples’ nonstationarity. Replacing the residue by the constant mean and subtracting the IMFs of low frequencies can help the nonstationary samples become stationary ones. A further step is taken to compare the loading characteristics extracted from the original nonstationary samples with those extracted from the processed stationary samples. Results indicate that nonstationarity effects on wind loads are notable in most cases. The passive wind tunnel simulation technique based on the assumption of stationarity is also examined, and it is found that the technique is basically conservative for use.

References listed at the end of the paper:
Lijie Li (1), Haichao Li (2), Fuzen Pang (2,3), Xueren Wang (3), Yuan Du (2) and Shuo Li (2)
(1) College of Computer Science and Technology, Harbin Engineering University, Harbin 150001, China
(2) College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China
(3) Naval Academy of Armament, Beijing 100161, China


ABSTRACT: The aim of this paper is to extend the modified Fourier-Ritz approach to evaluate the free vibration of four-parameter functionally graded moderately thick cylindrical, conical, spherical panels and shells of revolution with general boundary conditions. The first-order shear deformation theory is employed to formulate the theoretical model. In the modified Fourier-Ritz approach, the admissible functions of the structure elements are expanded into the improved Fourier series which consist of two-dimensional (2D) Fourier cosine series and auxiliary functions to eliminate all the relevant discontinuities of the displacements and their derivatives at the edges regardless of boundary conditions and then solve the natural frequencies by means of the Ritz method. As one merit of this paper, the functionally graded cylindrical, conical, spherical shells are, respectively, regarded as a special functionally graded cylindrical, conical, spherical panels, and the coupling spring technology is introduced to ensure the kinematic and physical compatibility at the common meridian. The excellent accuracy and reliability of the unified computational model are compared with the results found in the literatures.

References listed at the end of the paper:


ABSTRACT: Fundamental advantage of using corrugated web girder rather than plate girder reinforced with stiffeners is securing stability against shear buckling of web and unnecessary stiffeners despite the thinner web. Nonetheless, because shear buckling behavior of corrugated web is very complex, the design mechanism for beams and local, global, and interactive buckling problems should be considered in designing of its structural optimization for better economics and reasonableness. Therefore, this paper proposes a mathematical model for minimum weight design of sinusoidal web girder for securing better stability with smooth corrugation and aims at developing its optimum design program. The constraints for the optimum design were composed on the basis of the standards of EN 1993-1-5, DASt-R015, and DIN 18800, and the optimum program was coded in accordance with the standards based on Real-Coded Genetic Algorithms. The genetic operators for the developed program resulted in a stable solution with crossover probability between 12.5 and 50%, and the perturbation vector for outbreeding could obtain the best result with the model being applied of feasible design variable space of 20–30%. Additionally, the increase of yield strength resulted in decreased value of the objective function, and it was found through the change of the value of the constraint function that the thickness of web was an important factor in the optimum structural design.

References listed at the end of the paper:
4 “DASt-richtlinie 015,” in Träger Mit Schlanken Stegen, Stahlbau-Verlag, Köln, Germany, 1990.
ABSTRACT: An elastic wave is composed of compressional (longitudinal) waves and shear (transverse) waves which have different wave velocities in solids. The acoustic field presents complex interference patterns which means its phenomena and properties are difficult to reveal. Fortunately, the energy method is more accurate than the potential function approach in describing the physical properties of the acoustic field. However, the polarization state of particle vibration excited by an elastic wave is spatially periodic in the wave propagation direction. Therefore, the energy propagation direction is not consistent with the wave propagation direction using commonly used energy method. According to the polarization state of particle vibration, a time-space averaging method based on the spatial periodicity of energy flux in the solid is proposed. The method could eliminate the influence of the interference due to local energy exchange and retain the trend of energy propagation. Several conclusions are illustrated through the analysis of the scattering energy properties of a steel shell in sandy sediment. Sandy sediment can not be regarded as a fluid nor a general solid. Scattering energy excited by an incident shear wave mainly concentrates in the vicinity of the directions of backscattering and forward scattering. Especially, at low frequency, it plays an important role in the total scattering energy excited by an incident compressional and shear wave.

References listed at the end of the article:
ABSTRACT: In this paper, postbuckling and free nonlinear vibration of microbeams resting on nonlinear elastic foundation subjected to axial force are investigated. The equations of motion of microbeams are derived by using the modified couple stress theory. Using Galerkin’s method, the equation of motion of microbeams is reduced to the nonlinear ordinary differential equation. By using the equivalent linearization in which the averaging value is calculated in a new way called the weighted averaging value, approximate analytical expressions for the nonlinear frequency of microbeams with pinned–pinned and clamped–clamped end conditions are obtained in closed-forms. Comparisons with previous solutions are showed accuracy of the present solutions. Effects of the material length scale parameter and the axial compressive force on the frequency ratios of microbeams; and effect of the material length scale parameter on the buckling load ratios of microbeams are investigated in this paper.

References listed at the end of the paper:


ABSTRACT: In some mechanical models, the tensile armors of bent flexible pipes are treated as geodesics on a torus and, based on this hypothesis, the curvatures of these curves are calculated to obtain the acting stresses. However, a closed-form solution of the geodesic differential equations is not possible, which imposes difficulties on determining these curvatures. This work, therefore, proposes two alternative solutions to the nonlinear geodesic differential equations. The first relies on an artificial neural network (ANN) and the second is obtained by symbolic regression (SR). Both employ data from the numerical solution of the geodesic differential equations and showed good correlation with the complete dataset. Nevertheless, when tested against new data, the SR equations led to results almost equal to those obtained with the numerical solution of the differential equations and to null geodesic curvature. Despite also agreeing well with the numerical solution, the ANN indicates nonnull geodesic curvatures. Moreover, when compared to equations often employed in the design of flexible pipes, the SR equations may indicate different results, which can impact, for example, the fatigue or the instability analysis of the tensile armors of these pipes.

References listed at the end of the paper:
ABSTRACT: This paper focuses on the three-dimensional (3D) asymmetric problem of functionally graded (FG) truncated conical shell subjected to thermal field and inertia force due to the rotating part. The FG properties are assumed to be varied along the thickness according to power law distribution, whereas Poisson’s ratio is assumed to be constant. On the basis of 3D Green-Lagrange theory in general curvilinear coordinate, the fundamental equations are formulated and then two versions of differential quadrature method (DQM) including polynomial based differential quadrature (PDQ) and Fourier expansion-based differential quadrature (FDQ) are applied to discretize the resulting differential equations. The reliability of the present approach is validated by comparing with known literature where good agreement is reached using considerably few grid points. The effects of different mechanical boundary conditions, temperature fields, rotating angular speed, and shell thickness on the distributions of stress components and displacement in thickness direction for both axisymmetric and asymmetric cases are graphically depicted.

References listed at the end of the paper:

Gyapal Singh, Poonam Kumari and Rupam Hazarika (Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati 781039, India), “Analytical solution for bending analysis of axially
ABSTRACT: In this paper, the analytical solution is presented for axially functionally graded (AFG) angle-ply flat panels subjected to arbitrary boundary condition. Material properties of AFG panels are assumed to vary linearly along -direction. Reissner-type variation principle is used to derive the governing equations in mixed form. By employing extended Kantorovich method (EKM), a set of nonhomogeneous ordinary differential equations (ODEs) are obtained along the in-plane () and thickness () direction. The system of ODEs along the -direction has constant coefficients, solved analytically. However, the system of ODEs along -direction has variable coefficients, solved using modified power series method. The influence of property variation on the deflection and stresses is studied and discussed comprehensively for different sets of boundary conditions. Numerical results are validated through comparison with 3D FE. The presented analytical solution can serve as a benchmark for assessing the accuracy of the two-dimensional solution or 3D numerical solutions.

References listed at the end of the paper:
ABSTRACT: A corotational finite element formulation for two-dimensional beam elements with geometrically nonlinear behavior is presented. The formulation separates the rigid body motion from the pure deformation which is always small relative to the corotational element frame. The stiffness matrices and the mass matrices are evaluated using both Euler-Bernoulli and Timoshenko beam models to reveal the shear effect in thin and thick beams and frames. The nonlinear equilibrium equations are developed using Hamilton’s principle and are defined in the global coordinate system. A MATLAB code is developed for the numerical solution. In static analysis, the code employed an iterative method based on the full Newton-Raphson method without incremental loading, while, in dynamic analysis, the Newmark direct integration implicit method is also utilized. Several examples of flexible beams and frames with large displacements are presented. Not only is the method simple and time-saving, but it is also highly effective and highly accurate.

References listed at the end of the paper:
ABSTRACT: The static and dynamic stability of the composite beam with a single delamination are investigated using the Timoshenko beam theory. The mechanical model is discretized using the finite element method and the equation of motion is obtained using Hamilton’s principle. The coefficients of the mass and stiffness matrix for the damping matrix are determined using experimental modal analysis. The effect of harmonic excitation on the dynamic stability of a single delaminated composite beam is investigated using Bolotin’s harmonic balance method. The stability boundaries of the damped and undamped system are compared for different static load values and delamination lengths on the excitation frequency-excitation force amplitude parameter field.

References listed at the end of the paper:


ABSTRACT: The problem of optimal design of the statically indeterminate arch girder which constitutes the primary structural system of the arch bridge is presented. The task is to determine the optimal shape of the axis of the arch girder, as well as the optimal distribution of the cross section height, ensuring the minimum arch volume as well as fulfillment of the standard requirements. This optimisation task, with numerous control
functions and constraints, is formulated as a control theory problem with maintaining the formal structure of the minimum principle and then transformed to the multipoint boundary value problem and solved by means of numerical methods. The numerical results are obtained with optimal control methods, using the Dircol software. Since the changes in the shape and cross-section of the arch affect the distribution of the dead and moving loads transferred on the girder from the bridge deck, the optimisation procedure is combined with the finite element method analysis, which together with the complexity of the multidiscipline arch optimisation problem accounts for the novelty of the proposed approach. The numerical analysis reveals that the optimal girder shape is the frame-arched structure, with considerable lengths of straight sections and only short arch elements, in the areas of the application of concentrated forces and moments. The presented method can be successfully extended to optimisation of structures with different static schemes and load categories taken into account.

References listed at the end of the paper:
16. D. Kropiowska, Selected problems of the optimal design of bar systems within the formal structure of the minimum principle, Cracow University of Technology Publishing House, Cracow, 2016.


ABSTRACT: This paper presents a free vibration analysis of beams made of fibre-metal laminated beams. Due to its attractive properties, this class of composites has gained more and more importance in the aeronautic field. Several higher-order displacements-based theories as well as classical models (Euler-Bernoulli’s and Timoshenko’s ones) are derived, assuming Carrera’s Unified Formulation by a priori approximating the displacement field over the cross section in a compact form. The governing differential equations and the boundary conditions are derived in a general form that corresponds to a generic term in the displacement field.
approximation. The resulting fundamental term, named “nucleus”, does not depend upon the approximation order N, which is a free parameter of the formulation. A Navier-type, closed form solution is used. Simply supported beams are, therefore, investigated. Slender and short beams are considered. Three- and five-layer beams are studied. Bending, shear, torsional, and axial modes and frequencies are presented. Results are assessed for three-dimensional FEM solutions obtained by a commercial finite element code using three-dimensional elements showing that the proposed approach is accurate yet computationally effective.

References listed at the end of the paper:

ABSTRACT: A finite segment method is presented to analyze the mechanical behavior of skewed box girders. By modeling the top and bottom plates of the segments with skew plate beam element under an inclined coordinate system and the webs with normal plate beam element, a spatial elastic displacement model for skewed box girder is constructed, which can satisfy the compatibility condition at the corners of the cross section for box girders. The formulation of the finite segment is developed based on the variational principle. The major advantage of the proposed approach, in comparison with the finite element method, is that it can simplify a three-dimensional structure into a one-dimensional structure for structural analysis, which results in significant saving in computational times. At last, the accuracy and efficiency of the proposed finite segment method are verified by a model test.

References listed at the end of the paper:


ABSTRACT: This paper provides brief review on polygonal/polyhedral finite elements. Various techniques, together with their advantages and disadvantages, are listed. A comparison of various techniques with the recently proposed Virtual Node Polyhedral Element (VPHE) is also provided. This review would help the readers to understand the various techniques used in formation of polygonal/polyhedral finite elements.

PARTIAL INTRODUCTION: Meanwhile, various methods have been proposed over the years to form polygonal/polyhedral finite elements and to solve problems within polygonal/polyhedral meshes. These methods are as follows:

1) Voronoi cell finite element method (VCFEM) and polygonal finite element based on parametric variational principle and the parametric quadratic programming method
2) Hybrid polygonal element (HPE)
3) Conforming polygonal finite element method based on barycentric coordinates (conforming PFEM, or PFEM)
4) n-Sided polygonal smoothed finite element method (nSFEM)
5) Polygonal scaled boundary finite element method (PSBFEM)
6) Mimetic finite difference (MFD) and virtual element method (VEM)
7) Virtual node method (VNM)
8) Discontinuous Galerkin finite element method (DGFEM)
9) Trefftz/Hybrid Trefftz polygonal finite element (T-FEM or HT-FEM) and Boundary element based FEM (BEM-based FEM)
10) Hybrid stress-function (HS-F) polygonal element
11) Base forces element method (BFEM)
12) Other recent techniques/schemes

The methods above are briefly highlighted in the following sections.

References listed at the end of the paper:


ABSTRACT: Based on the Unified Strength Theory (UST), elastoplastic analysis of the two-layered circular lining is carried out. The stresses, displacements, and the elastic and plastic zones in both layers are discussed under different values of Young’s moduli of the inner and outer layers. The results reveal that, compared to the single-layered lining, the tangential stress distributions in the two-layered linings are more reasonable along the radial direction, which is beneficial to enhance the overall elastic and plastic ultimate bearing capacities. When considering the intermediate stress (i.e., the axial load), the elastic ultimate bearing capacity will be higher. However, the plastic ultimate bearing capacity remains unchanged. Moreover, a comparison between the Unified Strength Theory and Tresca Criterion is analyzed as well.

References listed at the end of the paper:


3. Q. Wu, Stress Analysis on Thick-Walled Cylinder of Multilayer Concrete Material with Functionally Graded Characteristics, North China Electric Power University, 2009.


ABSTRACT: In this work, the transfer entropy and surrogate data algorithm were introduced to identify the nonlinearity level of the system by using a numerical solution of nonlinear response of beams. A homogeneous Euler-Bernoulli beam was subjected to a time-varying concentrated load and resting on a nonlinear foundation. The Galerkin method was applied to discretize the dimensionless differential governing equation of the forced vibration, and then the fourth-order Runge-Kutta method was used to obtain the time-history response of the lateral displacement. In order to simulate different nonlinearity levels, different ratios between nonlinear parameters and linear parameters of foundation, as well as different Young’s moduli, were used. A nonlinearity index was proposed. In the case of different nonlinearity levels, the nonlinearity index was used to analyze the difference between the transfer entropy calculated from the original data and the transfer entropy calculated from the surrogate data. By comparing and analyzing the nonlinearity index values under different ratios, it was found that the nonlinearity index values generally increased with the increase of the ratio and the sum of nonlinearity index values had a positive correlation with the ratio. By comparing the nonlinearity index values of the transfer entropy results of beams with different Young's moduli, it was found that the sum of the nonlinearity index values generally decreased with the increase of Young's modulus. The numerical results demonstrate that the present approach could effectively quantify the nonlinearity in the response of a beam resting on a nonlinear foundation.

References listed at the end of the paper:

ABSTRACT: This study aimed at obtaining a semianalytical solution for nonlinear dynamic system of shallow arches. Taylor method was applied to find the analytical solution, and an investigation of their dynamic characteristic was carried out to verify the applicability of this methodology for the shallow arches under step or periodic excitation. A polynomial solution can be obtained from this multistep approach with respect to time, and direct buckling as well as indirect buckling of the shallow arches can be observed, also. The results indicated that the dynamic buckling load level was higher with higher shape factor. Additionally, a change of attractor in phase space was investigated. Coupling in symmetric mode as well as asymmetric mode was observed in case of indirect buckling, and a sensitive response was also manifested during sinusoidal and beating excitation. These results of applying multistep Taylor series for the investigation of displacement response and attractor change revealed that this analytical approach was valid in explaining the dynamic buckling behavior of shallow arches under direct and indirect snapping.

References listed at the end of the paper:


De-Min Zhao, Shan-Peng Li, Yun Zhang and Jian-Lin Liu (Department of Engineering Mechanics, College of Pipeline and Civil Engineering, China University of Petroleum (East China), Qingdao 266580, China),
ABSTRACT: Mechanical nonlinear vibration of slender structures, such as beams, strings, rods, plates, and even shells occurs extensively in a variety of areas, spanning from aerospace, automobile, cranes, ships, offshore platforms, and bridges to MEMS/NEMS. In the present study, the nonlinear vibration of an elastic string with large amplitude and large curvature has been systematically investigated. Firstly, the mechanics model of the string undergoing strong geometric deformation is built based on the Hamilton principle. The nonlinear mode shape function was used to discretize the partial differential equation into ordinary differential equation. The modified complex normal form method (CNFM) and the finite difference scheme are used to calculate the critical parameters of the string vibration, including the time history diagram, configuration, total length, and fundamental frequency. It is shown that the calculation results from these two methods are close, which are different with those from the linear equation model. The numerical results are also validated by our experiment, and they take excellent agreement. These analyses may be helpful to engineer some soft materials and can also provide insight into the design of elementary structures in sensors, actuators and resonators, etc.

References listed at the end of the paper:
ABSTRACT: Stochastic response of a plate on the generalized foundation driven by random excitation is solved in this paper. Governing differential equation is obtained by employing the Galerkin method. The generalized harmonic function technique is applied to the governing equation of motion. Using the stochastic averaging method (SAM), the system is approximated by the time homogeneous diffusive Markov process. Corresponding approximate stationary probability function is achieved by solving associated Fokker-Plank-Kolmogorov (FPK). An analytical solution is presented for the stationary probability of the amplitude and velocity. Validity of the stationary probability is verified by Monte-Carlo simulation. Parametric study is carried out to investigate effects of foundation parameters and excitation intensity on the stationary probability function. It is found that the fractional properties act similar to the foundation stiffness and damping and can be employed as a new control parameter for the support design.

References listed at the end of the paper:


References:

ABSTRACT: The high-strength concrete-filled thin-walled steel tubular (HCFTST) columns, as a relatively new type structure member, could reduce the section size to obtain the favorable architecture aesthetic effects and gain further economic benefits. In this paper, the HCFTST columns were optimized on the basis of the orthogonal array of L16 (4^5) with three tested parameters. The orthogonal range analysis (ORA) was utilized to research the alteration degree, and the orthogonal variance analysis (OVA) was employed to analyze the significant degree between different parameters. Moreover, the optimized combinations based on performance index including strength, ductility, and energy dissipation were recommended to offer certain reference for structural design and application. Finally, a modified damage assessment model was proposed and verified. It indicates that the HCFTST columns with reasonable design could display favorable performance and can be expected to have a widespread application in engineering structures.

References listed at the end of the paper:


ABSTRACT: Structural engineering demands increasingly lighter systems, which can cause instability problems and compromise performance. A high slenderness index of a structural element makes it susceptible to instability. It is important to understand the problem, the limits of stability, and its postcritical behavior. An example that can occur in collapsed arches under a cross load is the dynamic snap-through behavior, where the structure in a given equilibrium condition jumps to a new remote equilibrium setting, causing usually sudden curvature. The semirigid connections are a source of physical nonlinearity and can influence the overall stability of the structural system, in addition to the distribution of stresses in the same system. Conventional approaches make use of static considerations. However, instability problems are inherently evolutionary processes, so a transient analysis is necessary for a complete description of structural behavior. The present work evaluates the geometrically nonlinear dynamic behavior of collapsed arches subjected to transverse force and plane frames with semirigid connections. The time domain responses, via Newmark's Method and positional formulation of the Finite Element Method, were obtained in terms of displacements, velocities, acceleration, and phase diagrams.

References listed at the end of the paper:
4 L. R. B. Rosas, Dynamic analysis of framed structures with contact restraints. MSc dissertation, Universidade Federal de Ouro Preto, 2016.
5 A. R. D. Silva, Computational system for advanced static and dynamic analysis of steel structures, Graduation program of civil engineering, 2009.
15 H. M. Caldwell, Optimization of Shallow Arches against Snap-Through Buckling [Ph.D. thesis], Faculty of the Division of Graduate Studies and Research, Georgia Institute of Technology, 1977.
20 M. Greco, Nonlinear structural contact/impact analysis problems using the finite element method, Universidade de São Paulo, 2004.


ABSTRACT: A fast shape optimization strategy for free form shell structure design with structural dynamics criteria is proposed in this paper. The structures are modelled with Non-Uniform Rational B-Spline based isogeometric Kirchhoff-Love shell elements. The substitution of the traditional finite elements not only makes the mesh model geometrically exact but also avoids the laborious mesh regeneration during the design update. As for the structural response evaluation, the modal synthesis method is adopted to avoid a repeated evaluation of some substructures where there are no designed variables attached; thus, the model reanalysis is speeded up. A bottom-up strategy for the analytical design sensitivity evaluation is also proposed here; the element-level analytical sensitivity with respect to the inherent shape parameters is firstly calculated from which the design sensitivity is then extracted with the help of a sensitivity map. Finally, gradient based algorithm is used to solve the optimization problem. Several examples show that our approach is flexible and efficient for fast free form shell structure optimization.

References listed at the end of the paper:


ABSTRACT: Regular domain collocation method based on barycentric rational interpolation for solving irregular thin plate bending problems on Winkler foundation is presented in this article. Embedding the irregular plate into a regular domain, the barycentric rational interpolation is used to approximate the unknown function. The governing equation and the boundary conditions of thin plate bending problems on Winkler foundation in a rectangular region can be discretized by the differentiation matrices of barycentric rational interpolation. The additional method or the substitute method is used to impose the boundary conditions. The overconstraint equations can be solved by using the least square method. Numerical solutions of bending deflection for the irregular plate bending problems on Winkler foundation are obtained by interpolating the data on rectangular region. Numerical examples illustrate that the proposed method for irregular thin plate bending problems on Winkler foundation has the merits of simple formulations, efficiency, and relative error precision of 10–9 orders of magnitude.

References listed at the end of the paper:

ABSTRACT: An exact dynamic stiffness formulation is proposed for calculating the natural frequencies of shells of revolution based on the first-order Reissner-Mindlin theory. Equations of motion are reduced to be one-dimensional, should the circumferential wave number is specified, and then are rewritten in Hamilton form. Therefore, a shell of revolution with a moderate thickness is analysed as a special skeletal structure with five degrees of freedom at element ends. Dynamic stiffnesses are constructed directly from the one-dimensional governing vibration equations using classic skeletal theory. Number of natural frequencies below a specific value is counted by applying the Wittrick-Williams (W-W) algorithm, and exact eigenvalues can be simply obtained using bisection method. A solution to the number of clamped-end frequencies J0 in the W-W algorithm is also proposed and proven to be reliable. Numerical examples on a variety of shells with different boundary conditions are investigated, and results are well compared and validated. Influences of a variety of shell parameters on natural frequencies of both cylindrical and spherical shells are discussed in detail, demonstrating that the proposed dynamic stiffness formulation is applicable to analyse natural frequencies of moderately thick shells of revolution with high accuracy.

References listed at the end of the paper:
ABSTRACT:


The current paper shows the application of the boundary element method for the analysis of plates under shear stress causing plasticity. In this case, the shear deformation of a plate is considered by means of Reissner’s theory. The probability of failure of a Reissner’s plate due to a proposed index plastic behavior is calculated taking into account the uncertainty in mechanical and geometrical properties. The problem is developed in three dimensions. The classic plasticity’s theory is applied and a formulation for initial stresses that lead to the boundary integral equations due to plasticity is also used. For the plasticity calculation, the von Misses criterion is used. To solve the nonlinear equations, an incremental method is employed. The results show a relatively small failure probability for the ranges of loads between 0.6<W<1.0. However, for values between 1.0<W<2.5, the probability of failure increases significantly. Consequently, for W greater than or equal to 2.5, the plate failure is imminent. The results are compared to those that were found in the literature and the agreement is good.

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: Free vibration of antisymmetric angle-ply laminated plates with variable thickness is studied. Higher-order shear deformation plate theory (HSDT) is introduced in the present method to remove the shear correction factors and improve the accuracy of transverse shear stresses. The thickness variations are assumed to be linear, exponential, and sinusoidal. The coupled differential equations are obtained in terms of displacement and rotational functions and approximated using cubic and quartic spline. A generalized eigenvalue problem is obtained and solved numerically by employing the eigensolution techniques with eigenvectors as spline coefficients to obtain the required frequencies. The results of numerical calculations are presented for laminated plates with simply supported boundary conditions. Comparisons of the current solutions and those reported in literature are provided to verify the accuracy of the proposed method. The effects of aspect ratio, number of layers, ply-angles, side-to-thickness ratio, and materials on the free vibration of cylindrical plates are discussed in detail.

References listed at the end of the paper:


6 A. Shahrjerdi and F. Mustapha, Second order shear deformation theory (SSDT) for free vibration analysis on a functionally graded quadrangle plate, vol. 4, Intech, 2011.


ABSTRACT: The torsional behaviors of composite box girders with corrugated steel webs are more obvious than traditional concrete girders due to the lower torsional rigidity. In this paper, the torsion and distortion of this kind of composite girder are studied. The formulas for warping normal stress and shear stress were put forward according to the second theory of Umanskii, considering the accordion effect of corrugated steel webs. Then, the influences of different dimensional parameters on the torsional and distortional stress are investigated. Results show that the effect of parameters on stress is different and implicit in composite box girders with corrugated steel webs. Under eccentric loads, the warping torsional and distortional stress in this kind of girder should not be neglected. Compared with girders under corresponding symmetric loads, the total warping stress may be as big as flexural normal stress, and the total shear stress usually reaches 30 to 50 percentage of flexural shear stress. So the warping stress and additional shear stress due to warping torsion and distortion are suggested to be calculated by the proposed equations in structural analysis, which are usually not taken into account in conventional concrete box girders.

References listed at the end of the paper:

ABSTRACT: Elastic stress analysis of rotating variable thickness annular disk made of functionally graded material (FGM) is presented. Elasticity modulus, density, and thickness of the disk are assumed to vary radially according to a power-law function. Radial stress, circumferential stress, and radial deformation of the rotating FG annular disk of variable thickness with clamped-clamped (C-C), clamped-free (C-F), and free-free (F-F) boundary conditions are obtained using the numerical finite difference method, and the effects of the graded index, thickness variation, and rotating speed on the stresses and deformation are evaluated. It is shown that using FGM material could decrease the value of radial stress and increase the radial displacement in a rotating thin disk. It is also demonstrated that increasing the rotating speed can strongly increase the stress in the FG annular disk.

References listed at the end of the paper:


18 D. Gutzwiller, Automated design, analysis, and optimization of turbomachinery disks, University of Cincinnati, 2009.


ABSTRACT: This work describes a computational tool, based on an evolutionary algorithm, for the synthesis and optimization of submarine pipeline routes considering the incorporation of on-bottom stability criteria (OBS). This comprises a breakthrough in the traditional pipeline design methodology, where the definition of a route and the stability calculations had been performed independently: firstly, the route is defined according to geographical-topographical issues (including manual/visual inspection of seabed bathymetry and obstacles); afterwards, stability is verified, and mitigating procedures (such as ballast weight) are specified. This might require several design spirals until a final configuration is reached, or (most commonly) has led to excessive costs for the mitigation of instability problems. The optimization tool evaluates each candidate route by incorporating, as soft and hard constraints, several criteria usually considered in the manual design (pipeline length, bathymetry data, obstacles); also, with the incorporation of OBS criteria into the objective function, stability becomes an integral part of the optimization process, simultaneously handling minimization of length and cost of mitigating procedures. Case studies representative of actual applications are presented. The results show that OBS criteria significantly influences the best route, indicating that the tool can reduce the design time of a pipeline and minimize installation/operational costs.

References listed at the end of the paper:
ABSTRACT: Based on Timoshenko’s beam theory, this paper adopts segmented strategy in establishing the governing equations of a multibeam system subjected to various boundary conditions, in which free, clamped, hinged, and elastic constraints are considered. Meanwhile, Galerkin method is incorporated as a competitive alternative, in which a new set of unified, efficient, and reliable trial functions are proposed. A further optimization in regard to boundary distributions under forces is implemented and established on the least absorbed energy principle. High agreement is observed between the analytical results and the FEM results, verifying the correctness of the derivations. Complete comparisons between the analytical and the numerical results indicate the Galerkin method is beneficial when slender ratio is larger than 30, in which the continuity of the deformation is proved to be a crucial influencing factor. A modified numerical strategy about optimal boundary is employed and the remarks imply the algorithm can be availability used to reduce the energy absorption of the whole system.

References listed at the end of the paper:

3 K. F. Graff, Wave motion in elastic solids, Publication of Oxford University Press.
computational results by the GDQM are accurate. In addition, effects of boundary conditions, rotating speed, ply angle, ratio of radius over thickness, and ratio of length over radius on the frequency characteristics were also investigated.

Dawei Gao, Xiangyang Li and Haifeng Chen (School of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai 200093, China), “Application of improved particle swarm optimization in vehicle crashworthiness,” Mathematical Problems in Engineering, Article ID 8164609, Volume 2019, https://doi.org/10.1155/2019/8164609

ABSTRACT: In the optimization design process, particle swarm optimization (PSO) is limited by its slow convergence, low precision, and tendency to easily fall into the local extremum. These limitations make degradation inevitable in the evolution process and cause failure of finding the global optimum results. In this paper, based on chaos idea, the PSO algorithm is improved by adaptively adjusting parameters r1 and r2. The improved PSO is verified by four standard mathematical test functions. The results prove that the improved algorithm exhibits excellent convergence speed, global search ability, and stability in the optimization process, which jumps out of the local optimum and achieves global optimality due to the randomness, regularity, and ergodicity of chaotic thought. At last, the improved PSO algorithm is applied to vehicle crash research and is used to carry out the multiobjective optimization based on an approximate model. Compared with the results before the improvement, the improved PSO algorithm is remarkable in the collision index, which includes vehicle acceleration, critical position intrusion, and vehicle mass. In summary, the improved PSO algorithm has excellent optimization effects on vehicle collision.

References listed at the end of the paper:

The vibration characteristic of FGSSS are illustrated. In addition, the effects of the inertia, shear deformation, and foundation coefficients on free geometrical parameters, and boundary restraints are provided, which may serve as be new vibration results for FGSSS on Winkler and Pasternak foundations with various curvature types, accuracy and reliability by com expansion coefficients are determined by using Rayleigh supplementary functions are introduced to eliminate the potential jumps and boundary discontinuities. Then, the and rotation components consisted of standard double Fourier cosine series and several three novel honeycombs under axial compression, International Journal of Mechanical Sciences, vol. 99, pp. 274–286, 2015.

Xiancheng Wang, Wei Li, Jianjun Yao, Xihua Wan, Yu Fu and Tang Sheng (First author is from: State Key Laboratory of Fluid Power Transmission and Control, Zhejiang University, Hangzhou 310027, China), “Free vibration of functionally graded sandwich shallow shells on Winkler and Pasternak foundations with general boundary restraints”, Mathematical Problems in Engineering, Article ID 7527148, Volume 2019, https://doi.org/10.1155/2019/7527148

ABSTRACT: In this investigation, an exact method based on the first-order shear deformation shallow shell theory (FSDSST) is performed for the free vibration of functionally graded sandwich shallow shells (FGSSS) on Winkler and Pasternak foundations with general boundary restraints. Vibration characteristics of the FGSSS have been obtained by the energy function represented in the orthogonal coordinates, in which the displacement and rotation components consisted of standard double Fourier cosine series and several closed-form supplementary functions are introduced to eliminate the potential jumps and boundary discontinuities. Then, the expansion coefficients are determined by using Rayleigh-Ritz method. The proposed method shows good accuracy and reliability by comprehensive investigation concerning free vibration of the FGSSS. Numerous new vibration results for FGSSS on Winkler and Pasternak foundations with various curvature types, geometrical parameters, and boundary restraints are provided, which may serve as benchmark solutions for future research. In addition, the effects of the inertia, shear deformation, and foundation coefficients on free vibration characteristic of FGSSS are illustrated.
References listed at the end of the paper:


Yongqiang Yang and Zhongmin Wang (First author is from: School of Mechanical and Precision Instrument Engineering, Xi’an University of Technology, No. 5 South Jinhua Road, 710048, Xi’an, China), “Thermoelastic coupling vibration and stability analysis of rotating annular sector plates”, Mathematical Problems in Engineering, Volume 2019, Article ID 8573241, 18 pages, https://doi.org/10.1155/2019/8573241

ABSTRACT: This study investigates the thermoelastic coupling vibration and stability of rotating annular sector plates. Based on Hamilton’s principle and thermal conduction equation with deformation effect, the differential equation of transverse vibration for a rotating annular sector plate is established. The differential equation of vibration and corresponding boundary conditions are discretized by the differential quadrature method. Then, the thermoelastic coupling transverse vibrations under three different boundary conditions are calculated. The change curve of the first three order dimensionless complex frequencies of the rotating annular sector plate with the dimensionless angular speed are analyzed in the case of the thermoelastic coupling and uncoupling. The effects of the dimensionless angular speed, the ratio of inner to outer radius, the sector angle, and the dimensionless thermoelastic coupling coefficient on transverse vibration and stability of the annular sector plate are discussed. Finally, we obtained the type of instability and corresponding critical speed of the rotating annular sector plate in the case of the thermoelastic coupling and uncoupling.

References listed at the end of the paper:


ABSTRACT: A functionally graded curved beam subjected to a shear tension force as well as a concentrated force at the free end is solved based on the inverse method, and a general two-dimensional solution is presented. The explicit expressions are derived by assuming that the elastic properties within curved beams vary in the radial direction according to a power law, i.e., $E = E_0 r^n$, but are constant across the depth. After degenerating it into the isotropic homogeneous elastic cases, the results are in good consistency with existing analytical solutions. The stresses and displacements are firstly observed in different forms in terms of the different power function exponent $n$. These results will be useful as a guide for designing devices or as benchmark to assess other approximate methodologies.

References listed at the end of the paper:


S. G. Lekhnitskii, Theory of Elasticity of An Anisotropic Body, Mir Publishers, Moscow, Russia, 1981.


ABSTRACT: In this paper, the authors study the bifurcation problems of the composite laminated piezoelectric rectangular plate structure with three bifurcation parameters by singularity theory in the case of 1:2 internal resonance. The sign function is employed to the universal unfolding of bifurcation equations in this system. The proposed approach can ensure the nondegenerate conditions of the universal unfolding of bifurcation equations in this system to be satisfied. The study presents that the proposed system with three bifurcation parameters is a high codimensional bifurcation problem with codimension 4, and 6 forms of universal unfolding are given. Numerical results show that the whole parametric plane can be divided into several persistent regions by the transition set, and the bifurcation diagrams in different persistent regions are obtained.

References listed at the end of the paper:


ABSTRACT:

The paper is dedicated to the algebraic formulation of elastic frame equations. The obtained set of equations describe deformations of moderately thick frames made of both compressible and incompressible bars, grillages of rigid or pin-joined connections, and trusses. Plane as well as space structures are presented. The paper is an extension of the article of T. Lewiński written in 2001 related to thin bars. Algebraic equations with diagonal constitutive matrix are original and suitable for various engineering applications and for educational purposes.

References listed at the end of the paper:


In this paper, the authors present results on dynamic behavior analysis of the stiffened composite plate with piezoelectric patches under airflow by finite element method and experimental study. The first-order shear deformation plate theory and nine-noded isoparametric piezoelectric laminated plate finite element with five elastic degrees of freedom at each node and one electric degree of freedom per element per piezoelectric layer were used in the dynamic analysis of plates by finite element method. The modern equipment was used in the dynamic behaviors analysis of plates subjected to airflow load by experimental method. In this study, the results of the theoretical method have been compared with experimental studies.

References listed at the end of the paper:

References listed at the end of the paper:


Jingbang Li, Yanpeng Zhu, Shuaihua Ye, and Xiaorui Ma (Key Laboratory of Disaster Prevention and Mitigation in Civil Engineering of Gansu Province, Lanzhou University of Technology, Lanzhou 730050, China), “Internal Force Analysis and Field Test of Lattice Beam Based on Winkler Theory for Elastic Foundation Beam”, Mathematical Problems in Engineering, Article ID 5130654, Volume 2019, https://doi.org/10.1155/2019/5130654

ABSTRACT: As a new flexible supporting structure, prestressed anchor cable lattice beams have been widely used in high-slope support engineering and have achieved good results. However, theoretical research on the internal force analysis of lattice beams is far behind engineering practice. Based on the theory of the Winkler elastic foundation model, a mechanical model of a prestressed anchor cable lattice beam at the tension stage was established. Considering the nonhomogeneous lattice beam materials, a calculation method was given and applied to engineering examples. A calculation method of the measured moment was introduced in the field test conducted in the Zhouqu County “8·8” debris flow disaster reconstruction project. Comparisons between the test results and the theoretical results were performed. The results showed that the theoretical results of the distribution trend of the lattice beam moment were consistent with the test results, which verified the rationality of the proposed calculation method. The inertia moment of the beam section solved by the transformed section method was more realistic. The results of the transformed section method could improve the bending resistance of the lattice beam and reduce the reinforcement ratio. The greater the anchoring force was, the more obvious the lifting effect was. The anchoring force was an important influencing factor of the internal force of the lattice beam. The greater the anchoring force was, the greater the lattice beam moment was, and they showed the same proportional change phenomenon. Compared with the theoretical moment, the measured moment obtained by the test was smaller, which indicated that the lattice beam of the tested slope was safe at the present stage.

Yuan Cao, Rui Zhong, Dong Shao, Qingshan Wang, and Dongtao Wu (First and third author are from: Naval Research Academy, Beijing 100161, China), “Free In-Plane Vibrations of Orthotropic Rectangular Plates by Using an Accurate Solution”, Mathematical Problems in Engineering, Article ID 4687082, Volume 2019, https://doi.org/10.1155/2019/4687082

ABSTRACT: Many numerical methods have been developed for in-plane vibration of orthotropic rectangular plates with various boundary conditions; however, the exact results for such structures with elastic boundary conditions are very scarce. Therefore, the object of this paper is to present an accurate solution for free in-plane vibration of orthotropic rectangular plates with various boundary conditions by the method of reverberation ray matrix (MRRM) and improved golden section search (IGSS) algorithm. The boundary condition studied in this paper is defined as that a set of opposite edges is with one kind of simply supported boundary conditions, while the other set is with any kind of classical and general elastic boundary conditions or their combination. Its accuracy, reliability, and efficiency are verified by some numerical examples where the results are compared with other exact solutions in the published literature and the FEA results based on the ABAQUS software. Finally, some new accurate results for free in-plane vibration of orthotropic rectangular plates with elastic boundary conditions are examined and further can be treated as the reference data for other approximate methods or accurate solutions.

References listed at the end of the paper:


Zhifu Cao, Qingguo Fei; Dong Jiang; Shaoqing Wu; and Zhiruo Fan (Institute of Aerospace Machinery and Dynamics, Southeast University, Nanjing 211189, China), “Model Updating of a Stitched Sandwich Panel Based on Multistage Parameter Selection”, Mathematical Problems in Engineering, Article ID 1584953, Volume 2019, https://doi.org/10.1155/2019/1584953

ABSTRACT: The effective numerical model of stitched sandwich composite plays crucial role in dynamics analysis and structural design. A sensitivity-based multistage model updating method is proposed for modeling of the stitched sandwich panel using the experimental modal frequencies. Based on applying the periodic boundary condition, the initial equivalent finite element model of a stitched sandwich composite is constructed; the measured frequencies are obtained from the modal test. According to relative sensitivity analysis of modal frequencies with respect to updating parameters, the different well-conditioned groups of parameters are selected to be updated. This method is applied to a stitched sandwich panel with established configuration of the stitches. Results show that the proposed method with the smallest condition number of relative sensitivity matrix has a better performance than the multistage method using type-based parameter group selection and the traditional model updating approach.

References listed at the end of the paper:


ABSTRACT: The wave-based method (WBM) is a feasible method which investigates the free vibration characteristics of orthotropic cylindrical shells under general boundary conditions. Based on Reissner–Naghid’s shell theory, the governing motion equation is established, and the displacement variables are transformed into wave functions formed to satisfy the governing equations. On the basis of the kinematic relationship between the force resultant and displacement vector, the overall matrix of the shell is established. Comparison studies of this paper with the solutions in the literatures were carried out to validate the accuracy of the present method. Furthermore, by analyzing some numerical examples, the free vibration characteristics of orthogonal anisotropic cylindrical shells under classical boundary conditions, elastic boundary conditions, and their combinations are studied. Also, the effects of the material parameter and geometric constant on the natural frequencies for the orthotropic circular cylindrical shell under general boundary conditions are discussed. The conclusions obtained can be used as data reference for future calculation methods.

References listed at the end of the paper:


Lisheng Luo (1), Wenyuan He (1), and Xiaofeng Zhang (2)
(1) College of Civil Engineering and Architecture, Hainan University, Haikou 570228, China
(2) College of Materials Science and Engineering, Nanjing Forestry University, Nanjing 210037, China


ABSTRACT: The buckling loads of shell structures are sensitive to initial geometric imperfections. Conventional methods used to model geometric imperfections cannot determine the accuracy of buckling loads with high computational efficiency. A new computational approach based on particle swarm optimization (PSO) is proposed to obtain the lower bound of the buckling load of shell structures with geometric imperfections. The proposed approach assumes a nodal geometric position using uncertain parameters. The buckling loads of the shell structures are then optimized using the PSO-based approach. Both academic and practical numerical examples have been thoroughly investigated. Thus, the applicability and accuracy of the proposed method is critically validated.

References listed at the end of the paper:


ABSTRACT: This paper presents the finite element algorithm and results of dynamical analysis of cracked plate subjected to moving oscillator with a constant velocity and any motion orbit. There are many surveys considering the dynamic response of the plate when there is a change in number of cracks and the stiffness of the spring k. The numerical survey results show that the effect of cracks on the plate’s vibration is significant. The results of this article can be used as a reference for calculating and designing traffic structures such as road surface and bridge surface panels.

References listed at the end of the paper:


Wei Tian, Zhichun Yang, and Tian Zhao (First author is from: School of Aerospace, Xi’an Jiaotong University, Xi’an, China), “Analysis of Nonlinear Vibrations and Dynamic Responses in a Trapezoidal Cantilever Plate Using the Rayleigh-Ritz Approach Combined with the Affine Transformation”, Mathematical Problems in Engineering, Article ID 9278069, Volume 2019, https://doi.org/10.1155/2019/9278069

ABSTRACT: Nonlinear vibrations of a trapezoidal cantilever plate subjected to transverse external excitation are investigated. Based on von Karman large deformation theory, the Rayleigh-Ritz approach combined with the affine transformation is developed to obtain the nonlinear ordinary differential equation of a trapezoidal plate with irregular geometries. With the variation of geometrical parameters, there exists the 1:3 internal resonance for the trapezoidal plate. The amplitude-frequency formulations of the system in three different coupled conditions are derived by using multiple scales method for 1:3 internal resonance analysis. It is found that the strong coupling of two modes can change nonlinear stiffness behaviors of modes from hardening-spring to soft-spring characteristics. The detuning parameter and excitation amplitude have significant influence on nonlinear dynamic responses of the system. The bifurcation diagrams show that there exist the periodic, quasi-periodic, and chaotic motions for the trapezoidal cantilever plate in the 1:3 internal resonance cases and the nonlinear dynamic responses are dependent on the amplitude of excitation. The possible adverse dynamic behaviors and undesired resonance can be avoided by designing appropriate excitation and system parameters.

References listed at the end of the paper:

The minimum structural total weight is taken as the objective function, and a shape optimization program is developed by using the ANSYS Parametric Design Language. The structural total weight is taken as the objective function, and a shape optimization program is developed by using the ANSYS Parametric Design Language.
research results show that (1) users can easily get the required models only by inputting five parameters, i.e., the shell span (S), rise (F), latitudinal portions (Kn), radial loops (Nx), and thickness (T). (2) Under the conditions of different span and rise-span ratio, the optimal grid number and bar section for the Kiewitt spherical reticulated shell of triangular pyramid system existed after optimization; i.e., the structural total weight is the lightest. (3) The whole rigidity and stability of the Kiewitt spherical reticulated shell of triangular pyramid system are very nice, and the reticulated shell after optimization can still meet the stability requirement. (4) When conducting the reticulated shell design, the structural stability and carrying capacity can be improved by increasing the rise-span ratio or the rise. (5) From the perspective of stability, the rise-span ratio of the Kiewitt spherical reticulated shell of triangular pyramid system should not choose 1/7.

References listed at the end of the paper:

Xue-Qin Li, Wei Zhang, Xiao-Dong Yang, and Lu-Kai Song (The first 3 authors are from: College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, China), “A Unified Approach of Free Vibration Analysis for Stiffened Cylindrical Shell with General Boundary Conditions”, Mathematical Problems in Engineering, Article ID 4157930, Volume 2019, https://doi.org/10.1155/2019/4157930

ABSTRACT: A unified approach of free vibration analysis for stiffened cylindrical shell with general boundary conditions is presented in this paper. The vibration of stiffened cylindrical shell is modeled mathematically involving the first-order shear deformation shell theory. The improved Fourier series is selected as the admissible displacement function while the arbitrary boundary conditions are simulated by adjusting the equivalent spring stiffness. The natural frequencies and modal shapes of the stiffened shell are obtained by solving the dynamic model with the Rayleigh-Ritz procedure. Various numerical results of free vibration analysis for stiffened cylindrical shell are obtained, including natural frequencies and modes under simply supported, fixed, and clamped boundary conditions. Moreover, the effects of stiffener on natural frequencies are discussed. Compared with several state-of-the-art methods, the feasibility and validity of the proposed method are verified.

References listed at the end of the paper:

Qifeng Shan, Jingming Cai, Xiaopeng Li, and Jiawei Tan (First author is from: hejiang Industry Polytechnic College, Shaoxing, China), “Analysis of Concrete-Filled Square Steel Tube Short Columns under Eccentric Loading”, Mathematical Problems in Engineering, Article ID 8420181, Volume 2019, https://doi.org/10.1155/2019/8420181

ABSTRACT: The concrete-filled square steel tube (CFSST) columns have been widely applied in structural engineering. Although many constitutive models have been proposed to describe CFSST short columns under concentric loading, the applicability of the existing concentric model in the analysis of CFSST short columns under eccentric loading has not been properly verified. In this paper, the eccentric behaviors of CFSST short columns were investigated with the software of ABAQUS/standard. It was found that the contact stress between steel tube and inner concrete was seriously affected by eccentric ratios, indicating that the confinement effect of steel tube on inner concrete was different under concentric and eccentric loading. In this paper, a new stress-strain model of inner concrete which considered the influence of eccentricity was developed and verified with existing experimental results. It was found that the proposed stress-strain model was more accurate in simulating the eccentric behaviors of CFSST short columns.

References listed at the end of the paper:

ABSTRACT: As a new type of floor structure, steel vierendeel sandwich plates are widely applied in large-span buildings with multiple storeys. Shear connectors are important stressed members of such plates. To evaluate the seismic performance of the shear connectors, a full-scale test piece in two different connection forms, namely, A and B, is designed and tested under alternating load. Test analysis of the two connection specimens covers the failure modes, hysteresis curves, and main parameters (e.g., bearing capacity, ductility, stiffness degradation, and energy dissipation coefficient). The following results concerning type A connection are obtained: First, it exhibits good ductility and long yielding platform; second, elastoplasticity of steel is fully exerted with it; third, it absorbs and dissipates energy well with strong energy consumption; and fourth, when failure occurs, cracks usually happen in the heat-affected zone of the weld in the core zone. The following conclusions about type B are drawn: first, it has large bearing capacity with high stiffness; also, when failure occurs, the ribbed stiffeners crack and flexion deformity happen.

References listed at the end of the paper:


· A. A. C. I. Standard, Building Code Requirements for Structural Concrete (ACI 318-11), American Concrete Institute, 2011.

Lan Jiang, Kejian Ma, Huagang Zhang, Qin Wu, Hongna Lu, and Qizhu Yang (First and second authors are from: Collage of Civil Engineering, Hunan University, Changsha HN 731, China), “Seismic Behavior of Shear Connectors of Steel Vierendeel Sandwich Plate”, Mathematical Problems in Engineering, Article ID 8047393, Volume 2019, https://doi.org/10.1155/2019/8047393
Wei Wang, Sen Li, Lin-Quan Yao, and Shi-Chao Yi (First and third author are from: School of Rail Transportation, Soochow University, Suzhou 215131, China), “Pseudo-Three-Dimensional Analysis for Functionally Graded Plate Integrated with a Piezoelectric Fiber Reinforced Composite Layer”, Mathematical Problems in Engineering, Article ID 8586310, Volume 2019, https://doi.org/10.1155/2019/8586310

ABSTRACT: In this paper, a pseudo-three-dimensional method is proposed to investigate static behavior analysis of functionally graded (FG) plate integrated with a piezoelectric fiber reinforced composite (PFRC) layer by the hyperbolic shear and normal deformation theory. The present method is a displacement-based theory which accounts for hyperbolic variation of in-plane displacement field and parabolic variation of transverse displacement field. The linear electrical potential function in the PFRC layer is modeled. The governing equations of present method are derived by the minimum potential energy principle and Navier’s procedure is used to solve the equations. Numerical results are presented to demonstrate the efficiency of the proposed method. The effects of some parameters including material composition, aspect ratios, and applied voltages on the deformations of the plate are investigated. Compared with the available data of numerical method and 3D method, the presented method is more suitable for the smart FG structure.

References listed at the end of the paper:

ABSTRACT: This paper presents the development of a model of homogeneous, moderately thick shells for elastodynamic problems. The model is obtained by adapting and modifying SAM-H model (stress approach model of homogeneous shells) developed by Domínguez Alvarado and Díaz in (2018) for static problems. In the dynamic version of SAM-H presented herein, displacements and stresses are approximated by polynomials of the out-of-plane coordinate. The stress approximation coincides with the static version of SAM-H when dynamic effects are neglected. The generalized forces and displacements appearing in the approximations are the same as those involved in a classical, moderately thick shell model (CS model) but the stress approximation adopted herein is more complex: the 3D motion equations and the stress boundary conditions at the faces of the shell are verified. The generalized motion and constitutive equations of dynamic SAM-H model are obtained by applying a variant of Hellinger–Reissner functional. In the constitutive equations, Poisson’s effect of out-of-plane normal stresses on in-plane strains is not ignored; this is one important feature of SAM-H. To test the accuracy of dynamic SAM-H model, the following structures were considered: a hollow sphere and a catenoid. In each case, eigenfrequencies are first calculated and then a frequency analysis is performed applying a harmonic load. The results are compared to those of a CS model, MITC6 (mixed interpolation of tensorial components with 6 nodes per element) shell element calculations, and solid finite element computations. In the two problems, CS, MITC6, and dynamic SAM-H models yield accurate eigenfrequencies and eigenmodes. Nevertheless, the frequency analysis performed in each case showed that dynamic SAM-H provides much more accurate amplitudes of stresses and displacements than the CS model and the MITC6 shell finite element technique.

References listed at the end of the paper:


ABSTRACT: This paper investigates the flexural behavior of CFRP plate-strengthened concrete structures. Specimens of the CFRP plate-reinforced beam were designed and tested by the four-point flexural test. The load-deflection relationship, failure modes, and crack propagation were analyzed. The results showed that the postcracking stiffness and bearing capacity of the test beams can be improved by the additional anchoring measures for CFRP strengthening. The relationship between flexural moment and curvature was analyzed by introducing a MATLAB program. The calculation model between curvature, flexural moment, and stiffness was derived for the CFRP plate-strengthened structure. The recommended calculation model was applied in the analysis of deflection, and the theoretical values were compared with the test results.

References listed at the end of the paper:

In this paper, we present a simple, powerful, yet efficient and easily applicable technique based on the GDQ method for solving nonlinear problems. The proposed technique is implemented to some nonlinear engineering problems in structure analysis. The results reveal that the proposed technique is effective. Then, the proposed technique is used to explain the effects of the variation of cross section area on the nondimensional critical buckling loads for columns with and without elastic foundation for three sets of boundary conditions. Finally, the proposed technique is used to investigate the effect of the nonlinearity term of Winkler elastic foundation on the nondimensional critical buckling loads of nonuniform columns resting on elastic foundations. The effectiveness of the proposed technique is validated through comparing the present results with exact solutions and other numerical results available in references. The proposed method benefits the optimum design of columns against buckling in engineering applications. The most important conclusions from this paper can be summarized as follows. When the inertia ratio varies parabolically, the nondimensional critical buckling loads increase in comparison with varying linearly. Moreover, the nondimensional critical buckling loads increase in the presence of the elastic foundation.

References listed at the end of the paper:


A. G. Greenhill, “Determination of the greatest height consistent with stability that a vertical pole or mast can be made, and of the greatest height to which a tree of given proportions can grow,” Proceedings of the Cambridge Philosophical Society, vol. 4, pp. 65–73, 1880.


ABSTRACT: This paper aimed to study the longitudinal vibration characteristics of the 5000 m mining pipe in the ocean under different working wind conditions, offset angle, damping, and ore bin weight. Based on the finite element method, the mining pipe is simplified into beam element and discretized, and the physical and mathematical models of the mining pipe system are established. The Wilson-θ direct integral method is adopted for numerical calculation. The results show that the longitudinal vibration of the mining pipe is irregular, which presents the phenomenon of oscillation. The vibration amplitude decreases first and then increases from top to bottom, the minimum vibration amplitude appears at 1000 m, and the maximum vibration amplitude appears at the top of the mining pipe. Under the same working wind condition, the overall longitudinal vibration amplitude of the mining pipe can be increased by increasing the ore bin weight and the offset angle, but neither of them can change the frequency of the longitudinal vibration. The closer the excitation frequency generated by different working wind conditions is to the natural frequency, the larger the mining pipe longitudinal vibration amplitude is. The closer the vibration frequency generated by the same excitation frequency is to the natural
frequency, the stronger the vibration intensity is, and when damping is added, the vibration intensity decreases faster.

References listed at the end of the paper:

- X. Y. Qiu, Research for Passive Control for Longitudinal Vibration of Lifting Pipe in Deep Sea Mining System, Central South University, Changsha, China, 2014.
- Y. Li, Dynamic Analysis of 1000 m Ocean Pilot Mining System Based on Three—Dimensional Discrete Element Method Pipe Model, Central South University, Changsha, China, 2009.
- L. J. Xiao, Study on Kinematics and Dynamics Characteristics of Deep Ocean Mining Pipe, University of Science and Technology Beijing, Beijing, China, 2000.
- W. Song, Mechanical Analysis of Lifting Hard Pipe in Deep Sea Mining and Design of Collector, Southwest Petroleum University, Chengdu, China, 2018.
concentrated constraint in each field point is described in conjunction with Dirac delta function. A standard matrix eigenvalue problem containing various in-plane modal information of such annular panel is derived and solved through Rayleigh–Ritz procedure. Several numerical examples are presented to demonstrate the correctness and effectiveness of the proposed model by comparing the results with those from other approaches. Three representative types of point constraints, including point, line, and area configurations, are considered by collection of point constraints, and it is shown that the current model can make an accurate and efficient modal parameter prediction for annular panel with such most general case of point constraints.

References listed at the end of the paper:

ABSTRACT: The assembled cold-formed steel stud shear walls are the main lateral force resisting members of cold-formed steel residential buildings. In this paper, three cold-formed steel shear walls with different types of sheathing (gypsum board and OSB board) were tested under the monotonic lateral loading. The failure modes, the shear strength, and the load-displacement curves of the shear walls were obtained and analyzed to investigate the relationship between screws and shear walls. The test results showed that the material types of the sheathings influence the shear strength of the CFS shear wall greatly. The sum of shear strengths of CFS shear walls with one-side gypsum board and CFS shear walls with one-side OSB board is close to that of the CFS shear wall with the both-sided board (one side is gypsum board and the other side is OSB board). The shear strength of the screws between the board and the CFS stud plays a decisive role in the shear strength of the CFS shear wall, which is usually governed by the shear strength of the screw connections. The design methods of the shear strength and the lateral stiffness of the CFS shear walls were proposed and evaluated by comparing the calculated results with the test results. The comparison results demonstrated that the modified design method of shear strength is conservative and feasible to predict the shear strength of the CFS shear wall. The design method of the lateral stiffness of the CFS shear wall is available to calculate the lateral displacement of the CFS shear wall under the elastic stage, but it is not useful under the nonelastic stage. The proposed design methods can be served as a reference for engineering practice.

References listed at the end of the paper:
- North American Steel Framing Alliance, Prescriptive Method for Residential Cold-Formed Steel Framing, North American Steel Framing Alliance, Des Plaines, IL, USA, 1997.
- C. Yu, “Shear resistance of cold-formed steel framed shear walls with 0.686 mm, 0.762 mm, and 0.838 mm steel sheet sheathing,” Engineering Structures, vol. 32, no. 6, pp. 1522–1529, 2010.

ABSTRACT: This work gives information about the development of refined plate theory to study the static bending behavior of functionally graded material (FGM) plates. The significant advantage of our proposed theory is that only one unknown variable exists in its displacement formula and governing equation. To illustrate the accuracy and effectiveness of this theory, an analytical approach based on the Navier solution is employed to obtain the solution for static bending of simply supported FGM plates. A good agreement for static bending of FGM plates with other literature results has been instituted. This work also investigates the deflection, in-plane normal, and shear stresses of sinusoidally loaded FGM rectangular plates with four simply supported edges. The influence of some parameters on the bending performance of FGM plates is also carefully considered.

References listed at the end of the paper:

gradation law. The Mori shear correction factor is also derived for comparison purpose. The plates consist of a fully ceramic core and foundation. An element based on the refined first vibration analysis of functionally graded sandwich (FGSW) plates partially supported by a Pasternak foundation is employed to formulate a four-node quadrilateral finite element for free vibration analysis of functionally graded sandwich (FGSW) plates partially supported by a Pasternak foundation. An element based on the refined first-order shear deformation theory (RFSDT) which requires a shear correction factor is also derived for comparison purpose. The plates consist of a fully ceramic core and two functionally graded skin layers with material properties varying in the thickness direction by a power gradation law. The Mori–Tanaka scheme is employed to evaluate the effective moduli. The elements are

Cong Ich Le, Vu Nam Pham, and Dinh Kien Nguyen, “Free Vibration of FGSW Plates Partially Supported by Pasternak Foundation Based on Refined Shear Deformation Theories”, Mathematical Problems in Engineering, Article ID 7180453, 7 April, 2020, Volume 2020, https://doi.org/10.1155/2020/7180453

ABSTRACT: A refined third-order shear deformation theory (RTSDT), in which the transverse displacement is split into bending and shear parts, is employed to formulate a four-node quadrilateral finite element for free vibration analysis of functionally graded sandwich (FGSW) plates partially supported by a Pasternak foundation. An element based on the refined first-order shear deformation theory (RFSDT) which requires a shear correction factor is also derived for comparison purpose. The plates consist of a fully ceramic core and two functionally graded skin layers with material properties varying in the thickness direction by a power gradation law. The Mori–Tanaka scheme is employed to evaluate the effective moduli. The elements are
derived using Lagrangian and Hermitian polynomials to interpolate the in-plane and transverse displacements, respectively. The numerical result reveals that the frequencies obtained by the RTSDT element are slightly higher than the ones using the RFSDT element. It is also shown that the foundation supporting area plays an important role on the vibration of the plates, and the effect of the material distribution on the frequencies is dependent on this parameter. A parametric study is carried out to highlight the effects of the material inhomogeneity, the foundation stiffness parameters, and the foundation supporting area on the frequencies and vibration modes. The influence of the layer thickness and aspect ratios on the frequencies is also examined and highlighted.

References listed at the end of the paper:

important numerical results are presented in terms of significant input parameters. Then, some principle, and the first governing equations of motion are derived based on the von Kármán nonlinear relationship, Hamilton’s investigated by simulation. ABSTRACT: This approach simplifies the vibration problem of the three-dimensional cylindrical shell into that of a two-dimensional beam, which can be used to simplify the calculation process of radiated sound power. Added mass is used to approximate the fluid-structure coupling, further simplifying the calculation process. Calculation examples of underwater simply supported unstiffened and stiffened cylindrical shells verify the proposed method by comparison with analytical and numerical results. Finally, the effects of the size and spacing of the stiffeners on the sound radiation characteristics of underwater free-free stiffened cylindrical shells are discussed. The proposed method can be extended to the rapid calculation of the sound radiation characteristics of underwater slender complex cylindrical shells in the low-frequency range.


ABSTRACT: Based on the fact that beam-type modes play the main role in determining the sound radiation from an underwater thin slender (length-to-radius ratio \( L/a > 20 \)) elastic cylindrical shell, an equivalent-beam method is proposed for calculating the low-frequency radiated sound power of underwater thin slender unstiffened and stiffened cylindrical shells. The natural bending frequencies of the cylindrical shell are calculated by analytical and numerical methods and used to solve equivalent Young’s modulus of the equivalent beam. This approach simplifies the vibration problem of the three-dimensional cylindrical shell into that of a two-dimensional beam, which can be used to simplify the calculation process of radiated sound power. Added mass is used to approximate the fluid-structure coupling, further simplifying the calculation process. Calculation examples of underwater simply supported unstiffened and stiffened cylindrical shells verify the proposed method by comparison with analytical and numerical results. Finally, the effects of the size and spacing of the stiffeners on the sound radiation characteristics of underwater free-free stiffened cylindrical shells are discussed. The proposed method can be extended to the rapid calculation of the sound radiation characteristics of underwater slender complex cylindrical shells in the low-frequency range.


ABSTRACT: In this paper, the nonlinear dynamic responses of the blade with variable thickness are investigated by simulating it as a rotating pretwisted cantilever conical shell with variable thickness. The governing equations of motion are derived based on the von Kármán nonlinear relationship, Hamilton’s principle, and the first-order shear deformation theory. Galerkin’s method is employed to transform the partial differential governing equations of motion to a set of nonlinear ordinary differential equations. Then, some important numerical results are presented in terms of significant input parameters.

ABSTRACT: This paper addresses a simplified analytical method for evaluating the impact responses of the stiffeners in a ship side shell subjected to head-on collision by a bulbous bow. The stiffeners are classified as the “central stiffener” and the “lateral stiffener” according to their relative position to the bulbous bow. In analytical predictions, it is assumed that the flexural bending of the central stiffener and plate occurs simultaneously. However, the deformation mode of the central stiffener outside the indenter contact region is simplified as linear to derive its deformation resistance. The curved deformation mode of the lateral stiffener is proposed to calculate the deformation resistance and to consider the interaction effect with the plate, which can cause the plate to fracture earlier. Model tests with three specimens (one unstiffened plate for reference and two stiffened plates) quasistatically punched by a conical indenter are performed to validate the proposed analytical method. Resistance-penetration curves and damage shapes for the three specimens are obtained. The experimental results illustrate the effects of the stiffeners on the deformation resistance and fracture initiation of the stiffened plate and the influence of stiffener tripping on the lateral resistance. Moreover, the experimental and analytical predicted results correspond well, suggesting that the proposed analytical method can accurately predict the crashworthiness of a ship side shell subjected to bulbous bow collision.

References listed at the end of the paper:


ABSTRACT: The nonlinear vibrations and responses of a laminated composite cantilever plate under the subsonic air flow are investigated in this paper. The subsonic air flow around the three-dimensional cantilever rectangle laminated composite plate is considered to be decreasing from the wing root to the wing tip. According to the ideal incompressible fluid flow condition and the Kutta–Joukowski lift theorem, the subsonic aerodynamic lift on the three-dimensional finite length flat wing is calculated by using the Vortex Lattice (VL) method. The finite length flat wing is modeled as a laminated composite cantilever plate based on Reddy’s third-order shear deformation plate theory and the von Karman geometry nonlinearity is introduced. The nonlinear partial differential governing equations of motion for the laminated composite cantilever plate subjected to the subsonic aerodynamic force are established via Hamilton’s principle. The Galerkin method is used to separate the partial differential equations into two nonlinear ordinary differential equations, and the four-dimensional nonlinear averaged equations are obtained by the multiple scale method. Through comparing the natural frequencies of the linear system with different material and geometric parameters, the relationship of 1 : 2 internal resonance is considered. Corresponding to several selected parameters, the frequency-response curves are obtained. The hardening-spring-type behaviors and jump phenomena are exhibited. The influence of the force excitation on the bifurcations and chaotic behaviors of the laminated composite cantilever plate is investigated numerically. It is found that the system is sensitive to the exciting force according to the complicated nonlinear behaviors exhibited in this paper.

References listed at the end of the paper:


ABSTRACT: In this paper, free vibration analysis of the functionally graded porous (FGP) plates on the elastic foundation taking into mass (EFTIM) is presented. The fundamental equations of the FGP plate are derived using Hamilton’s principle. The mixed interpolation of the tensorial components (MITC) approach and the edge-based smoothed finite element method (ES-FEM) is employed to avoid the shear locking as well as to improve the accuracy for the triangular element. The EFTIM is a foundation model based on the two-parameter Winkler–Pasternak model but added a mass parameter of foundation. Materials of the plate are FGP with a power-law distribution and maximum porosity distributions in the forms of cosine functions. Some numerical examples are examined to demonstrate the accuracy and reliability of the proposed method in comparison with those available in the literature.

References listed at the end of the paper:

E. Winkler, Die Lehre von der Elastizität und Festigkeit, Prag, Dominicus, 1867.
P. L. Pasternak, On a New Method of Analysis of an Elastic Foundation by Means of Two Foundation Constants, Gosudarstvennoe Izdatelstvo Literatury po Stroitelstvu i Arkhitekture, Moscow, Russia, 1954, in Russian.

ABSTRACT: The multipulse homoclinic orbits and chaotic dynamics of a reinforced composite plate with the carbon nanotubes (CNTs) under combined in-plane and transverse excitations are studied in the case of 1:1 internal resonance. The method of multiple scales is adopted to derive the averaged equations. From the averaged equations, the normal form theory is applied to reduce the equations to a simpler normal form associated with a double zero and a pair of pure imaginary eigenvalues. The energy-phase method proposed by Haller and Wiggins is utilized to examine the global bifurcations and chaotic dynamics of the CNT-reinforced composite plate. The analytical results demonstrate that the multipulse Shilnikov-type homoclinic orbits and chaotic motions exist in the system. Homoclinic trees are constructed to illustrate the repeated bifurcations of multipulse solutions. In order to verify the theoretical results, numerical simulations are given to show the multipulse Shilnikov-type chaotic motions in the CNT-reinforced composite plate. The results obtained here imply that the motion is chaotic in the sense of the Smale horseshoes for the CNT-reinforced composite plate.

References listed at the end of the paper:

model was established by ABAQUS/Explicit, and the bending stiffness was calculated by the improved square tubes filled with aluminum foam, the three point bending tests were carried out on an INSTRON machine, the full-field deformation measurement was performed using a 3D-DIC test system, the numerical model was established by ABAQUS/Explicit, and the bending stiffness was calculated by the improved
analytical model based on shear-deformable beam theory. The discrepancies of experimental data, numerical results, and analytical predictions were acceptable, which were within 5%. The failure modes and mechanical properties of the filled tubes were experimentally captured and numerically predicted. Due to the filling effect of aluminum foam, the ultimate load, bending stiffness, and energy absorption of the filled CFRP square tubes increased, comparing to those of the hollow CFRP square tubes. With the increase of the aluminum foam density, the ultimate load, bending stiffness, and energy absorption of the filled tubes increased, while the specific ultimate load, specific bending stiffness, and specific energy absorption decreased.

References listed at the end of the paper:

Due to the influence of the environment and the magnesium alloy pipe online. In this paper, the laser vision system is used to measure the profile of magnesium curvature. In order to control the forming quality of the tube, it is necessary to measure the section profile of the tube. A measurement system has been developed and implemented. The accuracy and stability of the system are ensured by using a laser vision system. The experimental results show that the system is reliable and efficient. The system can be used to measure the section profile of the tube accurately and efficiently.
isolated outliers in the profile data, which seriously affects the accuracy and precision of the tube measurement.

An outlier identification algorithm based on robust locally weighted regression and PaïTa criterion is proposed. This algorithm is used to identify the typically isolated outliers in the measurement process and discuss its identification ability. Meanwhile, it is compared with the moving mean identifier and the Hampel identifier. Subsequently, the ellipse fitting of profile data was carried out, and the fitting ellipse parameters and fitting precision of the curved section were obtained. At the same time, the fitting results were compared before and after the outliers are eliminated. The experiment proves that the outlier identification method based on robust locally weighted regression and PaïTa criterion can effectively identify outliers in profile data, especially for spot outliers. This algorithm is a robust, accurate, and efficient outlier identification method, which can effectively improve the laser profile measurement accuracy of the pipe section and has great significance for the quality control of magnesium alloy tube.

References listed at the end of the paper:


ABSTRACT: An edge-based smoothed finite element method (ES-FEM) combined with the mixed interpolation of tensorial components technique (MITC) for triangular elements, named as ES-MITC3, was recently proposed to enhance the accuracy of the original MITC3 for analysis of plates and shells. In this study, the ES-MITC3 is extended to the static and vibration analysis of functionally graded (FG) porous plates reinforced by graphene platelets (GPLs). In the ES-MITC3, the stiffness matrices are obtained by using the strain smoothing technique over the smoothing domains created by two adjacent triangular elements sharing an edge. The effective material properties are variable through the thickness of plates including Young’s modulus estimated via the Halpin–Tsai model and Poisson’s ratio and the mass density according to the rule of mixture. Three types of porosity distributions and GPL dispersion pattern into the metal matrix are examined. Numerical examples are given to demonstrate the performance of the present approach in comparison with other existing methods. Furthermore, the effect of several parameters such as GPL weight fraction, porosity coefficient, porosity distribution, and GPL dispersion patterns on the static and free vibration responses of FG porous plates is discussed in detail.
References listed at the end of the paper:


ABSTRACT: The influence of soil heterogeneity is studied on the bending of circular thin plates using two modified Vlasov foundation models. The model parameters are determined reasonably using an iterative technique. According to the principle of minimum potential energy and considering transversely isotropic soils and Gibson soils, the governing differential equations and boundary conditions for circular thin plates on two modified Vlasov foundations are derived using a variational approach, respectively. The determination of attenuation parameters is a difficult problem, which has hindered the further application of the Vlasov foundation model. The equation that must be satisfied by the attenuation parameter is determined, and an iterative method is used to solve the problem. A comparative analysis is conducted between two modified
Vlasov models and the traditional Vlasov model. The results show that the governing equations and boundary conditions for circular thin plates resting on two modified foundations are consistent with those for a circular thin plate on traditional two-parameter foundation after degradation. The accuracy and reliability of the proposed solutions are demonstrated by comparing the obtained results with those reported in the literature. The heterogeneity of soils, including the transversely isotropic soils and Gibson soils, has a certain effect on characteristic parameters of the foundation models as well as the deformations and internal forces of circular thin plates. The present study could be employed as a reference for future engineering designs.

References listed at the end of the paper:


ABSTRACT: A spline finite point method (SFPM) based on a locking-free thin/thick plate theory, which is suitable for analysis of both thick and thin plates, is developed to study nonlinear bending behavior of functionally graded material (FGM) plates with different thickness in thermal environments. In the proposed method, one direction of the plate is discretized with a set of uniformly distributed spline nodes instead of meshes and the other direction is expressed with orthogonal functions determined by the boundary conditions. The displacements of the plate are constructed by the linear combination of orthogonal functions and cubic B-
spline interpolation functions with high efficiency for modeling. The locking-free thin/thick plate theory used by the proposed method is based on the first-order shear deformation theory but takes the shear strains and displacements as basic unknowns. The material properties of the FG plate are assumed to vary along the thickness direction following the power function distribution. By comparing with several published research studies based on the finite element method (FEM), the correctness, efficiency, and generality of the new model are validated for rectangular plates. Moreover, uniform and nonlinear temperature rise conditions are discussed, respectively. The effect of the temperature distribution, in-plane temperature force, and elastic foundation on nonlinear bending under different parameters are discussed in detail.

References listed at the end of the paper:
schemes have higher efficiency than previous schemes and are compared with available results in the literature, showing excellent agreement. Additionally, the proposed schemes is intr...
investigate the effect of elastic foundation parameters, different materials of sensors and actuators, and elastic and geometric characteristics of the composite plate on the natural frequencies and mode shapes.

References listed at the end of the paper:

Wei Ji, Kui Luo, and Jingwei Zhang, “Computation of Deflections for PC Box Girder Bridges with Corrugated Steel Webs considering the Effects of Shear Lag and Shear Deformation”, Mathematical Problems in Engineering, Article ID 4282398, 18 July 2020, Volume 2020, https://doi.org/10.1155/2020/4282398

ABSTRACT: Prestressed concrete (PC) girders with corrugated steel webs (CSWs) have received considerable attention in the past two decades due to their light self-weight and high prestressing efficiency. Most previous studies were focused on the static behavior of CSWs and simple beams with CSWs. The calculation of deflection is an important part in the static analysis of structures. However, very few studies have been conducted to investigate the deflection of full PC girders or bridges with CSWs and no simple formulas are available for estimating their deflection under static loads. In addition, experimental work on full-scale bridges or scale bridge models with CSWs is very limited. In this paper, a formula for calculating the deflection of PC box girders with CSWs is derived. The longitudinal displacement function of PC box girders with CSWs, which can consider the shear lag effect and shear deformation of CSWs, is first derived. Based on the longitudinal displacement function, the formula for predicting the deflection of PC box girders with CSWs is derived using the variational principle method. The accuracy of the derived formula is verified against experimental results from a scaled bridge model and the finite element analysis results. Parametric studies are also performed, and the influences of shear lag and shear deformation on the deflection of the box girder with CSWs are investigated by considering different width-to-span ratios and different girder heights. The present study provides an effective and efficient tool for determining the deflection of PC box girders with CSWs.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: This paper presents a model called SAM-FG (stress approach model of functionally graded shells) for linear elastic, thin, and moderately thick shells made of functionally graded materials. The model is an extension of the SAM-H model, originally created for homogeneous shells. Assuming that the material is orthotropic and that one of its orthotropic directions is the thickness direction, the extension consists in considering that the 3D compliance tensor may depend on the thickness coordinate. The model starts with a tunable polynomial approximation of the 3D stress field that contains the same generalized forces as SAM-H. This stress approximation verifies the 3D equilibrium equations and the stress boundary conditions at the faces of the shell. As in SAM-H, 5 generalized displacements appear in SAM-FG. By applying the Hellinger–Reissner functional and Reissner’s variational method, the generalized forces, strains, and equations in SAM-FG turn out to be the same as in SAM-H, except for the generalized constitutive equations. To prove the accuracy of the model, SAM-FG is first applied to a simply supported, functionally graded plate and its results are compared to other models. To validate the model for shell-like structures, SAM-FG results are compared to those obtained with solid finite element calculations for three case studies of structures subjected to an internal pressure. The first one deals with a hollow sphere made of an isotropic functionally graded material. The second case considers a hollow cylinder made of an orthotropic functionally graded material. In the last case, a catenoid with an isotropic functionally graded material is studied. In all cases, the mean displacements are correctly predicted, even if the main purpose of the SAM-FG model is not to calculate these fields accurately. The stress field approximations are very accurate, and since the implementation of the shell model in a finite element code would imply 5 degrees of freedom per node, SAM-FG is a good alternative to solid finite element calculations for the structural analysis of functionally graded shells with a reasonable computational cost.

References listed at the end of the paper:


ABSTRACT: The variable section structure could be the physical model of many vibration problems, and its analysis becomes more complicated either. It is very important to know how to obtain the exact solution of the modal function and the natural frequency effectively. In this paper, a general analytical method, based on segmentation view and iteration calculation, is proposed to obtain the modal function and natural frequency of the beam with an arbitrary variable section. In the calculation, the section function of the beam is considered as an arbitrary function directly, and then the result is obtained by the proposed method that could have high precision. In addition, the total amount of calculation caused by high-order Taylor expansion is reduced greatly by comparing with the original Adomian decomposition method (ADM). Several examples of the typical beam...
with different variable sections are calculated to show the excellent calculation accuracy and convergence of the proposed method. The correctness and effectiveness of the proposed method are verified also by comparing the results of the several kinds of the theoretical method, finite element simulation, and experimental method.

References listed at the end of the paper:


ABSTRACT: Numerical analyses and theoretic analyses are presented to study the elastic buckling of H-section beam web under combined bending and shear force. Results show that the buckling stress of a single web with clamped edges gives a good agreement with the buckling stress of an H-section beam web when the local buckling of the beam is dominated by the web buckling. Based on theoretic analyses, a parametric study is conducted to simplify the calculation of buckling coefficients. The parameters involved are clarified first, and the improved equations for the buckling coefficient and buckling stress are suggested. By applying the proposed
method, the web buckling slenderness ratio is defined. It is verified that the web buckling slenderness ratio has a strong correlation with the normalized ultimate strength of H-section beams when the buckling of the beams is dominated by web buckling. Finally, a design equation is proposed for the ultimate strength of H-section beams.

References listed at the end of the paper:

ABSTRACT: In this work, a general geometric nonlinear model of straight thin-walled box beams (STBBs) under combined eccentric and axial loads is established. In order to accurately reflect the behavior of STBB, the additional shear lag warping is added to enrich the displacement field. It is necessary to define the section shape function to describe the local section deformation. Therefore, extension, bending, torsion, distortion, and shear lag effects are expressed by the generalized coordinate method. Based on the stability of transverse unconstrained box beam theory, meaningful higher-order solutions can be obtained by defining a set of coupled deformation modes. The equilibrium equation is discretized by the Galerkin method, and the Newton–Raphson incremental method is used to derive and solve the nonlinear governing equations. On this basis, the analytical expression of stiffness matrix is established. For solving the stability problem, the effectiveness of the proposed method is verified by comparing the calculation results of shell element (Ansys) with other theories. Numerical examples even show that the proposed method can not only get the influence of shear lag but also obtain the variation of lateral buckling of the beam model.

References listed at the end of the paper:

References listed at the end of the paper:

ABSTRACT: As the main load-bearing structure of heavy machine tools, cranes, and other high-end equipment, the large-scale box structures usually bear moving loads, and the results of direct topology optimization usually have some problems: the load transfer skeleton is difficult to identify and all working conditions are difficult to consider comprehensively. In this paper, a layout design method of stiffened plates for the large-scale box structures under moving loads based on multiworking-condition topology optimization is proposed. Based on the equivalent principle of force, the box structures are simplified into the main bending functional section, main torsional functional section, and auxiliary functional section by the magnitude of loads and moments, which can reduce the structural dimension and complexity in topology optimization. Then, the moving loads are simplified to some multiple position loads, and the comprehensive evaluation function is constructed by the compromise programming method. The mathematical model of multiworking-condition topology optimization is established to optimize the functional sections. Taking a crossbeam of superheavy...
turning and milling machining center as an example, optimization results show that the stiffness and strength of the crossbeam are increased by 17.39% and 19.9%, respectively, while the weight is reduced by 12.57%. It shows that the method proposed in this paper has better practicability and effectiveness for large-scale box structures.

References listed at the end of the paper:

ABSTRACT: Functionally graded materials have been widely used in engineering and human health applications. The issues about mechanical behavior of functionally graded material have received considerable attention. However, because of the complexity of material property, geometric profile, and mechanical load, there is still lack of proper analytic solutions about deformation and stress in many articles. The principal goal of this research is to study the effect of mechanical load on deformation and stress in rotating thin-walled functionally gradient material annular disk with exponentially-varying profile and properties. The inner and outer surfaces of annular disk are subjected to different pressures simultaneously. For this purpose, the infinitesimal theory of elasticity and axisymmetric plane stress assumptions has been proposed to formulate the governing equation. The governing equation is a generalized confluent hypergeometric differential equation, based on Whittaker’s functions; this is the first time that closed-form solutions of mechanical behaviors are revealed about proposed functionally gradient material model. Besides, another four boundary conditions are also discussed, i.e., the inner and outer surfaces of the annular disk are considered to be the combinations of free and clamped conditions. Numeric examples of two different functionally graded material properties are given to demonstrate displacement and stress solutions. Moreover, uniform disks made of homogeneous material under different boundary conditions are investigated, which are special cases of the proposed rotating functionally gradient material disks. Finally, some conclusions are made at the end of the present paper.

References listed at the end of the paper:

A Multisource Data Analysis Method for Stress States of Oil Pipelines under Permafrost Thawing Settlement Load

ABSTRACT: Thaw settlement is one of the common geohazard threats for safe operation of buried pipelines crossing permafrost regions, as pipes need to bear additional bending stress induced by settlement load. In the present study, a novel coupled data analysis method was proposed for stress state estimation of buried steel pipeline under thawing settlement load. Multisource data including pipe bending strain derived by inertial measurement unit, pipe longitudinal strain derived by strain gauges, and thawing displacement loads derived by soil temperature monitoring were used to estimate the pipe’s mechanical states. Based on the derived data, finite element method-based pipe soil interaction model was established to predict pipe’s actual stress distribution. A monitored pipe segment of one crude oil pipeline in northeast China operated since 2010 was adopted as a prototype for the investigation, monitoring data derived in the last ten years was employed to predict the settlement loading, and relative accurate stress results was obtained via the established pipe soil interaction model. The mean absolute error (MAE) of the predicted pipe stresses compared with the monitoring results in 2014, 2017, and 2018 are 5.77%, 12.13%, and 13.55%, respectively. Based on the analyzed stress results, it can be found that the investigated pipe was subjected to an increasing settlement load from 2010–2016, made the bending stress increased up to 149.5 MPa. While after 2016, due to the depth of frost soil in this area is no more than 3.5 m, the thawing settlement load almost remained constant after 2016. As the investigated pipe is made by X65 line pipe steel, the von-Mises stress in pipe is much smaller than the allowable one indicating pipe’s structural safety status so far. The proposed method can also be referenced in the status monitoring of buried pipeline crossing other geological hazard regions.

References listed at the end of the paper:

Free Vibration and Static Bending Analysis of Piezoelectric Functionally Graded Material Plates Resting on One Area of Two-Parameter Elastic Foundation

ABSTRACT: Free vibration and static bending of piezoelectric functionally graded material plates resting on one area of the two-parameter elastic foundation is firstly investigated in this paper. The third-order shear deformation theory of Reddy and 8-node plate elements are employed to derive the finite element formulations of the structures; this theory does not need any shear correction factors; however, the mechanical response of the structure is described exactly. Verification problems are performed to evaluate the accuracy of the proposed theory and mathematical model. A wide range of parameter study is investigated to figure out the effect of geometrical, physical, and material properties such as the plate dimension, volume fraction index, piezoelectric effect, elastic foundation coefficients, and the square size of the area of the foundation on the free vibration and static bending of piezoelectric functionally graded material plates. These numerical results of this work aim to contribute to scientific knowledge of these smart structures in engineering practice.

References listed at the end of the paper:

and Kunieda. The results show that the current method can solve the axisymmetric vibrations’ equations differen-
tially. In this method, we take into consideration the terms of the inertial couples in the stress couples’ differen-
tial equations of motion. These inertial couples are omitted in the theories provided by Naghdi–Kalins and Kunieda. The results show that the current method can solve the axisymmetric vibrations’ equations of
In this paper, we focus on verifying the current method, particularly for free vibrations with free edge and clamped edge boundary conditions. To check the validity and accuracy of the current analytical method, the natural frequencies determined by this method are compared with those available in the literature and those obtained by a finite element calculation.

References listed at the end of the paper:

ABSTRACT: In order to obtain the effects of time-varying fluid on dynamical characteristics of cantilever beams, this paper gives a comprehensive study of cantilever beams vibrating in a fluid with variable depth. The mathematical model of the cantilever beams in time-varying fluid is derived by combining Euler–Bernoulli beam theory and velocity potential theory, and the influence of the time-varying fluid is discussed. Then, a two-way fluid-structure interaction (FSI) numerical simulation procedure is proposed to calculate the transient responses of the beam. The validity and accuracy are verified according to the comparison among theoretical analysis, numerical simulations, and experimental measurements. Results show that, besides the added mass effect, a damping-like term is also induced due to the motion of the fluid, which is proportional to the moving velocity of the fluid. Both the added mass and the added damping increase with the increment of the width of the beam. The surrounding fluid near the free end affects the beam more significantly. As a negative damping is caused while the fluid decreases, resulting in a much slower decay of the time responses. Therefore, the added damping should not be neglected in the analysis of the FSI problems with time-varying fluid.

References listed at the end of the paper:


A. Hossain and A. Mian, “Numerical analysis to predict dynamic response of mini cantilever beam submerged in viscous fluids,” American Society of Mechanical Engineers (ASME), vol. 18, pp. 1–6, 2011.


More papers published in the journal, Journal of the International Association for Shell and Spatial Structures (2014 and on)

Google the string, “Journal of the International Association for Shell and Spatial Structures”, then click on the entry that is followed by “https://www.ingentaconnect.com › content › iass › jiass” and search for “xx Issues are available”. Choose the volume number and issue.

Philipp Eisenbach, Ragunath Vasudevan, Manfred Grohmann, Klaus Bollinger and Stephan Hauser, “Parapluie - Ultra Thin Concrete Shell Made of UHPC By Activating Membrane Effects”, Journal of the International Association for Shell and Spatial Structures, Vol. 55 (2014) No. 4 December n. 182, pp. 201-212(12)

ABSTRACT: Parapluie is an architectural concrete shell structure for a bus stop shelter designed for a serial production by multiple reuse of the formwork. It is made of ultra-high-performance-concrete that is reinforced with a layered micro mat reinforcement distributed over the whole cross section with zero distance to the outer surfaces. This material composition leads to a highly ductile behavior that is substantiated by the biaxial homogenous cross section layout that allows a linear elastic structural analysis. The aim was to achieve a concrete shell that is as slender and lightweight as possible. By a parametric form finding process a system was developed that is able to transfer the loads of the shell mostly by membrane effects. The result is a concrete shell with no steel embedded items and an edge thickness of less than 25 mm.
This paper proposes a practical computational method for shaping lightweight structures made of discrete components. Previously proposed methods for designing such structures either focus on finding an equilibrated form, or are generally restricted to relatively small optimization applications. In this work, the complementary concepts of form finding and optimization are merged within a unified formulation: the general design problem is stated by discrete layout optimization whereas the force density equations are used to govern the equilibrium. The resulting formulation can address designs of lightweight structures including thousands of design settings and project constraints. Three real-world applications illustrate the capabilities of the proposed method.

The lateral resistance provided by the inclined cables to pylons of cable stayed bridges and communication tower masts is approximated by means of the equivalent spring method, proposed in the literature by several researchers. At first, a simple pylon is considered supported laterally by a set of two symmetrically arranged inclined cables. The concept of substituting the cables with a spring of equivalent stiffness is employed and the critical buckling load of the pylon is calculated analytically, based on linear buckling theory. Then, the above substitution is used in order to investigate the stability of such structures by means of nonlinear finite element analyses. Namely, the analytical solution is compared to numerical results, which are generated through linearized buckling analysis (LBA) of the spring-supported pylon as well as geometrically nonlinear analysis with initial imperfections (GNIA) of the actual cable-supported pylon, employing finite element software ADINA. The unstable nature of the post-buckling response and the imperfection sensitivity of such structures are highlighted and design implications are discussed.

The design and analysis of membrane structures supported by internal gas pressure continues to provide interesting challenges for the engineer. The inTENS software developed by Tensys is continually enhanced to address these topics, as illustrated in this paper by reference to an ongoing aerospace project and a recent artistic installation. The numerical conception is developed, from the draft made by architects up to the final structure. Several numerical tasks are performed to design a gridshell. The geometry of the gridshell is first considered. Then, an important iterative step mixing geometry and mechanical considerations is carried out. In particular, it is explained how the naturally straight beams are bent together during a very quick step leading to the final shape. Thanks to this active bending, double-curvature shapes are made and offer many interests like high stiffness for a lightweight structure. Lastly, the geometry of the membrane is drawn based on the numerical final geometry of the gridshell. The improvements of gridshells, including safety considerations as well as practical considerations are also developed, through the four gridshells recently built. Finally the model is improved to take into account the torsion which can have an important effect, especially when the beams have a rectangular cross section.

ABSTRACT: The finite element method was used to study the dynamic performance of single-layer cylindrical reticulated shell considering pile-soil-structure interaction (PSSI). The finite-element software ABAQUS was used in combination with a FORTRAN program. A viscoelastic artificial boundary was adopted to simulate three-dimensional foundation soil. The ground motions were transformed into equivalent loads of boundary nodes to provide a ground motion input associated with the viscoelastic boundary. Then an example was developed to verify the validity and rationality of the finite element calculation process. Finally, a 3D finite element integral model was established to make a comprehensive analysis of single-layer cylindrical reticulated shell's dynamic performances. The integral model consisted of single-layer cylindrical reticulated shell roof, supporting structure, piles and foundation soils. The results indicate that the first mode shape of the single-layer cylindrical reticulated shell remains horizontal when the PSSI is considered. The natural vibration frequencies of the shell decrease and become more intensive compared to the rigid foundation assumption. Furthermore, the peak acceleration of pile cap center increases nearly 5%~10% compared to the peak acceleration of free field under the action of earthquake. At the same time, the nodal displacement and nodal peak acceleration of single-layer cylindrical reticulated shell increase obviously considering pile-soil-structure interaction.


ABSTRACT: The paper considers non-developable foldable plate structures. It presents a design method to approximate any surface made by the translation of a generic curve along a straight line or connected segments. The method achieves a continuous, foldable 3D grid which approximates the target surface along two perpendicular directions. The parameters defining the target surface and the sharpness of the folded plates can be freely set.


ABSTRACT: Cable domes are tension domes, made of an assembly of prestressed cables in equilibrium with vertical struts and a perimeter beam. This paper introduces a new approach for efficient design of radial-type cable domes using influence surface analysis. The method has its basis on the Müller-Breslau Principle and the Principle of Virtual Work. A series of dome configurations were analyzed using the method and their behavior were compared. The results from the method were used to identify the critical load combinations for member designs. Particularly, domes vulnerable to wind uplift were easily recognized indicating the need for enhancement in prestressing forces. Influence surface analysis thus streamlines an otherwise cumbersome design process, thereby allowing for a substantially reduced design and computational effort.


ABSTRACT: This paper is a critical review on advantages and disadvantages of contemporary digital architecture, in retrospect to Vladimir Shukhov's design techniques, applied in the early 20th century. After investigating Shukhov's structural systems, this paper explores the relationship between performance and form, questioning the necessity of high-complexity structures. It will present unpublished archive material of his early work and stimulate a valuable discussion by comparing it with contemporary projects designed by renowned architects. The study on Shukhov focuses on his tessellation method of double-curved surfaces using simple standardized elements. The study of present digital approaches revolves around leading architects using computational tools (e.g. Foster and Partners, Buro Happold and Arup), who have materialized high complexity structures composed by irregular units. Our findings highlight advantages and disadvantages of contemporary computational approaches.
ABSTRACT: The "Modern Architecture's Thin Shells Adventure" started in the twenties, when the reinforced concrete was still developing and a new "air" – Modernity – was born. At that time, and during the following decades, it was very difficult to design thin shells because computers, as we know nowadays, did not exist and the existing tools to calculate such shells were very complicated. Also it was difficult to guarantee the right structural behaviour of this new structural form, being slender, light and big in size. This was the reason why in the 1930’s Eduardo Torroja developed the reduced model test to check the structural behaviour of this new structural form. In 1941 the Spanish engineer Ildefonso Sánchez del Río presented, at the Eduardo Torroja Institute, his own and innovative system design for shell structures. During three decades he built a lot of thin shells using his system design, like the Oviedo Sport Palace (100m span) and the Pola de Siero Market, which were published in the covers of the IASS bulletin.


ABSTRACT: This paper discusses a new formulation to evaluate reliability of elasto-plastic buckling load required in design of metal reticulated shells of general form under dead and snow loads. Several roofs of different geometries with a span around 50 meters are first analyzed to evaluate their buckling load considering both elastic buckling load and plastic strength. Then, for reliability analysis, general formulas for the evaluation of the elastic buckling load and plastic strength are formulated based on a perturbation-like method. The proposed formulation is applied to evaluate the reliability index of free form reticulated shells under dead and snow loads. For the reliability index, not only external loads but also Young’s modulus, yield strength, sectional area of members, knockdown factor for elastic buckling load, and several related structural factors are treated as probabilistic parameters. The global load factor is also evaluated in terms of reliability index using 100-year reference period for safety evaluation and 100-year return period for member proportioning. Finally, conclusions are drawn for future development of the present scheme for reticulated shells of free form.


ABSTRACT: In the field of digital fabrication, additive manufacturing (AM, sometimes called 3D printing) has enabled the fabrication of increasingly complex geometries, though the potential of this technology to convey both geometry and structural performance remains unmet. Typical AM processes produce anisotropic products with strength behavior that varies according to filament orientation, thereby limiting its applications in both structural prototypes and end-use parts and products. The paper presents a new integrated software and hardware process that reconsiders the traditional AM technique of fused deposition modelling (FDM) by adding material explicitly along the three-dimensional principal stress trajectories, or stress lines, of 2.5-D structural surfaces. As curves that indicate paths of desired material continuity within a structure, stress lines encode the optimal topology of a structure for a given set of design boundary conditions. The use of a 6-axis industrial robot arm and a heated extruder, designed specifically for this research, provides an alternative to traditional layered manufacturing by allowing for oriented material deposition. The presented research opens new possibilities for structurally performative fabrication.


ABSTRACT: Overall objective of this research is to evaluate the importance of geometric nonlinearity in the structural behaviour and design of shallow truss roofs, depending on their geometric configuration and on their material as well as cross-sectional properties, and eventually to propose simple analytical criteria for assessing whether linear analysis can be safely adopted for design. For that purpose, the simple von Mises truss model is analytically and numerically investigated, with emphasis on the interaction between geometric nonlinearity at
the system level and buckling, material nonlinearity and imperfections at the member level. The obtained results are compared to the criterion proposed in Eurocode 3 for adopting first order analysis for the design of steel structures. Interesting findings are reported that can then be extended to more complex reticulated shells.


**ABSTRACT:** Recently, owing to the development of structural materials and structural analysis technology, various large span structures with complex forms have been built. A structure with a structurally irrational shape might be one of them. Therefore, this study aims to create an index that can evaluate the mechanical performance of the shell shape at an early design stage. This study also proposes the ratio of the bending strain energy to the strain energy caused by external forces, which is called the bending strain energy ratio, as the index. The bending strain energy ratios are calculated for various shells with classic shapes, such as a sphere or cylinder, and complex free shapes. The relations between the index and the maximum responses and the shape characteristics are examined in detail. Furthermore, the index applicability is discussed.


**ABSTRACT:** To predict the load bearing capacity of single-layered steel grid shell structures, the behavior of the joints need to be considered. A parametric analysis is presented with the aim to decide whether a bolted joint has enough stiffness and strength to be applied in grid shells. Free-form roof structures with rectangular boundary are investigated with different geometrical properties, such as topography and topology. Each structure is designed with rigid and with semi-continuous bolted joints as well, and the smallest possible cross-section sizes are determined. The design method is based on nonlinear finite element analysis considering geometrical and material nonlinearities with imperfections, and the method is validated by analytical and test results. Results are presented for structures spanning 20 meters and using a single-bolted joint system called the socket joint with relatively small rigidity and strength. It is shown, that this free-form shape is highly imperfection-sensitive. Furthermore, the effect of analysis parameters such as imperfection shape or amplitude and simplified moment-rotation characteristics of the joints are presented.


**ABSTRACT:** The aim of this paper is to present some innovative strategies for the design of plated shell structures. Fabrication constraints are carefully considered, as the obtained shapes are covered with planar quadrilateral facets only. Different corrugation strategies are investigated, and our method guarantees extension of the shape generation to complex topologies. Few parameters control the amplitude of corrugations, which also gives us the opportunity to perform a sensitivity analysis on the influence of corrugations on the structural performance of folded-plate structures. The study focuses on the influence of the mechanical attachment between plates on the overall structural performance as well as fabrication rationality.


**ABSTRACT:** This paper describes the geometry and structural design of a flexibly formed, mesh-reinforced sandwich shell roof, as part of the NEST HiLo project, to be built in Dübendorf, Switzerland, in 2016. The computational design process consists of an integrated parametric model used for multi-objective evolutionary shape optimization of the shell, and subsequent analysis of its nonlinear behaviour.

ABSTRACT: A weightless wire coat hanger bent out of its plane is one of the simplest possible structures. All it does is transfer a force and moment around a closed space curve. Assembling a family of coat hangers enables us to build up trusses and frames and if we allow an infinite number of coat hangers which overlap we can assemble plates, shells and fully three dimensional structures. We can apply loads to these structures via a loading frame and wires, also made from coat hangers. A wire carrying an electric current produces a magnetic field in the space surrounding the wire. For the bent coat hanger we can imagine that there is a vector field surrounding the wire as a result of the force and moment in the wire. We can use this vector field to obtain expressions for the forces and moments in a shell in equilibrium with applied loads.


ABSTRACT: Lightweight concrete structures and structurally optimized systems are the focus of several research efforts. This is due to esthetical reasons but also in order to use material in a resource conserving way. Advancements in digitizing planning and fabrication processes, but also ongoing enhancements in material science for cementitious composites enable designers to build complex geometries of slender concrete structures. However, it can be observed that built architecture does not reflect the present possibilities at hand. One reason is the implementation on site; with increasing material performance, the sensitivity of concrete production increases to assure sufficient accuracy, workability and post-treatment. In combination with demands for quick assembly and simple disassembly of structural components, a prefabrication of concrete elements is indispensable. The possibility to reduce cross section dimensions on the one hand and the arising challenge how to realize load bearing connections on the other hand, is a contradiction investigated within this survey. The identification of mechanical principles of structural connections enables the development of design strategies for load bearing connections. Two selected case studies, illustrating adhesive and interlocking bonding of concrete elements are presented, verifying the feasibility on site. An adhesive bonding is presented for a concrete bench, designed as a Möbius strip. This innovative, thin concrete shell structure is built on the campus of the University of Kassel. Due to prefabrication in a concrete laboratory the partition of the object was necessary. An interlocking bonding is applied for the construction of a concrete mobile, designed for an exhibition in Amsterdam. With the focus on a quick and easy assembly and non-destructive disassembly, a micro-prestressing connection method is developed.


ABSTRACT: The simulation and construction of elastic gridshells in composite materials is nowadays a technique that one can consider mastered. The bracing of the grid in its final form remains however a time consuming step with a lot of manual work. The lack of alternatives to membrane covering is also an important limitation to the development of such technology. The proposed paper tries to tackle both issues through a novel concept of a hybrid structural skin made of an elastic gridshell braced with a concrete envelope. The idea is to use the gridshell as a formwork for the concrete and to guarantee a mechanical connection between the thin concrete skin and the main grid, so that the concrete ensures the bracing of the grid and that the thickness of the concrete is reduced to a minimum. To demonstrate the feasibility and interest of this structural concept, a 10 m² prototype has been built. The main aspects of the design and of the realization of the prototype are presented here (including detailing and mix design).

Silke Scheerer, Rostislav Chudoba, Maria Patricia Garibaldi and Manfred Curbach, “Shells Made of Textile Reinforced Concrete – Applications in Germany”, Journal of the International Association for Shell and Spatial Structures, Vol. 58 (2017) No. 1 March n. 191, pp. 79-93(15)

ABSTRACT: Textile reinforced concrete (in short: TRC) is a relatively new building material. It is characterized by the possibility to produce very thin layers with a high tensile strength. Due to the use of flexible reinforcement, TRC is particularly suitable for shell building. In this paper we want to give a short overview about the development of TRC in Germany and the typical material properties. Further we want to describe realized projects in the fields of new shell buildings and of strengthening of reinforced concrete shell
structures. The focus is here on manufacturing methods, and we want to demonstrate the potential of textile reinforced concrete for building constructions. We close with a short outlook.


ABSTRACT: This paper presents a numerical study of spatial steel structures covering the design of a hollow ball-tube bolted joint system (HB) and its application to a single-layer spherical reticulated dome of type Kiewit 6 (K6). First, a so-called hollow ball-tube bolted joint system (HB) has been designed, and its bending rigidity was determined. Based on the bending-rotation curves of the HB joint system obtained through numerical simulation, a finite element model of single-layer reticulated domes with HB joint system is developed using nonlinear beam element with end-spring elements in ANSYS software. Results are compared with the rigid dome, designed by the continuum method. The analysis has been conducted using key parameters such as loading system, ratio of rise to span with a constant span and fixed support condition around the edge.


ABSTRACT: This paper analyses the buckling shapes of spherical shells subjected to concentrated load. A theoretical investigation, based upon geometric considerations, shows a variety of possible buckling shapes, including polygonal ones. The results show that there exists a certain difference between the geometric behavior of shells characterized by different radius-thickness ratios. An analogy between the buckling edge of the shell and a compressed planar elastic ring is also shown, which gives a better view on the point of transformation of the buckling edge from a circle to a polygon. The results of numerical and experimental analyses are also exhibited to verify the theoretical achievements.


ABSTRACT: For large-span single-layer reticulated structures, the main recent challenge is to develop a new joint that can provide the structure with enough stiffness, whilst also meeting various important requirements, such as easy assembly on the construction site. In this paper, a new joint, named the bolt-column-plate (BCP) joint, is developed, and a three-dimensional FE model of the joint is established. Combined with theoretical analysis, the mechanical performance of the joint is investigated, under both static and quasi-static loads. A parametric study is conducted to i) Obtain the stiffness, strength, rotation behavior and failure mode of the joint under different static load conditions, including axial pressure, axial tension, pure bending, bending with axial force, eccentric pressure and eccentric tension; ii) Obtain the M-Φ hysteresis curves of the joint under quasi-static loads, and investigate hysteretic performance, energy dissipation and ductility; iii) Investigate the load-transferring mechanism of the joint under static and quasi-static load conditions. Finally, the data provided by the simulations proves that the new joint has good mechanical performance, under both static and quasi-static loads. This provides guidance for the practical application of this kind of joint system in real structures.


ABSTRACT: The present paper discusses reliability of dynamic buckling of single layer reticulated domes under dead and seismic loads. First, several domes with different safety factors for dead load are designed based on elasto-plastic buckling analysis. Second, the dynamic buckling loads obtained based on dynamic nonlinear analysis of these domes are analyzed aiming at formulating a mathematical expression for buckling loads in terms of related structural variables. Then, an equation for the dynamic buckling load is formulated explicitly in terms of the related variables. Third, concerning dynamic buckling under dead and seismic loads, a performance function for reliability is expressed in terms of seismic input acceleration intensity as action and buckling
strength as resistance. Fourth, a trial is performed to evaluate an approximate value of reliability index using a performance function, then solved successively using AFOSM method, and the values of reliability index for reticulated domes using 50-year and 100-year reference periods are searched considering the related stochastic properties. Finally, the paper discusses the relationship between reliability index and safety factor for dead load in the two cases of reference period from a viewpoint of structural design for ordinary structures.


ABSTRACT: The present paper aims at investigating the buckling strength and its reliability of a two-way single layer grid dome stiffened by diagonal braces under uniform and non-uniform snow loads. The dome is supported by a substructure which is composed of a set of four enclosed eaves as a tension ring and a two-story frame underneath. The eaves, looking circular if projected on a plan, are arranged around the dome in order not to raise too much tensile stresses into the diagonal braces in the dome. First, characteristics of linear buckling, elastic buckling and elasto-plastic buckling are investigated with emphasis on the effectiveness of diagonal braces to increase the buckling strength. Secondly, with relation to reliability analysis, the elasto-plastic buckling load, defining the ultimate strength, is investigated considering the stochastic properties of steel members. The mean value and coefficient of variation of the ultimate strength are evaluated based on the stochastic properties and geometric imperfections. Thirdly, a formulation is presented to analyze the reliability of ultimate strength, then followed by its numerical analysis. Finally, based on the results the relationship between the reliability index and a global load factor is discussed in detail, revealing thereby the ratio of safety.


ABSTRACT: Deployable scissor grids are articulated networks of bars that can rapidly transform between different configurations. The past decades various types of scissor grids have been developed for diverse applications. Double curvature is often desired to obtain functional and appealing shapes with a good structural performance. Consequently, polar scissor units have been extensively studied for their ability to generate doubly curved scissor grids that undergo large volume expansions. Unfortunately, this double curvature could only be spherical. We propose a generalization of the polar scissor unit that can be used to translate the existing spherical scissor grids into non-spherical ones while maintaining their kinematic behaviour. Consequently, this generalization unlocks a large unexplored design potential and broadens the applicability of this scissor grid type. This paper presents the geometry and kinematics of the generalized polar scissor units and resulting scissor grids. In addition, it introduces a joint model that preserves the geometric compatibility. Scale models are used to verify and illustrate these new concepts.


ABSTRACT: The design of gridshells is subject to strong mechanical and fabrication constraints, which remain largely unexplored for non-regular patterns. The main technological constraints for glazed gridshells are related to the planarity of facets and the existence of torsion-free offsets. The authors propose indicators to evaluate a priori the quality of design space of gridshells covered with different patterns for these fabrication constraints. By comparing these metrics, the kagome grid pattern is identified as a pattern with a complexity similar to the ubiquitous quadrilateral pattern. Finally, the authors propose to generate gridshells with planar facets with the marionette technique and to explore the resulting design space by the means of multi-objective optimization. The results of the study show that our framework for shape modeling has similar performances as more usual frameworks, like NURBS modeling, while maintaining the facet planarity.

ABSTRACT: In this study, we show the formation of frequency band structures in origami-based mechanical metamaterials composed of the Triangulated Cylindrical Origami (TCO). Interestingly, the folding behavior of this structure can exhibit both axial and rotational motions under external excitations. Therefore, these two motions can be strongly coupled with each other, which leads to unique dynamic behavior, particularly wave mixing effects. To analyze the folding behavior of the TCO cells, we model their triangular facets into a network of linear springs. We assemble a 1D chain of multiple TCO unit cells stacked vertically in various arrangements, e.g., changing their stacking sequences and/or orientation angles. We study frequency responses of this system to investigate wave mixing effects between axial and rotational motions under dynamic excitations. This dynamic analysis on the multi-cell structure demonstrates the formation of tunable frequency band structures, which can be manipulated by the arrangement of the unit cells and their initial configurations. By taking advantage of their unique dynamic mechanisms, the origami-based mechanical metamaterials have great potential to be used for controlling structural vibrations in an efficient manner.

ABSTRACT: This contribution outlines the merits of Frei Otto and his teams in the field of studies on natural structures and structural optimization. Frei Otto formulated fundamental questions on the evaluation and efficiency of structures. With his approach, "lightness" becomes more than an aesthetic appearance but an aspect that can actually be numerically described and, in another step, turns into a basic approach for the design of structures. Some key points of this development are described in this paper.

ABSTRACT: In several of Frei Otto's early membrane structures, acoustics was a rather relevant design aspect that could not be controlled through classical form-finding approaches based on physical models. Moreover, it is possible to add that, geometrically speaking, Frei Otto's membranes could naturally perform acoustically, because of their anticlastic shape and the ability of the convex areas to scatter sound. In this paper, two of Frei Otto's key projects are revisited and redesigned parametrically using mathematical optimisation: first, the Dance Pavilion that was conceived for the Federal Garden Exhibition in Cologne (1957); and, second, the large umbrellas that were built at the same venue in 1971. His architectural form of "necessity" represents the structural optimum, that is, a buildable technology, which can now be informed by other performance criteria, such as acoustics. This paper was inspired by the rock set designs of Mark Fisher and – in particular – by the retractable umbrellas that Frei Otto designed, in 1977, for the second leg of Pink Floyd's "In the Flesh Tour", which was also known as the "Animals Tour".

ABSTRACT: Transparency is a social demand – in both politics and architecture. Therefore, outstanding glass constructions are often located in buildings of political significance. We raised the question whether it is feasible to design a 26.0 m spherical glass shell to cover the assembly hall of the Austrian Parliament in Vienna. This structure will be post-tensioned by means of a cable net to prevent a decompression of the glass. The paper introduces in the full numerical design process: global form finding, a research on available joint designs and the calculation of the minimum cable force that is necessary to ensure that there is no tension in the glass at all. Additionally, a buckling analysis as a function of the joint stiffness ensured a stable structure. Based on this we proposed a method on how to cover a post-breakage scenario. It was concluded that it is feasible to design ambitious full glass shells while using the glass as a load-bearing material.

ABSTRACT: This article examines the early thin shell concrete designs of the structural engineer Jack Christiansen (1927-2017), a 2016 recipient of the Eduardo Torroja Medal. With no proper training in shell behavior, Christiansen started his career designing cylindrical concrete shells based on the 1952 American
Society of Civil Engineers (ASCE) Manual 31. This manual, and its approach to solving indeterminate behavior, both directed Christiansen's early design and provided a framework for significant creative work outside its bounds. His designs of long, spanning shells and short, arching shells (between 1954 and 1958) were adapted to a variety of architectural spaces, utilizing emerging structural methods like prestressing. These designs constitute the first era of Christiansen's career, and set the stage for more varied shell geometries to come.

ABSTRACT: Adaptive structural systems possess the ability of geometrical and mechanical adjustment with regard to changing functional, loading, or environmental conditions. In particular, gridshells following bending-active principles in their deformation behavior, require a comprehensive approach in dealing with aspects of form-finding and adaptive structural behavior. The respective framework provides systems of multi-curvature configurations with transformability capabilities that are implemented through a step-by-step process of an initially non-deformed planar grid. In the current paper an adaptive bending-active plate gridshell is proposed. This is a proposal of a structural concept and not of a specific structural/architectural solution. It consists of an array of paired elastic member stripes, which combined with interconnecting telescopic bars and cables of variable length connecting the supports, operate the necessary deformation in providing the system's planar expansion and erection. The topology of the structure and its configurability are initially digitally investigated. Twelve different cases have been developed, based on control parameters of the supports' displacement and the telescopic tubes' length modification. A particular system configuration has been realized in a small-scale model, and further investigated following a sequential nonlinear static Finite-Element Analysis (FEA), in its form-finding and load-deformation behavior.

ABSTRACT: A structure that can transform from a compact bundle of scissor units to a fully expanded structural configuration is called a deployable scissor structure. Although these structures have numerous advantages over traditional structures (lightweight, compact, high-volume expansion) their practical realisation is quite limited due to their complex design process and high displacements. Research on their geometric and kinematic behaviour is ongoing; however, research on the use of barrel vault shaped scissor structures for real-life shelter applications, fully loaded as described in the European Standards, is absent. In this paper, in order to enhance the understanding and the use of scissors structures for disaster relief, the structural behaviour of barrel vault shaped scissor structures is discussed and analysed. The paper analyses the deformation, the internal forces and the stress distribution of the scissor elements of a barrel vault shaped scissor structure under wind and snow loading. The paper provides the readers with insight in the structural behaviour of barrel vault scissor structures when used as a shelter, helping them making judicious choices for the design parameters and promoting the application of these innovative and promising structures for temporary use.

ABSTRACT: Deployable structures can transform, expand and contract due to their geometric, material and mechanical properties; applications spread across multiple fields including aerospace technology and temporary, mobile and transformable architecture. There are many different types of deployable structures. For instance, the art of origami has developed concepts for paper folds that can expand and contract. Another type is that of scissor-hinged structures, made by bars joined by pivots. These two different types, origami and scissors, have so far remained separate types within the field. This geometry research unifies both types and makes an origami-scissor structure, which has a double deployment. This new technology has potential applications in architecture and engineering, such as transportable pavilions, aerospace or robotic applications.
ABSTRACT: A method is presented for design of curved surface of frame supported membrane structures. Since a uniform stress state is desired, the minimal surface is often chosen as an ideal target curved surface. Another ideal shape is a developable surface that can be generated from a plane sheet. Therefore, in this paper, the minimal surface, the developable surface, and an intermediate surface between them are chosen as the target curved surface. The cutting patterns are generated by reducing the uniform stress from the plane sheet obtained from the curved surface, where correction coefficients are incorporated. In the numerical examples, the properties of self-equilibrium shape and its stress distribution are investigated for surfaces generated from the three kinds of target curved surfaces.

ABSTRACT: Shells are long-span and inherently light-weight structures used for both their aesthetic and structural benefits. This paper develops a robust methodology for the reinforced concrete (RC) roof shell design of Akrotiri, an archaeological site in Santorini island, Greece. The methodology uses Oasys GSA and finite element package Abaqus which allow both form finding analysis and dimensioning to be conducted. Through the step-by-step application of this method, a protective shell cover is designed and its applicability demonstrated.

ABSTRACT: The aim of this article is to propose parameterization with planar facets of dome structures. The technique introduced in this paper starts from an input parameterization and creates a dual pattern with planar quadrilateral facets. The derivation of the analytical solution allows to link the method with the creation of meshes with planar hexagonal facets and of circle packing on spheres. The method can be used in various contexts and allows designers to design with two superimposed parameterizations, which allows for a potential decoupling between structure and envelope.

ABSTRACT: Origami, the art of folding sheets of paper, has been appreciated as a source of inspiration for structural design. Structural origami is a field that is rapidly developing through a collaboration between engineering, design, art, and computation. This paper introduces aspects of structural origami, to share recent exciting developments in this field.

ABSTRACT: Mobile deployable scissor structures are transportable and can be transformed rapidly from a compact folded state offering a huge volume expansion. Intended geometrical incompatibilities during transformation can be introduced as a design strategy to obtain bistability, which allows instantaneously achieving some structural stability in the deployed state. In such bistable deployable structures, these incompatibilities result in the elastic bending of some specific members that are under compression with a controlled snap-through behaviour. Attempts to optimally design deployable bistable structures remain scarce, since the underlying structural-mechanical concepts are complex. Furthermore, the requirement of flexibility during deployment while ensuring some structural stability in the deployed state prevents the use of simple design methodologies relying on the structural behaviour under service loads only. In this contribution, the trends and challenges of using computational tools in the structural analysis and design process of deployable bistable structures are discussed. Computational tools are crucial for the geometrical and structural design, for
the definition of a rigorous design methodology and for a deeper understanding of the complex transformation behaviour of these structures.


ABSTRACT: A study was made of a deployable geodesic full sphere of human size, which may be used as a skeleton for personal shelter, assembled with triangular grids of scissor units. A geodesic pattern provides structural uniformity and triangular grids give geometrical stability to the deployed configuration. The design processes of two models (PET and CFRP material) and their unfolding tests are shown, alongside a comparison with numerical studies. A one-man unfolding scheme is also investigated.


ABSTRACT: When the existing literature on the research of scissor structures is thoroughly investigated, it is seen that different researchers use different terminologies and classifications especially for the definition of the primary units and the motion type. Some of the studies define the whole geometry based on the geometric properties of the primary scissor units and the unit lines while some other studies define it according to the loops. All these studies use different names for similar elements. This article aims to review the literature on the classification and terminology of scissor structures and represent the state of art on the studies. Tables are represented showing all approaches in the literature. In addition, the article criticizes the missing points of each terminology and definition, and proposes some new terminology. In order to arrive at this aim, different definitions of the primary scissor units and motion types used in key studies in the literature are investigated thoroughly. With several examples, it is demonstrated that naming the scissor units according to the resulting motion type might be misleading and it is better to specify the motion type for the whole structure. A classification for transformation of planar curves is presented.


ABSTRACT: This research work aims to find out the main influencing factors on the stability performance, especially the critical loads and the instability modes, of the single-layer aluminum reticulated shells with semi-rigid joints. The moment-rotation curves of a new developed joint system, the improved TEMCOR joint, are introduced into the research which significantly improve the shear behavior and decrease the amount of bolts. Based on the bending stiffness curves of the new joints, the finite element models of semi-rigidly jointed single-layer aluminum reticulated shells are established. Parametric analysis of the reticulated shells is carried out using finite element analysis software ANSYS. The parameters considered in the numerical simulation are bending stiffness, ratio of rise to span, asymmetric load distribution and initial imperfection. Then, the influence of the different parameters on the critical loads, instability modes and joint stiffness status is identified. Finally, through regression analysis, formulae are derived for the calculation of critical loads of the single-layer aluminum reticulated shells with semi-rigid joints. The differences between the numerical simulation and the proposed formulae are summarize to prove that the formulae are effective and convenient for evaluating the critical loads of the aluminum single-layer reticulated shells.


ABSTRACT: Single-layer reticulated dome is a typical imperfection-sensitive structure. Initial crookedness of member as a typical imperfection innately exists in reticulated dome. The approach to establish reticulated dome with crooked member is firstly presented, followed by the study of its effect on load-carrying capacity of single-layer three-way reticulated dome. The main conclusions are summarized as follows: load-carrying capacity of the reticulated dome is influenced by initial member crookedness. Compared with the perfect dome, mean of limit load reductions of imperfect ones is 9.35%. The limit load reduction of the imperfect dome is
closely related to the distributions of crooked member, and some of them can evidently reduce the limit load. Limit load of the dome obeys extreme I type distribution. Instability modes of imperfect domes considered here belong to nodal instability triggered by member buckling, and there is a dimple in each imperfect dome. The position of dimple is not unique, and it appears in different locations depending on the shape of the imperfect dome. Moreover, the member buckling and the overall buckling of imperfect domes happen simultaneously, i.e. the synchronous instability.


ABSTRACT: Modern architectural design has seen a shift towards iconic doubly-curved envelopes enclosing large column-free spaces. Gridshells have long been considered an efficient solution to such designs, but their actual use in practice has not spread worldwide. For elastic gridshells, their advantages in terms of substantial material savings can often be overshadowed by the significant challenges associated with their construction. Similarly, for rigid gridshells, the manufacture of a large number of different members and nodal connections is often a barrier to their implementation. This paper proposes an effective way of designing, fabricating and erecting gridshells. The "Patchwork Gridshell" consists of a number of efficient elastic gridshell patches assembled using rigid gridshell frames. It can easily generate a number of different configurations, use a wide range of materials, and allows more architectural expression of practical long-span forms. The benefits of combining the ingenuously simple efficiency of elastic lattices and the power of digital fabrication are demonstrated by digitally rebuilding four alternative configurations of the Japan Pavilion of the Hanover Expo 2000 as a case study. The result is a flexible digital workflow which creates large column-free spaces that are capable of being constructed efficiently by non-specialist contractors.

Avelino, Ricardo Maia (1); Baverel, Olivier (2); Lebée, Arthur (2)
(1) MSc. Student at École des Ponts ParisTech.
(2) Laboratoire Navier, UMR 8205, École des Ponts ParisTech, IFSTTAR, CNRS, Université Paris Est.

ABSTRACT: This article discusses design strategies to improve the mechanical behavior of elastic gridshells with singularities. The advantage of meshing with one or more singularity is to allow a wider range of surfaces to be meshed with equal-length, quadrilateral meshes, known as Chebyshev nets. However, the application of this meshing process will influence the fabrication and the mechanical behavior of the structures. The erection process is simulated by means of the dynamic relaxation method, bending the bars to their final position. This simulation shows that a faceted shape is found instead of a smooth surface. This deformed shape makes the structure softer under applied gravity load. Two strategies are investigated in this paper to enable the construction of gridshells with singularities. The first consists in extending the bars close to the singularities edge-lines to have a smoother gridshell after the erection process. The second strategy applies post-tension cables to the patches to increase the local curvature in the faceted zones. Both strategies increase the stiffness and buckling load of the final structure.

References listed at the end of the paper:
loads through tension only. Once a formfound geometry is set, structural analysis needs to assess the structure’s
disciplines. Formfinding is performed in order to find a geometry that all

ABSTRACT:

Journal of the International Association for Shell and Spatial Structures


O. Baverel, C. Douthe and JF. Caron, “Nexorade: a structure for ‘free form’ architecture”, in International Conference on

ABSTRACT: The talent, knowledge and approaches of the structural designer Laurent Ney (1964–present) are increasingly recognized by engineering, architecture and construction awards. Most of the writing on his work has focused on his design philosophy or on individual projects. The aim of this paper is threefold: 1) to provide a social, historic and geological context for his work, 2) to showcase how he masters digital and numerical shape finding and optimization approaches to inform his design and construction decisions and 3) to illustrate how his works revive underutilized public spaces and augment people’s happiness and well-being. The three chosen case studies are all large-span steel structures: one beam bridge (Centner) and two shell structures (steel/glass gridshell over the courtyard of the Dutch Maritime Museum and the hanging steel shell of the Knokke Lichtenlijn footbridge). The scholarship presented in this paper forms the basis for one of the contemporary lectures of CEE262 "Structures and the Urban Environment," a course first taught by Prof. Billington in 1974 at Princeton University.

ABSTRACT: Max Borges Jr. (1918 – 2009) was an architect of thin shell concrete structures in Cuba in the 1950's. During this time, Félix Candela (1910 – 1997) owned a construction company that was dedicated to the design and construction of thin shells. Candela also owned an international reputation as a designer of thin shells in the hyperbolic paraboloid (hypar) form. The two men worked together for the first time on a project in Mexico City in 1954, and since then collaborated on several more, most of them in Cuba. This paper illustrates the architect – engineer relationship between Borges and Candela and documents the collaborative projects between them. The research grew out of a course co-taught by the authors, where the course was inspired by the style of teaching of David Billington (1927 – 2018) that integrates engineering with the humanities. Billington believed in scholarship based on historical studies and documentation of heritage structures. This paper is in tribute to this great man who continues to inspire.

ABSTRACT: Qualitative and quantitative characteristics of geometrical and mechanical changes of nominally plane steel sheets folded in one direction, caused by big elastic shape transformations were invented on the basis of the authors' tests, analyzes and computational models of thin-walled folded sheets transformed into shell shapes. Both geometrical and mechanical changes produce significant restrictions in using sheets for shell forms. The deliberate transformations and sheets' characteristics are required to obtain attractive and innovative forms of roof shells and their consistent structures as well as entire buildings. The search for effective solutions related to free forms of buildings and shape transformations of sheets especially in the fields of: shape transformation, effort and stabilization of their walls is necessary due to the high sensitivity of thin-walled open profiles to boundary conditions and loads. A method for shaping such free form buildings that effectively exploit specific orthotropic properties of the transformed sheeting is presented.
ABSTRACT: The article describes a new construction system for shell structures made from door- and window cut-offs resulting from cross laminated timber (CLT) production lines. For the first time, form-fitting fasteners made of beech laminated veneer lumber are used in a shell made of engineered wood plates, enabling a particularly simple, fast and precise construction. The efficient planning and production of a multitude of differently shaped elements is made possible by a CAD plug-in developed by the authors. The article presents the general application possibilities and limitations of the system, as well as the case study of a shell demonstrator with a span of 12 meters, built from 229 hexagonal plates. A detailed structural analysis is presented for the demonstrator, including an experimental load test to confirm the FEM results.

ABSTRACT: This paper investigates the seismic response characteristics of long-span domes. The natural periods of the prominent modes are longer than medium-span domes, which leads to a greater contribution from the higher modes to the response of the long-span dome. The acceleration distributions, particularly the vertical acceleration distributions are sensitive to the dominant mode shapes of these higher modes. This leads to inaccuracies when applying the previously proposed response evaluation methods. The vibration modes of multi-storey supporting substructures also affect the excited vibration modes of the roof. In this paper, the dynamic characteristics and seismic response of 150m-span domes supported by multi-storey substructures are studied. The effects of the post- yield stiffness of multi-storey substructures are also analysed by considering two structural systems, buckling- restrained braced frames (BRBF) and damped spine frames. A simple design procedure to evaluate the equivalent static loads using amplification factors and incorporating the effects of higher modes is proposed based on response spectrum analysis and equivalent linearrisation procedures. The accuracy of the proposed method is evaluated by comparing the responses with those obtained from non-linear response history analysis.

ABSTRACT: Deployable bar structures on a rectangular base present the problems of closing the ends and longitudinal stabilization. Some proposals have been made to resolve them, mainly by creating mouths, but their application to composite geometries is problematic. On-the-bias deployable structures adequately solve both problems as they are supported around their entire perimeter, have a strong three-dimensional operation and only use load-bearing bars. The text analyses this type of deployable structures, their requirements and possibilities.
A study on the combination of polar and translational units in a single deployable structure is then carried out, focusing on the study of on-the-bias deployable structures with perimeter polar modules that allow the effective height of the designs to be increased. Finally, the architectural possibilities of the system are studied, which make it possible to resolve overhangs, vertical openings in the roof, and T- or L-shaped ground plans, guaranteeing the modularity of the system.

ABSTRACT: The paper presents a complete study of the work done by Pier Luigi Nervi for the design and construction of a series of concrete hangars between 1935 and 1940. This research is enclosed in the framework of the exhibition entitled "Pier Luigi Nervi, il modello come strumento di progetto e costruzione" that gathers researches from Università degli Studi di Bologna, Università di Roma Tor Vergata and Politecnico di Milano.
The exhibition was used as a starting point for a general discussion about the meaning of the logical passage that leads engineers and architects from physical scaled models to numerical structural models. The Politecnico di Milano contributed to re-writing the first experiences of Pier Luigi Nervi and Arturo Danusso in the structural modeling. Scaled models, nowadays substituted by finite element methods, were widely used in the past, for the understanding of the structural behavior of complex structures. Unfortunately, many of these masterpieces have been destroyed during the years (as happened to the two original models tested by Pier Luigi Nervi and reproduced for the exhibition). In the last part of the paper, based on numerical results, the structural behavior of these hangars is deeply discussed, underlining all the principal strengths and weaknesses of these complex structures.


ABSTRACT: To ensure unloading of the whole amount of stored product by gravity, the steel silos are often placed on supporting frame structure. The values of stresses in the joints between the thin shell and supporting frame elements are extremely high. It can cause local loss of stability in the shell. To prevent it, many designers place stiffening elements above the supports. Here the question is how high should be the stiffening elements? The appropriate solution is that they should rise to that level till which the values of meridional normal stresses above the supports and in the middle between them are equalized. But where is this level? Many researchers worked on values and ways of distribution of normal meridional stresses above the supports of the cylindrical shells. As a result of their efforts are determined critical height $H_c$ of the shell and the ideal position $H_i$ of intermediate stiffening ring. But these heights are considerably different between each other. To which of them our vertical stiffening elements should achieve? Considering the nonlinear behaviour of the steel, the effects of changes in geometry during loading and imperfections caused by welding works, the author tried to obtain an answer to this question.


ABSTRACT: The load factor is one of the keys in anti-buckling design for safety together for construction cost, and studies have been becoming demanded in a recent situation that super large and super light spatial structures have been constructed. This paper investigates the relationship between reliability index $\beta$ and snow load factor $\gamma$ for anti-buckling design of a simply supported cylindrical lattice shell roof under simultaneous action of both dead load and asymmetric snow load. The cylindrical lattice shell analyzed is composed of an equilateral triangle grid of which members are of steel circular hollow sections. Members are connected rigidly to nodes at their both ends. The snow distribution as a main target is assumed in a way that the snow depth on the half of the arch-like roof is half of the amount on the other half roof. The snow fall depth is here assumed 50cm evaluated as 100-year return period, and its probability is assumed as Gumbel distribution with 100-year reference period. The probability distribution of buckling strength $P_c$ including geometrical and material nonlinearities is approximately evaluated based on a first-order perturbation. The reliability is calculated based on AFOSM, and the relationship in a form of $\beta$ to $\gamma$ is finally expressed for design use.


ABSTRACT: Closed-form equations for determination of reactions and internal forces of linear-elastic symmetric arches with constant cross-sections are derived. The derivation of the equations was initially made for segmental, three-hinged, two-hinged, and hingeless arches. Not all derived equations are simple, but still not excessively complex to apply, and they reveal several new insights into the structural behavior of arches. The first is an extremely simple approximate equation for horizontal reactions of a hingeless arch under self-weight, which could be also applied with excellent accuracy to catenary and parabolic arches, and with a desirable level of accuracy to two- and three-hinged arches with a relatively wide range of geometries. The second insight is an
approximately linear relationship between reactions and between internal forces of arches with different structural systems, which helps understand the global structural behavior of arches in a new way and enables inference of some other insights presented in the paper. The third insight reflects the relationships between normal force distribution and its eccentricity in different types of arches. Finally, the fourth insight regards the comparison of behavior of arches under the self-weight with those loaded with uniformly distributed load along their span.

Journal of the International Association for Shell and Spatial Structures, Vol. 61, No. 3, pp 211-226(14) 3 September n. 4, 2020,


ABSTRACT: Measuring guided wave propagation in long bones is of interest to the medical community. When an inclination exists between the probe and the tested specimen surface, a bias is introduced on the guided mode wavenumbers. The aim of this study was to generalize the bidirectional axial transmission technique initially developed for the first arriving signal. Validation tests were performed on academic materials such a bone-mimicking plate covered with either a silicon or fat-mimicking layer. For any inclination, the wavenumbers measured with the probe parallel to the waveguide surface can be obtained by averaging the wavenumbers measured in two opposite directions.

ABSTRACT: The far-field radiation originating from a finite-length pipe is well studied, especially for steady-state conditions. However, because all physical systems do not begin in steady state, these radiation characteristics are only valid after the transient portion of the solution has decayed. Understanding transient radiation characteristics may be important (particularly for systems transmitting very short-duration signals), as they can differ quite significantly. A numerical complication to this problem involves dealing with a sharp corner in the domain of interest. While many numerical studies have attempted to couple solutions from the domains inside and outside a pipe, the analysis presented in this work treats the computational domain as a single region by expressing the entire physical domain as a map from a simple rectangular domain in generalized curvilinear coordinates. This method will be introduced in detail and general results of transient radiation will be presented for an infinitely baffled, finite-length pipe using the finite-difference method expressed in generalized curvilinear coordinates. Comparison will be made to previous results [P. Stepanishen and R. A. Tougas, J. Acoust. Soc. Am. 93, 3074–3084 (1993)] that used a semi-analytic approach with certain assumptions.

ABSTRACT: An explicit expression for the group velocity of wave packets, propagating in a laminate anisotropic composite plate in prescribed directions, is proposed. It is based on the cylindrical guided wave asymptotics derived from the path integral representation for wave fields generated in the composites by given localized sources. The expression derived is theoretically confirmed by the comparison with a known representation for the group velocity vector of a plane guided wave. Then it is experimentally validated against

ABSTRACT: Deep back cavities are usually required for micro-perforated panel (MPP) constructions to achieve good low frequency absorption. To overcome the problem, a close-box loudspeaker with a shunted circuit is proposed to substitute the back wall of the cavity of the MPP constructions to constitute a composite absorber. Based on the equivalent circuit model, the acoustic impedance of the shunted loudspeaker is formulated first, then a prediction model of the sound absorption of the MPP backed by shunted loudspeaker is developed by employing the mode solution of a finite size MPP coupled by an air cavity with an impedance back wall. The MPP absorbs mid to high frequency sound, and with properly adjusted electrical parameters of its shunted circuit, the shunted loudspeaker absorbs low frequency sound, so the composite absorber provides a compact solution to broadband sound control. Numerical simulations and experiments are carried out to validate the model.

Andrea Colombi, Lapo Boschi, Philippe Roux and Michel Campillo, “Green's function retrieval through cross-correlations in a two-dimensional complex reverberating medium”, The Journal of the Acoustical Society of America 135 (3), 1034 (March 2014); https://doi.org/10.1121/1.4864485

ABSTRACT: Cross-correlations of ambient noise averaged at two receivers lead to the reconstruction of the two-point Green's function, provided that the wave-field is uniform azimuthally, and also temporally and spatially uncorrelated. This condition depends on the spatial distribution of the sources and the presence of heterogeneities that act as uncorrelated secondary sources. This study aims to evaluate the relative contributions of source distribution and medium complexity in the two-point cross-correlations by means of numerical simulations and laboratory experiments in a finite-size reverberant two-dimensional (2D) plate. The experiments show that the fit between the cross-correlation and the 2D Green's function depends strongly on the nature of the source used to excite the plate. A turbulent air-jet produces a spatially uncorrelated acoustic field that rapidly builds up the Green's function. On the other hand, extracting the Green's function from cross-correlations of point-like sources requires more realizations and long recordings to balance the effect of the most energetic first arrivals. When the Green's function involves other arrivals than the direct wave, numerical simulations confirm the better Green's function reconstruction with a spatially uniform source distribution than the typical contour-like source distribution surrounding the receivers that systematically gives rise to spurious phases.

Christopher Bergevin and Elizabeth S. Olson, “External and middle ear sound pressure distribution and acoustic coupling to the tympanic membrane”, The Journal of the Acoustical Society of America 135(3), 1294 (March 2014); https://doi.org/10.1121/1.4864475

ABSTRACT: Sound energy is conveyed to the inner ear by the diaphanous, cone-shaped tympanic membrane (TM). The TM moves in a complex manner and transmits sound signals to the inner ear with high fidelity, pressure gain, and a short delay. Miniaturized sensors allowing high spatial resolution in small spaces and sensitivity to high frequencies were used to explore how pressure drives the TM. Salient findings are: (1) A substantial pressure drop exists across the TM, and varies in frequency from about 10 to 30 dB. It thus appears reasonable to approximate the drive to the TM as being defined solely by the pressure in the ear canal (EC) close to the TM. (2) Within the middle ear cavity (MEC), spatial variations in sound pressure could vary by more than 20 dB, and the MEC pressure at certain locations/frequencies was as large as in the EC. (3) Spatial variations in pressure along the TM surface on the EC-side were typically less than 5 dB up to 50 kHz. Larger surface variations were observed on the MEC-side.

Dayi Ou and Cheuk Ming Mak, “Minimizing the transient vibroacoustic response of a window to sonic booms by using stiffeners”, The Journal of the Acoustical Society of America 135(4), 1672 (April 2014); https://doi.org/10.1121/1.4867366

ABSTRACT: A stiffened-window strategy is proposed for reducing the window's transient responses to sonic booms. Additional movable and controllable stiffeners are used, which can improve the window's transient
vibration and noise isolation performance without significantly reducing transparency. A simple prediction model is proposed as a design tool for implementing the stiffened-window structure, which allows for the computation of a plate with arbitrary elastic boundary conditions and arbitrarily located stiffeners. The predicted results agree well with experimental data. Also, the feasibility and validity of the stiffened-window strategy for improving the window’s performance in response to sonic booms is demonstrated by parametric studies.

Pei Li, Shanshan Yao, Xiaoming Zhou, Guoliang Huang and Gengkai Hu, “Effective medium theory of thin-plate acoustic metamaterials”, The Journal of the Acoustical Society of America 135(4), 1844 (April 2014); https://doi.org/10.1121/1.4868400

ABSTRACT: Effective dynamic properties of acoustic metamaterials made of multilayered flexible thin-plates with periodically attached mass-spring resonators are studied. By using the transfer matrix method, the thin-plate acoustic metamaterial under the plane wave incidence is characterized by a homogeneous effective medium with anisotropic mass density. An approximate analytic expression of effective mass density is derived for a single-layer metamaterial in the normally incident case, and it is shown that the effective mass density can follow either Lorentz or Drude medium models. For the obliquely incident case, it is found that effective mass density is dependent on the lateral wave number of incident waves. Such spatial dispersion comes from the coincidence effect between the incident acoustic wave and flexural wave in the thin plate, and it occurs at much lower frequencies than that for a uniform plate without resonators. Based on the observed spatial dispersion, an acoustic device made of thin-plate metamaterials is designed for frequency-controlled acoustic directive radiation in the low-frequency regime.


ABSTRACT: A theoretical model built upon three-dimensional elasticity theory is developed to investigate the acoustic radiation from multilayered anisotropic plates subjected to a harmonic point force excitation. Fourier transform technique and stationary phase method are combined to predict the far-field radiated sound pressure of one-side water immersed plate. Compared to equivalent single-layer plate models, the present model based on elasticity theory can differentiate radiated sound pressure between dry-side and wet-side excited cases, as well as discrepancies induced by different layer sequences for multilayered anisotropic plates. These results highlight the superiority of the present theoretical model especially for handling multilayered anisotropic structures.

References listed at the end of the paper:


References listed at the end of the paper:
Thomas Lehrmann Christiansen, Ole Hansen, Erik Vilain Thomsen and Jørgen Arendt Jensen, “Modal radiation patterns of baffled circular plates and membranes”, The Journal of the Acoustical Society of America 135(5), 2523 (May 2014); https://doi.org/10.1121/1.4869688

ABSTRACT: The far field velocity potential and radiation pattern of baffled circular plates and membranes are found analytically using the full set of modal velocity profiles derived from the corresponding equation of motion. The derivation is valid for a plate or membrane subjected to an external excitation force, which is used as a sound receiver in any medium or as a sound transmitter in a gaseous medium. A general, concise expression is given for the radiation pattern of any mode of the membrane and the plate with arbitrary boundary conditions. Specific solutions are given for the four special cases of a plate with clamped, simply supported, and free edge boundary conditions as well as for the membrane. For all non-axisymmetric modes, the velocity potential along the axis of the radiator is found to be strictly zero. In the long wavelength limit, the radiation pattern of all axisymmetric modes approaches that of a monopole, while the non-axisymmetric modes exhibit multipole behavior. Numerical results are also given, demonstrating the implications of having non-axisymmetric excitation using both a point excitation with varying eccentricity and a homogeneous excitation acting on half of the circular radiator.


ABSTRACT: A model describing the sound propagation between two infinite adsorbing plates is proposed in order to investigate the extension to the audible sound range of the Frequency Response method applied to the measurement of diffusion in micropores. The model relates adsorption parameters (i.e., diffusivity and equilibrium constant) to an acoustic quantity (i.e., propagation constant). The equations describing sound propagation in the presence of adsorbing boundaries are obtained on the basis of the classical Kirchhoff theory [(1868), Ann. Phys. (Leipzig) 134, 177–193]. The solution is derived using the Low Reduced Frequency Approximation method [Tijdeman, (1975). J. Sound Vib. 39, 1–33].


ABSTRACT: In the present work, the interaction of Rayleigh waves with a delamination in a fiber reinforced composite plate was analyzed. Rayleigh waves, upon interacting with delamination mode, convert into Lamb waves in the delamination zone. These guided Lamb modes have the capability to mode convert back into Rayleigh modes when they interact with the edge of the delamination. A unidirectional glass/epoxy laminate with a delamination of known size was fabricated and tested using air-coupled ultrasonics. Finite element models were developed to understand the mode conversions occurring at various sections of the delamination. Particle displacements along with numerical and experimental velocities were considered to identify each mode. Conclusions were drawn based on the velocity analysis.

Qian Geng, Huan Li and Yueming Li, “Dynamic and acoustic response of a clamped rectangular plate in thermal environments: Experiment and numerical simulation”, The Journal of the Acoustical Society of America 135(5), 2674 (May 2014); https://doi.org/10.1121/1.4870483

ABSTRACT: Experiments were performed to investigate the vibration and acoustic response characteristics of a clamped rectangular aluminum plate in thermal environments. Modal tests were carried out to study the influence of thermal environment on natural vibration. With the increment of structural temperature, natural frequencies of the plate decrease obviously. Mode shape interchange was observed for the modes with frequencies very close to each other. The thermally induced softening effect has unequal influences on the plate
along the two in-plane directions. Numerical methods were also employed to study the experimental phenomena. Calculated results indicated that the initial deflection has a great influence on the natural vibration of the heated plate. Even a slight curvature can reduce the thermally induced softening effect obviously. Dynamic response tests were carried out under acoustic and mechanical excitations, and the measured results indicate that the variation in damping determines the response amplitudes at resonant peaks in the test.


ABSTRACT: Wave propagation in sandwich panels with a poroelastic core, which is modeled by Biot's theory, is investigated using the waveguide finite element method. A waveguide poroelastic element is developed based on a displacement-pressure weak form. The dispersion curves of the sandwich panel are first identified as propagating or evanescent waves by varying the damping in the panel, and wave characteristics are analyzed by examining their motions. The energy distributions are calculated to identify the dominant motions. Simplified analytical models are also devised to show the main physics of the corresponding waves. This wave propagation analysis provides insight into the vibro-acoustic behavior of sandwich panels lined with elastic porous materials.


ABSTRACT: A model for the acoustic properties of a plate perforated with slots of rectangular shape is proposed. The model is based on known expressions for the complex density and compressibility of a pore of rectangular shape together with the radiation impedance of a rectangular shaped piston in a baffle. For the so-called end correction of a rectangular aperture in a plate, an approximate solution is shown to fit an exact solution for the imaginary part of the radiation impedance, the latter solution based on the work of Lindemann [J. Acoust. Soc. Am, 55, 708–717 (1974)]. Two different procedures are tested to calculate the mutual influence of the apertures on the end correction, the one calculating the mutual impedance of neighboring pistons in the plate, the other by calculating the end correction of a piston placed in the end of an infinitely long tube. The model is used calculating the input impedance and absorption coefficient of a Helmholtz resonator with such a plate, comparing with measurement results. The fit between predicted and measured results, using plates with narrow slits, is good, but it is believed that the model also cover a wider range of dimensions for such a slotted plate.

Robiel Martinez Corredor, Juan E. Santos, Patricia M. Gauzellino and José M. Carcione, “Reflection and transmission coefficients of a single layer in poroelastic media”, The Journal of the Acoustical Society of America 135(6), 3151 (June 2014); https://doi.org/10.1121/1.4875713

ABSTRACT: Wave propagation in poroelastic media is a subject that finds applications in many fields of research, from geophysics of the solid Earth to material science. In geophysics, seismic methods are based on the reflection and transmission of waves at interfaces or layers. It is a relevant canonical problem, which has not been solved in explicit form, i.e., the wave response of a single layer, involving three dissimilar media, where the properties of the media are described by Biot's theory. The displacement fields are recast in terms of potentials and the boundary conditions at the two interfaces impose continuity of the solid and fluid displacements, normal and shear stresses, and fluid pressure. The existence of critical angles is discussed. The results are verified by taking proper limits—zero and 100% porosity—by comparison to the canonical solutions corresponding to single-phase solid (elastic) media and fluid media, respectively, and the case where the layer thickness is zero, representing an interface separating two poroelastic half-spaces. As examples, it was calculated the reflection and transmission coefficients for plane wave incident at a highly permeable and compliant fluid-saturated porous layer, and the case where the media are saturated with the same fluid.


ABSTRACT: Coupled wavenumbers in infinite fluid-filled isotropic and orthotropic cylindrical shells are considered. Using the Donnell-Mushtari (DM) theory for thin shells, compact and elegant asymptotic
expansions for the wavenumbers are found at an intermediate fluid loading for both the coupled rigid-duct modes (“fluid-originated”) and the coupled structural wavenumbers (“structure-originated modes”) over the entire frequency range where DM theory is valid. The coupled rigid-duct expansions are found to be valid for \( \theta(1) \) orthotropy and for all circumferential orders, whereas the coupled structural wavenumber expansions are valid for small orthotropy and for low circumferential orders. These two above results are then used to derive the expansions for a set of multiple complex roots that display a locking behavior at this intermediate fluid-loading. The expansions are matched with the numerical solutions of the coupled dispersion relation and the match is found to be good over most of the frequency range.

Olivier Robin, Alain Berry and Stéphane Moreau, “Experimental vibroacoustic testing of plane panels using synthesized random pressure fields”, The Journal of the Acoustical Society of America 135(6), 3434 (June 2014); https://doi.org/10.1121/1.4872298
ABSTRACT: The experimental reproduction of random pressure fields on a plane panel and corresponding induced vibrations is studied. An open-loop reproduction strategy is proposed that uses the synthetic array concept, for which a small array element is moved to create a large array by post-processing. Three possible approaches are suggested to define the complex amplitudes to be imposed to the reproduction sources distributed on a virtual plane facing the panel to be tested. Using a single acoustic monopole, a scanning laser vibrometer and a baffled simply supported aluminum panel, experimental vibroacoustic indicators such as the Transmission Loss for Diffuse Acoustic Field, high-speed subsonic and supersonic Turbulent Boundary Layer excitation are obtained. Comparisons with simulation results obtained using a commercial software show that the Transmission Loss estimation is possible under both excitations. Moreover and as a complement to frequency domain indicators, the vibroacoustic behavior of the panel can be studied in the wave number domain.

ABSTRACT: Understanding the physics governing the interaction of sound with targets in an underwater environment is essential to improving existing target detection and classification algorithms. To illustrate techniques for identifying the key physics, an examination is made of the acoustic scattering from a water-filled cylindrical shell. Experiments were conducted that measured the acoustic scattering from a water-filled cylindrical shell in the free field, as well as proud on a sand-water interface. Two modeling techniques are employed to examine these acoustic scattering measurements. The first is a hybrid 2-D/3-D finite element (FE) model, whereby the scattering in close proximity to the target is handled via a 2-D axisymmetric FE model, and the subsequent 3-D propagation to the far field is determined via a Helmholtz integral. This model is characterized by the decomposition of the fluid pressure and its derivative in a series of azimuthal Fourier modes. The second is an analytical solution for an infinitely long cylindrical shell, coupled with a simple approximation that converts the results to an analogous finite length form function. Examining these model results on a mode-by-mode basis offers easy visualization of the mode dynamics and helps distinguish the different physics driving the target response.

ABSTRACT: Ultrasonic guided waves are very useful for structural health monitoring. They have the potential to interrogate and detect damage in a structure over a large area with few transducers. Guided plate modes (Lamb waves) are used and proposed for damage detection at a distance in semi-monococque structures such as airplane fuselages and spacecraft structures. The interaction of guided plate waves with stiffening members such as ribs, stringers, or the integral stiffeners used in spacecraft structures limits the distance over which structural health monitoring non-destructive evaluation systems can detect damage. This paper develops a simple explanatory model for the scattering of low-order ultrasonic Lamb waves crossing a stiffening device. The model illuminates the underlying mechanics of waves crossing a stiffener. The model shows that stopbands for transmission of S0 (longitudinal pressure) waves across a stiffener line up with flexural resonances of
the stiffener. It also demonstrates why transmission of A0 (flexural) waves is more complicated and harder to predict. The model is shown to agree well with both boundary element method calculations and experimental measurements.


ABSTRACT: An ultrasonic evaluation procedure for the interlayer interfacial normal stiffness and the intralayer longitudinal wave velocity of multilayered plate-like structures is proposed. Based on the characteristics of the amplitude reflection spectrum of ultrasonic wave at normal incidence to a layered structure with spring-type interlayer interfaces, it is shown that the interfacial normal stiffness and the longitudinal wave velocity in the layers can be simultaneously evaluated from the frequencies of local maxima and minima of the spectrum provided that all interfaces and layers have the same properties. The effectiveness of the proposed procedure is investigated from the perspective of the sensitivity of local extremal frequencies of the reflection spectrum. The feasibility of the proposed procedure is also investigated when the stiffness of each interface is subjected to small random fluctuations about a certain average value. The proposed procedure is applied to a 16-layered cross-ply carbon-fiber-reinforced composite laminate. The normal stiffness of resin-rich interfaces and the longitudinal wave velocity of plies in the thickness direction evaluated from the experimental reflection spectrum are shown to be consistent with simple theoretical estimations.


ABSTRACT: While the structural-acoustic coupling between flexible structures and closed acoustic cavities has been extensively studied in the literature, the modeling of structures coupled through open cavities, especially connected in cascade, is still a challenging task for most of the existing methods. The possible presence of micro-perforated panels (MPPs) in such systems adds additional difficulties in terms of both modeling and physical understanding. In this study, a sub-structuring methodology based on the Patch Transfer Function (PTF) approach with a Compound Interface treatment technique, referred to as CI-PTF method, is proposed, for dealing with complex systems involving cascade open/closed acoustic cavities and MPPs. The co-existence of apertures and solid/flexible/micro-perforated panels over a mixed separation interface is characterized using a compound panel subsystem, which enhances the systematic coupling feature of the PTF framework. Using several typical configurations, the versatility and efficiency of the proposed method is illustrated. Numerical studies highlight the physical understanding on the behavior of MPP inside a complex vibroacoustic environment, thus providing guidance for the practical design of such systems.


ABSTRACT: Membrane-type acoustic metamaterials (MAMs) have demonstrated unusual capacity in controlling low-frequency sound transmission/reflection. In this paper, an analytical vibroacoustic membrane model is developed to study sound transmission behavior of the MAM under a normal incidence. The MAM is composed of a prestretched elastic membrane with attached rigid masses. To accurately capture finite-dimension rigid mass effects on the membrane deformation, the point matching approach is adopted by applying a set of distributed point forces along the interfacial boundary between masses and the membrane. The accuracy and capability of the theoretical model is verified through the comparison with the finite element method. In particular, microstructure effects such as weight, size, and eccentricity of the attached mass, pretension, and thickness of the membrane on the resulting transmission peak and dip frequencies of the MAM are quantitatively investigated. New peak and dip frequencies are found for the MAM with one and multiple eccentric attached masses. The developed model can be served as an efficient tool for design of such membrane-type metamaterials.
T. Y. Li, Y. Y. Miao, W. B. Ye, X. Zhu and X. M. Zhu, “Far-field sound radiation of a submerged cylindrical shell at finite depth from the free surface”, The Journal of the Acoustical Society of America 136(3), 1054 (September 2014); https://doi.org/10.1121/1.4890638

ABSTRACT: The far-field sound radiation behavior of a circular cylindrical shell submerged at finite depth from the free surface is studied. Based on the Flügge shell theory and the Helmholtz equation, the structure-acoustic coupling equation is established. An image method is applied so that the sound boundary condition of the free surface can be satisfied. Analytical expression of the far-field sound pressure is obtained using the stationary phase method and the Graf's addition theorem. In order to evaluate the effect of the submerged depth on sound radiation, the results of the submerged cylindrical shell at finite depth from the free surface are compared with those of the submerged cylindrical shell in the infinite fluid. The characteristics of the far-field sound pressure with the change of the depth are investigated. It is found that the submerged depth has a significant influence on the far-field sound pressure radiated from the submerged cylindrical shell due to the free surface effects. The work provides more understanding on the sound radiation properties of the submerged circular cylindrical shell without assuming infinite fluid field, which was commonly used in previous studies.

Benjamin Elie, François Gautier and Bertrand David, “Acoustic signature of violins based on bridge transfer mobility measurements”, The Journal of the Acoustical Society of America 136(3), 1385 (September 2014); https://doi.org/10.1121/1.4892762

ABSTRACT: This paper is an attempt to solve two problems related to musical acoustics. The first one consists in defining a signature of an instrument, namely, summarizing its vibroacoustical behavior. The second one deals with the existing relationship between the musical sound and the vibroacoustic properties of the instrument body. The violin is the application of this paper. A proposed solution for the first problem consists in an estimation of the bridge transfer mobility and the mean-value of the lateral bridge transfer mobility. The second problem is studied via the comparison between the amplitudes of harmonics, extracted from a glissando audio signal, and the lateral bridge transfer mobility: Both curves exhibit similar features. This is the main result of the paper. This is evidenced by successfully identifying which violin is played in an audio recording, using the computation of the Pearson distance between the distribution of the amplitude of harmonics and a database of measured mobilities.


ABSTRACT: This Letter deals with an analysis of bending edge waves propagating along the free edge of a Kirchhoff plate supported by a Winkler foundation. The presence of a foundation leads to a non-zero cut-off frequency for this wave, along with a local minimum of the associated phase velocity. This minimum phase velocity corresponds to a critical speed of an edge moving load and is analogous to that in the classical 1D moving load problem for an elastically supported beam.


ABSTRACT: Elastic cylindrical shells are fitted with an internal mechanism which is optimized so that, in the quasi-static regime, the combined system exhibits prescribed effective acoustic properties. The mechanism consists of a central mass supported by an axisymmetric distribution of elastic stiffeners. By appropriate selection of the mass and stiffness of the internal mechanism, the shell's effective acoustic properties (bulk modulus and density) can be tuned as desired. Subsonic flexural waves excited in the shell by the attachment of stiffeners are suppressed by including a sufficiently large number of such stiffeners. The effectiveness of the proposed metamaterial is demonstrated by matching the properties of a thin aluminum shell with a polymer insert to those of water. The scattering cross section in water is nearly zero over a broad range of frequencies at the lower end of the spectrum. By arranging the tuned shells in an array the resulting acoustic metamaterial is capable of steering waves. As an example, a cylindrical-to-plane wave lens is designed by varying the bulk modulus in the array according to the conformal mapping of a unit circle to a square.
Malte Misol, Thomas Haase, Hans Peter Monner and Michael Sinapius, “Causal feedforward control of a stochastically excited fuselage structure with active sidewall panel”, The Journal of the Acoustical Society of America 136(4), 1610 (October 2014); https://doi.org/10.1121/1.4895710

ABSTRACT: This paper provides experimental results of an aircraft-relevant double panel structure mounted in a sound transmission loss facility. The primary structure of the double panel system is excited either by a stochastic point force or by a diffuse sound field synthesized in the reverberation room of the transmission loss facility. The secondary structure, which is connected to the frames of the primary structure, is augmented by actuators and sensors implementing an active feedforward control system. Special emphasis is placed on the causality of the active feedforward control system and its implications on the disturbance rejection at the error sensors. The coherence of the sensor signals is analyzed for the two different disturbance excitations. Experimental results are presented regarding the causality, coherence, and disturbance rejection of the active feedforward control system. Furthermore, the sound transmission loss of the double panel system is evaluated for different configurations of the active system. A principal result of this work is the evidence that it is possible to strongly influence the transmission of stochastic disturbance sources through double panel configurations by means of an active feedforward control system.


ABSTRACT: A finite element model of a bare top plate with braces and a bridge plate was created using orthotropic material properties. The natural variation of the wood properties including dependence on moisture content was also determined. The simulated modes were then compared to experimentally obtained modes from top plate prototypes. Uncertainty analysis was also performed to determine the statistical bound of natural variability between wood samples. The natural frequencies of the model fall within the computed error bound. These results reinforce the importance of obtaining accurate material properties for acoustic guitar modeling.


ABSTRACT: In order to address noise control problems in the design stage, structural-acoustic optimization procedures can be used to find the optimal design for reduced noise or vibration. However, most structural-acoustic optimization procedures are not general enough to include both heavy fluid loading and complex forcing functions. Additionally, it can be difficult to determine and assess trade-offs between weight and sound radiation. A structural-acoustic optimization approach is presented for minimizing the radiated power of structures with heavy fluid loading excited by complex forcing functions. The procedure is demonstrated on a curved underwater panel excited by a point drive and by turbulent boundary layer flow. To facilitate more efficient analysis, an uncorrelated pressure assumption is made for the turbulent boundary layer forcing function. The thicknesses of groups of elements were used as the design variables with an adaptive covariance matrix evolutionary strategy as the search algorithm. The objective function was a weighted sum of total sound power and panel mass and the Pareto front was computed to show the optimum trade-off between the two objectives. The optimal designs are presented which illustrate the best methods for reducing radiated sound and mass simultaneously.


ABSTRACT: A limitation currently facing active structural acoustic control (ASAC) researchers is that an ideal minimization quantity for use in the control algorithms has not been developed. A novel parameter termed the “weighted sum of spatial gradients” (WSSG) was recently developed for use in ASAC and shown to effectively attenuate acoustic radiation from a vibrating flat simply supported plate in computer simulations. This paper extends this research from computer simulations and provides experimental test results. The results presented show that WSSG is a viable control quantity and provides better results than the volume velocity approach. The paper also investigates several of the challenges presented by the use of WSSG. These include determining a method to measure WSSG experimentally, an analysis of the influence of noise on WSSG control results and
complications presented when degenerate modes exist. Results are shown and discussed for several experimental configurations.

Yangyang Chen, Guoliang Huang, Xiaoming Zhou, Gengkai Hu and Chin-Teh Sun, “Analytical coupled vibroacoustic modeling of membrane-type acoustic metamaterials: Plate model”, The Journal of the Acoustical Society of America 136(6), 2926 (December 2014); https://doi.org/10.1121/1.4901706

ABSTRACT: By considering the elastic membrane's dissipation, the membrane-type acoustic metamaterial (MAM) has been demonstrated to be a super absorber for low-frequency sound. In the paper, a theoretical vibroacoustic plate model is developed to reveal the sound energy absorption mechanism within the MAM under a plane normal incidence. Based on the plate model in conjunction with the point matching method, the in-plane strain energy of the membrane due to the resonant and antiresonant motion of the attached masses can be accurately captured by solving the coupled vibroacoustic integrodifferential equation. The sound absorption ability of the MAM is quantitatively determined, which is also in good agreement with the prediction from the finite element method. In particular, microstructure effects including eccentricity of the attached masses, the depth, thickness, and loss factor of the membrane on sound absorption peak values are discussed.


ABSTRACT: Model-based processing is a theoretically sound methodology to address difficult objectives in complex physical problems involving multi-channel sensor measurement systems. It involves the incorporation of analytical models of both physical phenomenology (complex vibrating structures, noisy operating environment, etc.) and the measurement processes (sensor networks and including noise) into the processor to extract the desired information. In this paper, a model-based methodology is developed to accomplish the task of online failure monitoring of a vibrating cylindrical shell externally excited by controlled excitations. A model-based processor is formulated to monitor system performance and detect potential failure conditions. The objective of this paper is to develop a real-time, model-based monitoring scheme for online diagnostics in a representative structural vibrational system based on controlled experimental data.

Jean-Gabriel Minonzio, Josquin Foiret, Petro Moilanen, Jalmari Pirhonen, Zuomin Zhao, Maryline Talmant, Jussi Timonen and Pascal Laugier, “A free plate model can predict guided modes propagating in tubular bone-mimicking phantoms”, The Journal of the Acoustical Society of America 137(1), EL98 (January 2015); https://doi.org/10.1121/1.4903920

ABSTRACT: The goal of this work was to show that a non-absorbing free plate model can predict with a reasonable accuracy guided modes measured in bone-mimicking phantoms that have circular cross-section. Experiments were carried out on uncoated and coated phantoms using a clinical axial transmission setup. Adjustment of the plate model to the experimental data yielded estimates for the waveguide characteristics (thickness, bulk wave velocities). Fair agreement was achieved over a frequency range of 0.4 to 1.6 MHz. A lower accuracy observed for the thinnest bone-mimicking phantoms was caused by limitations in the wave number measurements rather than by the model itself.

Franck Sgard, Noureddine Atalla and Hugues Nélisse, “Prediction of the niche effect for single flat panels with or without attached sound absorbing materials”, The Journal of the Acoustical Society of America 137(1), 117 (January 2015); https://doi.org/10.1121/1.4901713

ABSTRACT: The sound transmission loss (STL) of a test sample measured in sound transmission facilities is affected by the opening in which it is located. This is called the niche effect. This paper uses a modal approach to study the STL of a rectangular plate with or without an attached porous material located inside a box-shaped niche. The porous material is modeled as a limp equivalent fluid. The proposed model is validated by comparison with finite element/boundary element computations. Using a condensation of the pressure fields in the niche, the niche effect is interpreted in terms of a modification of the modal blocked pressure fields acting on the panel induced by the front cavity and by a modification of the radiation efficiency of the panel modes due to the presence of the back cavity. The modal approach is then used to investigate the impact of (1) the presence of a porous material attached to the panel on the niche effect and (2) the niche effect on the assessment
of the porous material insertion loss. A simplified model for the porous material based on a transfer matrix approach is also proposed to predict the STL of the system and its validity is discussed.

ABSTRACT: As the first step toward developing a generic model for the acoustically radiating vibrational modes of the violin and related instruments, the modes of both freely supported and edge-constrained top and back plates have been investigated as functions of shape, arching height, elastic anisotropy, the f-holes and associated island area, thickness graduations, and the additional boundary constraints of the ribs, soundpost, and bass-bar present in the assembled instrument. Comsol shell structure finite element software has been used as a quasi-experimental tool, with physical and geometric properties varied smoothly, often over several orders of magnitude, allowing the development of the plate modes to be followed continuously from those of an initially square plate to those of doubly-arched, guitar-shaped, orthotropic plates and their dependence on all the above factors.

M. Michau, A. Berry, Ph. Micheau and Ph. Herzog, “Optimal virtual mechanical impedances for the vibroacoustic active control of a thin plate”, The Journal of the Acoustical Society of America 137(1), 199 (January 2015); https://doi.org/10.1121/1.4904550
ABSTRACT: In order to reduce the acoustic power radiated by a flexible panel, dual colocated actuator / sensor pairs are used to modify its vibration. The control strategy implemented for harmonic disturbances leads to locally impose a virtual mechanical impedance to the structure, using the linear relation between the actuator input and the control output of each pair. This virtual mechanical impedance is computed in order to minimize the radiated acoustic power. The proposed approach consists in two steps: (1) the matrix of optimal virtual mechanical impedance is calculated by measuring the primary disturbance and the transfer functions between actuators and structural/acoustic sensors and (2) the virtual mechanical impedance objective is achieved using a real-time integral controller. It is shown that such an optimal control approach leads to better sound power reduction than a classical active damping strategy where the virtual mechanical impedance is defined as real positive. Theoretical and experimental results are compared, also showing that the method proposed here is robust regarding variations of the primary disturbance.

ABSTRACT: This paper studies the acoustical properties of hard-backed porous layers with periodically embedded air filled Helmholtz resonators. It is demonstrated that some enhancements in the acoustic absorption coefficient can be achieved in the viscous and inertial regimes at wavelengths much larger than the layer thickness. This enhancement is attributed to the excitation of two specific modes: Helmholtz resonance in the viscous regime and a trapped mode in the inertial regime. The enhancement in the absorption that is attributed to the Helmholtz resonance can be further improved when a small amount of porous material is removed from the resonator necks. In this way the frequency range in which these porous materials exhibit high values of the absorption coefficient can be extended by using Helmholtz resonators with a range of carefully tuned neck lengths.

A. Climente, Andrew N. Norris and José Sánchez-Dehesa, “Scattering of flexural waves from a hole in a thin plate with an internal beam”, The Journal of the Acoustical Society of America 137(1), 293 (January 2015); https://doi.org/10.1121/1.4904551
ABSTRACT: The scattering of flexural waves by a hole in a thin plate traversed by a beam is modeled here by coupling the Kirchhoff–Love and the Euler–Bernoulli theories. A closed form expression is obtained for the transfer matrix (T-matrix) relating the incident wave to the scattered cylindrical waves. For this purpose, a general method has been developed, based on an analogous impedance method for acoustic waves, for calculating the T-matrix for flexural wave scattering problems. The T-matrix for the problem considered displays a simple structure, composed of distinct sub-matrices which decouple the inside and the outside fields.
The conservation of energy principle and numerical comparisons with a commercial finite element simulator have been used to prove the theory.


ABSTRACT: This paper presents the study of non-classical nonlinear response of fiber-reinforced composites. Nonlinear elastic wave methods such as nonlinear resonant ultrasound spectroscopy (NRUS) and nonlinear wave modulation spectroscopy have been used earlier to detect damages in several materials. It was observed that applying these techniques to composites materials becomes difficult due to the significant inherent baseline nonlinearity. Understanding the non-classical nonlinear nature of the composites plays a vital role in implementing nonlinear acoustic techniques for material characterization as well as qualitative nondestructive testing of composites. Since fiber reinforced composites are orthotropic in nature, the baseline response variation with fiber orientation is very important. This work explores the nature of the inherent nonlinearity by performing nonlinear resonant spectroscopy (NRS) in intact unidirectional carbon/epoxy samples with different fiber orientations with respect to major axis of the sample. Factors such as frequency shifts, modal damping ratio, and higher harmonics were analyzed to explore the non-classical nonlinear nature of these materials. Conclusions were drawn based on the experimental observations.


ABSTRACT: A generic physical model for the vibro-acoustic modes of the violin is described treating the body shell as a shallow, thin-walled, guitar-shaped, box structure with doubly arched top and back plates. comsol finite element, shell structure, software is used to identify and understand the vibrational modes of a simply modeled violin. This identifies the relationship between the freely supported plate modes when coupled together by the ribs and the modes of the assembled body shell. Such coupling results in a relatively small number of eigenmodes or component shell modes, of which a single volume-changing breathing mode is shown to be responsible for almost all the sound radiated in the monopole signature mode regime below about 1 kHz for the violin, whether directly or by excitation of the Helmholtz f-hole resonance. The computations describe the influence on such modes of material properties, arching, plate thickness, elastic anisotropy, f-holes cut into the top plate, the bass-bar, coupling to internal air modes, the rigid neck-fingerboard assembly, and, most importantly, the soundpost. Because the shell modes are largely determined by the symmetry of the guitar-shaped body, the model is applicable to all instruments of the violin family.


ABSTRACT: The dispersion relation of the acoustic field in a sub-wavelength slot (its width is smaller than the acoustic wavelength) between two identical plates immersed in an inviscid liquid is theoretically analyzed. Each plate has a phononic crystal structure consisting of periodical grooves drilled in one of outer sides of each plate. It is found that highly localization of acoustic energy can be achieved in the sub-wavelength slot when a traveling acoustic wave is incident upon the slots. The associate physical principle is as follows: The lowest anti-symmetric non-leaky A, mode of the Lamb wave of each individual thin plate propagating as an evanescent wave extends to the liquid from opposite direction; when the width of the slot is much smaller than the characteristic decay length of the evanescent wave in the liquid, the constructive interference of evanescent waves of the both plates takes place, leading to a strong acoustic field in the slot. This system has potential to serve as an excellent candidate for the ultrasensitive microscopic chemical/biological stimulators and sensors.


ABSTRACT: The measurement of stress in a structure presents considerable interest in many fields of engineering. In this paper, the diagnostic potential of nonlinear elastic guided waves in a prestressed plate is investigated. To do so, an analytical model is formulated accounting for different aspects involved in the phenomenon. The fact that the initial strains can be finite is considered using the Green Lagrange strain tensor,
and initial and final configurations are not merged, as it would be assumed in the infinitesimal strain theory. Moreover, an appropriate third-order expression of the strain energy of the hyperelastic body is adopted to account for the material nonlinearities. The model obtained enables to investigate both the linearized case, which gives the variation of phase and group velocity as a function of the initial stress, and the nonlinear case, involving second-harmonic generation as a function of the initial state of stress. The analysis is limited to Rayleigh-Lamb waves propagating in a plate. Three cases of initial prestress are considered, including prestress in the direction of the wave propagation, prestress orthogonal to the direction of wave propagation, and plane isotropic stress.

Raef Cherif and Noureddine Atalla, “Experimental investigation of the accuracy of a vibroacoustic model for sandwich-composite panels”, The Journal of the Acoustical Society of America 137(3), 1541 (March 2015); https://doi.org/10.1121/1.4908239
ABSTRACT: This paper presents a detailed experimental validation of a general laminate model to predict the vibroacoustic behavior of flat sandwich-composite panels. The accuracy of the model is investigated using a thin and a thick sandwich panel over a large frequency band. Several indicators are compared including the structural wavenumber, modal density, damping loss factor, radiation efficiency, and sound transmission loss. The accuracy of a simpler model based on identifying effective properties of an equivalent orthotropic panel from the General Laminate Model is also discussed. Results show that the vibroacoustic behaviors of flat sandwich-composite panels are accurately estimated using the used model and compare well to the equivalent panel model (for total transmission loss). This experimental investigation is generic and can be used as a benchmark to validate other sandwich models.

Xinyi Fu, Zhongkun Jin, Yao Yin and Bilong Liu, “Sound absorption of a rib-stiffened plate covered by anechoic coatings”, The Journal of the Acoustical Society of America 137(3), 1551 (March 2015); https://doi.org/10.1121/1.4913782
ABSTRACT: Underwater vehicles are often equipped with anechoic coatings to absorb the sound waves of active sonar and attenuate the noise emitted from the vessels. Rubber layers with periodically distributed air cavities are widely used as anechoic coatings. In this paper, the sound absorption of anechoic coatings embedded with doubly periodic cavities and backed with periodically rib-stiffened plates is investigated using a finite element method (FEM) with Bloch-periodic boundary conditions. Numerical results given by the FEM are compared with those of a simplified transfer impedance approach to explain the shifting of the main absorption peak. Further a simplified FEM approach, which reduces calculation time significantly and maintains the reasonable accuracy, is proposed for a comparison. The results indicate that the plate and the ribs can have significant impacts on the absorption performance of anechoic coatings, especially at low frequencies.

ABSTRACT: Traditional loudspeaker equalization algorithms cannot decide the order of an equalizer before the whole equalization procedure has been completed. Designers have to try many times before they determine a proper order of the equalization filter. A method which solves this drawback is presented for loudspeaker equalization using balanced model truncation. The order of the equalizer can be easily decided using this algorithm and the error between the model and the loudspeaker can also be readily controlled. Examples are presented and the performance of the proposed method is discussed with comparative experiments.

George Bissinger and Robert Mores, “Model-based auralizations of violin sound trends accompanying plate-bridge tuning or holding”, The Journal of the Acoustical Society of America 137(4), EL293 (April 2015); https://doi.org/10.1121/1.4915062
ABSTRACT: To expose systematic trends in violin sound accompanying “tuning” only the plates or only the bridge, the first structural acoustics-based model auralizations of violin sound were created by passing a bowed-string driving force measured at the bridge of a solid body violin through the dynamic filter (DF) model radiativity profile “filter” \( R_s(f) \) (frequency-dependent pressure per unit driving force, free-free suspension, anechoic chamber). DF model auralizations for the more realistic case of a violin held/played in a reverberant
auditorium reveal that holding the violin greatly diminishes its low frequency response, an effect only weakly compensated for by auditorium reverberation.

Hsin-Yuan Chiang and Yu-Hsi Huang, “Vibration and sound radiation of an electrostatic speaker based on circular diaphragm”, The Journal of the Acoustical Society of America 137(4), 1714 (April 2015); https://doi.org/10.1121/1.4916275

ABSTRACT: This study investigated the lumped parameter method (LPM) and distributed parameter method (DPM) in the measurement of vibration and prediction of sound pressure levels (SPLs) produced by an electrostatic speaker with circular diaphragm. An electrostatic speaker with push-pull configuration was achieved by suspending the circular diaphragm (60 mm diameter) between two transparent conductive plates. The transparent plates included a two-dimensional array of holes to enable the visualization of vibrations and avoid acoustic distortion. LPM was used to measure the displacement amplitude at the center of the diaphragm using a scanning vibrometer with the aim of predicting symmetric modes using Helmholtz equations and SPLs using Rayleigh integral equations. DPM was used to measure the amplitude of displacement across the entire surface of the speaker and predict SPL curves. LPM results show that the prediction of SPL associated with the first three symmetric resonant modes is in good agreement with the results of DPM and acoustic measurement. Below the breakup frequency of 375 Hz, the SPL predicted by LPM and DPM are identical with the results of acoustic measurement. This study provides a rapid, accurate method with which to measure the SPL associated with the first three symmetric modes using semi-analytic LPM.


ABSTRACT: Parametric array (PA) loudspeakers generate directional audible sound via the PA effect, which can make private listening possible. The practical applications of PA loudspeakers include information technology devices that require large power efficiency transducers with a wide frequency bandwidth. Piezoelectric micromachined ultrasonic transducers (PMUTs) are compact and efficient units for PA sources [Je, Lee, and Moon, Ultrasonics 53, 1124–1134 (2013)]. This study investigated the use of an array of PMUTs to make a PA loudspeaker with high power efficiency and wide bandwidth. The achievable maximum radiation bandwidth of the driver was calculated, and an array of PMUTs with two distinct resonance frequencies ($f_1 = 100$ kHz, $f_2 = 110$ kHz) was designed. Out-of-phase driving was used with the dual-resonance transducer array to increase the bandwidth. The fabricated PMUT array exhibited an efficiency of up to 71%, together with a ±3-dB bandwidth of 17 kHz for directly radiated primary waves, and 19.5 kHz (500 Hz to 20 kHz) for the difference frequency waves (with equalization).

Andrea Colombi, Philippe Roux, Sebastien Guenneau and Matthieu Rupin, “Directional cloaking of flexural waves in a plate with a locally resonant metamaterial”, The Journal of the Acoustical Society of America 137(4), 1783 (April 2015); https://doi.org/10.1121/1.4915004

ABSTRACT: This paper deals with the numerical design of a directional invisibility cloak for backward scattered elastic waves propagating in a thin plate (A, Lamb waves). The directional cloak is based on a set of resonating beams that are attached perpendicular to the plate and are arranged at a sub-wavelength scale in ten concentric rings. The exotic effective properties of this locally resonant metamaterial ensure coexistence of bandgaps and directional cloaking for certain beam configurations over a large frequency band. The best directional cloaking was obtained when the resonators’ length decreases from the central to the outermost ring. In this case, flexural waves experience a vanishing index of refraction when they cross the outer layers, leading to a frequency bandgap that protects the central part of the cloak. Numerical simulation shows that there is no back-scattering in these configurations. These results might have applications in the design of seismic-wave protection devices.
Yanni Zhang and Jie Pan, “Underwater sound radiation from an elastically coated plate with an embedded and distributed inhomogeneity”, The Journal of the Acoustical Society of America 137(5), 2915 (May 2015); https://doi.org/10.1121/1.4916595

ABSTRACT: This paper studies the effects of an embedded and distributed inhomogeneity on the underwater sound radiation from an elastically coated plate. Embedding a signal conditioning plate (SCP) in the coating material provides an extra parameter for controlling the sound radiation of the plate, as compared with the previous design with an SCP on the coating surface [Y. Zhang and J. Pan, J. Acoust. Soc. Am. 133(1), 173–185 (2013)]. For such a configuration, the vibration and sound responses of the coated plate to a point force excitation are described by three coupled Fredholm integral equations of the second kind. Its acoustical properties are examined by comparing the radiation powers from plates without an SCP, with a surface SCP, and with an embedded SCP. The differences in the sound powers are explained through resonance and scattering caused by the interaction of the embedded SCP with structural waves. The effects of the depth of the embedded SCP in the coating material on the sound radiation properties of the plate are discussed in detail.


ABSTRACT: An analytical model of axisymmetric vibrations of hollow elastic circular cylinders with arbitrary boundary conditions is presented. Free vibrations of cylinders with free or fixed boundaries and forced vibrations of cylinders with specified non-uniform displacement or stress on the boundaries are considered. Three series solutions are used and each term in each series is an exact solution to the exact governing equations of motion. The terms in the expressions for components of displacement and stress are products of Bessel and sinusoidal functions and are orthogonal to each other. Complete sets of functions in the radial and axial directions are formed by terms in the first series and the other two, respectively. It is therefore possible to satisfy arbitrary boundary conditions. It is shown that just two terms in each series are sufficient to determine several resonance frequencies of cylinders with certain specified boundary conditions. The error is less than 1%. Numerical results are also presented for forced vibration of hollow steel cylinders of length 10 mm and outer diameter 10 mm with specified normal displacement or stress. Excellent agreement with finite element results is obtained at all frequencies up to 1 MHz. Convergence of the series is also discussed.


ABSTRACT: Accurate prediction of the acoustics of fluid-structure interaction is important in devising quieting designs for engineering systems equipped with extensive flow duct networks where the thin duct wall panels are in contact with the flowing fluid. The flow unsteadiness generates acoustic waves that propagate back to the source region to modify the flow process generating them. Meanwhile the unsteady flow pressure excites the thin panels to vibrate, which in turn modifies the flow processes. Evidently a strong coupling between the fluid aeroacoustics and the panel structural dynamics exists. Such coupled physical processes have to be thoroughly understood; otherwise, effective quieting design is never achieved. This paper reports an analysis, using a time-domain numerical methodology the authors have recently developed, of the nonlinear aeroacoustic-structural interaction experienced by a flexible panel in a duct carrying a uniform mean flow. With no mean flow, the numerical results agree well with existing theories and reveal the physics of duct transmission loss. Four regimes of aeroacoustic-structural interaction are identified when the duct flow velocity increases from low subsonic to low supersonic values. Insight in the underlying physics of duct transmission loss at different velocities are highlighted and discussed.


ABSTRACT: Previous work has demonstrated that structural vibrations of brass wind instruments can audibly affect the radiated sound. Furthermore, these broadband effects are not explainable by assuming perfect coincidence of the frequency of elliptical structural modes with air column resonances. In this work a mechanism is proposed that has the potential to explain the broadband influences of structural vibrations on
acoustical characteristics such as input impedance, transfer function, and radiated sound. The proposed mechanism involves the coupling of axial bell vibrations to the internal air column. The acoustical effects of such axial bell vibrations have been studied by extending an existing transmission line model to include the effects of a parasitic flow into vibrating walls, as well as distributed sound pressure sources due to periodic volume fluctuations in a duct with oscillating boundaries. The magnitude of these influences in typical trumpet bells, as well as in a complete instrument with an unbraced loop, has been studied theoretically. The model results in predictions of input impedance and acoustical transfer function differences that are approximately 1 dB for straight instruments and significantly higher when coiled tubes are involved or when very thin brass is used.

Roson Kumar Pattanayak, Prabhakaran Manogharan, Krishnan Balasubramaniam and Prabhu Rajagopal, “Low frequency axisymmetric longitudinal guided waves in eccentric annular cylinders”, The Journal of the Acoustical Society of America 137(6), 3253 (June 2015); https://doi.org/10.1121/1.4921269

ABSTRACT: This paper studies the effect of axially uniform eccentricity on the modal structures and velocities of the lower order axisymmetric guided wave mode L(0,2) in circular tubes or pipes. The semi-analytical finite element method is mainly used, supported by fully three-dimensional finite element models and validated using experiments. The studies show that even a small eccentricity in the pipe can cause a loss in the L(0,2) mode axisymmetry, leading to its confinement in the thinned side of the pipe cross-section and also a reduction in mode velocities. The physics of this phenomenon is related to the feature-guiding and mode confinement effects noted in recent years in the literature, particularly studies on waveguides with local cross-section variations and curvature.

Renata Sisto, Arturo Moleti and Alessandro Altoè, “Decoupling the level dependence of the basilar membrane gain and phase in nonlinear cochlea models”, The Journal of the Acoustical Society of America 138(2), EL155 (August 2015); https://doi.org/10.1121/1.4928291

ABSTRACT: In animal experiments, the strong dependence on stimulus level of the basilar membrane gain and tuning is not matched by a corresponding change in the phase slope in the resonant region. Linear models, in which the gain dependence on the stimulus level has to be schematized by explicitly changing the tuning parameters of the resonant model, do not easily match this feature of the experimental data. Nonlinear models predict a phase slope that is relatively decoupled from tuning. In addition, delayed-stiffness and feed-forward models also show a significant intrinsic decoupling between gain and tuning, which helps in matching the experimental data.

References listed at the end of the paper:


ABSTRACT: It has recently been proposed that the effects of structural vibrations on the radiated sound of brass wind instruments may be attributable to axial modes of vibration with mode shapes that contain no radial nodes [Kausel, Chatziioannou, Moore, Gorman, and Rokni, J. Acoust. Soc. Am. 137, 3149–3162 (2015)]. Results of experiments are reported that support this theory. Mechanical measurements of a trumpet bell demonstrate that these axial modes do exist in brass wind instruments. The quality factor of the mechanical resonances can be on the order of 10 or less, making them broad enough to encompass the frequency range of previously reported effects attributed to bell vibrations. Measurements of the input impedance show that damping bell vibrations can result in impedance changes of up to 5%, in agreement with theory. Measurements of the acoustic transfer function demonstrate that the axial vibrations couple to the internal sound field as proposed, resulting in changes in the transfer function of approximately 1 dB. In agreement with theory, a change in the sign of the effect is observed at the frequency of the structural resonance.

George Zweig, “Linear cochlear mechanics”, The Journal of the Acoustical Society of America 138(2), 1102 (August 2015); https://doi.org/10.1121/1.4922326

ABSTRACT: An active, three-dimensional, short-wavelength model of cochlear mechanics is derived from an older, one-dimensional, long-wavelength model containing time-delay forces. Remarkably, the long-wavelength model with nonlocal temporal interactions behaves like a short-wavelength model with instantaneous interactions. The cochlear oscillators are driven both by the pressure and its time derivative, the latter presumably a proxy for forces contributed by outer hair cells. The admittance in the short-wavelength region is used to find an integral representation of the transfer function valid for all wavelengths. There are only two free parameters: the pole position in the complex frequency plane of the admittance, and the slope of the transfer-function phase at low frequencies. The new model predicts a dip in amplitude and a corresponding rapid drop in phase, past the peak of the traveling wave. Linear models may be compared by their wavelengths, and if they have the same dimension, by the singularity structure of their admittances.

Ashley J. Hicks, Michael R. Haberman and Preston S. Wilson, “Subwavelength acoustic metamaterial panels for underwater noise isolation”, The Journal of the Acoustical Society of America 138(3), EL254 (September 2015); https://doi.org/10.1121/1.4929730

ABSTRACT: Acoustically thin metamaterial underwater noise isolation panels have been developed that provide as much as 16 dB of noise isolation for a panel with a thickness just 160th of the wavelength in the host medium (fresh water) at 2.5 kHz. The panels are composed of thin layers of neoprene rubber and polyoxymethylene containing air-filled voids. The level of isolation provided by the panels is shown to correlate positively with the volume fraction of air voids within the panel.

References listed at the end of the paper:

ABSTRACT: An analytical treatment is presented for circular flexural plate transducers that have nonuniform electromechanically active-passive mechanical systems with particular interest in underwater applications. The analysis is made using the energy method that was previously applied to calculating parameters of uniform fully active (bimorph) circular plate transducers [B. S. Aronov, J. Acoust. Soc. Am. 118(2), 627–637 (2005)]. It is shown that the vibration mode shapes remain sufficiently similar to those for uniform plates for a large range of relative dimensions of active and passive laminates of radially nonuniform mechanical systems, and they may be used for calculating transducer parameters. Therefore the transducers can be considered as having a single degree of freedom, and their operational characteristics can be determined using the same technique as previously used for uniform plates. Dependences of the resonance frequencies, effective coupling coefficients, and parameters of the equivalent electromechanical circuit on relative dimensions of active and passive laminates for several combinations of the active and passive materials are presented and compared with those parameters of uniform plates having the same overall dimensions. The results of experimental verification are in good agreement with theoretical predictions.


ABSTRACT: Dynamic acousto-elastic testing is applied to a mixture of lipid-coated microbubbles in water. A dynamic change of ambient pressure is produced by a 16 kHz pressure wave having a peak pressure amplitude of 28 kPa. The induced changes of phase velocity and attenuation are captured by a sequence of short ultrasound pulses with a center frequency of 4 MHz. As a consequence of the dispersion brought about by the resonance of microbubbles at a frequency close to 2 MHz, time-domain approaches like the cross-correlation method are shown to be unsuited to determine the variation in ultrasound wavespeed. A frequency-domain analysis shows that the acousto-elastic effect (first order pressure derivative of ultrasound phase velocity) depends on the ultrasound frequency. The acousto-elastic effect tends to that measured in water for an ultrasound frequency above the resonance frequency of microbubbles, while it is two orders of magnitude larger for an ultrasound frequency close to or below the resonance frequency of microbubbles. Besides the large magnitude of the acousto-elastic effect observed for an ultrasound frequency below the resonance frequency of microbubbles, the first order pressure derivative of ultrasound phase velocity is negative. This supports the occurrence of shell buckling of lipid-coated microbubbles induced by the 16 kHz pressure wave.

Masahiro Toyoda, Shota Fujita and Kimihiro Sakagami, “Numerical analyses of the sound absorption of cylindrical microperforated panel space absorbers with cores”, The Journal of the Acoustical Society of America 138(6), 3531 (December 2015); https://doi.org/10.1121/1.4936944

ABSTRACT: Microperforated panels (MPPs) are next-generation absorption materials because they can provide wideband sound absorption without fibrous materials and can be composed of diverse materials to meet global environmental demands. The fundamental absorbing mechanism is Helmholtz-resonance absorption due to perforations and an air cavity. MPPs are typically backed by rigid flat walls, but to reduce the restrictions on the MPP absorber properties, one of the authors has proposed MPP space sound absorbers without backing structures, including three-dimensional cylindrical microperforated panel space absorbers (CMSAs). Advantages of MPPs without backing structures are design flexibility and ease of use. Besides, the absorption characteristics of a CMSA with a core, which has a rigid cylindrical core inside the CMSA, have been experimentally tested, but a method to predict the absorption characteristics is necessary to design CMSAs with
cores. Herein the two-dimensional combined Helmholtz integral formulation method is employed, and its prediction accuracy is evaluated by comparing the measured and predicted absorption characteristics of a CMSA with a core. Furthermore, a parametric study with regard to the core size is carried out to investigate the transition of the absorbing mechanism.

Muttalip Aşkı̇n Temiz, Ines Lopez Arteaga, Gunilla Efraimsson, Mats Åbom and Avraham Hirschberg, “The influence of edge geometry on end-correction coefficients in micro perforated plates”, The Journal of the Acoustical Society of America 138(6), 3668 (December 2015); https://doi.org/10.1121/1.4937748

ABSTRACT: Global expressions are proposed for end-correction coefficients in micro perforated plates (MPPs) using non-dimensional parameters. MPPs are sound absorbers with small perforation diameters such that the Stokes boundary layers fill up almost the entire perforation. Sound absorption does not only occur within the perforation, but also takes place just outside of it. The latter contribution plus the outside inertia effect on the transfer impedance of the MPP are referred to as end-corrections. In order to determine them, an analytical solution employing the very thin Stokes layer assumption has been derived. However, this assumption requires empirical coefficients in the end-corrections for accurate results. To explore the effects of various parameters a numerical model is used. This model is verified with open-end reflection coefficient measurements. The most prominent result from this study is that compared to plate thickness, the ratio of perforation diameter to Stokes layer thickness (Shear number) and edge geometry affect the end-correction coefficients more significantly. The effect of plate thickness can be neglected for practical purposes, therefore, expressions for the end-corrections in terms of Shear number and edge geometry are provided. The relative error of these expressions is <3% compared to the numerical results.

Vincent Phong and Dimitri Papamoschou, “Normal incidence acoustic insertion loss of perforated plates with bias flow”, The Journal of the Acoustical Society of America 138(6), 3907 (December 2015); https://doi.org/10.1121/1.4937602

ABSTRACT: The transmission of sound at normal incidence through perforated plates with bias flow is investigated experimentally and theoretically over a large parameter space. A specially designed experimental apparatus enabled the measurement of insertion loss with bias flow Mach number up to 0.25. A theoretical model for insertion loss was constructed based on inviscid, one-dimensional wave propagation with mean flow through a single contraction/expansion chamber. The mass end correction of the contraction is modified for hole interaction effects and mean flow. Hydrodynamic losses are modeled using a vena contracta coefficient dependent on both perforation geometry and Reynolds number. Losses in acoustic energy that occur in the mixing region downstream of the perforations are modeled as fluctuations in entropy. The proposed model was validated experimentally over a range of plate thickness, porosity, and hole size. The experimental results indicate an increase in insertion loss with increasing frequency, followed by saturation and decline as resonant conditions are established in the perforations. The insertion loss at low frequency increases with increasing Mach number through the perforation. The proposed model captures these trends and its predictions are shown to be more accurate than those of past models.


ABSTRACT: In a previously published paper [C. Wang, J. Acoust. Soc. Am. 137(6), 3514–3522 (2015)], the modal sound transmission coefficients of a single leaf panel were discussed with regard to the inter-modal coupling effects. By incorporating such effect into the equivalent modal radiation impedance, which is directly related to the modal sound transmission coefficient of each mode, the overall sound transmission loss for both normal and randomized sound incidences was computed through a simple modal superposition. Benefiting from the analytical expressions of the equivalent modal impedance and modal transmission coefficients, in this paper, behaviors of modal sound transmission coefficients in several typical frequency ranges are discussed in detail. Asymptotic solutions are also given for the panels with relatively low bending stiffnesses, for which the sound transmission loss has been assumed to follow the mass law of a limp panel. Results are also compared to numerical analysis and the renowned mass law theories.

Samuel Raetz, Jérôme Laurent, Thomas Dehoux, Daniel Royer, Bertrand Audoin and Claire Prada, “Effect of refracted light distribution on the photoelastic generation of zero-group velocity Lamb modes in optically low-
Zero-group velocity (ZGV) Lamb modes are associated with sharp local acoustic resonances and allow, among other features, local measurement of Poisson's ratio. While the thermoelastic generation of Lamb waves in metal plates has been widely studied, the case of materials of low-optical absorption remains unexplored. In materials such as glasses, the generation of bulk elastic waves has been demonstrated to be sensitive to the refracted light distribution. In this paper, a detailed analysis of the effect of light refraction on the laser-based generation of ZGV Lamb modes is presented. Experiments are performed on a bare glass plate without the need for an additional layer for light absorption or reflection. Using an appropriate tilted volume source, it is shown that the laser-ultrasonic technique allows non-contact measurement of the Poisson's ratio.

Chenxi Li, Ben Cazzolato and Anthony Zander, “Acoustic impedance of micro perforated membranes: Velocity continuity condition at the perforation boundary”, The Journal of the Acoustical Society of America 139(1), 93 (January 2016); https://doi.org/10.1121/1.4939489

ABSTRACT: The classic analytical model for the sound absorption of micro perforated materials is well developed and is based on a boundary condition where the velocity of the material is assumed to be zero, which is accurate when the material vibration is negligible. This paper develops an analytical model for finite-sized circular micro perforated membranes (MPMs) by applying a boundary condition such that the velocity of air particles on the hole wall boundary is equal to the membrane vibration velocity (a zero-slip condition). The acoustic impedance of the perforation, which varies with its position, is investigated. A prediction method for the overall impedance of the holes and the combined impedance of the MPM is also provided. The experimental results for four different MPM configurations are used to validate the model and good agreement between the experimental and predicted results is achieved.

Robin R. Wareing, John L. Davy and John R. Pearse, “The sound insulation of single leaf finite size rectangular plywood panels with orthotropic frequency dependent bending stiffness”, The Journal of the Acoustical Society of America 139(1), 520 (January 2016); https://doi.org/10.1121/1.4940125

ABSTRACT: Current theories for predicting the sound insulation of orthotropic materials are limited to a small range of infinite panels. This paper presents a method that allows for the prediction of the sound insulation of a finite size orthotropic panel. This method uses an equation for the forced radiation impedance of a finite size rectangular panel. This approach produces an equation that has three nested integrals. The long numerical calculation times were reduced by using approximate formulas for the azimuthally averaged forced radiation impedance. This reduced the number of nested integrals from three to two. The resulting predictions are compared to results measured using two sample sizes of four different thicknesses of plywood and one sample size of another three different thicknesses of plywood. Plywood was used for all the tests because it is somewhat orthotropic. It was found during testing that the Young's moduli of the plywood were dependent on the frequency of excitation. The influence of the frequency dependent Young's moduli was then included in the prediction method. The experimental results were also compared with a simple isotropic prediction method.

Benjamin Trévisan, Kerem Ege and Bernard Laulagnet, “Vibroacoustics of orthotropic plates ribbed in both directions: Application to stiffened rectangular wood panels”, The Journal of the Acoustical Society of America 139(1), 227 (January 2016); https://doi.org/10.1121/1.4939706

ABSTRACT: This paper is focused on the vibroacoustic behavior of a rectangular ribbed wood panel. This is done by developing an analytical model based on a variational approach, taking into account the kinetic and strain energies of a special orthotropic plate, 11 ribs oriented in a first direction and 1 other strong stiffener oriented in the perpendicular direction, which are considered as beams tied to the plate. A modal decomposition is adopted on the basis of the simply supported orthotropic plate. This allows calculating the modes of the wood panel (ribbed modes) in the frequency range 0–5000 Hz. The acoustical radiation of the baffled panel is also calculated. The radiation coefficients of the ribbed modes are presented and compared, when possible, to similar unribbed plate modes. Finally, the vibroacoustic analysis of the structure shows that an excitation placed on the hard point makes the panel particularly radiative and decreases the apparent critical frequency.
Gang Wang, Wen L. Li, Jingtao Du and Wanyou Li, “Prediction of break-out sound from a rectangular cavity via an elastically mounted panel”, The Journal of the Acoustical Society of America 139(2), 684 (February 2016); https://doi.org/10.1121/1.4941653

ABSTRACT: The break-out sound from a cavity via an elastically mounted panel is predicted in this paper. The vibroacoustic system model is derived based on the so-called spectro-geometric method in which the solution over each sub-domain is invariably expressed as a modified Fourier series expansion. Unlike the traditional modal superposition methods, the continuity of the normal velocities is faithfully enforced on the interfaces between the flexible panel and the (interior and exterior) acoustic media. A fully coupled vibro-acoustic system is obtained by taking into account the strong coupling between the vibration of the elastic panel and the sound fields on the both sides. The typical time-consuming calculations of quadruple integrals encountered in determining the sound power radiation from a panel has been effectively avoided by reducing them, via discrete cosine transform, into a number of single integrals which are subsequently calculated analytically in a closed form. Several numerical examples are presented to validate the system model, understand the effects on the sound transmissions of panel mounting conditions, and demonstrate the dependence on the size of source room of the “measured” transmission loss.

Mathieu Chekroun, Jean-Gabriel Minonzio, Claire Prada, Pascal Laugier and Quentin Grimal, “Measurement of dispersion curves of circumferential guided waves radiating from curved shells: Theory and numerical validation”, The Journal of the Acoustical Society of America 139(2), 790 (February 2016); https://doi.org/10.1121/1.4941652

ABSTRACT: A method is proposed to evaluate in a non-contact way the phase velocity dispersion curves of circumferential waves around a shell of arbitrary shape immersed in a fluid. No assumptions are made about the thickness or the material of the shell. A geometrical model is derived to describe the shape of the radiated wavefronts in the surrounding fluid, and predict the positions of its centers of curvature. Then the time-reversal principle is applied to recover these positions and to calculate the phase velocity of the circumferential waves. Numerical finite-difference simulations are performed to evaluate the method on a circular and on an elliptic thin shell. Different dispersion curves can be recovered with an error of less than 10%.

Henrik Bjurström and Nils Ryden, “Detecting the thickness mode frequency in a concrete plate using backward wave propagation”, The Journal of the Acoustical Society of America 139(2), 649 (February 2016); https://doi.org/10.1121/1.4941250

ABSTRACT: Material stiffness and plate thickness are the two key parameters when performing quality assurance/quality control on pavement structures. In order to estimate the plate thickness non-destructively, the Impact Echo (IE) method can be utilized to extract the thickness resonance frequency. An alternative to IE for estimating the thickness resonance frequency of a concrete plate, and to subsequently enable thickness determination, is presented in this paper. The thickness resonance is often revealed as a sharp peak in the frequency spectrum when contact receivers are used in seismic testing. Due to a low signal-to-noise ratio, IE is not ideal when using non-contact microphone receivers. In studying the complex Lamb wave dispersion curves at a frequency infinitesimally higher than the thickness frequency, it is seen that two counter-directed waves occur at the same frequency but with phase velocities in opposite directions. Results show that it is possible to detect the wave traveling with a negative phase velocity using both accelerometers and air-coupled microphones as receivers. This alternative technique can possibly be used in non-contact scanning measurements based on air-coupled microphones.

Troy M. Bouman, Andrew R. Barnard and Mahsa Asgarisabet, “Experimental quantification of the true efficiency of carbon nanotube thin-film thermophones”, The Journal of the Acoustical Society of America 139(3), 1353 (March 2016); https://doi.org/10.1121/1.4944688

ABSTRACT: Carbon nanotube thermophones can create acoustic waves from 1 Hz to 100 kHz. The thermoacoustic effect that allows for this non-vibrating sound source is naturally inefficient. Prior efforts have not explored their true efficiency (i.e., the ratio of the total acoustic power to the electrical input power). All previous works have used the ratio of sound pressure to input electrical power. A method for true power efficiency measurement is shown using a fully anechoic technique. True efficiency data are presented for three different drive signal processing techniques: standard alternating current (AC), direct current added to
alternating current (DCAC), and amplitude modulation of an alternating current (AMAC) signal. These signal processing techniques are needed to limit the frequency doubling non-linear effects inherent to carbon nanotube thermophones. Each type of processing affects the true efficiency differently. Using a 72 W\textsubscript{in} input signal, the measured efficiency ranges were $4.3 \times 10^{-5} - 319 \times 10^{-5}$, $1.7 \times 10^{-5} - 308 \times 10^{-5}$, and $1.2 \times 10^{-5} - 228 \times 10^{-5}$% for AC, DCAC, and AMAC, respectively. These data were measured in the frequency range of 100 Hz to 10 kHz. In addition, the effects of these processing techniques relative to sound quality are presented in terms of total harmonic distortion.

Hanyin Cui, Weijun Lin, Hailan Zhang, Xiuming Wang and Jon Trevelyan, “Backward waves with double zero-group-velocity points in a liquid-filled pipe”, The Journal of the Acoustical Society of America 139(3), 1179 (March 2016); https://doi.org/10.1121/1.4944046

ABSTRACT: Hollow cylinders often exhibit backward propagation modes whose group and phase velocities have opposite directions, and these exhibit a minimum possible frequency at which the group velocity vanishes at a nonzero wavenumber. These zero-group-velocity (ZGV) points are associated with resonant conditions in the medium. On the basis of ZGV resonances, a non-contact and laser ultrasound technique has been developed to measure elastic constants of hollow pipes. This paper provides a theoretical and numerical investigation of the influence of the contained liquid on backward waves and associated ZGV modes, in order to explore whether this ZGV technique is suitable for in-service non-destructive evaluations of liquid-filled pipes. Dispersion spectra and excitation properties have been analyzed. It is found that the presence of the liquid causes an increased number of backward modes and ZGVs which are highly excitable by a point source. In addition, several guided modes twice undergo a change of sign in the slopes of their dispersion curves, leading to two ZGV points. This phenomenon of double ZGVs in one backward wave, which is caused by strong mode repulsions, has not been found in isotropic hollow cylinders, but it can be observed in a fluid-filled thin-walled pipe.


ABSTRACT: The intersections between Lamb mode dispersion curves of free isotropic plates at real values of frequency and wave number are examined for the full allowed range of Poisson's ratio $\sigma$. The generic intersections between the dispersion curves for symmetric and anti-symmetric branches are classified into three types. Type F intersections are conditioned by the two additional real solutions of Rayleigh's cubic equation that occur for $\sigma < 0.26308$. Types I and II intersections occur for all values of $\sigma$, and are distinguished by the vanishing or divergence of the tangent functions in the defining equations for the Lamb modes. A brief discussion is provided of intersections between branches of like symmetry and additional intersections between unlike symmetry branches that occur for special values of $\sigma$.

Vladislav S. Sorokin, “Effects of corrugation shape on frequency band-gaps for longitudinal wave motion in a periodic elastic layer”, The Journal of the Acoustical Society of America 139(4), 1898 (April 2016); https://doi.org/10.1121/1.4945988

ABSTRACT: The paper concerns determining frequency band-gaps for longitudinal wave motion in a periodic waveguide. The waveguide may be considered either as an elastic layer with variable thickness or as a rod with variable cross section. As a result, widths and locations of all frequency band-gaps are determined by means of the method of varying amplitudes. For the general symmetric corrugation shape, the width of each odd band-gap is controlled only by one harmonic in the corrugation series with its number being equal to the number of the band-gap. Widths of even band-gaps, however, are influenced by all the harmonics involved in the corrugation series, so that the lower frequency band-gaps can emerge. These are band-gaps located below the frequency corresponding to the lowest harmonic in the corrugation series. For the general non-symmetric corrugation shape, the mth band-gap is controlled only by one, the mth, harmonic in the corrugation series. The revealed insights into the mechanism of band-gap formation can be used to predict locations and widths of all frequency band-gaps featured by any corrugation shape. These insights are general and can be valid also for other types of wave motion in periodic structures, e.g., transverse or torsional vibration.

ABSTRACT: This paper presents the study of influence of laminate sequence and fabric type on the baseline acoustic nonlinearity of fiber-reinforced composites. Nonlinear elastic wave techniques are increasingly becoming popular in detecting damage in composite materials. It was earlier observed by the authors that the non-classical nonlinear response of fiber-reinforced composite is influenced by the fiber orientation [Chakrapani, Barnard, and Dayal, J. Acoust. Soc. Am. 137(2), 617–624 (2015)]. The current study expands this effort to investigate the effect of laminate sequence and fabric type on the non-classical nonlinear response. Two hypotheses were developed using the previous results, and the theory of interlaminar stresses to investigate the influence of laminate sequence and fabric type. Each hypothesis was tested by capturing the nonlinear response by performing nonlinear resonance spectroscopy and measuring frequency shifts, loss factors, and higher harmonics. It was observed that the laminate sequence can either increase or decrease the nonlinear response based on the stacking sequence. Similarly, tests were performed to compare unidirectional fabric and woven fabric and it was observed that woven fabric exhibited a lower nonlinear response compared to the unidirectional fabric. Conjectures based on the matrix properties and interlaminar stresses were used in an attempt to explain the observed nonlinear responses for different configurations.

Wojciech P. Rdzanek, “The acoustic power of a vibrating clamped circular plate revisited in the wide low frequency range using expansion into the radial polynomials”, The Journal of the Acoustical Society of America 139(6), 3199 (June 2016); https://doi.org/10.1121/1.4954265

ABSTRACT: This study deals with the classical problem of sound radiation of an excited clamped circular plate embedded into a flat rigid baffle. The system of the two coupled differential equations is solved, one for the excited and damped vibrations of the plate and the other one—the Helmholtz equation. An approach using the expansion into radial polynomials leads to results for the modal impedance coefficients useful for a comprehensive numerical analysis of sound radiation. The results obtained are accurate and efficient in a wide low frequency range and can easily be adopted for a simply supported circular plate. The fluid loading is included providing accurate results in resonance.

Bibi I. S. Murat, Pouyan Khalili and Paul Fromme, “Scattering of guided waves at delaminations in composite plates”, The Journal of the Acoustical Society of America 139(6), 3044 (June 2016); https://doi.org/10.1121/1.4953016

ABSTRACT: Carbon fiber laminate composites are increasingly employed for aerospace structures as they offer advantages, such as a good strength to weight ratio. However, impact during the operation and servicing of the aircraft can lead to barely visible and difficult to detect damage. Depending on the severity of the impact, fiber and matrix breakage or delaminations can occur, reducing the load carrying capacity of the structure. Efficient nondestructive testing and structural health monitoring of composite panels can be achieved using guided ultrasonic waves propagating along the structure. The scattering of the A. Lamb wave mode at delaminations was investigated using a full three-dimensional (3D) finite element (FE) analysis. The influence of the delamination geometry (size and depth) was systematically evaluated. In addition to the depth dependency, a significant influence of the delamination width due to sideways reflection of the guided waves within the delamination area was found. Mixed-mode defects were simulated using a combined model of delamination with localized material degradation. The guided wave scattering at cross-ply composite plates with impact damage was measured experimentally using a non-contact laser interferometer. Good agreement between experiments and FE predictions using the mixed-mode model for an approximation of the impact damage was found.

Tian Ran Lin, Jiwen Tan, Yifan Zhou, Jingliang Jiang and Kai Zhang, “A study of ribbing effect on the vibration response and transmission of an L-shaped plate”, The Journal of the Acoustical Society of America 139(6), 3063 (June 2016); https://doi.org/10.1121/1.4953018

ABSTRACT: This paper presents an analytical solution for the vibration response of a ribbed L-shaped plate using a modal expansion solution approach. The analytical model is then employed to study the ribbing effect on vibration reduction and transmission between the two plate components of the L-shaped plate. It is found that for the system considered in the study, a rib inserted between the excitation force and the source plate can
lead to a large vibration reduction for both source and receiving plates except at a frequency band near the fundamental resonant frequency of the rib where the rib's flexural stiffness is negligible. A reduced vibration transmission to the receiving plate can also be achieved by placing a rib near the plate/plate junction, attributed to the increased moment impedance at the coupling after the rib insertion. Increasing the rib's flexural stiffness under this condition can further reduce vibration transmission in the low frequency bands while increasing the rib's mass can lead to a reduced vibration transmission in the higher frequency bands. The insights obtained from this study are relevant to vibration control of structures such as transformer tanks and machine covers.

Tai-Yun Huang, Chen Shen and Yun Jing, “Membrane- and plate-type acoustic metamaterials”, The Journal of the Acoustical Society of America 139(6), 3240 (June 2016); https://doi.org/10.1121/1.4950751

ABSTRACT: Over the past decade there has been a great amount of research effort devoted to the topic of acoustic metamaterials (AMMs). The recent development of AMMs has enlightened the way of manipulating sound waves. Several potential applications such as low-frequency noise reduction, cloaking, angular filtering, subwavelength imaging, and energy tunneling have been proposed and implemented by the so-called membrane- or plate-type AMMs. This paper aims to offer a thorough overview on the recent development of membrane- or plate-type AMMs. The underlying mechanism of these types of AMMs for tuning the effective density will be examined first. Four different groups of membrane- or plate-type AMMs (membranes with masses attached, plates with masses attached, membranes or plates without masses attached, and active AMMs) will be reviewed. The opportunities, limitations, and challenges of membrane- or plate-type AMMs will be also discussed.

References listed at the end of the paper:
viscoelastic and anisotropic materials

5. an elastic layer

4. solid plate in air. Theory and measurement

References listed at the end of the paper:


Magne Aanes, Kjetil Daae Lohne, Per Lunde and Magne Vestreheim, “Beam diffraction effects in sound transmission of a fluid-embedded viscoelastic plate at normal incidence”, The Journal of the Acoustical Society of America 140(1), EL67 (July 2016); https://doi.org/10.1121/1.4954893

ABSTRACT: The characteristics of a sound beam transmitted through a fluid-embedded viscoelastic plate at normal incidence can deviate significantly from those of a plane-wave. Phenomena such as frequency shift, signal amplification or reduction, and changed beam properties, are observed for resonance peaks associated with specific leaky Lamb modes. When interpreting measurements using plane-wave theory, such deviations will influence the measurement of material parameters and plate thickness. The finite-element-based models used in this study describe the signal chain from the electrical voltage excitation at the piezoelectric transducer terminals to the sound pressure propagated through the plate and fluid to the position at which it is measured by a hydrophone. The measured phenomena are described at a quantitative level.

References listed at the end of the paper:


Stefan Bilbao and Reginald Harrison, “Passive time-domain numerical models of viscothermal wave propagation in acoustic tubes of variable cross section”, The Journal of the Acoustical Society of America 140(1), 728 (July 2016); https://doi.org/10.1121/1.4959025

ABSTRACT: Numerical modeling of wave propagation in acoustic tubes is a subject of longstanding interest, particularly for enclosures of varying cross section, and especially when viscothermal losses due to boundary layer effects are taken into consideration. Though steady-state, or frequency domain methods, are a common avenue of approach, recursive time domain methods are an alternative, allowing for the generation of wideband responses, and offer a point of departure for more general modeling of nonlinear wave propagation. The design of time-domain methods is complicated by numerical stability considerations, and to this end, a passive representation is a useful design principle leading to simple stable and explicit numerical schemes, particularly in the case of viscothermal loss modeling. Such schemes and the accompanying energy and stability analysis are presented here. Numerical examples are presented for a variety of duct profiles, illustrating strict energy dissipation, and for comparison of computed input impedances against frequency-domain results.

Hossep Achdjian, Emmanuel Moulin, Farouk Benmeddour, Jamal Assaad, Lucie Dupont and Lynda Chehami, “Reverberation of flexural waves scattered by a local heterogeneity in a plate”, The Journal of the Acoustical Society of America 140(1), 157 (July 2016); https://doi.org/10.1121/1.4954747

ABSTRACT: A statistical model is proposed to relate the scattering properties of a local heterogeneity in a plate to the statistical properties of scattered and reverberated flexural waves. The contribution of the heterogeneity is isolated through the computation of differential signals consisting of a subtraction of the signals recorded after and before introduction of the heterogeneity. The theoretical expression of the average reverberation envelope of these differential signals is obtained as a function of the scattering cross-section of the heterogeneity. Successful numerical and experimental validations in various cases of canonical heterogeneities with known scattering cross-sections are shown. These satisfying results offer a way to estimate the scattering cross-section of an unknown scatterer from the reverberated differential signals.

Xiping He, Xiuli Yan and Na Li, “Directivity pattern of the sound radiated from axisymmetric stepped plates”, The Journal of the Acoustical Society of America 140(2), 1387 (August 2016); https://doi.org/10.1121/1.4961363

ABSTRACT: For the purpose of optimal design and efficient utilization of the kind of stepped plate radiator in air, in this contribution, an approach for calculation of the directivity pattern of the sound radiated from a stepped plate in flexural vibration with a free edge is developed based on Kirchhoff–Love hypothesis and Rayleigh integral principle. Experimental tests of directivity pattern for a fabricated flat plate and two fabricated plates with one and two step radiators were carried out. It shows that the configuration of the measured directivity patterns by the proposed analytic approach is similar to those of the calculated approach. Comparison of the agreement between the calculated directivity pattern of a stepped plate and its corresponding theoretical piston show that the former radiator is equivalent to the latter, and the diffraction field generated by the unbaflled upper surface may be small. It also shows that the directivity pattern of a stepped radiator is
independent of the metallic material but dependent on the thickness of base plate and resonant frequency. The thicker the thickness of base plate, the more directive the radiation is. The proposed analytic approach in this work may be adopted for any other plates with multi-steps.

Jost Leonhardt Fischer, Rolf Bader and Markus Abel, “Aeroacoustical coupling and synchronization of organ pipes”, The Journal of the Acoustical Society of America 140(4), 2344 (October 2016); https://doi.org/10.1121/1.4964135

ABSTRACT: A synchronization experiment on two mutual interacting organ pipes is compared with a theoretical model which takes into account the coupling mechanisms by the underlying first principles of fluid mechanics and aeroacoustics. The focus is on the Arnold-tongue, a mathematical object in the parameter space of detuning and coupling strength which quantitatively captures the interaction of the synchronized sound sources. From the experiment, a nonlinearly shaped Arnold-tongue is obtained, describing the coupling of the synchronized pipe–pipe system. This is in contrast to the linear shaped Arnold-tongue found in a preliminary experiment of the coupled system pipe-loudspeaker. To understand the experimental result, a coarse-grained model of two nonlinear coupled self-sustained oscillators is developed. The model, integrated numerically, is in very good agreement with the synchronization experiment for separation distances of the pipes in the far field and in the intermediate field. The methods introduced open the door for a deeper understanding of the fundamental processes of sound generation and the coupling mechanisms on mutual interacting acoustic oscillators.


ABSTRACT: The propagation speed of ultrasonic waves in pre-stressed media can be evaluated either at the natural or initial frames of reference. In this paper general equations that can be applied to the partial wave technique are presented in order to obtain the dispersion spectra of acoustoelastic Lamb waves in anisotropic plates in either frame of reference. Employing these equations, dispersion curves for the fundamental modes in a pre-stressed transversely isotropic aluminum plate were numerically obtained in both reference frames under longitudinal and transverse loading with the material transverse axis along each of the Cartesian directions, as well as the propagation along a non-principal direction. Results confirm that due to the material natural anisotropy, the speed variation depends not only on the pre-stress direction but also on the material orientation as well as on the polarization of the propagating mode. Similar to bulk waves, the relationship between the speed at the natural and initial frames is a function of the load direction.

Andrea Colombi, “Resonant metalenses for flexural waves in plates”, The Journal of the Acoustical Society of America 140(5), EL423 (November 2016); https://doi.org/10.1121/1.4967179

ABSTRACT: The dispersion curves of a cluster of closely spaced rods supported by a thin plate are characterised by subwavelength bandgaps and slow group velocities induced by local resonance effects. A recent analytical study [Williams, Roux, Rupin, and Kuperman (2015). Phys. Rev. B 91, 104307], has shown how the slow velocity branch depends, amongst other parameters, on the height of the rods that make up the cluster. Such metamaterial, offering easy-to-tune spatial velocity gradients, is a perfect candidate for building gradient index lenses such as Lunenburg, Maxwell, and 90° rotating. Here theoretical results are combined with numerical simulations to design and test metalenses for flexural waves. The lenses are obtained by tuning the height of the cluster of rods such that they provide the required refractive index profile. Snapshots and videos from three-dimensional numerical simulations in a narrow band centered at about 4 kHz are used to analyse the performances of three types of gradient index metalens (Lunenburg, Maxwell, and 90° rotating).

References listed at the end of the paper:


ABSTRACT: A two-dimensional active acoustic metamaterial with controllable anisotropic density is introduced. The material consists of composite lead–lead zirconate titanate plates clamped to an aluminum structure with air as the background fluid. The effective anisotropic density of the material is controlled, independently for two orthogonal directions, by means of an external static electric voltage signal. The material is used in the construction of a reconfigurable waveguide capable of controlling the direction of the acoustic waves propagating through it. An analytic model based on the acoustic two-port theory, the theory of piezoelectricity, the laminated pre-stressed plate theory, and the S-parameters retrieval method is developed to predict the behavior of the material. The results are verified using the finite element method. Excellent agreement is found between both models for the studied frequency and voltage ranges. The results show that,
below 1600 Hz, the density is controllable within orders of magnitude relative to the uncontrolled case. The results also suggest that simple controllers could be used to program the material density toward full control of the directivity and dispersion characteristics of acoustic waves.


ABSTRACT: Modeling and experiments are used to investigate Lamb wave propagation in the direction perpendicular to an applied stress. Sensitivity, in terms of changes in velocity, for both symmetrical and anti-symmetrical modes was determined. Codes were developed based on analytical expressions for waves in loaded plates and they were used to give wave dispersion curves. The experimental system used a pair of compression wave transducers on variable angle wedges, with set separation, and variable frequency tone burst excitation, on an aluminum plate 0.16 cm thick with uniaxial applied loads. The loads, which were up to 600 με, were measured using strain gages. Model results and experimental data are in good agreement. It was found that the change in Lamb wave velocity, due to the acoustoelastic effect, for the S mode exhibits about ten times more sensitive, in terms of velocity change, than the traditional bulk wave measurements, and those performed using the fundamental Lamb modes. The data presented demonstrate the potential for the use of higher order Lamb modes for online industrial stress measurement in plate, and that the higher sensitivity seen offers potential for improved measurement systems.

Mahsa Asgarisabet, Andrew R. Barnard and Troy M. Bouman, “Near field acoustic holography measurements of carbon nanotube thin film speakers”, The Journal of the Acoustical Society of America 140(6), 4237 (December 2016); https://doi.org/10.1121/1.4971328

ABSTRACT: Carbon nanotube (CNT) thin film speakers produce sound with the thermoacoustic effect. Better understanding of the physical acoustic properties of these speakers will drive future design improvements. Measuring acoustic properties at the surface of the CNT thin film is difficult because the films, themselves, do not vibrate, are fragile and have a high surface temperature. In order to measure the surface particle velocity and sound pressure level (SPL), near field acoustic holography (NAH) has been used by employing probe microphones. NAH images the acoustic quantities of the source system using the set of acoustic pressure measurements on a hologram parallel to the source surface. It is shown that the particle velocity at the surface of an open-air, double-sided speaker is nominally zero, as expected. However, the SPL distribution is not uniform on the source surface, contrary to common lumped parameter model assumptions. Also, particle velocity and sound intensity distributions on the hologram have been obtained in this study. Finally, measured directivity patterns of the planar CNT speaker are reported.

Patrick Kurzeja, Holger Steeb, Marc A. Strutz and Jörg Renner, “Oscillatory fluid flow in deformable tubes: Implications for pore-scale hydromechanics from comparing experimental observations with theoretical predictions”, The Journal of the Acoustical Society of America 140(6), 4378 (December 2016); https://doi.org/10.1121/1.4971365

ABSTRACT: Oscillatory flow of four fluids (air, water, two aqueous sodium-tungstate solutions) was excited at frequencies up to 250 Hz in tubes of two materials (steel, silicone) covering a wide range in length, diameter, and thickness. The hydrodynamical response was characterized by phase shift and amplitude ratio between pressures in an upstream (pressure excitation) and a downstream reservoir connected by the tubes. The resulting standing flow waves reflect viscosity-controlled diffusive behavior and inertia-controlled wave behavior for oscillation frequencies relatively low and high compared to Biot's critical frequency, respectively. Rigid-tube theories correspond well with the experimental results for steel tubes filled with air or water. The wave modes observed for silicone tubes filled with the rather incompressible liquids or air, however, require accounting for the solid's shear and bulk modulus to correctly predict speed of pressure propagation and deformation mode. The shear mode may be responsible for significant macroscopic attenuation in porous materials with effective frame-shear moduli lower than the bulk modulus of the pore fluid. Despite notable effects of the ratio of densities and of acoustic and shear velocity of fluid and solid, Biot's frequency remains an approximate indicator of the transition from the viscosity to the inertia controlled regime.

References listed at the end of the paper:


ABSTRACT: The metamaterial under investigation here consists of a periodic arrangement of unit plates in a grid-like frame such that there is a contrast in the local areal mass between cell interior and cell wall. In the low frequency range and under normal incidence this metamaterial panel exhibits a sound transmission loss significantly larger than the transmission loss of an unstructured panel with the same homogeneous mass per unit area. However, when the incident sound field is diffuse, the relative advantage of the metamaterial barrier is reduced or eliminated. A sequence of experiments is documented to demonstrate that the relative advantage of the metamaterial barrier can be realized even in a diffuse sound field by creating a hybrid barrier system which embeds the metamaterial layer between a normalizing waveguide layer on the incident side and an absorbing layer on the transmitted side. The sound normalizing waveguide layer is a lattice structure, and the absorbing layer is high performance glass fiber mat. By using measurements of the transmission loss of a 1.2 m square panel system the role of each of these components is demonstrated.

Ting Wang, Meiping Sheng and Qinghua Qin, “Sound transmission loss through metamaterial plate with lateral local resonators in the presence of external mean flow”, The Journal of the Acoustical Society of America 141(2), 1161 (February 2017); https://doi.org/10.1121/1.4976194
ABSTRACT: In the context of sound incident upon a metamaterial plate, explicit formulas for sound transmission loss (STL) are derived in the presence of external mean flow. Metamaterial plate, consisting of homogeneous plate and lateral local resonators (LLRs), is homogenized by using effective medium method to obtain the effective mass density and facilitate the calculation of STL. Results show that (a) vigorously oscillating LLRs lead to higher STL compared with bare plate, (b) increasing Mach number of the external mean flow helps obtain higher STL below the coincidence frequency but decreases STL above the coincidence frequency due to the added mass effect of light fluid loading and aerodynamic damping effect, (c) the coincidence frequency shifts to higher frequency range for the refracted effect of the external mean flow. However, effects of the flow on STL within negative mass density range can be neglected because of the lateral local resonance occurring. Moreover, hysteretic damping from metamaterial can only smooth the transmission curves by lowering higher peaks and filling dips. Effects of incident angles on STL are also examined. It is demonstrated that increasing elevation angle can improve the sound insulation, while the azimuth angle does not.

Junjuan Zhao, Xianhui Li, Yueyue Wang, Wenjiang Wang, Bin Zhang and Xiaoling Gai, “Membrane acoustic metamaterial absorbers with magnetic negative stiffness”, The Journal of the Acoustical Society of America 141(2), 840 (February 2017); https://doi.org/10.1121/1.4976042
ABSTRACT: A membrane absorber usually requires a large back cavity to achieve low-frequency sound absorption. This paper describes the design of a membrane acoustic metamaterial absorber in which magnetic negative stiffness is employed to reduce the size of the back cavity. As a baseline for the present research, analysis of a typical membrane sound absorber based on an equivalent circuit model is presented first. Then, a theoretical model is established by introducing negative stiffness into a standard absorber. It is demonstrated that a small cavity with negative stiffness can achieve the acoustic impedance of a large cavity and that the absorption peak is shifted to lower frequencies. Experimental results from an impedance tube test are also presented to validate this idea and show that negative stiffness can be employed to design compact low-frequency membrane absorbers.

Sankalp Tiwari and Anurag Gupta, “Effects of air loading on the acoustics of an Indian musical drum”, The Journal of the Acoustical Society of America 141(4), 2611 (April 2017); https://doi.org/10.1121/1.4979782
ABSTRACT: The effects of air loading on the acoustical properties of tabla, an Indian musical drum, are investigated by idealizing it as a composite membrane backed by a rigid cylindrical cavity. The coupled
boundary value problem for membrane vibration and acoustic pressure, assuming acoustic radiations to be the only source of dissipation, is solved using a Green's function method. It is shown that air loading helps in only fine tuning of the harmonicity of the composite membrane in the right hand tabla, but significantly improves the harmonicity in the left hand tabla. In both cases, it increases the decay time of the musically important modes. With a suitably defined error as the objective function, optimum tabla designs are found, which yield the most harmonic frequency spectrum. The obtained results are found to be consistent with the actual design of the tabla. Modal sound synthesis of the percussion instrument has also been attempted.

Michel Tran-Van-Nhieu, Gérard Maze and Dominique Déculotot, “Approximate solutions to acoustic scattering from a ribbed finite plate”, The Journal of the Acoustical Society of America 141(5), 3091 (May 2017); https://doi.org/10.1121/1.4982039

ABSTRACT: Acoustic scattering from a finite plate reinforced by parallel ribs with arbitrary rib spacing is investigated by applying thin plate and beam theories. The modal component of the surface pressure is calculated by an asymptotic expression that is only valid for higher-order modes at high frequencies. An approximate expression is derived for the far field scattered pressure by inverting matrices the rank of which is equal to twice the number of ribs. When the ribs are regularly spaced, approximate analytical expressions are proposed to calculate Bragg and forward Bloch–Floquet waves scattering separately from backward Bloch–Floquet waves scattering. These solutions are useful to deal with scattering problems where flexural waves are strongly attenuated after reflection on the edges of the plate. Finally the relevancy of the approximate expressions is evaluated by comparing numerical simulations to experimental data.

Wenbo Duan, Ray Kirby and Peter Mudge, “On the scattering of torsional waves from axisymmetric defects in buried pipelines”, The Journal of the Acoustical Society of America 141(5), 3250 (May 2017); https://doi.org/10.1121/1.4983192

ABSTRACT: This article develops a numerical model suitable for analysing elastic wave scattering in buried pipelines. The model is based on a previous so-called hybrid approach, where a nominally infinite length of pipe is split up into uniform and non-uniform regions. The key challenge for buried structures is in enforcing the appropriate boundary conditions in both the axial and radial directions, which must encompass the entire length of the structure, as well as the surrounding material. Accordingly, the focus of this article is on developing a model suitable for accurately applying these boundary conditions, and so the analysis is restricted here to the study of axisymmetric defects and to an incident sound field that consists of the fundamental torsional mode only. It is shown that this problem may be addressed in a numerically efficient way provided one carefully choses a perfectly matched layer for the surrounding material, and then integrates over this layer using a complex co-ordinate stretching function. This enables the use of mode matching to deliver a convergent system of equations that enforce the appropriate axial and radial boundary conditions.

Oskar Tofeldt and Nils Ryden, “Zero-group velocity modes in plates with continuous material variation through the thickness”, The Journal of the Acoustical Society of America 141(5), 3302 (May 2017); https://doi.org/10.1121/1.4983296

ABSTRACT: Lamb modes with zero group velocity at nonzero wave numbers correspond to local and stationary resonances in isotropic plates. Lamb modes can be utilized for nondestructive evaluation of the elastic properties and thickness. One example of an application is the testing of plate-like concrete structures. In this example, continuous variation in the material velocity through the thickness may occur. This is usually not accounted for in analyses, and with this as starting point, two inhomogeneous and nonsymmetric cases with continuous material variations are investigated using a semi-analytical finite element technique and a simulated measurement application. In a numerical study limited to the lowest zero-group velocity mode, results show that these modes for the inhomogeneous cases are generated with similar behavior and the same detectability as in the case of an isotropic plate. However, a complex relationship between mode frequency and material velocity exists for the inhomogeneous cases. This hinders the evaluation and interpretation of representative estimations such as those for a cross-sectional mean value of the plate properties. This may lead to errors or uncertainties in practical applications.
Loic Grau and Bernard Laulagnet, “Semi-analytical modeling of ground/plate interaction for general elastic boundary conditions”, The Journal of the Acoustical Society of America 141(6), EL507 (June 2017); https://doi.org/10.1121/1.4984043

ABSTRACT: This letter introduces ground/plate interaction using the concept of ground cross-modal impedance in the case of general elastic boundary conditions. Navier equations are generally used to account for ground vibration with two propagating waves, the dilatational wave and the shear wave. The plate equation of motion follows the Kirchhoff-Love hypothesis, where shear and rotational inertia are neglected in the plate thickness. The general elastic boundary conditions are expressed analytically through a two-dimensional Fourier series in the plate displacement solution. This study shows that the plate general boundary conditions have a small influence on the plate velocity. However, two categories of boundary conditions could be implemented, especially at low frequency.

Atanu Sahu, Partha Bhattacharya, Arup Guha Niyogi and Michael Rose, “A mobility based vibroacoustic energy transmission simulation into an enclosure through a double-wall panel”, The Journal of the Acoustical Society of America 141(6), EL598 (June 2017); https://doi.org/10.1121/1.4989729

ABSTRACT: Double-wall panels are known for their superior sound insulation properties over single wall panels as a sound barrier. The sound transmission phenomenon through a double-wall structure is a complex process involving vibroacoustic interaction between structural panels, the air-cushion in between, and the secondary acoustic domain. It is in this context a versatile and a fully coupled technique based on the finite-element–boundary element model is developed that enables estimation of sound transfer through a double-wall panel into an adjacent enclosure while satisfying the displacement compatibility across the interface. The contribution of individual components in the transmitted energy is identified through numerical simulations.

References listed at the end of the paper:


Marguerite Jossic, Adrien Mamou-Mani, Baptiste Chomette, David Roze, François Ollivier and Christophe Josserand, “Modal active control of Chinese gongs”, The Journal of the Acoustical Society of America 141(6), 4567 (June 2017); https://doi.org/10.1121/1.4985108

ABSTRACT: Instruments that belong to the gong family exhibit nonlinear dynamics at large amplitudes of vibration. In the specific case of the xiaoluo gong, this nonlinear behavior results in a pitch glide of several modes of the instrument in addition to harmonic distortion and internal resonances. This study applies a linear
modal active control to a xiaoluo gong in an attempt to change its sound properties. First, a modal damping control of the fundamental mode based on a linear identification and a state space controller is applied in the small amplitude regime (no pitch glide). Results indicate that modal control influences not only the controlled mode but also the frequency components involved in distortion or internal resonance phenomena. Second, a modal damping control is performed in the large amplitude regime (in the presence of pitch glide). Results show that modal control does not affect the pitch glide. However, the controller becomes effective at a time trigger which is related to the instantaneous frequency.

Dayi Ou and Cheuk Ming Mak, “Optimization of natural frequencies of a plate structure by modifying boundary conditions”, The Journal of the Acoustical Society of America 142(1), EL56 (July 2017); https://doi.org/10.1121/1.4991356

ABSTRACT: A combined approach based on finite element method and genetic algorithm (FEM-GA) is proposed for optimizing the natural frequencies of plate structures. This approach can identify the optimal boundary conditions so that the plate's natural frequencies can be adjusted simultaneously to their corresponding target values. In this approach, the natural frequencies of plates with arbitrary boundary conditions are calculated by FEM, while GA is employed for searching the optimal solutions of the multiple-objective optimization problem. The FEM is validated by comparing with previous results. The proposed approach is illustrated by numerical examples. The results demonstrate the effectiveness of this approach.

References listed at the end of the paper:


Yaoguang Liu, Xiadong Liu, Jun Xu, Xiaojun Hu and Zhaowang Xia, “Inverse identification of the acoustic porous parameters of double-layered poroelastic structures by acoustic rigidity approximation”, The Journal of the Acoustical Society of America 142(1), 72 (July 2017); https://doi.org/10.1121/1.4990521

ABSTRACT: A method to characterize the porous parameters (i.e., tortuosity, flow resistivity, viscous, and thermal lengths) of double-layered poroelastic structures is proposed and validated. The porosity, elastic coefficients (estimated), frame density, and thickness of each layer are assumed to be known. The way is to first identify the effective density and bulk modulus of each layer by a system of equations established based on the measured surface impedance of the structures backed by various air cavities, and then extract the porous parameters from the above identified parameters through the least square method at frequencies where the effect of vibration of frame is trivial. Because of the insensitivity to the surface impedance and the negligibility of the thermal loss compared to the viscous dissipation, the two acoustical bulk moduli are assumed to be identical. Two double-layered structures are constructed, which parameters are identified by the proposed method, and further verified by experiments. The results show that for double-layered structures constructed by materials
with large frame density (viscous length) or small flow resistivity, the identified precision would be better. In addition, because of the identical assumption, the ratio of two thermal lengths should not exceed two or be less than one half.

Yanni Zhang, Hai Huang and Jie Pan, “Underwater sound radiation from an elastically coated infinite plate with periodic inhomogeneities of finite width”, The Journal of the Acoustical Society of America 142(1), 91 (July 2017); https://doi.org/10.1121/1.4985127

ABSTRACT: The underwater sound radiation from a line-force-driven coated infinite plate with periodically attached distributed inhomogeneities is investigated. A typical example of a distributed inhomogeneity is a signal conditioning plate (SCP), which can be inserted between the coating and a hydrophone to increase the strength of the incoming signal. Using the wavenumber transform approach, the surface normal velocity and radiated sound power of the plate are determined by solving the indexed equations of the wavenumber components. This study demonstrates that the elastic coating between the base plate and periodic inhomogeneities may reduce the effect of band-passes and band-gaps on the radiated sound power caused by the inhomogeneities. This is explained in detail by the insulation effect of the coating as a decoupler. The effect of the SCP’s width and spatial period on the radiated sound is also examined. Finally, recommendations are given for the application of SCPs for underwater sensing purposes.


ABSTRACT: Sound generation due to an orifice plate in a hard-walled flow duct which is commonly used in air distribution systems (ADS) and flow meters is investigated. The aim is to provide an understanding of this noise generation mechanism based on measurements of the source pressure distribution over the orifice plate. A simple model based on Curle's acoustic analogy is described that relates the broadband in-duct sound field to the surface pressure cross spectrum on both sides of the orifice plate. This work describes careful measurements of the surface pressure cross spectrum over the orifice plate from which the surface pressure distribution and correlation length is deduced. This information is then used to predict the radiated in-duct sound field. Agreement within 3 dB between the predicted and directly measured sound fields is obtained, providing direct confirmation that the surface pressure fluctuations acting over the orifice plates are the main noise sources. Based on the developed model, the contributions to the sound field from different radial locations of the orifice plate are calculated. The surface pressure is shown to follow a U\(^{-3} \) velocity scaling law and the area over which the surface sources are correlated follows a U\(^{-1.8} \) velocity scaling law.


ABSTRACT: A model is presented of a composite beam with one elastic and one piezoelectric layer. A reduced set of piezoelectric equations of state that has only the longitudinal components of stress and strain and the transverse components of electric field and charge density is consistently used to include the effect of piezoelectric coupling in all the equations. The equi-potential boundary conditions on the electrodes, the open-circuit condition, and the Gauss condition are satisfied. The position of the neutral axis and the dynamic equilibrium equation are derived after including the effect of piezoelectric coupling. All equations are combined to derive an equation of motion that contains only the displacement and the mechanical excitation. The solution to the equation is expressed in terms of a complete set of functions and an auxiliary function that contains the electric potential. The latter is needed to satisfy piezoelectric boundary conditions at the ends of the beam. The electric potential varies along the length of the beam and has a quadratic variation between the electrodes. Analytical expressions for displacement and potential, and numerical results at low frequencies and in the neighborhood of resonance, are presented for certain sets of boundary conditions.
Ning Pei and Leonard J. Bond, “Comparison of acoustoelastic Lamb wave propagation in stressed plates for different measurement orientations”, The Journal of the Acoustical Society of America 142(4), EL327 (October 2017); https://doi.org/10.1121/1.5004388

ABSTRACT: High order Lamb waves are investigated for the effects of stress on both symmetrical and anti-symmetrical modes in an aluminum plate for wave propagation and load parallel. Data are compared with those for the case of load and measurement axis perpendicular. It is the S mode which exhibits significantly higher sensitivity to stress than other Lamb modes. For aluminum the use of the S mode for stress measurement is found to be about six times more sensitive, than bulk waves, for the load-measurement axes parallel case and this compares with about ten times for the case of load-measurement axes perpendicular.

References listed at the end of the paper:
- 4. See supplementary material at http://dx.doi.org/10.1121/1.5004388 for discussion and definition of the various terms used in Eqs. (2) and (3).

Xiwen Dai and Yves Aurégan, “Flexural instability and sound amplification of a membrane-cavity configuration in shear flow”, The Journal of the Acoustical Society of America 142(4), 1934 (October 2017); https://doi.org/10.1121/1.5006187

ABSTRACT: The scattering of sound by a membrane-covered cavity in a duct with shear flow is calculated with a linear model based on the multimodal method. The model is verified by comparison against the previous experiments focused on sound suppression of a stable system with high-tension membranes and a low-speed flow. It is shown in this paper that such a situation is drastically changed when the flow velocity is larger than the in vacuo flexural wave speed of the membrane. One of the neutral hydrodynamic modes can be destabilized under certain conditions, and this flexural instability can lead to sound amplification. For a given flow profile, the axial growth rate of the instability increases with the mean flow velocity but saturates at high velocities. For a given mean flow velocity, there is an optimum boundary layer thickness for the instability. Increasing the structural damping tends to stabilize the instability and thus inhibit the sound amplification.


ABSTRACT: In dynamic elastography, the goal is to estimate the Young’s modulus from audio-frequency wave propagation in soft-tissues. Within this frequency range, the shear wavelength is centimeter-sized while the compressional wavelength is meter-sized. Thus, the experimental data are usually collected in the near-field of the source. Near-field effects have been widely studied for bulk wave propagation. However, the near- and transient-fields of surface and guided waves have received less attention. In this work, the transient surface displacement field in soft-solid elastic plates in vacuum is analyzed. Due to the high Poisson’s ratio, mode conversion has special characteristics in soft-solids. They are analyzed through this work where it is shown that the transient-field over the surface can be interpreted by tracing a few reflections. The authors show the existence of a critical distance needed for the formation of Rayleigh-Lamb modes. Below this distance, only direct surface waves propagate without contribution from reflected waves. Thus, the dispersion curve differs
from that predicted by Rayleigh-Lamb modes. Instead, the authors propose a model based on the interference of surface waves, which agree with the experimental data. In addition, the conditions needed in order to retrieve the shear wave phase velocity from the surface field are given.

Kevin M. Lee, Preston S. Wilson and Mark S. Wochner, “Attenuation of low-frequency underwater sound using an array of air-filled balloons and comparison to effective medium theory”, The Journal of the Acoustical Society of America 142(6), 3443 (December 2017); https://doi.org/10.1121/1.5014052

ABSTRACT: The ultimate goal of this work is to accurately predict the attenuation through a collection of large (on the order of 10-cm-radius) tethered encapsulated bubbles used in underwater noise abatement systems. Measurements of underwater sound attenuation were performed during a set of lake experiments, where a low-frequency compact electromechanical sound source was surrounded by different arrays of encapsulated bubbles with various individual bubbles sizes and void fractions. The measurements were compared with an existing predictive model [Church, J. Acoust. Soc. Am. 97, 1510–1521 (1995)] of the dispersion relation for linear propagation in liquid containing encapsulated bubbles. Although the model was originally intended to describe ultrasound contrast agents, it is evaluated here for large bubbles, and hence low frequencies, as a design tool for future underwater noise abatement systems, and there is good quantitative agreement between the observations and the model.

Zhao Li, Liwen Jing and Ross Murch, “Propagation of monopole source excited acoustic waves in a cylindrical high-density polyethylene pipeline”, The Journal of the Acoustical Society of America 142(6), 3564 (December 2017); https://doi.org/10.1121/1.5016962

ABSTRACT: Acoustic wave propagation (up to 50 kHz) within a water-filled high-density polyethylene (HDPE) pipeline is studied using laboratory experiments and theoretical analysis. Experiments were carried out in a 15 m length of cylindrical HDPE pipeline using acoustic transducers to acquire signals uniformly spaced along the axis of the pipe. By proposing the use of the iterative quadratic maximum likelihood algorithm to this experimental configuration, wavenumbers, attenuations, and mode amplitudes could be accurately extracted from the measurement data. To allow comparisons with theoretical analysis, dispersion curves of the wavenumbers, attenuations, and acoustic power characteristics of the axisymmetric and nonaxisymmetric modes are predicted by extending an existing waveguide model. The model extensions included the introduction of a monopole acoustic source into the water medium so that amplitude variations with respect to individual modes and frequencies could be investigated in detail. In addition, stiffness coefficients of HDPE material are carefully used to account for viscoelastic effects. The comparisons between the theoretical predictions and experimental results demonstrate a very good match and are a validation of the theoretical model.

Elhadji Barra Ndiaye, Hugues Duflo, Pierre Maréchal and Pascal Pareige, “Thermal aging characterization of composite plates and honeycomb sandwiches by electromechanical measurement”, The Journal of the Acoustical Society of America 142(6), 3691 (December 2017); https://doi.org/10.1121/1.5017609

ABSTRACT: After identifying the parameters of the piezoelectric transducer, the mechanical impedance of the front medium is deduced. More particularly, the wave propagation velocity and attenuation are deduced in the inspected plate. By fitting the electrical impedance measurement results, the aging of composite materials is quantified, showing the effectiveness of this means of nondestructive evaluation. A specific measurement tool and protocol are proposed. Several estimators are identified on the basis of Gaussian fits of the resonances observed on the electrical impedance measurements. Those estimators are identified and the obtained results show that both the frequencies and widths of the resonances peaks vary according to the health of the plate, or aging duration. This method is applied successfully on non-perfect sandwich plates, porous, and with non-ideally flat surface. The sensitivity and limits of the most relevant estimators are discussed for the two studied plate families.
ABSTRACT: The development of reliable guided waves inspection systems is conditioned by an accurate knowledge of their dispersive properties. The semi-analytical finite element method has been proven to be very practical for modeling wave propagation in arbitrary cross-section waveguides. However, when it comes to computations on complex geometries to a given accuracy, it still has a major drawback: the high consumption of resources. Recently, discontinuous Galerkin finite element method (DG-FEM) has been found advantageous over the standard finite element method when applied as well in the frequency domain. In this work, a high-order method for the computation of Lamb mode characteristics in plates is proposed. The problem is discretised using a class of DG-FEM, namely, the interior penalty methods family. The analytical validation is performed through the homogeneous isotropic case with traction-free boundary conditions. Afterwards, functionally graded material plates are analysed and a numerical example is presented. It was found that the obtained results are in good agreement with those found in the literature.


ABSTRACT: A method to recover the elastic properties, thickness, or orientation of the principal symmetry axes of anisotropic plates is presented. This method relies on the measurements of multimode guided waves, which are launched and detected in arbitrary directions along the plate using a multi-element linear transducer array driven by a programmable electronic device. A model-based inverse problem solution is proposed to optimally recover the properties of interest. The main contribution consists in defining an objective function built from the dispersion equation, which allows accounting for higher-order modes without the need to pair each experimental data point to a specific guided mode. This avoids the numerical calculation of the dispersion curves and errors in the mode identification. Compared to standard root-finding algorithms, the computational gain of the procedure is estimated to be on the order of 200. The objective function is optimized using genetic algorithms, which allow identifying from a single out-of-symmetry axis measurement the full set of anisotropic elastic coefficients and either the plate thickness or the propagation direction. The efficiency of the method is demonstrated using data measured on materials with different symmetry classes. Excellent agreement is found between the reported estimates and reference values from the literature.


ABSTRACT: The radiation loading on a vibratory finite cylindrical shell is conventionally evaluated through the direct numerical integration (DNI) method. An alternative strategy via the fast Fourier transform algorithm is put forward in this work based on the general expression of radiation impedance. To check the feasibility and efficiency of the proposed method, a comparison with DNI is presented through numerical cases. The results obtained using the present method agree well with those calculated by DNI. More importantly, the proposed calculating strategy can significantly save the time cost compared with the conventional approach of straightforward numerical integration.

References listed at the end of the paper:
Chong Wang, “Forced sound transmission through a finite-sized single leaf panel subject to a point source excitation”, The Journal of the Acoustical Society of America 143(3), 1567 (March 2018); https://doi.org/10.1121/1.5027248

ABSTRACT: In the case of a point source in front of a panel, the wavefront of the incident wave is spherical. This paper discusses spherical sound waves transmitting through a finite sized panel. The forced sound transmission performance that predominate in the frequency range below the coincidence frequency is the focus. Given the point source located along the centerline of the panel, forced sound transmission coefficient is derived through introducing the sound radiation impedance for spherical incident waves. It is found that in addition to the panel mass, forced sound transmission loss also depends on the distance from the source to the panel as determined by the radiation impedance. Unlike the case of plane incident waves, sound transmission performance of a finite sized panel does not necessarily converge to that of an infinite panel, especially when the source is away from the panel. For practical applications, the normal incidence sound transmission loss expression of plane incident waves can be used if the distance between the source and panel d and the panel surface area S satisfy \( d/S^{1/2} \approx 0.5 \). When \( d/S^{1/2} \approx 0.1 \), the diffuse field sound transmission loss expression may be a good approximation. An empirical expression for \( d/S^{1/2} \approx 0 \) is also given.

Wojciech P. Rdzanek, “Sound scattering and transmission through a circular cylindrical aperture revisited using the radial polynomials”, The Journal of the Acoustical Society of America 143(3), 1259 (March 2018); https://doi.org/10.1121/1.5025159

ABSTRACT: The problem of sound scattering and transmission through a circular cylindrical aperture in a flat thick rigid wall has been revisited rigorously using the radial polynomials. The acoustic power transmission and back scattering coefficients have been presented in the form of highly convergent hypergeometric series described earlier in the literature for vibrating circular pistons and plates based on the crucial property of the polynomials in terms of the Hankel transform. The problem is solved by using the continuity conditions at both aperture outlets. The complex integrals necessary to satisfy the continuity conditions are expressed as the exact formulas, which makes the final results for the acoustic power coefficients much more accurate than in the case of numerical integration. A significant improvement has also been reached in numerical efficiency. On average,
the calculations are 500 times more efficient compared to numerical integration with no accuracy loss. Additionally, the acoustic pressure on the aperture outlets has been presented exactly in the form of a highly convergent hypergeometric series as well as using the modal impedance coefficients.

Takahiro Hayashi, “Defect imaging for plate-like structures using diffuse field”, The Journal of the Acoustical Society of America 143(4), EL260 (April 2018); https://doi.org/10.1121/1.5030915

ABSTRACT: Defect imaging utilizing a scanning laser source (SLS) technique produces images of defects in a plate-like structure, as well as spurious images occurring because of resonances and reverberations within the specimen. This study developed defect imaging by the SLS using diffuse field concepts to reduce the intensity of spurious images, by which the energy of flexural waves excited by laser can be estimated. The experimental results in the different frequency bandwidths of excitation waves and in specimens with different attenuation proved that clearer images of defects are obtained in broadband excitation using a chirp wave and in specimens with low attenuation, which produce diffuse fields easily.

References listed at the end of the paper:
Based on preliminary measurements, a mat approach is presented that uses smart materials to eliminate the wolf note with little effects to the cello's sound.

**ABSTRACT:** This study deals with the deduction of parameters of Micro-Perforated Panel (MPP) systems from impedance tube data. It is shown that there is an ambiguity problem that exists between the MPP thickness and its open area ratio. This problem makes it difficult to invert the reflection coefficient data fitting and therefore to deduct the MPP parameters. A technique is proposed to reduce this ambiguity by using an equation that links the hole diameter to the open area ratio. Reflection coefficient data obtained for two specimens with different characteristics is employed for searching the MPP parameters using a simulated annealing algorithm. The results obtained demonstrate the effectiveness of this technique.

Bing Li, Ming-hang Li and Tong Lu, “Interface waves in multilayered plates”, The Journal of the Acoustical Society of America 143(4), 2541 (April 2018); [https://doi.org/10.1121/1.5033902](https://doi.org/10.1121/1.5033902)

**ABSTRACT:** In this paper, the characteristic equation of interface waves in multilayered plates is derived. With a reasonable assumption undertaken for the potential functions of longitudinal and shear waves in the nth layer medium, the characteristic equation of interface waves in the N-layered plate is derived and presented in a determinant form. The particle displacement and stress components are further presented in explicit forms. The dispersion curves and wave structures of interface waves in both a three-layered Al-Steel-Ti and a four-layered Steel-Al-Steel-Ti plate are displayed subsequently. It is observed in dispersion curves that obvious dispersion occurs on the low frequency band, whereas the phase velocities converge to the corresponding true Stoneley wave mode velocities at high frequency, and the number of interface wave modes equals the number of interfaces in multilayered plates (if all individual interfaces satisfy the existence condition of Stoneley waves). The wave structures reveal that the displacement components of interface waves are relatively high at interfaces, and the amplitude distribution varies from frequency to frequency. In the end, a similarly structured three-layered Al-Steel-Ti plate is tested. In this experiment, theoretical group velocity and experimental group velocity are compared. According to the discussion and comparison, the predicted group velocities are in good agreement with the experimental results. Thus, the theory of interface wave in multilayered plates is proved. As a result, the proposed theoretical approach represents a leap forward in the understanding of how to promote the characteristic study and practical applications of interface waves in multilayered structures.


**ABSTRACT:** A method is presented to design an optimal unimorph beam that flexes and generates voltage in response to a distributed load acting over its length using an analytical model. The objective is to design a beam that resonates at a specified frequency at which there is a peak in the excitation. The associated open-circuit voltage sensitivity and gain bandwidth product are functions to be maximized. For specific boundary conditions and pairs of materials, the dimensional ratio of the thickness of the piezoelectric layer to the square of the length of the beam is chosen such that the beam resonates at the specified frequency. The two optimum values of the dimensionless ratio of the thicknesses of the elastic and piezoelectric layers associated with the maximum values of the two functions of interest are determined through a simple one-dimensional search. Figures of merit and numerical results are used to show the effect of boundary conditions and properties of materials on the functions of interest. All beams with the optimum ratio of thicknesses are equally good and the dimensions of a beam for a specific application are to be chosen by considering principles of design for manufacture and the external electronic circuit.

Philipp Neubauer, Johannes Tschesche, Joachim Bös, Tobias Melz and Holger Hanselka, “An active-system approach for eliminating the wolf note on a cello”, The Journal of the Acoustical Society of America 143(5), 2965 (May 2018); [https://doi.org/10.1121/1.5037467](https://doi.org/10.1121/1.5037467)

**ABSTRACT:** Wolf notes are generally undesirable sounds that occur in string instruments, particularly in cellos. State-of-the-art passive wolf note eliminators affect the whole cello sound and can become ineffective when environmental conditions and, therefore, the cello's structural properties change. In this paper, an approach is presented that uses smart materials to eliminate the wolf note with little effects to the cello's sound. Based on preliminary measurements, a mathematical model of the cello for generating the wolf note and for
developing a wolf note elimination controller is set up. The controller consists of a wolf detection criterion that triggers a velocity feedback controller to actively induce damping into the cello's body whenever a wolf note is detected. The controller setup is experimentally validated by an implementation on a test cello. The velocity feedback to induce the active damping is implemented by means of a piezoelectric patch actuator attached to the cello's body. Both the results of the mathematical model and the results of the experimental investigation show a good performance in eliminating the wolf note on a cello.

Kevin Jose, Anindya Chatterjee and Anurag Gupta, “Acoustics of Idakkā: An Indian snare drum with definite pitch”, The Journal of the Acoustical Society of America 143(5), 3184 (May 2018); https://doi.org/10.1121/1.5038111
ABSTRACT: The vibration of a homogeneous circular membrane backed by two taut strings is shown to yield several harmonic overtones for a wide range of physical and geometric parameters. Such a membrane is present at each end of the barrel of an idakkā, an Indian snare drum well known for its rich musicality. The audio recordings of the musical drum are analyzed and a case is made for the strong sense of pitch associated with the drum. A computationally inexpensive model of the string-membrane interaction is proposed assuming the strings to be without inertia. The interaction essentially entails wrapping/unwrapping of the string around a curve on the deforming membrane unlike the colliding strings in Western snare drums. The range of parameters for which harmonicity is achieved is examined and is found to be conforming with what is used in actual drum playing and construction.

James Gaffney, Alan McAlpine and Michael J. Kingan, “A theoretical model of fuselage pressure levels due to fan tones radiated from the intake of an installed turbofan aero-engine”, The Journal of the Acoustical Society of America 143(6), 3394 (June 2018); https://doi.org/10.1121/1.5038263
ABSTRACT: An existing theoretical model to predict the pressure levels on an aircraft's fuselage is improved by incorporating a more physically realistic method to predict fan tone radiation from the intake of an installed turbofan aero-engine. Such a model can be used as part of a method to assess cabin noise. Fan tone radiation from a turbofan intake is modelled using the exact solution for the radiated pressure from a spinning mode exiting a semi-infinite cylindrical duct immersed in a uniform flow. This approach for a spinning duct mode incorporates scattering/diffraction by the intake lip, enabling predictions of the radiated pressure valid in both the forward and aft directions. The aircraft's fuselage is represented by an infinitely long, rigid cylinder. There is uniform flow aligned with the cylinder, except close to the cylinder's surface where there is a constant-thickness boundary layer. In addition to single mode calculations it is shown how the model may be used to rapidly calculate a multi-mode incoherent radiation from the engine intake. Illustrative results are presented which demonstrate the relative importance of boundary-layer shielding both upstream and downstream of the source, as well as examples of the fuselage pressure levels due to a multi-mode tonal source at high Helmholtz number.

Masoud Golzari and Ali Asghar Jafari, “Sound transmission loss through triple-walled cylindrical shells with porous layers”, The Journal of the Acoustical Society of America 143(6), 3529 (June 2018); https://doi.org/10.1121/1.5041270
ABSTRACT: Sound transmission loss through triple-walled sandwich cylindrical shells in the presence of an external mean flow is analytically examined. Love's theory and a simplified method based on Biot's theory are considered to describe the motions of thin isotropic shells and wave propagation in the porous material cores, respectively. The random incidence transmission loss in a diffuse field is calculated numerically by considering the limiting incidence angle due to the total internal reflection. The analytical model and numerical code are validated against both experimental and analytical results reported by previous studies. The transmission loss of triple-walled structure in the diffuse sound field is compared with its double-walled counterpart at the same weight. The results generally show a superior performance in the sound insulation for the triple-walled shell, considerably at mid-high and high frequencies, in comparison with its double-walled counterpart at the same weight. The effects of sandwich shell configuration and air gap depth are also investigated on the sound transmission loss.
ABSTRACT: A generalization of the commonly used pressure jump modeling of thin porous layers is proposed. The starting point is a transfer matrix model of the layer derived using matrix exponentials. First order expansions of the propagating terms lead to a linear approximation of the associated phenomena and the resulting matrix is further simplified based on physical assumptions. As a consequence, the equivalent fluid parameters used in the model may be reduced to simpler expressions and the transfer matrix rendered sparser. The proposed model is validated for different backing conditions, from normal to grazing incidence and for a wide range of thin films. In the paper, the physical hypotheses are discussed, together with the origin of the field jumps.

Marguerite Jossic, Olivier Thomas, Vivien Denis, Baptiste Chomette, Adrien Mamou-Mani and David Roze, “Effects of internal resonances in the pitch glide of Chinese gongs”, The Journal of the Acoustical Society of America 144(1), 431 (July 2018); https://doi.org/10.1121/1.5038114

ABSTRACT: The framework of nonlinear normal modes gives a remarkable insight into the dynamics of nonlinear vibratory systems exhibiting distributed nonlinearities. In the case of Chinese opera gongs, geometrical nonlinearities lead to a pitch glide of several vibration modes in playing situation. This study investigates the relationship between the nonlinear normal modes formalism and the ascendant pitch glide of the fundamental mode of a xiaoluo gong. In particular, the limits of a single nonlinear mode modeling for describing the pitch glide in playing situation are examined. For this purpose, the amplitude-frequency relationship (backbone curve) and the frequency-time dependency (pitch glide) of the fundamental nonlinear mode is measured with two excitation types, in free vibration regime: first, only the fundamental nonlinear mode is excited by an experimental appropriation method resorting to a phase-locked loop; second, all the nonlinear modes of the instrument are excited with a mallet impact (playing situation). The results show that a single nonlinear mode modeling fails at describing the pitch glide of the instrument when played because of the presence of 1:2 internal resonances implying the nonlinear fundamental mode and other nonlinear modes. Simulations of two nonlinear modes in 1:2 internal resonance confirm qualitatively the experimental results.

Andriejus Demčenko, Rab Wilson, Jonathan M. Cooper, Michael Mazilu and Arno W. F. Volker, “Ultrasonic waves in uniaxially stressed multilayered and one-dimensional phononic structures: Guided and Floquet wave analysis”, The Journal of the Acoustical Society of America 144(1), 81 (July 2018); https://doi.org/10.1121/1.5044528

ABSTRACT: This paper shows that acoustoelasticity in one-dimensional (1D) multilayered isotropic hyperelastic materials can be understood through the analysis of elastic wave velocities as a function of applied stress. This theoretical framework is used for eigenvalue analyses in stressed elastic structures through a reformulation of the stiffness matrix method, obtaining modal solutions, as well as reflection and transmission coefficients for different multilayered configurations. Floquet wave analysis for the stressed 1D structures is supported using numerical results.


ABSTRACT: An analytical model is presented of axisymmetric circular hollow piezoelectric ceramic cylinders with arbitrary dimensions and boundary conditions. Forced vibrations of the cylinders with specified potentials on the electroded surfaces and displacement or stress on the boundaries are considered. The exact, linearized, axisymmetric governing equations are used in the analysis. Three series solutions are used, and each term in each series is an exact solution to the exact governing equations of motion. The terms in the series expressions for components of displacement, stress, electric potential, and electrical displacement are products of Bessel and sinusoidal functions and are orthogonal to other terms. Complete sets of functions in the radial and axial directions are formed by terms in the first series and the other two, respectively. It is, therefore, possible to satisfy arbitrary boundary conditions on all surfaces of the hollow piezoelectric cylinder. Numerical results are presented for hollow piezoelectric cylinders of various dimensions. Input electrical admittance and displacements are computed for three special cases in bands that include several resonance frequencies, and they are in excellent agreement with those computed using atila—a finite element package.
Penglin Gao, José Sánchez-Dehesa and Linzhi Wu, “Poisson-like effect for flexural waves in periodically perforated thin plates”, The Journal of the Acoustical Society of America 144(2), 1053 (August 2018); https://doi.org/10.1121/1.5051648

Abstract: The Poisson-like effect, describing the redirection of waves by 90°, is shown to be feasible for flexural waves propagating in perforated thin plates. It is demonstrated that the lowest order symmetric leaky guided mode (S0 mode) is responsible for the splitting of wave motion in two orthogonal directions. The S0 mode shows a feature of stationary waves containing standing wave modes in one and two orthogonal directions for smaller and larger holes, respectively. The former case is well understood thanks to the phenomenon of Wood's anomaly, which was first observed in optical gratings supposed to be transparent. On the contrary, the strong scattering caused by the larger holes leads to a mixed mode occurring when the incident wave is totally transmitted. The mixed mode easily couples with the incoming waves and, therefore, the Poisson-like effect activated under this mechanism is much stronger. Using the Poisson-like effect, a device is proposed in which about 82% of the incident mechanical energy is redirected to the perpendicular direction. Results obtained with arrays of free holes also apply to inclusions with parameters properly chosen. The findings may provide applications in beam splitting and waveguiding.

Preeti Gulia and Arpan Gupta, “Enhancing the sound transmission loss through acoustic double panel using sonic crystal and porous material”, The Journal of the Acoustical Society of America 144(3), 1435 (September 2018); https://doi.org/10.1121/1.5054296

Abstract: Acoustic panels are widely used for sound insulation in various applications. Sound transmission loss (STL) through the panel is due to a change in acoustic impedance as sound travels from one medium to another. In double panels, STL further increases due to multiple reflections in air cavity. Recently the sonic crystal (SC) has emerged as an interesting research topic which provides sound attenuation in specific frequency bands. The present paper aims at combining the property of a SC with the acoustic panel for enhancing the STL through the double panel. Initially, an analytical method is developed to obtain the STL through the double panel. Further finite element (FE) simulations are performed using acoustic structure interaction to obtain the STL through the double panel which is in good agreement with the analytical predictions. The SC, along with the double panel, is analyzed using the FE method for the combined effect of both sound attenuators. Further, glass wool is considered as a filler material between the double panel as well as between the double panel and the SC assembly. It is found that the combined structure of the double panel and the SC with glass wool as filler gives the best STL for all different cases for the same external dimensions.

Heying Feng, Yehui Peng, Xiaoting Zhang and Xuejun Li, “Influence of tube geometry on the performance of standing-wave acoustic resonators”, The Journal of the Acoustical Society of America 144(3), 1443 (September 2018); https://doi.org/10.1121/1.5053578

Abstract: A general and simple calculation method is presented to investigate the effects of tube shape on the resonant frequency and performance of a resonator. First, the resonant frequency of a variable cross-section resonator is modeled using a transfer matrix. Then, the amplification ratio of the pressure amplitude (ARPA), defined as the ratio of the pressure amplitude at the small end to that at the large end of the resonator, is used to evaluate its performance. The ARPA value for a variable cross-section resonator can be directly calculated from its resonant frequency. It is shown that the ARPA value is closely related to the compression ratio. However, its value is only determined by the resonator itself and is independent of the working conditions. Therefore, the ARPA index is potentially a more convenient tool for evaluating the performance of resonators compared with other indexes. Additionally, the presented method is validated by a comparison with analytical results and experimental data. Moreover, the harmonic frequencies for cylindrical, exponential, conical, half-cosine, 3/4 cosine, and Horn–Cone shape tubes are numerically investigated, in addition to the influence of the resonator shape on the resonance frequency and ARPA. Finally, optimal shape parameters for several types of resonators are suggested.
Xiuyuan Peng, Jun Ji and Yun Jing, “Composite honeycomb metasurface panel for broadband sound absorption”, The Journal of the Acoustical Society of America 144(4), EL255 (October 2018); https://doi.org/10.1121/1.5055847

ABSTRACT: Composite honeycomb sandwich panels have been adopted in a wide range of applications owing to their excellent mechanical properties. This paper demonstrates a design of a composite honeycomb metasurface panel that can achieve 90% sound absorption from 600 to 1000 Hz with a thickness less than 30 mm. The panel is comprised of periodically and horizontally arranged honeycomb “supercells” which consist of unit cells of different geometric parameters (pore size). Two different analytical models (Helmholtz resonator model and micro-perforated panel model) are used to calculate the sound absorption of the panel, and they are further validated by a numerical model. The relatively broadband sound absorption is found to be attributed to the coupling between unit cells, which is illustrated by both the complex frequency plane theory and the calculated sound intensity field.

References listed at the end of the paper:

Pablo L. Rendón, Roberto Velasco-Segura, Carlos Echeverría, David Porta, Antonio Pérez-López, R. Teo Vázquez-Turner and Catalina Stern, “Using Schlieren imaging to estimate the geometry of a shock wave radiated by a trumpet bell”, The Journal of the Acoustical Society of America 144(4), EL310 (October 2018); https://doi.org/10.1121/1.5063810

ABSTRACT: The Schlieren method has been used before to visualize weak shock waves radiated from the open ends of brass instruments, but no attempt has previously been undertaken, however, to measure the geometry of the radiated wavefronts using the Schlieren images. In this paper Schlieren visualization is used to estimate the geometry of the two-dimensional shock wavefronts radiated from the bell of a trumpet at different frequencies. It is observed that the geometry of the shocks does change with frequency, in the expected manner. The propagation speeds of these shocks are also calculated, and they too exhibit the anticipated behavior. References listed at the end of the paper:

ABSTRACT: Closely packed nested structure circular tubes form three types of clearances: circular clearances, concentric clearances, and longitudinal clearances. The cross-sectional shape of rice straw, including the above-mentioned three types of clearances, is similar to that of the samples of the present study. Herein, the propagation constant and characteristic impedance of the circular, concentric, and longitudinal clearances surrounded by three cylindrical surfaces are treated as a transfer matrix. Then, by connecting these transfer matrices in parallel, a transfer matrix integrating these clearances is determined, and the sound absorption coefficient is calculated. Test samples that have three types of clearances are also created, and measure their sound absorption coefficients. The contributions of the concentric and circular clearances are significant because of the dimensions of the used tubes. The results of the calculations that took eccentricity into account revealed no significant impact on the sound absorption coefficient in wide-frequency range. The results of the calculations that took flexure into account revealed that the theoretical value was close to the measured value in the low-frequency range.

Armin M. A. Huber and Markus G. R. Sause, “Classification of solutions for guided waves in anisotropic composites with large numbers of layers”, The Journal of the Acoustical Society of America 144(6), 3236 (December 2018); https://doi.org/10.1121/1.5082299

ABSTRACT: Guided waves are used for the non-destructive evaluation in automotive and aerospace industries. There is a trend leaning away from isotropic materials to the manufacturing based on composites. However, the elastic wave dynamics in such materials is considerably more complicated. Much effort has been committed to the calculation of guided waves' dispersion curves in composites. Lots of methods and tools are available, but it becomes difficult when there are more than one hundred layers. In this paper the calculation of dispersion diagrams and mode shapes using the stiffness matrix method is demonstrated. Boundary conditions are implemented into the stiffness matrix method that allow for the separate tracing of the various mode families. Shear horizontal modes are modeled with the transfer matrix method without facing any numerical instability. It is elucidated just how the occurrence of the mode families depends on the system's symmetry and wave propagation direction. As a result, the robustness and reliability of guided wave modeling by using the stiffness method is improved, and more information about the modes is yielded. This is demonstrated on exemplary layups of the fiber reinforced polymer T800/913, with up to 400 layers. Referencing is made against results from DISPERSE (Imperial College London, London, UK) for selected cases.

Christophe Droz (1), Olivier Robin (2), Mohamed Ichchou (1) and Noureddine Atalla (2)
(1) Vibroacoustics & Complex Media Research Group, LTDS – CNRS UMR 5513, Ecole Centrale de Lyon, France
(2) Groupe d'acoustique de l'Université de Sherbrooke, Faculté de génie, Département de génie mécanique, Sherbrooke, Canada

“Improving sound transmission loss at ring frequency of a curved panel using tunable 3D-printed small-scale resonators”, The Journal of the Acoustical Society of America 145(1), EL72 (January 2019); https://doi.org/10.1121/1.5088036

ABSTRACT: An important dip in the sound transmission loss of curved panels occurs at the ring frequency. The relevance of using small-scale resonators to solve this issue is experimentally demonstrated on an aircraft sidewall panel. The effect of varying the spatial distribution of single frequency resonators (including combination with a broadband soundproofing treatment), as well as using multi-frequency resonators with a fixed spatial distribution is studied. Large improvement of the measured sound transmission loss under a diffuse acoustic field excitation is obtained around the ring frequency with limited added mass and very small alteration of the overall sound insulation performance.

References listed at the end of the paper:

Nansha Gao, Zhengyu Wei, Hong Hou and Anastasiiia O. Krushynska, “Design and experimental investigation of V-folded beams with acoustic black hole indentations”, The Journal of the Acoustical Society of America 145(1), EL79 (January 2019); https://doi.org/10.1121/1.5088027

ABSTRACT: This paper proposes a strategy to broaden complete bandgap attenuating flexural and longitudinal modes, and to shift them to lower frequencies by spatially folding designs. Numerical simulations show that the V-folded acoustic black hole beam exhibits an ultra-wide complete bandgap below 1 kHz due to longitudinal-flexural wave transformation, and experimental results verify this finding. The proposed folded beams are easy-to-fabricate, of compact dimensions, and exhibit excellent wave attenuation functionality that makes them promising for low-frequency vibration reduction and wave attenuation applications.

References listed at the end of the paper:

ABSTRACT: This paper is an extension of the previous work by Yang [J. Acoust. Soc. Am. 143, 1102–1105 (2018)], which dealt with achieving acoustic absorption using a microperforated panel (MPP) in the absence of the backing cavity. It was shown experimentally that a MPP can attenuate the acoustic wave without necessarily being accompanied by a backing cavity, provided it is placed in an acoustic environment where the acoustic pressure on the two sides of the MPP is different in terms of the amplitude and/or phase. Such an environment was found in a curved duct with a curved MPP aligned along its axial direction. To further obtain the physics underlying the design, a model is developed in this work to study the property of the acoustic transmission through the duct bend and an eigenvalue analysis is made to study its influence on the decay rate of each mode. It is shown that the treatment results in attenuation for all duct modes including the fundamental mode. A geometrical acoustic approximation is made to assist in interpreting the acoustic absorption effect on each mode and a comparison with the finite element method result is used to validate the proposed model.

Shuichi Sakamoto, Yuki Maruyama, Kohei Yamaguchi and Kohei Ii, “Experiment and estimation of the sound absorption coefficient for clearance of corrugated honeycomb”, The Journal of the Acoustical Society of America 145(2), 724 (February 2019); https://doi.org/10.1121/1.5089427

ABSTRACT: The sound absorption coefficient of thin tubes with a honeycomb-corrugated structure was estimated via theoretical analysis assuming the dimensions of the tube and the known physical properties of air. This analysis yields a propagation constant and characteristic impedance, which can be modeled as a one-dimensional transfer matrix. The sound absorption coefficient is then calculated by the transfer-matrix method and the results of comparison with the experiments are reported. The corrugated clearance was divided into elements for which approximations that assumed the clearance between two planes and took into account the perimeter and cross-sectional area of each element were considered. The theoretical value of the sound absorption coefficient obtained using this method was shown to be in good agreement with the experimental results. The experimental value of the sound absorption coefficient was larger than the theoretical value in the previous method in the analysis wherein each divided element was approximated by the distance between two planes taking into account the thickness and cross-sectional area of the clearance.

J.P. Szabo and A.D. Bent, “Reduction in edge effects for small panels characterized by a parametric array source”, The Journal of the Acoustical Society of America 145(2), 795 (February 2019); https://doi.org/10.1121/1.5090108

ABSTRACT: This study sought to explore effects of panel size on underwater acoustic transmission and reflection measurements made with a truncated parametric array source. The transmission loss (TL) and reflection loss spectra of aluminum panels of several different sizes were determined experimentally, and compared to predictions from plane wave theory in the 5–100 kHz frequency range. For the smallest panel size, there were significant discrepancies between experimental data and plane wave theory, which were attributed to contributions from edge-diffracted waves and interferences from the mounting fixture for the panel. For reflection measurements, the latter interference could be corrected for in part by measurement of the reflected signal from the sample holder (with no panel present), and subtracting this signal from reference and test panel waveforms. In order to reduce the contributions from edge diffracted waves in TL measurements, an alternative panel mounting system was investigated, which involved surrounding the panel in a reflective baffle. There was a significant improvement in agreement of experimental TL spectra with plane wave theory for the smallest aluminum panel when the baffle mounting arrangement was used.
ABSTRACT: Geometrically nonlinear vibrations of thin plates and shells with variable thickness are investigated numerically with the purpose of synthesizing the sound of cymbals. In cymbal making, taper refers to the gradual change in thickness from the centre to the rim and is known to be a key feature that determines the tone of the instrument. It is generally used in conjunction with shape variations in order to enable the cymbal to play a bell-like sound when hit near its centre, or a crash sound when struck close to the edge. The von Kármán equations for thin plates with thickness and shape variations are derived, and a numerical method combining a Rayleigh–Ritz approach together with a Störmer–Verlet scheme for advancing the problem in time is detailed. One main advantage of the method is its ability to implement easily any frequency-dependent loss mechanism which is a key property for sound synthesis. Also, the accuracy of the computation of the nonlinear restoring force is especially preserved. The method is employed to synthesize the sounds of cymbal-like instruments. The impact of taper is addressed and the relative effects of both thickness and shape variations, are contrasted.

Quoc Bao Nguyen and Cyril Touzé, “Nonlinear vibrations of thin plates with variable thickness: Application to sound synthesis of cymbals”, The Journal of the Acoustical Society of America 145(2), 977 (February 2019); https://doi.org/10.1121/1.5091013

ABSTRACT: Leaky Lamb waves have the potential to be used to perform non-destructive testing on a set of several parallel and immersed plates. Short-time Fourier transform and two-dimensional Fourier transform have both been successfully used to measure the propagation properties: phase and group velocity, and leaky attenuation. Experimental measurements were validated by comparison between theory, experimentation and finite-element simulations (using comsol multiphysics software) in the case of one immersed plate in water. These signal processing techniques proved to be efficient in the case of multi-modal propagation. They were applied to two immersed plates to identify the leaky Lamb mode generated in the second plate. Dispersion curves of the system composed by two immersed and parallel plates are computed. When plates have the same thickness, leaky Lamb modes propagate from the first to the second plate without any mode change, with the apparent attenuation being weaker in the second plate. Considering that the second plate is continuously supplied in energy by the first one, an energy-based model is proposed herein to estimate the apparent attenuation in the second plate. Despite our extremely simplifying assumption, this model proved to be in good agreement with both finite-element modelling and experimentation.

Munawwar Mohabuth, Andrei Kotousov and Ching-Tai Ng, “Large acoustoelastic effect for Lamb waves propagating in an incompressible elastic plate”, The Journal of the Acoustical Society of America 145(3), 1221 (March 2019); https://doi.org/10.1121/1.5092604

ABSTRACT: In this paper, the effect of a large pre-stress on the propagation of small amplitude Lamb waves in an incompressible elastic plate is investigated. Using the theory of incremental elasticity, the dispersion equations, which give the phase velocity of the symmetric and anti-symmetric wave modes as a function of the wavenumber, plate thickness, and pre-stress state, are derived for a general strain energy function. By considering the fourth-order strain energy function of incompressible isotropic elasticity, the correction to the phase velocity due to the pre-stress is obtained implicitly to the second order in the pre-strain/stress, and depends on the second, third, and fourth-order elastic constants. Numerical results are presented to show the dependence of the phase velocity of the Lamb wave modes upon the applied stress. These are compared to the first-order correction, and agree well with the limiting and asymptotic values obtained previously. It is envisaged that the present results may well find important practical applications in various guided wave based ultrasonic techniques utilising gels and rubber-like materials.

Qi Li and Jeffrey S. Vipperman, “Three-dimensional pentamode acoustic metamaterials with hexagonal unit cells”, The Journal of the Acoustical Society of America 145(3), 1372 (March 2019); https://doi.org/10.1121/1.5093622

ABSTRACT: Acoustic cloaking is an important application of acoustic metamaterials. Pentamode acoustic cloaks have isotropic mass density and anisotropic stiffness. A different kind of pentamode material is proposed
in this paper. It is composed of three-dimensional hexagonal unit cells built with double-cone structures. The structure is amenable for creating spherical pentamode geometries, which might be used for acoustic cloaking. The band structures show that there are band gaps for shear waves, where only compressional waves exist. The effective compressional wave velocities are calculated from the band structures for various parameters. The effective properties can be varied by changing the parameters independently. High anisotropy and large variation of effective properties are demonstrated, suggesting good potential for acoustic cloaking. The geometry of the unit cell can be designed to give the appropriate properties required for cloaking.

ABSTRACT: Micro-perforated panels (MPPs) are widely used for broadband sound absorptions. For a MPP exposed to a grazing flow, existing acoustic impedance formulas based on different flow parameters give inconsistent results, thus calling for a systematic investigation of the issue to find more intrinsic flow parameters allowing for a reliable acoustic impedance prediction. In this study, three-dimensional CFD simulations are conducted on a MPP hole with a backing space in a flow duct. Numerical results allow identifying the flow velocity gradient in the viscous sublayer as the intrinsic flow parameter and show its linear relationship with a flow-related term in the acoustic resistance formula. Through a linear regression analysis, an acoustic resistance formula is established within a certain flow range (Mach number up to 0.25) under the linear acoustic regime. The validity of the impedance formula is demonstrated through comparisons with existing results and experimental data reported in the literature, showing good agreement and superiority in terms of the prediction accuracy.

Junjuan Zhao, Xianhui Li, Wenjiang Wang, Yueyue Wang, Liying Zhu and Yunan Liu, “Membrane-type acoustic metamaterials with tunable frequency by a compact magnet”, The Journal of the Acoustical Society of America 145(5), EL400 (May 2019); https://doi.org/10.1121/1.5107431
ABSTRACT: In this letter, a membrane-type acoustic metamaterial with a compact magnet (MAMM) is presented. To investigate its frequency-tunable properties, a theoretical model considering both static and dynamic effects of magnetic force is established. Analytical investigations indicate that tuning of the magnetic force exerted on the centralized rigid iron platelet leads to the shift in the MAMM's transmission loss peaks. The experimental anti-resonance frequencies of the MAMM derived from the impedance tube measurements exhibited good consistency with those predicted theoretically. Continuously tuned in a wide frequency range, this structure can well adapt to the noise source variation in insulation design.

Cameron A. McCormick and Micah R. Shepherd, “Optimization of an acoustic black hole vibration absorber at the end of a cantilever beam”, The Journal of the Acoustical Society of America 145(6), EL593 (June 2019); https://doi.org/10.1121/1.5113960
ABSTRACT: Structures whose thickness follow a power law profile exhibit the “acoustic black hole” (ABH) effect and can be used for effective vibration reduction. However, it is difficult to know a priori what constitutes the best design. A new block matrix formulation of the transfer matrix method is developed for use in the optimization of an ABH vibration absorber at the end of a cantilever beam. Results indicate that introduction of the ABH significantly alters the dynamics of the beam, which must be considered in determining the optimal design for a given vibration reduction problem.

References listed at the end of the paper:
Karl A. Fisher, Owen Mays, Peter Haugen and David Obenauf, “Inspection of plate weldments through an interposed layer of viscoelastic material using an elastic–electromagnetic scanning method”, The Journal of the Acoustical Society of America 145(6), 3510 (June 2019); https://doi.org/10.1121/1.5111136

ABSTRACT: In this article, an elastic-microwave based non-destructive evaluation method is presented to inspect for cracks in weldments and thinning of coated steel plates. The approach uses a microwave interferometer operating at 94 GHz to record the total surface displacement of a coated steel plated as it is driven by an incident elastic field. These spatiotemporal data coupled with wavefield processing algorithms provide powerful detection and localization capabilities. From these wavefield data sets, a plate thickness mapping capability has been demonstrated that can detect thickness changes on the order of 0.79 mm (1/32 in.). It is also shown that a topological energy analysis of the wavefield data can detect and locate small flaws on the order of 5–10 mm (0.19–0.40 in.) in the welded joint. Note, all of these results are obtained through a 50.8 mm (2 in.) thick viscoelastic coating without disturbing the coating or the coating bond. At present the algorithm cannot resolve individual flaws within a grid space, just their cumulative effect. Even with the current limitations, this detection approach appears to be a promising alternative to traditional phased array imaging methods where the coating layer must be removed prior to inspection.


ABSTRACT: Acoustic measurements of turbulent jets in the vicinity of a flat plate, mimicking a neighbouring wing, were compared to results from two wavepacket-based source models previously studied in the literature: the Tailored Green’s Function method, which considers the radiation of the turbulent structure in the vicinity of a semi-infinite flat plate, and the Boundary Element Method, which can represent the full geometry of the plate used in the experiments. Particular interest is given to analysing how the angle of attack of the plate (\(\alpha\)) affects the sound radiated by an installed jet with trailing edge 6 diameters away from the nozzle and 1 diameter away from the centerline for \(0^\circ \leq \alpha \leq 45^\circ\). The results herein confirm the behaviour identified by the models: the scattered acoustic field follows the rotation of the plate, shifting a silence region with negligible scattered sound, and creating regions with lower noise levels in positions that correspond to the ground for an aircraft with engines under its wings. This is further explored by means of a Mach number analysis for \(M = 0.5, 0.7,\) and 0.9, showing that this trend is present whenever trailing-edge scattering of jet disturbances is dominant in the acoustic field.
Leping Feng, “Enhancement of low frequency sound absorption by placing thin plates on surface or between layers of porous materials”, The Journal of the Acoustical Society of America 146(2), EL141 (August 2019); https://doi.org/10.1121/1.5121571

ABSTRACT: Rigid thin plates can be used, either on the surface or between layers of materials, to improve the sound absorption properties of porous materials at low frequencies, especially for materials with low sound absorption. Measurement results obtained from a 100 mm impedance tube, for different combinations of porous materials and thin plates, are supplied. Possible physical explanations are discussed. The size of the plate, together with the original properties of the porous material, determines the useful frequency region of the method. The technique of surface-placed thin plates can be directly applied to existing structures without making any changes of the original system, and the results are comparable to those with more complicated modifications.


ABSTRACT: It is helpful to evaluate scattering and acoustic radiation forces on spheres for idealized cases in which the effects of energy dissipation are ignorable. Let x denote the product of the acoustic wave number and the sphere's radius. Previously expansions were obtained for fluid and solid spheres involving powers of x and algebraic expressions containing material properties. The present analysis concerns the case of empty elastic shells and reveals how expansion coefficients also depend on shell thickness. Incident waves considered are plane traveling and standing waves, though relevance to Bessel wave-fields is also noted. The expansions give leading-order corrections to the usual Rayleigh scattering approximation.

References listed at the end of the paper:

Reference list at the end of the paper:


ABSTRACT: The acoustic properties of skulls and how they might affect hearing was investigated. Broadband noise was projected through the skull and spectrally analyzed using a Fast Fourier Transform and in 1/3-octave bands. Energetic peaks were found centered near 1050 and 4000 Hz, and troughs near 100 and 650 Hz, in addition to substantial individual differences (e.g., range greater than 29 dB around 900 Hz). Acoustic patterns from each skull were subsequently compared with air and bone conduction sensory thresholds. Individual skull patterns reliably correlated with bone conduction thresholds, but not air conduction thresholds, indicating a possible mediating role of the skull to hearing.

References listed at the end of the paper:
Vahid Naderyan, Richard Raspet, Craig J. Hickey and Mohammad Mohammadi, “Acoustic end corrections for micro-perforated plates”, The Journal of the Acoustical Society of America 146(4), EL399 (October 2019); https://doi.org/10.1121/1.5129560

ABSTRACT: Micro-perforated plates (MPPs) are acoustically important elements in micro-electro-mechanical systems (MEMS). In this work an analytical solution for perforated plates is combined with finite element method (FEM) to develop formulas for the reactive and resistive end effects of the perforations on the plate. The reactive end effect is found to depend on the hole radius and porosity. The resistive end effect is found to depend on hole radius only. FEM is also used to develop an understanding of the loss mechanism that corresponds to the resistive end effects. The developed models can be used in optimization studies of the MEMS and MPPs.

References listed at the end of the paper:


Peter A. Kerrian, Amanda D. Hanford, Dean E. Capone and Benjamin S. Beck, “Development of a perforated plate underwater acoustic ground cloak”, The Journal of the Acoustical Society of America 146(4), 2303 (October 2019); https://doi.org/10.1121/1.5127844

ABSTRACT: One of the commonly investigated transformation acoustic device is the ground cloak, which conceals a scattering object on a reflecting surface. Multiple studies have numerically simulated acoustic ground cloaks, but because of the challenges associated with realizing a homogeneous anisotropic metamaterial, only two acoustic ground cloaks have been built and tested. Perforated plastic plates in air were used to construct two and three dimensional ground cloaks and alternating layers of brass and water were used to construct an extended area ground cloak underwater. With underwater mass density anisotropy previously demonstrated for perforated steel plates, the primary focus of this article is to build and evaluate an underwater ground cloak with perforated steel plates. The cloak was evaluated at a water-air pressure release reflecting surface. The cloak successfully concealed the scattering object over a broad frequency range of 7–12 kHz.


ABSTRACT: This paper presents a technique for measuring the complex shear modulus of thin slabs of viscoelastic solids based on the measurement of the reflection and transmission of plane shear waves through a sample inserted between two delays lines. Reproducible shear wave transmission through the sample is achieved by inserting bond layers with controlled thickness between the delay lines and the sample and by characterizing beforehand the bond rheology. The frequency dependent complex shear modulus is quantitatively evaluated from the transmission and reflection coefficients using an exact model of interferences within the delay line-bond-sample-bond-delay line sandwich and by selecting the solution among the multiple solutions of the inverse problem from considerations on time of flight and sample thickness. Thanks to its reproducibility and accuracy, this method appears as an original and efficient technique for quantitatively characterizing the high frequency shear modulus of attenuating materials.

Lynda Chehami, Emmanuel Moulin, Julien de Rosny and Claire Prada, “Accuracy of Green's function estimation from correlation of diffuse elastic waves on thin plates”, The Journal of the Acoustical Society of America 146(5), 3505 (November 2019); https://doi.org/10.1121/1.5134066

ABSTRACT: In a reverberant cavity, when a noise field is sufficiently diffuse, the correlation of the signal measured by two sensors provides an estimation of the Green's function (GF) between them. Here, the convergence of this passive estimation in the case of elastic waves on thin plates is studied. A statistical approach is proposed, which relates the similarity between the cross correlation and the GF to the structural
properties of the plate and the number of uncorrelated sources. The analysis is sustained by experimental results obtained on an aluminum plate. This study allows us to evaluate the efficiency of passive structural health monitoring of plate-like structures based on noise correlation. Finally, a most interesting finding shows an absolute upper bound of the signal-to-noise ratio for GF quality reconstruction: 4Ns/5, independently of the plate properties.

Thomas J. Graham, Alastair P. Hibbins, J. Roy Sambles and Timothy A. Starkey, “Underwater acoustic surface waves on a periodically perforated metal plate”, The Journal of the Acoustical Society of America 146(6), 4569 (December 2019); https://doi.org/10.1121/1.5139651

ABSTRACT: Acoustic surface waves are supported at the surface of appropriately structured elastic materials. Here the excitation and propagation of the lowest-order surface mode supported by a square array of open-ended cavities on a metal plate submerged in water is demonstrated. This mode, which has a half-wavelength character in the cavity, arises due to inter-cavity interaction by evanescent diffraction of the pressure field, and forms a band from zero-frequency to an asymptotic limit frequency. The authors perform an acoustic characterization of the pressure field close to the surface of the perforated plate in the 60–100 kHz frequency range; sound is pulsed from a fixed point-like acoustic source, and the evolution of the acoustic field across the sample surface is measured as a function of time and space with a traversing detector. Using Fourier analysis, the dispersion is imaged between points of high-symmetry (Γ,X,M) and at planes in momentum-space at fixed frequencies. Beaming of acoustic energy on the surface over a narrow frequency band was observed, caused by the anisotropic mode dispersion of the acoustic surface wave on the square lattice. The measured dispersion shows good agreement with the predictions of a numerical model.

References listed at the end of the paper:

ABSTRACT: In this paper, the sound transmission loss (STL) of multi-layered infinite micro-perforated plates (MPPs) is studied. A prediction model for the STL of the multi-layered infinite MPPs is developed, where each MPP may or may not have a perforation, and the number of MPPs is arbitrary. When the frequency of interest is well below the critical frequency of the plate such that the effect of flexural vibration can be neglected compared to that of the inertia term, the mass is replaced by an equivalent complex mass. For numerical examples, single-, double- and triple-layered MPPs are studied. As the perforation ratio increases, the magnitude of the equivalent complex mass decreases rapidly, which in turn results in a decrease of the STL. It is observed that for very small perforation ratios, the mass-spring resonance frequencies in double- and triple-layered MPPs move toward a higher frequency as the perforation ratios increase. In addition, the dips at the resonance frequencies become blunt with increases in the perforation ratios due to the artificial damping induced by micro-perforations. It is also found that at a high frequency, the STL shows dips regardless of the perforation ratios when the wavenumber and air gap depths satisfy certain conditions.


ABSTRACT: This work aims to investigate the acoustic characteristics of a piezoelectric micro-perforated panel (MPP) absorber, which is made of a perforated polyvinylidene fluoride (PVDF) film with a backed airgap of 2 cm, as a combination of an active component and passive absorber. In addition to its inherent passive dissipation, as the PVDF-MPP was driven with proper voltages and oscillation frequencies, sound absorption coefficients of the absorber adjacent to the driving frequencies were significantly increased. Compared with mostly previous reported hybrid passive-active absorbers, this one is more compact, and its acoustic property is adjustable, it may provide an approach to achieve intelligent noise control.

References listed at the end of the paper:


Wei-Li Ma, Xian-Fang Li and Kang Yong Lee, “Third-order shear deformation beam model for flexural waves and free vibration of pipes”, The Journal of the Acoustical Society of America 147(3), 1634 (March 2020); https://doi.org/10.1121/10.000855

ABSTRACT: A third-order shear deformation beam model is proposed to analyze dynamic behavior of straight hollow cylinders of annular cross-section, in which shear stress vanishes on the inner and outer surfaces of the pipe. Shear deformation, warping, and rotational inertia of cross-section are all considered, and the shear correction factor is not needed. A single governing differential equation is derived for analyzing flexural wave propagation and free vibration of straight pipe-beams. The phase and group speeds of flexural waves propagating in pipes are determined for acoustic and optical modes. The dispersion of flexural waves is analyzed. The frequency equations are obtained explicitly for pipe-beams with ten typical boundary conditions including clamped, pinned, guided, and free ends. The natural frequencies of clamped-free, clamped-clamped, and pinned-pinned pipe-beams are evaluated for the first four vibration modes. A comparison of this paper's numerical results of the natural frequencies with the previous ones is made and turns out the effectiveness of the suggested method. The influences of the pipe's thickness and length on the natural frequencies and mode shapes for a cantilever pipe are presented.

Abdelhak Oulmane and Annie Ross, “Effects of material parameters on the transient dynamics of an impacted plate with partial constrained layer damping treatment”, The Journal of the Acoustical Society of America 147(3), 1939 (March 2020); https://doi.org/10.1121/10.000890

ABSTRACT: Due to their dynamic properties, viscoelastic materials are largely used in different sectors of industry to reduce noise and vibration in mechanical structures. In particular, partial constrained layer damping (PCLD) treatments have been used and studied in order to lessen stationary vibration and ringing noise. In the present work, simulations are performed to predict the effect of PCLD on the initial transient dynamic response of a planar impacted structure. The structure is a simply supported, rectangular aluminum plate impacted at its center with a small steel sphere. A parametric study is carried out based on a finite element model using ABAQUS 6.5 [Dassault Systèmes (ABAQUS Inc., Silicon Valley, CA)], whose results are well correlated with previous experiments. The model reflects the effects of several PCLD parameters on the initial transient response of the padded plate. The results from the parametric study show that the stiffness of the viscoelastic layer is a crucial parameter in the initial transient dynamic response of the impacted plate. It is also shown that the pads locally modify the dynamic properties of the plate thus causing changes in the time evolution of the deformation field. The combined use of PCLD to reduce both the initial transient response of the impacted structure and the ensuing flexural vibration could open the way for a better reduction of impact noise.

Hao Dong, Yong Shen and Hao Gao (Key Laboratory of Modern Acoustics (MOE), Institute of Acoustics, Nanjing University, Nanjing, China), “Shape optimization of acoustic horns using the multimodal method”, The Journal of the Acoustical Society of America 147(4), EL326 (April 2020); https://doi.org/10.1121/10.0001037

ABSTRACT: This paper presents a method for the shape optimization of an acoustic horn with respect to the impedance matching property based on the discrete multimodal method. The method models the horn as a series of short cylinders and takes mode coupling across the discontinuities into account. The optimization employs a
ABSTRACT: Automotive mufflers are heavy, large, and loud at low frequencies. Carbon nanotube (CNT) speakers are solid-state, lightweight, flexible, and capable of handling high temperatures. This makes them suitable as loudspeakers in active exhaust noise cancellation applications. A coaxial CNT speaker designed for active noise control in an exhaust system is developed. Test results for resistance, in-pipe axial sound pressure level, and efficiency are presented. The maximum in-pipe sound pressure level was above 120 dB (re 20 μPa) using 105 W of electrical power. The maximum power efficiency was 0.008%. The weight, dimensions, and sound pressure level of the speaker show promise for active exhaust noise cancellation applications.

References listed at the end of the paper:

ABSTRACT: The existing non-paraxial expression of audio sounds generated by a parametric array loudspeaker (PAL) is hard to calculate due to the fivefold integral in it. A rigorous solution of the Westervelt equation under the quasilinear approximation is developed in this paper for circular PALs by using the spherical
harmonics expansion, which simplifies the expression into a series of threefold summations with uncoupled angular and radial components. The angular component is determined by Legendre polynomials and the radial one is an integral involving spherical Bessel functions, which converge rapidly. Compared to the direct integration over the whole space, the spherical expansion is rigorous, exact, and can be calculated efficiently. The simulations show the proposed expression can obtain the same accurate results with a speed of at least 15 times faster than the existing one.

ABSTRACT: This work investigates anomalous transmission effects in periodic dissipative media, which is identified as an acoustic analogue of the Borrmann effect. For this, the scattering of acoustic waves on a set of equidistant resistive sheets is considered. It is shown both theoretically and experimentally that at the Bragg frequency of the system, the transmission coefficient is significantly higher than at other frequencies. The optimal conditions are identified: one needs a large number of sheets, which induce a very narrow peak, and the resistive sheets must be very thin compared to the wavelength, which gives the highest maximal transmission. Using the transfer matrix formalism, it is shown that this effect occurs when the two eigenvalues of the transfer matrix coalesce (i.e., at an exceptional point). Exploiting this algebraic condition, it is possible to obtain similar anomalous transmission peaks in more general periodic media. In particular, the system can be tuned to show a peak at an arbitrary long wavelength.

Paul Williams, Ray Kirby and James Hill, “Mode matching in axisymmetric fluid-filled pipes: Scattering by a flange”, The Journal of the Acoustical Society of America 147(6), 4202 (June 2020); https://doi.org/10.1121/10.0001473
ABSTRACT: Long range ultrasonic testing of pipelines sends an ultrasonic wave along a pipe wall and then detects scattering from defects present. It is well known that scattering by pipe fixtures and fittings, such as a flange, can cause distortion and interfere with the ability to identify defects. This article develops a theoretical model to investigate scattering from a flange in a fluid-filled pipe with elastic walls. Mode matching is used as this is a computationally efficient way to examine long lengths of pipe and for enforcing the appropriate axial continuity conditions over area discontinuities. A recent article presented a mode matching approach for a similar problem, and it is demonstrated here that a re-casting of the equations is necessary to ensure all of the appropriate matching conditions are enforced. Mode matching predictions are also compared with an alternative point collocation approach in order to provide an independent benchmark. Excellent agreement between mode matching and point collocation is demonstrated, and reflection and transmission coefficients are generated in order to show the resonant behaviour of a flange and illustrate that its influence is significant and strongly frequency dependent.

Zhimin Xu, Wei He, Xiangjun Peng, Fengxian Xin and Tian Jian Lu, “Sound absorption theory for micro-perforated panel with petal-shaped perforations”, The Journal of the Acoustical Society of America 148(1), 182 (July 2020); https://doi.org/10.1121/10.0001462
ABSTRACT: Micro-perforated panel (MPP) absorbers with circular perforations are used in many noise control applications due to their attractive wide-brand sound absorption performance. Different from a common MPP with circular perforations, a unique type of MPP absorber with petal-shaped perforations is proposed. The sound absorption theory for the MPP with petal-shaped perforations is developed by accurately considering the fluid velocity in the petal-shaped perforation hole. This theory can account for the effect of altered perforation morphology (from circular to petal) on sound absorption. Finite element simulations are performed to validate the proposed theory, with good agreement achieved. The sound absorption of MPP with petal-shaped perforations is compared with that of the traditional MPP with the same porosity. It is demonstrated that the change in hole shape significantly modifies the fluid velocity field and the flow resistivity in/of the hole, and hence the sound absorption of the proposed MPP with petal-shaped perforations can outperform that of the traditional MPP in the considered case. This work proposes a general MPP theory that not only contains the classical Maa's theory for circular MPP, but also accounts for the MPP with petal-shaped perforations.
Muhammad Afzal and Sajid Shafique, “Attenuation analysis of flexural modes with absorbent lined flanges and different edge conditions”, The Journal of the Acoustical Society of America 148(1), 85 (July 2020); https://doi.org/10.1121/10.0001495

ABSTRACT: The analysis of fluid-structure coupled waveforms and the attenuation of these waveforms in a flexible waveguide is carried out. The physical configuration contains an expansion chamber connected by an extended inlet/outlet by means of vertical lined flanges. The governing boundary value problem is solved by using Mode-Matching (MM) technique. The associated eigen expansions of field potentials include non-orthogonal eigenfunctions and the related eigen-sub-systems are classified in the non-Sturm Liouville category, whereby the use of generalized orthogonal characteristics has ensured the point-wise convergence of solution. The low frequency approximation (LFA) which relies on the limited propagating modes is developed and is compared with MM solution. In the low frequency regime, a good agreement between MM and LFA results is found. Furthermore, the numerical experiments are performed to analyze the effects of absorbent linings and edge conditions on the attenuation of flexural modes. The guiding structure is exited with the structure-borne mode incident as well as the fluid-borne mode incident. It is found that the use of edge conditions and the absorbent linings significantly affect the attenuation of structure-borne mode and fluid-borne mode, respectively.

Jiaxin Zhong, Shuping Wang, Ray Kirby and Xiaojun Qiu, “Insertion loss of a thin partition for audio sounds generated by a parametric array loudspeaker”, The Journal of the Acoustical Society of America 148(1), 226 (July 2020); https://doi.org/10.1121/10.0001568

ABSTRACT: Unlike the audio sound generated by traditional sources, the directivity of that generated by a parametric array loudspeaker (pal) deteriorates significantly after passing through a thin partition. To study this phenomenon, the pal radiation model based on the Westervelt equation, and the plane wave expansion method are used to calculate the sound fields behind a sheet of aluminum foil and a porous material blanket under the quasi-linear assumption, where the paraxial approximation is assumed only for ultrasonic waves. The audio sounds generated by a point monopole and a traditional directional source are presented for comparison. Both simulation and experiment results show that the transmitted sound from a pal behind the thin partition is small and less focused on the radiation axis because most of the ultrasounds forming the directivity of the pal is blocked by the thin partition which has little effect on the traditional audio sources.


ABSTRACT: The system formed by a trumpet player and his/her instrument can be seen as a non-linear dynamic system and modeled by physical equations. Numerical tools can then be used to study these models and clarify the influence of the model parameters. The acoustic input impedance, for instance, is strongly dependent on the geometry of the air column and is therefore of primary interest for a musical instrument maker. In this study, a method of continuation of periodic solutions based on the combination of the Harmonic Balance Method (HBM) and the Asymptotic Numerical Method (ANM) is applied to a physical model of brass instruments. It allows the study of the evolution of the system where one parameter of the model (static mouth pressure) varies. This method is used to compare different B♭ trumpets on the basis of two descriptors (hysteresis behavior and dynamic range) computed from the continuation outputs. Results show that this methodology enables the differentiation of instruments in the space of the calculated descriptors. Calculations for different values of the lip parameters are also performed to confirm that the obtained categorization is independent of variations of lip parameters.

Congshuang Jiang, Xianhui Li, Tuo Xing and Bin Zhang, “Additional length model for the impedance end correction of microperforated panels”, The Journal of the Acoustical Society of America 148(2), 566 (August 2020); https://doi.org/10.1121/10.0001642

ABSTRACT: An additional length model is usually used to describe the reactive part of the impedance end correction of microperforated panels, which is extended to describe the resistive part. The cross-sectional impedance is computed along the axis of one perforation cell with a circular hole. Except for the obvious jumps
in the narrow regions at the inlet and outlet of the perforation, the impedance varies linearly along the axis following exactly that of the viscous wave in the circular hole. The additional length for the impedance end correction is obtained by extrapolating the linearly varying impedance inside the hole. Empirical models for the resistive and reactive additional lengths are obtained based on the thermoviscous acoustic simulation with 96 test cases. Within an error of about 10%, a unified additional length model is presented for both the resistive and reactive parts of the impedance end correction. Comparison with other existing models shows the accuracy of the proposed model.

Sipei Zhao, Feng Niu and Xiaojun Qiu, “Effects of geometric properties of a static pressure tube on its frequency response”, The Journal of the Acoustical Society of America 148(3), 1289 (September 2020); https://doi.org/10.1121/10.0001816

ABSTRACT: Static pressure tubes are widely used to measure the static pressure in turbulent flows. Existing work focuses on the alteration of the static pressure tubes to the flow field. This paper investigates the effects of the geometric properties of a static pressure tube on the frequency response. A theoretical formulation is developed to describe the relationship between the sound pressure inside and outside the tube. The numerical simulation results show that the peaks in the frequency response move to lower frequencies when the tube diameter, tube length, and orifice depth increase and when the orifice diameter decreases. Experiments with a 3D-printed static pressure tube were conducted to verify the analytical results. The proposed model can be used to optimize the static pressure tube in the design stage or to correct the measurement results afterwards instead of cumbersome experimental calibration.


ABSTRACT: In this study, we design a type of rotationally symmetric lattice with curved beams and investigate the wave propagation properties of the structure. The analytical model of the structure is established to obtain the mass and stiffness matrices first. Because the dimensions of the mass and stiffness matrices will become very large if the structure is meshed with a number of small elements, we introduce the symplectic solution method to overcome the above difficulties of solving the eigenvalue problem. The effects of geometrical parameters and slenderness ratios on the distributions of bandgaps and variations of group velocities are investigated. We also numerically investigate the dynamic wave dispersion behavior and the transient responses of displacement and transmission coefficients in lattices subjected to excitations. Excellent agreement is obtained between the results obtained by the symplectic solution method and numerical simulations. The special wave-attenuation property of this type of structure is demonstrated and validated through experimental testing. The measured transmission coefficients in lattices with different geometrical parameters and slenderness ratios are in good agreement with the numerical simulations. The work provides a method for calculating wave behaviors in lattices and obtains lower bandgaps and directional wave propagation.


ABSTRACT: When investigating the wave propagation and mode conversions in a thin aluminum plate partially immersed in water, a kind of wave packet interaction was observed. It was found that the transmitted ultrasonic signal consists of different wave packets, which contain essential information of different wave types. When the incident angle is very small, the signals can be identified as the major wave packet followed by its tail. The major packet includes the information of the incident wave while the tail is related to the mode conversion and propagation in the plate. When the incident angle increased, the major packet was literally engulfed by its tail, indicating that the directly transmitted incident ultrasound disappeared and more energy was coupled into the plate. The interactions between different wave packets found here reveal the excitation and propagation mechanisms of Lamb waves in plates, which would benefit applications in ultrasonic imaging, signal recognition, underwater acoustic communication, and so on.
can be solved to obtain the system response. As shown by numerical applications on typical naval test cases, the


ABSTRACT: This paper proposes a numerically stable method for modelling a fluid-loaded multilayered cylindrical shell excited by a plane wave, which solves the fluid instability problem that is usually observed when using the well-known transfer matrix method (TMM). In the considered modelling, each layer can be either a viscoelastic coating described by a general three-dimensional (3D) elasticity model or an intermediate perfect fluid layer. The transfer matrix of each layer relating the state vector at the layer's two interfaces is estimated with an appropriate standard method. Instead of multiplying together the layer transfer matrices in order to deduce the transfer matrix of the multilayer cylinder, we propose an alternative approach. This one consists in writing the continuity relations at each interface of the considered systems and in building a global matrix that can be solved to obtain the system response. As shown by numerical applications on typical naval test cases, the


ABSTRACT: The reflection of audio sounds generated by a parametric array loudspeaker (PAL) is investigated in this paper. The image source method and the non-paraxial PAL radiation model under the quasilinear approximation are used to calculate the reflected audio sound from an infinitely large surface with an arbitrary incident angle. The effects of the surface absorption in the ultrasound frequency range are studied, and the simulation and experiment results show that the reflection behavior of audio sounds generated by a PAL is different from those generated by traditional audio sources. The reason is that the reflected sound generated by the PAL consists of the reflection of audio sounds generated by incident ultrasounds and the audio sounds generated by the reflected ultrasound, and it is the latter that determines the directivity of the reflected audio sound.


ABSTRACT: To study the effect of “warming up” a wind instrument, the acoustic impedance spectrum at the mouthpiece of a trombone was measured after different durations of playing. When an instrument filled with ambient air is played in a room at 26–27 °C, the resonance frequencies initially fall. This is attributed to CO2 in the breath initially increasing the density of air in the bore and more than compensating for increased temperature and humidity. Soon after, the resonance frequencies rise to near or slightly above the ambient value as the effects of temperature and humidity compensate for that of increased CO2. The magnitudes and quality factors of impedance maxima decrease with increased playing time whereas the minima increase. Using the measured change in resonance frequency, it proved possible to separate the changes in impedance due to changes in density and changes in acoustic losses due to water condensing in the bore. When the room and instrument temperature exceed 37 °C, condensation is not expected and, experimentally, smaller decreases in magnitudes and quality factors of impedance maxima are observed. The substantial compensation of the pitch fall due to CO2 by the rise due to temperature and humidity is advantageous to wind players.


ABSTRACT: The reflection of audio sounds generated by a parametric array loudspeaker (PAL) is investigated in this paper. The image source method and the non-paraxial PAL radiation model under the quasilinear approximation are used to calculate the reflected audio sound from an infinitely large surface with an arbitrary incident angle. The effects of the surface absorption in the ultrasound frequency range are studied, and the simulation and experiment results show that the reflection behavior of audio sounds generated by a PAL is different from those generated by traditional audio sources. The reason is that the reflected sound generated by the PAL consists of the reflection of audio sounds generated by incident ultrasounds and the audio sounds generated by the reflected ultrasound, and it is the latter that determines the directivity of the reflected audio sound.


ABSTRACT: This paper proposes a numerically stable method for modelling a fluid-loaded multilayered cylindrical shell excited by a plane wave, which solves the fluid instability problem that is usually observed when using the well-known transfer matrix method (TMM). In the considered modelling, each layer can be either a viscoelastic coating described by a general three-dimensional (3D) elasticity model or an intermediate perfect fluid layer. The transfer matrix of each layer relating the state vector at the layer's two interfaces is estimated with an appropriate standard method. Instead of multiplying together the layer transfer matrices in order to deduce the transfer matrix of the multilayer cylinder, we propose an alternative approach. This one consists in writing the continuity relations at each interface of the considered systems and in building a global matrix that can be solved to obtain the system response. As shown by numerical applications on typical naval test cases, the
The Journal of the Acoustical Society of America 148(6), 3445 (December 2020); https://doi.org/10.1121/10.0002778

Maxime Farin, Chloë Palerm, Claire Prada and Julien de Rosny, “Localization of unbounded contacts on vibrating elastic plates”, The Journal of the Acoustical Society of America 148(6), 3445 (December 2020);

ABSTRACT: Detection and localization of unbounded contacts in industrial structures are crucial for user safety. However, most structural health monitoring techniques are either invasive, power-consuming, or rely on time-varying baseline comparison. A passive acoustic method is proposed to localize unbounded contacts in plate-like structures, using the acoustic emissions by the contacts when they are excited by ambient noise. The technique consists of computing the correlation matrix of the signals measured by a set of receivers and applying to this matrix a beamforming algorithm accounting for flexural wave dispersion. To validate the technique, an experimental setup is developed in which three idealized unbounded contacts are created on a thin plate excited by a shaker. How the quality of the defect localization depends on the defect type, receiver number, and the characteristics of the noise is investigated. Finally, it is shown that the localization of unbounded contacts is possible using either an acoustic ambient noise source or a more realistic jet engine noise.


ABSTRACT: In this paper, we present a shape optimization method for designing stiffeners on thin-walled or shell structures. Solutions are proposed to deal with a stiffness maximization problem and a volume minimization problem, which are subject to a volume constraint and a compliance constraint, respectively. The boundary shapes of the stiffeners are determined under a condition where the stiffeners are movable in the in-plane direction to the surface. Both problems are formulated as distributed-parameter shape optimization problems, and the shape gradient functions are derived using a material derivative method and an adjoint variable method. The optimal free-boundary shapes of the stiffeners are obtained by applying the derived shape gradient function to the H1 gradient method for shells, which is a parameter-free shape optimization method proposed by one of the authors. Several stiffener design examples are presented to validate the proposed method and demonstrate its practical utility.

References listed at the end of the paper:

ABSTRACT: This paper demonstrates the application of factor screening to multivariable crashworthiness design of the vehicle body subjected to the side impact loading. Crashworthiness, influenced unequally by disparate factors such as the structural dimensions and material parameters, represents a natural benchmark criterion to judge the passive safety quality of the automobile design. In order to single out the active factors which pose a profound influence on the crashworthiness of vehicle bodies subjected to the side impact loading, the unreplicated saturated factorial design is adopted to tackle the obstacle from the factor screening due to its huge benefits in the efficiency and accuracy. In this paper, two different kinds of vehicles are analyzed by the unreplicated saturated factorial design for multivariable crashworthiness and the optimization results enhance the crashworthiness of vehicle. This method overcomes the limitations of design variables selection which depends essentially on experience, and solves the in-efficiency problems caused by the direct optimization design without the selection of variables. It will shorten the design cycle, decrease the development costs and will have a certain reference value for the improvement of the vehicle’s crashworthiness performance.

References listed at the end of the paper:

- Economic Commission for Europe (ECE) (2003) Regulation No. 95, uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision, October

ABSTRACT: This paper describes a design methodology for piezoelectric energy harvesters that thinly encapsulate the mechanical devices and exploit resonances from higher-order vibrational modes. The direction of polarization determines the sign of the piezoelectric tensor to avoid cancellations between opposite polarizations in the same circuit. The resultant modified equations of state are solved by finite element method (FEM). Combining this method with the solid isotropic material with penalization (SIMP) method for piezoelectric material, we have developed an optimization methodology that optimizes the piezoelectric material layout and polarization direction. Updating the density function of the SIMP method is performed based on sensitivity analysis, the sequential linear programming on the early stage of the optimization, and the phase field method on the latter stage of the optimization to obtain clear optimal shapes without intermediate density. Numerical examples are provided that illustrate the validity and utility of the proposed method.

References listed at the end of the paper:


ABSTRACT: The paper deals with a new uniform crashworthiness concept of car bodies optimization of high-speed trains. The design optimization was done from the point of view of structural protection of occupants’ survival space. For the reason that it is impossible to find a highly probable scenario for the derailment, the authors decided to find the solution in the form of rigid frame structure (survival cells), which will provide safety space for the passengers. In the optimization example a typical passenger car body was divided into cells of approximately equal dimensions. The optimization problem was to minimize the mass of the structure with stress constraints. The survival cell was subjected to a sequence of high value loads. The loads are acting in an asynchronous way in three load directions what gives the optimized structure uniform crashworthiness. The optimization strategy consists of three stages. In the first step, the constant criterion surface algorithm (CCSA) of topology optimization is applied to find a preliminary solutions. For improving the manufacture properties of this solution, a new concept of design space constraints was proposed. The sizing optimization with evolutionary algorithms was used to define a thin-walled structure in the second step. For evolutionary optimization a standard procedure was employed. Finally, CCSA optimization algorithm was applied again to remove excessive material from a car body structure. As the optimization result a new design proposition of a car body with multiple survival cells of high uniform stiffness was obtained. By maintaining passengers’ survival space, the passive safety of a high-speed car body was significantly increased.

References listed at the end of the paper:

- CEN (2002) Railway applications—structural requirements of railway vehicle bodies. EN 12663
- CEN (2008) Railway applications—crashworthiness requirements for railway vehicle bodies. EN 15227

ABSTRACT: Reliability-based design optimization (RBDO) in practical applications is hindered by its huge computational cost during structure reliability evaluating process. Kriging-model-based RBDO is an effective method to overcome this difficulty. However, the accuracy of Kriging model depends directly on how to select the sample points. In this paper, the local adaptive sampling (LAS) is proposed to enhance the efficiency of constructing Kriging models for RBDO problems. In LAS, after initialization, new samples for probabilistic constraints are mainly selected within the local region around the current design point from each optimization iteration, and in the local sampling region, sample points are first considered to be located on the limit state constraint boundaries. The size of the LAS region is adaptively defined according to the nonlinearity of the performance functions. The computation capability of the proposed method is demonstrated using three mathematical RBDO problems and a honeycomb crash-worthiness design application. The comparison results show that the proposed method is very efficient.

References listed at the end of the paper:

Kuczera RC, Mourelatos ZP, Nikolaidis E (2010) System RBDO with correlated variables using probabilistic re-analysis and local metamodels. ASME, Montréal, Quebec
Lee I, Choi KK, Gorsich D (2011a) Equivalent standard deviation to convert high-reliability model to low-reliability model for efficiency of sampling-based RBDO. ASME, Washington, DC

ABSTRACT: Full-vehicle finite element models have a large number of degrees of freedom. This makes them ill suited for design work, numerical optimization or stochastic analyses in an early development phase, because they require a high level of detailed information, most of which is yet unavaiable. They are also computationally expensive, thus severely limiting the number of function evaluations. Both difficulties can be alleviated through the use of substitute models, which capture only the relevant mechanisms, associated with a smaller number of degrees of freedom. This work provides a substitute modeling and calibration methodology which improves output value prediction for substantial deviations from the reference design, including three significant innovations. First, a new measure to quantify the agreement of calibrated and reference model is proposed. Second, a multi-model calibration is introduced, which incorporates an array of reference models for calibration and cross validation. Third, the calibration is performed on the basis of a hybrid objective function, weighting the agreement of the time dependent system states, called physics-based contribution, and the time independent output values, called predictive or regression-based. This ensures a large range of validity while simultaneously improving the predictive quality of the model. It is also shown that the discretization of the structural mass has negligible influence on the target values, allowing for reduced model complexity.

References listed at the end of the paper:

- Kamal MM (1970) Analysis and simulation of vehicle to barrier impact. SAE paper 700414
ABSTRACT: Design optimization is presented for the crashworthiness improvement of an automotive body structure. The optimization objective was to improve automotive crashworthiness conditions according to the defined criterion (occupant chest deceleration) during a full frontal impact. The controllable factors used in this study consisted of six internal parts of the vehicle’s frontal structure in a condition that their thickness was the “design parameter”. First using the Taguchi method, this study analyzed the optimum conditions in discontinuous design area and impact factors and their optimal levels of design objectives were obtained by analyzing the experimental results. Next to model a precise understanding of the explicit mathematical input–output relationship, fuzzy logic is utilized which make use of full factorial design set of experimental test cases resulted from Taguchi predicting formulations. Interestingly, the optimum conditions for automotive crashworthiness occurred with 2.72% improvement in the defined crashworthiness criterion in comparison with the baseline design while selected structural parts experienced mass reduction by 8.23%.

References listed at the end of the paper:


ABSTRACT: A framework is developed for structural optimization using an Element Free Galerkin (EFG) method for analyzing the structure, a kriging for surrogate model, and a Genetic Algorithm (GA) for finding the optimum design. The framework is tested for a plate with curvilinear stiffeners which are now possible with additive manufacturing such as 3-D printing. The efficiency and accuracy of the framework is compared with two other approaches: 1) MD.PATRAN, MD.NASTRAN and VisualDOC as implemented in EBF3PanelOpt, a Computational Design Environment being developed at Virginia Tech to optimally design panels with curvilinear stiffeners, and 2) a kriging, MD.PATRAN and MD.NASTRAN and genetic algorithms. All three approaches use optimization methods on both the shape and size design variables. The optimization scheme is a two-step optimization approach that divides the design variables into size and shape variables. First, the buckling parameter is maximized over the shape design variable, and then the mass is minimized over the size variable with constraint on buckling. The comparison between the three approaches shows the efficiency of the developed framework.

References listed at the end of the paper:

**ABSTRACT:** An automated optimization procedure based on successive response surface method is presented. The method is applied to weight optimization of a stiffened plate used in marine structures. In the design space the surrogate model is spanned sequentially into an optimally restricted subspace that is converging towards at least a local optimum. Both objective function and all constraint functions are modeled using linear response surface method enabling the use of a robust and efficient simplex algorithm for the optimizations. Special attention is paid to CAD and FEM-model linking that plays a central role in practical industrial applications. In this project SOLIDWORKS and ANSYS software are adopted for structural modeling and analysis, respectively, and the optimization is carried out in a MatLab environment. The reported results achieved in this project prove the robustness and effectiveness of the proposed approach.

**References listed at the end of the paper:**

- IACS (2009) Common Structural Rules for Bulk Carriers
- Tamijani AY, Kapania RK (2010b) Buckling and static analysis of curvilinearly stiffened plates using mesh-free method. AIAA J 48(12):2739–2751
Guangyong Sun, Zueguan Song, Seokheum Baek and Qing Li, “Robust optimization of foam-filled thin-walled structure based on sequential Kriging metamodel”, Structural and Multidisciplinary Optimization, Vol. 49, No. 6, pp 897-913, June 2014.

ABSTRACT: Deterministic optimization has been successfully applied to a range of design problems involving foam-filled thin-walled structures, and to some extent gained significant confidence for the applications of such structures in automotive, aerospace, transportation and defense industries. However, the conventional deterministic design could become less meaningful or even unacceptable when considering the perturbations of design variables and noises of system parameters. To overcome this drawback, a robust design methodology is presented in this paper to address the effects of parametric uncertainties of foam-filled thin-walled structure on design optimization, in which different sigma criteria are adopted to measure the variations. The Kriging modeling technique is used to construct the corresponding surrogate models of mean and standard deviation for different crashworthiness criteria. A sequential sampling approach is introduced to improve the fitness accuracy of these surrogate models. Finally, a gradient-based sequential quadratic program (SQP) method is employed from 20 different initial points to obtain a quasi-global robust optimum solution. The optimal solutions were verified by using the Monte Carlo simulation. The results show that the presented robust optimization method is fairly effective and efficient, the crashworthiness and robustness of the foam-filled thin-walled structure can be improved significantly.

References listed at the end of the paper:


ABSTRACT: This paper presents a gradient based topology optimization method for Discrete Material and Thickness Optimization of laminated composite structures, labelled the DMTO method. The capabilities of the proposed method are demonstrated on mass minimization, subject to constraints on the structural criteria; buckling load factors, eigenfrequencies, and limited displacements. Furthermore, common design guidelines or rules, referred to as manufacturing constraints, are included explicitly in the optimization problem as series of linear inequalities. The material selection and thickness variation are optimized simultaneously through interpolation functions with penalization. Numerical results for several parameterizations of a finite element model of a generic main spar from a wind turbine blade are presented. The different parameterizations represent different levels of complexity with respect to manufacturability. The results will thus give insight into the relation between potential weight saving and design complexity. The results show that the DMTO method is capable of solving the problems robustly with only few intermediate valued design variables.

References listed at the end of the paper:

Rory Clune (1), Denis Kelliher (2), James C. Robinson (3) and John S. Campbell (3)
(1) MIT, Cambridge, Massachusetts, USA
(2) University College Cork, Cork, Ireland
(3) Kepler Engineering Software Ltd., National Software Centre, Mahon, Cork, Ireland


ABSTRACT: Cardiovascular stents have been used since the 1990s to treat atherosclerosis, one of leading causes of death in the western world, and structural optimization has led to significant improvements in stent performance. Much of the potential variation in stent geometry, however, has remained unconsidered. This paper presents a non-uniform rational basis spline (NURBS) parameterization of a stent, the inclusion of structural fatigue resistance as a design consideration, and the results of a design optimization based on response surface techniques. Results show the feasibility and merits of the NURBS approach, which models a much broader range of shapes than was previously possible. Multi-objective optimization produces a range of geometrically diverse Pareto-optimal designs; these can be used to develop future clinical design guides, accounting for the variation observed across patients. We conclude by motivating future work with increasingly complex physical modeling and optimization capabilities.

References listed at the end of the paper:
- Myers RH, Montgomery DC, Anderson-Cook CM (1971) Response surface methodology. Allyn and Bacon, Boston

ABSTRACT: Most of the conventional design methods of large-scale domes need deep engineering insight; furthermore, they hardly give the most economical solutions. Therefore, in this paper, a new practical design algorithm is presented to automate optimal geometry and sizing design of the latticed space domes through the idea of using parametric mathematical functions. Moreover, a simple approach is developed for the optimal sizing design of trusses with outsized number of elements. The robust technique of particle swarm optimization is employed to find the solution of the propounded optimization problem. Some numerical examples on the minimum weight design of several famous domes are provided to demonstrate the efficiency of the proposed design algorithm.

References listed at the end of the paper:

ABSTRACT: In this study, a two-stage optimization framework is proposed for cylindrical or flat stiffened panels under uniform or non-uniform axial compression, which are extensively used in the aerospace industry. In the first stage, traditional sizing optimization is performed. Based on the buckling or collapse-like deformed shape evaluated for the optimized design, the panel can be divided in sub-regions each of which shows characteristic deformations along axial and circumferential directions. Layout optimization is then performed using a stiffener spacing distribution function to represent the location of each stiffener. A layout coefficient is assigned to each sub-region and the overall layout of the panel is optimized. Three test problems are solved in order to demonstrate the validity of the proposed optimization framework: remarkably, the load-carrying capacity improves by 17.4%, 66.2% and 102.2% with respect to the initial design.

References listed at the end of the paper:


Bo Wang, Peng Hao, Gang Li, Kuo Tian, Kaifan Du, Xiaojun Wang, Xi Zhang and Xiaohan Tang, “Two-stage size-layout optimization of axially compressed stiffened panels”, Structural and Multidisciplinary Optimization, Vol. 50, No. 2, pp 313-327 August 2014,

**ABSTRACT:** This paper presents a numerical shape optimization method for the optimum free-form design of shell structures. It is assumed that the shell is varied in the out-of-plane direction to the surface to determine the optimal free-form. A compliance minimization problem subject to a volume constraint is treated here as an example of free-form design problem of shell structures. This problem is formulated as a distributed-parameter, or non-parametric, shape optimization problem. The shape gradient function and the optimality conditions are theoretically derived using the material derivative formulae, the Lagrange multiplier method and the adjoint variable method. The negative shape gradient function is applied to the shell surface as a fictitious distributed traction force to vary the shell. Mathematically, this method is a gradient method with a Laplacian smoother in the Hilbert space. Therefore, this shape variation makes it possible both to reduce the objective functional and to maintain the mesh regularity simultaneously. With this method, the optimal smooth curvature distribution of a shell structure can be determined without shape parameterization. The calculated results show the effectiveness of the proposed method for the optimum free-form design of shell structures.

**References listed at the end of the paper:**


ABSTRACT: It is impractical to implement arbitrary-shaped piezoelectric patches from the view point of manufacturability of fragile piezoelectric ceramics, thus using designable electrode layers to deliver desired actuation forces provides a more realistic option in engineering applications. This study develops a topological design method of surface electrode distribution over piezoelectric sensors/actuators attached to a thin-walled shell structure for reducing the sound radiation in an unbounded acoustic domain. In the optimization model, the sound pressure norm at specific reference points under excitations at a certain excitation frequency or in a given frequency range is taken as the objective function. The pseudo densities for indicating absence and presence of surface electrodes at each element are taken as the design variables, and a penalized relationship between the densities and the active damping effect is employed. The vibrating structure is discretized with finite element model for the frequency response analysis and the sound radiation analysis in the unbounded acoustic domain is treated by boundary element method. The applied voltage on each actuator is determined by the constant gain velocity feedback (CGVF) control law. The technique of the complex mode superposition in the state space, in conjunction with a model reduction transformation, is adopted in the response analysis of the system characterized by a non-proportional active damping property. In this context, the adjoint-variable sensitivity analysis scheme is derived. The effectiveness and efficiency of the proposed method are demonstrated by numerical examples, and several key factors on the optimal designs are also discussed.

References listed at the end of the paper:

ABSTRACT: Gridshells are defined as structures that have the shape and rigidity of a double curvature shell but consist of a grid instead of a continuous surface. This study concerns those obtained by elastic deformation of an initially flat two-way grid. This paper presents a novel approach to generate gridshells on an imposed shape under imposed boundary conditions. A numerical tool based on a geometrical method, the compass method, is developed. It is coupled with genetic algorithms to optimize the orientation of gridshell bars in order to minimize the stresses and therefore to avoid bar breakage during the construction phase. Examples of application are shown.

References listed at the end of the paper:


Kristo Mela, “Resolving issues with member buckling in truss topology optimization using a mixed variable approach”, Structural and Multidisciplinary Optimization, Vol. 50, No. 6, pp 1037-1049 December 2014, ABSTRACT: In this paper, several issues related to member buckling in truss topology optimization are treated. In the conventional formulations, where cross-sectional areas of ground structure members are the design variables, member buckling constraints are known to be very difficult to handle, both numerically and theoretically. Buckling constraints produce a feasible set that is non-connected and non-convex. Furthermore, the so-called jump in the buckling length phenomenon introduces severe difficulties for determining the correct buckling strength of parallel consecutive compression members. These issues are handled in the paper by employing a mixed variable formulation of truss topology optimization problems. In this formulation, member buckling constraints become linear. Parallel consecutive members of the ground structure are identified as chains, and overlapping members are added to the ground structure between each pair of nodes of a chain. Buckling constraints are written for every member, and linear constraints on the binary member existence variables disallow impractical topologies. In the proposed approach, Euler buckling as well as buckling according to various design codes, can be incorporated. Numerical examples demonstrate that the optimum topology depends on whether the buckling constraints are derived from Euler’s theory or from design codes. References listed at the end of the paper:


ABSTRACT: A double stage sequential optimization algorithm for finding the optimal fiber content and its distribution in solid composites, considering uncertain design parameters, is presented. In the first stage, the optimal amount of fiber in a Fiber Reinforced Composite (FRC) structure with uniformly distributed fibers is conducted in the framework of a Reliability Based Design Optimization (RBDO) problem. In the second stage, the fiber distribution optimization having the aim to more increase in structural reliability is performed by defining a fiber distribution function through a Non-Uniform Rational B-Spline (NURBS) surface. The output of stage 1 (optimal fiber content for homogeneously distributed fibers) is considered as the input of stage 2. The output of stage 2 is Reliability Index (RI) of the structure with optimal fiber content and optimal fiber distribution. First order reliability method in order to approximate the limit state function and a homogenization approach, based on the assumption of random orientation of fibers in the matrix, are implemented. The proposed combined model is able to capture the role of available uncertainties in FRC structures through a computationally efficient algorithm using all sequential, NURBS and sensitivity based techniques. Performed case studies show as an increase in model uncertainties yields to structural unreliability. Moreover, when system unreliability increases fiber distribution optimization becomes more influential.

References listed at the end of the paper:


ABSTRACT: This paper proposes a convenient numerical form-finding method for designing the minimal surface, or the equally tensioned surface of membrane structures with specified arbitrary boundaries. Area minimization problems are formulated as a distributed-parameter shape optimization problem. The internal volume or the perimeter is added as a constraint according to the structure type such as a pneumatic or a suspension membrane. It is assumed that the membrane is varied in the out-of-plane and/or the in-plane direction to the surface. The shape sensitivity function for each problem is derived using the material derivative method. The minimal surface is determined without shape parameterization by the free-form optimization method, a gradient method in the Hilbert space, where the shape is varied by the traction force in proportion to the sensitivity function under the Robin boundary condition. The calculated results show the effectiveness and practical utility of the proposed method for optimal form-finding of membrane structures.

References listed at the end of the paper:

ABSTRACT: Multilevel optimization including progressive failure analysis and robust design optimization for composite stiffened panels, in which the ultimate load that a post-buckled panel can bear is maximized for a chosen weight, is presented for the first time. This method is a novel robust multiobjective approach for structural sizing of composite stiffened panels at different design stages. The approach is integrated at two design stages labelled as preliminary design and detailed design. The robust multilevel design methodology integrates the structural sizing to minimize the variance of the structural response. This method improves the product quality by minimizing variability of the output performance function. This innovative approach simulates the sequence of actions taken during design and structural sizing in industry where the manufacture of the final product uses an industrial organization that goes from the material characterization up to trade constraints, through preliminary analysis and detailed design. The developed methodology is validated with an example in which the initial architecture is conceived at the preliminary design stage by generating a Pareto front for competing objectives that is used to choose a design with a required weight. Then a robust solution is sought in the neighbourhood of this solution to finally find the layup for the panel capable of bearing the highest load for the given geometry and boundary conditions.

References listed at the end of the paper:
- Cheung YK (1968) The finite strip method in the analyze of elastic plates with two opposite simply supported ends. ICE Proc 40(6):1–7
Version A (2011) 6.11 documentation. Dassault Systemes Simulia Corp., Providence, RI, USA

ABSTRACT: In this paper a fusion metamodeling approach is suggested as a method for reducing the experimental and computational effort generally required for calibrating the parameters of FEM simulations models. The metamodel is used inside an optimization routine for linking data coming from two different sources: simulations and experiments. The method is applied to a real problem: the optimal design of a metal foam filled tube to be used as an anti-intrusion bar in vehicles. The model is hierarchical, in the sense that one set of data (the experiments) is considered to be more reliable and it is labeled as “high-fidelity” and the other set (the simulations) is labeled as “low-fidelity”. In the proposed approach, Gaussian models are used to describe results of computer experiments because they are flexible and they can easily interpolate data coming from deterministic simulations. Since the results of experiments are obviously fully accurate, but aleatory, a second stage (“linkage”) model is used, which adjusts the prediction provided by the first model to more accurately represent the real experimental data. In the paper, the modeling and prediction ability of the method is first demonstrated and explained by means of artificially generated data and then applied to the optimization of foam filled tubular structures. The fusion metamodel yields comparable predictions (and optimal solution) if built over calibrated simulations vs. non-calibrated FEM models.

References listed at the end of the paper:


Xia H., Yu Din Y., Mallick B. (2011) Bayesian hierarchical model for combining misaligned two resolution metrology data. IIE Trans 43:242–258
Shu-yuan Zhao, Jian-jun Li, Chuan-xin Zhang, Wen-jiao Zhang, Xiu Lin, Xiao-dong He and Yong-tao Yao, “Thermo-structural optimization of integrated thermal protection panels with one-layer and two-layer corrugated cores based on simulated annealing algorithm”, Structural and Multidisciplinary Optimization, Vol. 51, No. 2, pp 479-494, February 2015,

ABSTRACT: To explore weight saving potential capability, a multidisciplinary optimization procedure based on simulated annealing algorithm was proposed to unveil the minimum weight design for integrated thermal protection system subjected to in-service thermal and mechanical loads. The panel configurations with one-layer and two-layer corrugated cores are considered for comparison. Heat transfer and structural field analysis for each panel configuration were performed to obtain the temperature, buckling, stress and deflection responses for structural components of interest, which were then considered as critical constraints of the optimization problem. Sensitivity analysis was performed to disclose the effect of individual design variables on the thermo-structural extreme responses, and the designed thermal protection system performance and weight for the two configurations were discussed. The results demonstrated that the two-layer structure provides superior structural efficiency and performance to resist thermal buckling deformation in comparison with the one-layer panel. Its area-specific weight is reduced by more than 14–29 % with respect to the one-layer panel design, and 30–50 % weight efficient can be implemented at higher thermal buckling constraint levels, while keeping considerable temperature, stress and deflection margins.

References listed at the end of the paper:
- Martin JD, Simpson TW (2005) Use of kriging models to approximate deterministic computer models. AIAA J 43 (7):853–863
References listed at the end of the paper:

- Ravishankar B, Sankar BV, Haftka RT (2011) Uncertainty analysis of integrated thermal protection system with rigid insulation bars. 52nd AIAA/ASME/ASCE/AHS structures, structural dynamics and materials conference AIAA 1767
- Villanueva D, Haftka RT, Sankar BV (2010) Including future tests in the design of an integrated thermal protection system. 51st AIAA/ASME/ASCE/AHS structures, structural dynamics, and materials conference AIAA 2597

Pankaj Joshi, Sameer B. Mulani and Rakesh K. Kapania, “Multi-objective vibro-acoustic optimization of stiffened panels”, Structural and Multidisciplinary Optimization, Vol. 51, No. 4, pp 835-848, April 2015, ABSTRACT: A multi-objective vibro-acoustic design optimization of straight or curvilinearly stiffened panels excited by an acoustic diffuse field is performed. During design optimization, the panel mass and the radiated acoustic power are the two objectives to be minimized while satisfying constraints on buckling, von Mises stress and crippling. Based on the concept of plane wave propagation, a diffuse acoustic field is developed for use along with a finite element model. To represent the panel’s structural behavior, the dynamic analysis of the panel is performed for the developed diffuse acoustic excitation and the radiated acoustic power is calculated using the velocities obtained from the dynamic analysis. A baseline design is obtained by optimization study with mass as an objective to be minimized while constraints are put on buckling, von Mises stress and crippling. The obtained baseline grid stiffened panel is used for a comparative study of a panel with curvilinear stiffeners in vibro-acoustics with diffuse sound field as the source of the excitation.

References listed at the end of the paper:

ABSTRACT: This paper investigates the use of stability and serviceability objective functions in the shape optimization of truss arch footbridges prone to in-plane snap-through buckling. The objective functions evaluated relate to global linear buckling, geometrically nonlinear response, fundamental frequency, linear compliance, and maximum deflection. These objective functions are applied to help define the global structural shape for the 2D configuration of a truss arch footbridge subject to its governing code-defined load combination. The strength criterion of maximum axial force, the global stability responses of critical linear buckling load and nonlinear limit load, and the serviceability responses of fundamental frequency and unfactored live load deflection are used to evaluate the optimized topologies. These structural performance results are compared to those of a benchmark structure prone to in-plane snap-through buckling. The results highlight that improvement in stability and serviceability behavior can be obtained by altering the global structural form according to the presented objective functions. Stable optimized topologies, which are not prone to in-plane snap-through buckling, are achieved without the use of computationally expensive, geometrically nonlinear analysis functions.

References listed at the end of the paper:

- Achtziger W (1997) Topology optimization of discrete structures: an introduction in view of computational and nonsmooth aspects. In: Rozvany GIN (ed) Topology optimization in structural form according to the presented objective functions. Stable optimized topologies, which are not prone to in-plane snap-through buckling, are achieved without the use of computationally expensive, geometrically nonlinear analysis functions.


- MD. NASTRAN R2.1 (1999) MSC Software Corporation, Santa Ana, California, USA
- MD. NASTRAN R2.1 (1999) MSC Software Corporation, Santa Ana, California, USA


A practical approach to optimize a continuum/structural eigenfrequency is presented, including design of the distribution of material anisotropy. This is often termed free material optimization (FMO). An important aspect is the separation of the overall material distribution from the local design of constitutive matrices, i.e., the design of the local anisotropy. For a finite element (FE) model the amount of element material is determined by a traditional optimality criterion (OC) approach. In this respect the major value of the present formulation is the derivation of simple eigenfrequency gradients with respect to material density and from this values of the element OC. Each factor of this expression has a physical interpretation. Stated alternatively, the
optimization problem of material distribution is converted into a problem of determining a design of uniform OC values. The constitutive matrices are described by non-dimensional matrices with unity norms of trace and Frobenius, and thus this part of the optimized design has no influence on the mass distribution. Gradients of eigenfrequency with respect to the components of these non-dimensional constitutive matrices are therefore simplified, and an additional optimization criterion shows that the optimized redesign of anisotropy are described directly by the element strains. The fact that all components of an optimal constitutive matrix are expressed by the components of a strain state, imply a reduced number of independent components of an optimal constitutive matrix. For 3D problems from 21 to 6 parameters, for 2D from 6 to 3 parameters, and for axisymmetric problems from 10 to 4 parameters.

References listed at the end of the paper:
- Jacobi CGJ (1846) Über ein leichtes verfahren die in der theorie der sacularstorungen vorkommenden gleichungen numerichen aufzulosen. Crelle’s J 30:51–95


ABSTRACT: In this work optimum stiffness design of laminated composite structures is performed using the commercially available programs ANSYS and MATLAB. Within these programs a Free Material Optimization algorithm is implemented based on an optimality condition and a heuristic update scheme. The heuristic update scheme is needed because commercially available finite element analysis software is used. When using a commercial finite element analysis code it is not straightforward to implement a computationally efficient gradient-based optimization algorithm. Examples considered in this work are a clamped-clamped 2D plate loaded in two load cases and a point loaded six layered 3D double curved corner hinged shell. The first example displays the effect of varying the size of patches having the same parametrization, and the second illustrates the benefit of using a layered free material parametrization. The results provide information concerning topology, material anisotropy, and the direction having the maximum stiffness. The obtained results are compared to gradient-based optimization solutions using Discrete Material Optimization and Continuous Fiber Angle Optimization implemented in a research code, where full access to the finite element analysis core is granted. This comparison displays the possibility of using commercially available programs for stiffness design of laminated composite structures.

References listed at the end of the paper:
- ANSYS Inc (2013a) ANSYS Release 14.0 Documentation
ABSTRACT: The purpose of this work is to develop a level set topology optimization method for an unstructured three-dimensional mesh and apply it to wing box design for coupled aerostructural considerations. The paper develops fast marching and upwind schemes suitable for unstructured meshes, which make the level set method robust and efficient. The method is applied to optimize a representative wing box internal structure for the NASA Common Research Model. The objective is to minimize the total compliance of the wing box. The trim condition that aerodynamic lift must balance the total weight of the aircraft is enforced by allowing the root angle of attack to change. The adjoint method is used to obtain the coupled shape sensitivities required to perform aerostructural optimization of the wing box. Optimum solutions for several aerodynamic and body force load cases, as well as a ground load case, are presented.

References listed at the end of the paper:
ABSTRACT: This paper presents a new approach to the topology optimization of columns exposed to a loss of stability. The idea is to replace a conventional maximization of a buckling load by a locally formulated topology optimization problem based on compliance minimization. In order to do this, the standard instability analysis of a compressed column is performed first and the buckling mode is determined. Then the compressive loading is replaced by a transverse one which is selected so as to generate a bending moment, the distribution of which coincides with the one representing the considered buckling mode. Minimization of compliance is performed for the bent structure and optimal topology is generated. Finally, the critical load for the optimal column is calculated. The selected numerical results obtained with the use of the above technique, under the assumption that the buckling load is unimodal, are presented. The above approach allows generating optimal topologies which by nature requires local formulation of the design problem.

References listed at the end of the paper:


ABSTRACT: An approach to take into account global and local stability in the design optimization of truss-like structures is presented. It is based on the use of frame elements and a single global stability constraint. A detailed discussion on key aspects of the proposed approach is presented, together with numerical examples. The proposed approach ensures global stability and does not require the use of Euler formula, avoiding several difficulties encountered in truss optimization. Besides, the examples illustrate that global stability is an important aspect to be taken into account in most practical cases.

References listed at the end of the paper:

Hui Yang, Rongqiang Liu, Yan Wang, Zongquan Deng and Hongwei Guo, “Experiment and multiobjective optimization design of tape-spring hinges”, Structural and Multidisciplinary Optimization, Vol. 51, No. 6, pp 1373–1384, June 2015,

ABSTRACT: Flexible tape-spring hinges can be folded elastically and are able to self-deploy by releasing stored strain energy with fewer component parts and slight weights. This study presents a detailed investigation of the folding and deployment of single-layer tape-spring (SLTS) hinges and double-layer tape-spring (DLTS) hinges under pure bend loading. The material properties of tape-spring hinges are measured using an INSTRON machine. A DLTS hinge construction is created, and its moment-rotation relationship during quasi-static deployment is measured. An experiment is conducted to verify the validation of the numerical models for the DLTS hinges. The quasi-static deployment behavior of SLTS hinges and DLTS hinges is then analyzed using nonlinear finite element ABAQUS/Explicit solver, starting from the complete folded configuration. The DLTS hinge has good quasi-static deployment performances with regard to maximum stress (S.), steady moment (M.) and the peak moment (M.) during the DLTS hinge quasi-static deployment. In addition, the sampling designs of the DLTS hinges are created based on a three-level full factorial design of experiments (DOE) method. The surrogate models of S., M. and M. of the DLTS hinges are derived using response surface method (RSM) to reduce the computational cost of quasi-static folding and deployment of numerical simulations. The Multiobjective optimization design (MOD) of the DLTS hinge is performed using modified non-dominated sorting genetic algorithm (NSGA-II) algorithm to achieve the optimal design. The finite element models for the optimal design based on numerical method are established to validate the optimization results.

References listed at the end of the paper:


ABSTRACT: This paper investigates topology design optimization for maximizing critical buckling loads of thin-walled structures using a moving iso-surface threshold (MIST) method. Formulation for maximizing linear buckling loads with additional constraints on load-path continuity and lower bound of eigenvalue is firstly presented. New physical response functions are proposed and expressed in terms of the strain energy densities determined in the two-steps of finite element buckling analysis. A novel approach by introducing a connectivity coefficient is developed to ensure continuity of effective load-path in optimum topology. The lower bound of eigenvalue is defined to eliminate spurious localized buckling modes. The MIST algorithm and its interfaces with commercial finite element (FE) software are given in detail. Numerical results are presented for topology optimization of plate-like structures to maximize critical buckling forces or displacements considering in-plane and out-of-plane buckling respectively. The FE analyses of the re-meshed final solid topologies with and without void material reveal that the presence of the void material has a significant effect on the out-of-plane buckling loads and a minor influence on the in-plane buckling loads.

References listed at the end of the paper:


ABSTRACT: The hierarchical topology optimization model for multiscale design of structures addresses the problem of finding optimal material distributions at different but interconnected structural length scales with the objective of optimally design the structure and its material. In this work some new developments on this model are presented. An algorithm is mounted to address specific features of multiscale design such as multiple material design constrains. Furthermore, previous design parameterizations assume micro design variables associated with each finite element, trying to approximate a pointwise optimal material definition, and leading to very efficient designs but of problematic manufacturability. Here one reduces the total number of problem design variables by assuming a design parameterization where the design is uniform within mechanically consistent larger subdomains—“design subdomains”. This eases applicability, manufacturability, and is a very effective approach for practical design problems involving for example sandwich-type structures, where larger subdomains identify structural constituents such as a soft core between two solid face-sheets. The parameterization to include “design subdomains” and the introduction of local material design constraints requires an appropriate derivation of the optimality conditions. The main structural applications presented here are related to sandwich type of structures. The influence of the designer choices for “design subdomains” characterizing the macrostructure, and “material unit cell” representing the microstructure, will also be studied in the solutions obtained. The examples show the effectiveness of the methodology presented to fully benefit from an enlarged design space incorporating structural and material designs, and thus efficiently maximize the mechanical component structural performance.
Daniel Peeters, Daniel van Baalen and Mostafa Abdallah, “Combining topology and lamination parameter optimization”, Structural and Multidisciplinary Optimization, Vol. 52, No. 1, pp 105-120, July 2015,

ABSTRACT: Two dimensional composite structures are designed for maximum stiffness under multiple load cases. Both the topology and the fibre angle distribution are optimised simultaneously. To solve the topology optimisation, a density approach is used. The stiffness is parametrised in terms of lamination parameters, not directly in terms of the fibre angles. To force the fictitious density to either zero or one both implicit and explicit penalisation are used. Both penalisation approaches are implemented and both give a satisfactory result. Once the optimum lamination parameter and density distribution is found, some post-processing steps are necessary: the boundaries of the structure are determined by post-processing the density distribution. The fibre angle distribution is found by matching the lamination parameter distribution. Finally the fibre paths are determined. A number of examples are worked out to demonstrate the technique for balanced, unbalanced, single and multiple load case problems. The results show that the proposed technique is widely applicable and that there are considerable benefits in extending topology optimisation to handle composites.

References listed at the end of the paper:

- Bruhn EF, Bollard RJH, et al. (1973) Analysis and design of flight vehicle structures. SR Jacobs
- Buchanan S (2007) Development of a wingbox rib for a passenger jet aircraft using design optimization and constrained to traditional design and manufacture requirements. ALTair Engineering
- Felippa CA (2001) introduction to finite element methods. University of Colorado, Boulder

REFERENCES

· Ijsselmuinen ST (2011) Optimal design of variable stiffness composite structures using lamination parameters, Ph. D. Thesis. Delft University of Technology, Delft, Netherlands

Soeren N. Soerensen and Mathias Stolpe, “Global blending optimization of laminated composites with discrete material candidate selection and thickness variation”, Structural and Multidisciplinary Optimization, Vol. 52, No. 1, pp 137-155, July 2015,

ABSTRACT: A method capable of simultaneous topology and thickness optimization of laminated composites has previously been published by one of the authors. Mass constrained compliance minimization subject to certain manufacturing constraints was solved on basis of interpolation schemes with penalization. In order to obtain large patchwise material candidate continuity while also accommodating variable laminate thickness, a bi-linear stiffness parameterization was introduced, causing a non-convex problem. In this present work, we introduce an alternative problem formulation that holds identical capabilities but is, however, convex in the original mixed binary nested form. Convexity is the foremost important property of optimization problems, and the proposed method can guarantee the global or near-global optimal solution; unlike most topology optimization methods. The material selection is limited to a distinct choice among predefined numbers of candidates. The laminate thickness is variable but the number of plies must be integer. We solve the convex mixed binary non-linear programming problem by an outer approximation cutting-plane method augmented with a few heuristics to accelerate the convergence rate. The capabilities of the method and the effect of active versus inactive manufacturing constraints are demonstrated on several numerical examples of limited size, involving at most 320 binary variables. Most examples are solved to guaranteed global optimality and may constitute benchmark examples for popular topology optimization methods and heuristics based on solving sequences of non-convex problems. The results will among others demonstrate that the difficulty of the posed problem is highly dependent upon the composition of the constitutive properties of the material candidates. References listed at the end of the paper:
ABSTRACT: In the real world, structural systems may not have linear static characteristics. However, structural optimization has been developed based on static responses because sensitivity analysis regarding static finite element analysis is developed quite well. Analyses other than static analyses are heavily required in the engineering community these days. Techniques for such analyses have been extensively developed and many software systems using the finite element method are easily available in the market. On the other hand, development of structural optimization using such analyses is fairly slow due to many obstacles. One obstacle is that it is very difficult and expensive to consider the nonlinearities or dynamic effects in the way of conventional optimization. Recently, the equivalent static loads method for non-linear static response structural optimization (ESLSO) has been proposed for structural optimization with various responses: linear dynamic response, nonlinear static response, and nonlinear dynamic response. In ESLSO, finite element analysis other than static analysis is performed, equivalent static loads (ESLs) are generated, linear static response structural optimization is carried out with the ESLs and the process iterates. A software system for the automatic use of ESLSO is developed and described. One of the advantages of ESLSO is that it can use well developed commercial software systems for structural analysis and linear static response structural optimization. Various analysis and optimization systems are integrated in the developed system. The structure of the system is systematically defined and the software is developed by the C++ language on the Windows operating system.


Duddeck F (2011) New approaches for shape and topology optimization for crashworthiness. 2011 NAFEMS world Congress. Boston, USA


Lee JJ, Jung UJ, Park GJ (2013a) Shape optimization of the workpiece in the forging process using equivalent static loads. Finite Elem Anal Des 69:1–18


Microsoft Press (1998) MFC Library Reference, Redmond, WA, USA

Müllershön H, Erhart A, Schmacher P (2013) Topology and topometry optimization of crash applications with the equivalent static load method. 10th World Congress on Structural and Multidisciplinary Optimization. Orland, Florida, USA


ABSTRACT: This paper presents a new gradient based method for performing discrete material and thickness optimization of laminated composite structures. The novelty in the new method lies in the application of so-called casting constraints, or thickness filters in this context, to control the thickness variation throughout the laminate. The filters replace the layerwise density variables with a single continuous through-the-thickness design variable. Consequently, the filters eliminate the need for having explicit constraints for preventing intermediate void through the thickness of the laminate. Therefore, the filters reduce both the number of constraints and design variables in the optimization problem. Based upon a continuous approximation of a unit step function, the thickness filters are capable of projecting discrete 0/1 values to the underlying layerwise or “physical” density variables which govern the presence of material in each layer through the thickness of the laminate. Combined with an in-plane density filter, the method enables manufacturers to control the length scale of the geometry while obtaining near discrete designs. Together with the applied manufacturing constraints it is now possible for manufacturers to steer the design towards a higher level of manufacturability. The method is demonstrated for mass minimization with displacement and manufacturing constraints. The results show that the method indeed is capable of obtaining near discrete designs which obey the governing constraints.

References listed at the end of the paper:
35. Lund E, Sørensen R, Sørensen SN (2013) Multi-criteria multi-material topology optimization of laminated composite structures including local constraints. In: Book of Abstracts, 10th World Congress on Structural and Multidisciplinary, Optimization, Orlando, Florida, USA

ABSTRACT: A new two-stage stochastic partial differential equation (PDE)-constrained optimization methodology is developed for the active vibration control of structures in the presence of uncertainties in mechanical loads. The methodology relies on the two-stage stochastic optimization formulation with an embedded first-order black-box PDE-constrained optimization procedure. The PDE-constrained optimization procedure utilizes a first-order active-set algorithm with a conjugate gradient method. The objective function is determined through solution of the governing PDEs and its gradient is computed using automatic differentiation with hyper-dual numbers. The developed optimization methodology is applied to the problem of post-impact vibration control (via applied electromagnetic field) of an electrically conductive carbon fiber reinforced composite plate subjected to an uncertain, or stochastic, impact load. The corresponding governing PDEs consist of a nonlinear coupled system of equations of motion and Maxwell’s equations. The conducted computational study shows that the obtained two-stage optimization solution allows for a significant suppression of vibrations caused by the randomized impact load in all impact load scenarios. Also, the effectiveness of the developed methodology is illustrated in the case of a deterministic impact load, where the two-stage strategy enables one to practically eliminate post-impact vibrations.

References listed at the end of the paper:

ABSTRACT: Advanced fiber placement (AFP) composite manufacturing technology offers a means to tailor composite fibers for complex loading environments and significantly improve the overall structural efficiency. This paper introduces a new method to optimize the continuously varying fiber paths for AFP using a level set method. The paths of the fibers are defined by constant level set function values, describing a series of continuous equally spaced fiber paths. The sensitivity of the structural compliance to a change in level set function definition of the fiber path is derived. The sensitivities are used to optimize the level set defined fiber paths to minimize structural compliance, while maintaining the continuous fiber paths and producing a solution that can be manufactured using AFP. The optimization method is demonstrated in three numerical studies.

References listed at the end of the paper:


Dianzi Liu, Vassili V. Toropov, David C. Barton and Osvaldo M. Querin, “Weight and mechanical performance optimization of blended composite wing panels using lamination parameters”, Structural and Multidisciplinary Optimization, Vol. 52, No. 3, pp 549-562, September 2015,
ABSTRACT: In this paper, a lamination parameter-based approach to weight optimization of composite aircraft wing structures is addressed. It is a bi-level procedure where at the top level lamination parameters and numbers of plies of the pre-defined angles (0, 90, 45 and −45°) are used as design variables, the material volume is treated as an objective function to be minimized subject to the buckling, strength and ply percentage constraints. At the bottom level the optimum stacking sequence is obtained subject to the requirements on blending and preservation of mechanical properties. To ensure composite blending, a multi-stage optimization is performed by a permutation genetic algorithm aiming at matching the lamination parameters passed from the top level optimization as well as satisfying the layup rules. Two new additional criteria, the 90° ply angle jump index and the stack homogeneity index, are introduced to control the uniformity of the three ply angles (0, 90, 45 and −45°) spread throughout the stack as well as improve the stack quality and mechanical performance by encouraging 45° angle changes between neighbouring groups of plies. The results of the application of this approach are compared to published results to demonstrate the potential of the developed technique.

References listed at the end of the paper:

- Altair OptiStruct Software Package (2011) Ver. 11.0, Altair Engineering, Inc., Troy, MI, USA
- Ansys Elements Reference (2007) Ver.11, ANSYS, Inc., Canonsburg, PA, USA
- Liu D, Toropov VV, Querin OM, Barton DC (2009) Stacking sequence optimization of composite panels for blending characteristics using lamination parameters. 8th World Congress of Structural and Multidisciplinary Optimization, Lisbon, Portugal
- Michalewicz Z (1992) Genetic algorithms + data structures = evolution programs. Springer-Verlag
- The references listed at the end of the paper:

ABSTRACT: In the field of automotive safety, the lightweight design of crash absorbers is an important research topic with a direct effect on the occupant safety levels. The design of these absorbers usually requires an optimization of their crashworthiness, which can include multi-objective and reliability-based optimization techniques. This process is very time-consuming, and in spite of the continuous growing of computational power, the problem needs a reliable solving scheme. The use of surrogate models and parallel computing are suitable alternatives to deal with this issue. However, the strongly non-linear response functions obtained from the finite element simulations need careful treatment. This work contributes with the application of a surrogate-based reliability-based design optimization method to an original design of a crash absorber made of metal and a glass-fiber reinforced polymer which is subjected to a frontal impact. Multi-adaptive regression splines models are employed to emulate the original responses, and three different approaches in the sampling stage of the method are compared. The absorbed energy and the mass of the element are considered as objective functions, while the peak value of the force transmitted to the occupants of the vehicle is the design constraint. A discussion of the employed materials is presented and the proposed approaches are compared. Finally, several Pareto fronts are obtained as a solution to the probabilistic problem. Results show that a combination of aluminum and glass fiber reinforced polymer is optimum for this problem, and some design rules are offered.

References listed at the end of the paper:

- Niu MCY (2010) Composite airframe structures, practical design information and data. Conmilit Press Ltd., Hong Kong


Cook GR, Johnson WH (1983) A constitutive model and data for metals subjected to large strains, high strain rates and high temperatures.. In: Proceedings of Seventh International Symposium on Ballistics


European New Car Assessment Programme (Euro NCAP) (2012) Frontal impact testing protocol, version 6.0


ABSTRACT: Plates with ribs or stiffeners (stiffened plates) have been widely used as primary or secondary load bearing structures. Such structures could be fabricated by casting—a conventional yet important manufacturing process, their load bearing capacities are strongly dependent on the layout and sizes of the stiffeners. Thus it is necessary to establish specific topology optimization model and algorithm to obtain optimum layout, sizes and shapes of the stiffeners with casting constraints being considered. In this paper, we propose a new Heaviside-function based directional growth topology parameterization (H-DGTP) of the casting constraints for simultaneously optimizing the layout and height of the stiffeners. By using the new explicit parameterization, we can obtain a clear stiffener layout with optimized height. The differentiability of the parameterization is obtained by the use of a smooth approximation of the Heaviside function. In order to be applicable to a non-uniform mesh, a base surface is introduced and the minimum length of a stiffener can be controlled. Several numerical examples are presented to show the validity of this method.

References listed at the end of the paper:

References listed at the end of the paper:

- Zhu J, Gu X, Zhang W, Beckers P (2012a) Optimum structure design of a multilayer piezoelectric composite disk controlling thermal stress on thermal Stresses, National Taiwan University of Science and Technology, Taipei, Taiwan: 623–626


ABSTRACT: This article deals with a nonlinear multi-variable optimization problem to minimize the critical thermal stress induced in a layered composite plate. The numerical model is solved by using the finite element analysis while the optimization is done by applying the particle swarm optimization technique. The plate contains nontraditional interfaces between the layers while their profiles follow a power law. Different parameters are optimized either individually or in combination by applying single and multi-variable optimizations so as to minimize the critical induced thermal stress in the structure. These optimized parameters include the interface profile parameter, the height of the nontraditional interface on the right surface relative to the mid-surface, and the thicknesses of the layers of the plate. It is found that the critical stress can be minimized greatly when tailoring the geometrical and interface parameters by using their optimum values.

References listed at the end of the paper:


Hanfeng Yin, Hongbing Fang, Youye Xiao, Guilin Wen and Qixiang Qing, “Multi-objective robust optimization of foam-filled tapered multi-cell thin-walled structures”, Structural and Multidisciplinary Optimization, Vol. 52, No. 6, pp 1051-1067, December 2015,

ABSTRACT: Foam-filled multi-cell thin-walled structure has recently gained attentions for its excellent energy absorption capacity. Tapered thin-walled structure is less likely to fail by global buckling, and is more capable of bearing oblique impact loads. Thus, foam-filled tapered multi-cell thin-walled structure (FTMTS) may be an extremely excellent energy absorber candidate in future vehicle body. This paper focuses on the crashworthiness of four kinds of axisymmetric FTMTSs with different cell numbers. According to our study, we find that FTMTSs have very excellent energy absorption capacity as well as strong capacity of avoiding global buckling. According to our investigation, it was found that the crashworthiness of FTMTS was largely affected by design parameters such as geometric sizes and foam density. In order to find optimal designs of FTMTSs, it is very essential to carry out crashworthiness optimization for FTMTSs. However, the conventional deterministic design is likely to become less meaningful or even unacceptable when considering the uncertainties of design parameters due to the manufacturing or installation deviation. In order to overcome this drawback, a multi-objective robust optimization procedure which employs Kriging metamodels, multi-objective particle swarm optimization (MOPSO) algorithm, “k-sigma” robust design theory and Monte Carlo simulation (MCS) was developed. The comparison of the Pareto fronts obtained by the developed multi-objective robust optimization technique and the experimental data was performed.
optimization procedure and the traditional multi-objective deterministic optimization algorithm shows that the robust optimization result is more reliable than the deterministic optimization result. The robust optimal design of FTMTS not only has very excellent crashworthiness but also has very high reliability when considering the uncertainty of design parameters.

References listed at the end of the paper:

Youn Doh Ha, “Generalized isogeometric shape sensitivity analysis in curvilinear coordinate system and shape optimization of shell structures”, Structural and Multidisciplinary Optimization, Vol. 52, No. 6, pp 1069-1088, December 2015,

ABSTRACT: A generalized sensitivity formulation described in a curvilinear coordinate system is proposed. Utilizing it, the continuum-based isogeometric shell sensitivity analysis method for the shell components is developed in the curvilinear coordinates derived from the given NURBS geometry. In isogeometric approach, the designs are embedded into the NURBS basis functions and the control points so that geometrically exact shell models can be incorporated in both response and sensitivity analyses. The precise shape sensitivities can be obtained by considering accurate and continuous normal and curvatures in the boundary integrals of the boundary resultants of the shell and their material derivatives. Through numerical examples, the developed isogeometric shape sensitivity is verified to demonstrate excellent agreements with finite difference sensitivity. Also, the importance of higher order geometric information in the sensitivity expressions is identified. For the shape optimization problem of the shell, the proposed method works well with boundary resultants accompanying severe curvature changes.

References listed at the end of the paper:
- Bletzinger KU, Ramm E (2001) Structura
References listed at the end of the paper:


ABSTRACT: The paper describes a procedure to find the structurally and thermally efficient design of load-carrying thin-walled precast High Performance Concrete Sandwich Panels (HPCSP) with an optimal economical solution. A systematic optimization approach is based on the selection of material’s performances and HPCSP’s geometrical parameters as well as on material cost function in the HPCSP design. Cost functions are presented for High Performance Concrete (HPC), insulation layer, reinforcement and include labour-related costs. The present study reports the economic data corresponding to specific manufacturing process and actual financial parameters for the Danish prefabrication industry. The strength based design of HPCSP is in compliance with the format of Eurocode 2 and takes into account failure modes related to flexure, shear, HPCSP buckling/slenderness, local HPC plate buckling and maximum deflections. The solution of the optimization problem is performed in the computer package software Matlab® with SQPlab package and integrates the processes of HPCSP design, quantity take-off and cost estimation. The proposed optimization process outcomes in complex HPCSP design proposals to achieve minimum cost of HPCSP.

References listed at the end of the paper:

- ACI Committee 318 (2008) Building Code requirements for structural concrete and commentary (American Concrete Institute)
- Arora JS (2012) Introduction to optimum design. Academic, Boston
Buhler ER (2008) In proceedings: Concrete Technology Forum - Focus on Sustainable Development. Denver, Colorado
Hansen S (2012b) Optimization of the thermal bridge effect of ribs in sandwich panels of high performance concrete. 11th International Conference on Sustainable Energy Technologies, Vancouver
Hodicky K, Hulin T, Schmidt JW, Stang H (2013a) Assesment risk of fracture in thin-walled fiber reinforced and regular high performance concretes sandwich elements. Proceedings of the 8th International Conference on Fracture Mechanics of Concrete and Concrete Structures, Toledo, pp 1257–1266
Maximos HN, Pong WA, Tadros MK, Martin LD (2007) Behavior and design of composite precast prestressed concrete sandwich panels with NU-tie. University of Nebraska, Lincoln
· PCI Committee on Precast Sandwich Wall Panels (2011) State of the art of precast/prestressed concrete sandwich wall panels. PCI J 56:131–176
· Wade TG, Porter ML, Jacobs DR (1988) Glass-fiber composite connectors for insulated concrete sandwich walls. Engineering Research Institute, Iowa State University, Ames


ABSTRACT: Normally, automobile bumper system absorbs the collision kinetic energy by deflection in low-speed crash and by deformation in high-speed crash. The main component of this system is the bumper beam, generally made of steel. The purpose of this paper is to improve energy absorption and light the weight of bumper by applying Fruit Fly Optimization Algorithm (FOA) in frontal bumper beam. The simulation of the frontal crash by using the Finite Element (FE) model is based on the New Car Assessment Program (NCAP). The most important parameters including the type of materials, thicknesses and layup of composite layers are studied by Rescaled Range Analysis (RRA). Then, the diminution of the value of Head Injury Criterion (HIC) is treated as optimization objective in the simulation of FE model, the thicknesses of composite beam are designed and analyzed through Fruit Fly Optimization Algorithm (FOA). In addition, the optimization results are compared with the results analyzed by Genetic Algorithm (GA). It can be observed from the results that the value of HIC is reduced by 6.37%, the new composite beam will be just 4.84% lighter than the steel part, and its peak value of collision energy absorption is 1.36 times larger than that of the steel part. In conclusion, the FOA can be applied in design of the new composite bumper beam in improving energy absorption and lightweight.

References listed at the end of the paper:
Shown to be a good energy absorber in vehicle bodies.

In addition, the ARBFs are globally metamodels that are adaptively improved at various local regions where the Pareto optimal designs are located. The performance of this novel method was first evaluated using six mathematical functions.

ABSTRACT: An adaptive RBF-based multi-objective optimization method for crashworthiness design of functionally graded multi-cell tube was developed for efficiently and effectively solving MOO problems. The ARBFs are globally metamodels that are adaptively improved at various local regions where the Pareto optimal designs are located. The performance of this novel method was first evaluated using six mathematical functions. In addition, the ARBF-based MOO method was also used in a practical application, i.e., the crashworthiness optimization of a new kind of thin-walled structure named functionally graded multi-cell tube (FGMT) that was shown to be a good energy absorber in vehicle bodies.


References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: Piezoelectric energy harvesting which scavenges electric power from ambient vibration energy has received significant attention as an ultimate solution to realize self-powered wireless sensors. For designing a piezoelectric energy harvester, it is of great importance to develop a high-fidelity electromechanical model which predicts the output power under various vibration conditions. To the best of our knowledge, however, there has been no systematic approach to account for variability in the material properties and geometry of a piezoelectric energy harvester. This paper thus presents (1) the hierarchical model calibration to improve the predictive capability of the electromechanical model and (2) the design of energy harvesting (EH) skin to maximize the output power to reliably operate self-powered wireless sensors. In this study, the hierarchical model calibration infers statistical information of unknown model variables (compliance, piezoelectric strain coefficient, and relative permittivity). The calibrated electromechanical model is then used to design EH skin based on the piezoelectric material segmentation to avoid voltage cancellation. The output power predicted by the calibrated electromechanical model is statistically compared with the measured one. Finally, it is concluded from the feasibility demonstration that EH skin can sufficiently generate the output power to realize self-powered wireless sensors without batteries.

References listed at the end of the paper:

Lee S, Youn BD (2011a) A design and experimental verification methodology for an energy harvester skin structure. Smart Mater Struct 20:057001
Yoon H, Youn BD (2014) Stochastic quantification of the electric power generated by a piezoelectric energy harvester using a time–frequency analysis under non-stationary random vibrations. Smart Mater Struct 23:045035

ABSTRACT: This paper presents a methodology for the multi-objective (MO) robust optimization of plate structures under stress criteria, based on Mixed Super-Elements (MSEs). The optimization is performed with a classical Genetic Algorithm (GA) method based on Pareto-optimal solutions. It considers antagonist objectives among them stress criteria and thickness parameters distributed along the plate. This work aims at providing fast and efficient objective calculations. Our method is based on the implementation of MSEs for each zone of the plate featured by its own thickness. They are constructed with a Mixed Finite Element Model (MFEM) based on a displacement-stress mechanical formulation, and is enhanced with a sub-structuring modal reduction method in order to reduce the size of each constant thickness MSE. Those methods combined enable a fast and stress-wise efficient structure analysis, which improves the performance of the repetitive GA. A few cases minimizing the mass and the maximum Von Mises stress within a plate structure under dynamic loads put forward the relevance of our method with promising results. For the sake of robustness, both discrete frequencies and frequency bands are studied. The MO optimization is able to satisfy multiple damage criteria with different thickness distributions. It brings simplicity, saves computational time and the Pareto-front presentation with stress objective provides a good overview of the possibilities for the designers.

References listed at the end of the paper:
ABSTRACT: Topology optimization has been successfully used in several case studies in aerospace and automotive industries to generate innovative design concepts that lead to weight savings. This motivates the exploration of this new approach for the design of an aircraft flat pressure bulkhead. However, no studies were conducted on this type of structure. Therefore, this paper presents and discusses the challenges associated with the design of flat pressurized plate using topology optimization (SIMP (Solid Isotropic Material with Penalization) method). A simply supported rectangular plate is used as the design case and a typical layout is defined as a comparison basis. The mass of the interpreted design concepts are obtained with a simplified sizing approach taking into consideration stress and displacement constraints. Results show that the topology layout is not unique as it is sensitive to optimization parameters. Moreover, the interpretation of the layout is challenging as they are driven by complex interactions. Finally, the performance of the topology design concept is at most comparable with the typical layout and no significant improvement is obtained. The study highlights the importance of performing an extensive topology study in order to better understand the behavior of the design before creating a concept. An improved topology design process is finally proposed in order to provide guidance to industrial designers. 

References listed at the end of the paper:


7. Bruhn EF (1973) Analysis and design of flight vehicle structures. S.R. Jacobs, Cincinnati

Suchao Xie, Xifeng Liang, Hui Zhou and Jian Li, “Crashworthiness optimisation of the front-end structure of the lead car of a high-speed train”, Structural and Multidisciplinary Optimization, Vol. 53, No. 2, pp 339-347, February 2016,

ABSTRACT: To improve the crashworthiness of vehicles, the crashworthiness of the vehicle structure itself has to be optimised. Through the collision analysis of a certain high-speed train, this research found that the front-end structure is most important in the crashworthiness optimisation design of the vehicle; the constitutive material models required for this numerical simulation of an entire vehicle were obtained by performing loading tests at different strain rates; according to the highly non-linear characteristics of the ensuing structural deformation under impact loading, this research used specific energy absorption (SEA) as an objective function to construct a multi-parameter optimisation model of the front-end structure of the vehicle. Based on this, the optimisation analysis was conducted. In the optimisation, the optimal SEA value (3.6988 kJ/kg) of the structure is obtained by 130-step iteration using a modified method of feasible directions (MMFD)—a gradient optimisation method; the optimal value obtained after 101 iterations by applying a direct search method—Hooke-Jeeves (HJ) algorithm is 3.6454 kJ/kg; and the optimal value acquired after 192 iterations of a global optimisation method—adaptive simulated annealing (ASA)—is 3.6132 kJ/kg. Moreover, the optimum results were validated by collision analysis of the optimal structure using a MMFD model. The variation analysis of the
structural SEA with each variable show that the optimisation model is able to extend the range of each design variable.

References listed at the end of the paper:

- Xu FX, Sun GY, Li GY, Li Q (2014) Experimental study on crushworthiness of tailor-welded blank (TWB) thin-walled high-strength steel (HSS) tubular structures. Thin-Walled Struct 74:12–27
ABSTRACT: In structural optimization to failure constraints, computing the gradients of a large number of functions with respect to a large number of design variables may not be computationally practical. Often, the number of constraints in these optimization problems is reduced using constraint aggregation at the expense of a higher mass of the optimal structural design. This work presents results of structural and coupled aerodynamic and structural design optimization of aircraft wings using a novel matrix-free augmented Lagrangian optimizer. By using a matrix-free optimizer, the computation of the full constraint Jacobian at each iteration is replaced by the computation of a small number of Jacobian-vector products. The low cost of the Jacobian-vector products allows optimization problems with thousands of failure constraints to be solved directly, mitigating the effects of constraint aggregation. The results indicate that the matrix-free optimizer reduces the computational work of solving the optimization problem by an order of magnitude compared to a traditional sequential quadratic programming optimizer. Furthermore, the use of a matrix-free optimizer makes the solution of large multidisciplinary design problems, in which gradient information must be obtained through iterative methods, computationally tractable.

References listed at the end of the paper:

- Martinez HJ (1988) Local and superlinear convergence of structured secant methods from the viewpoint class. Tech. rep. Rice University, Houston

ABSTRACT: Controlling the values of natural frequencies of a structure plays an important role to keep the dynamic behavior of structures in a desirable level. This paper is concerned with the optimal design of large-scale dome structures with multiple natural frequency constraints. This optimization problem is highly nonlinear with several local optima in its search space. The idea of cascading, which allows a single optimization problem to be tackled with a number of autonomous optimization stages is used. The procedure utilized in this paper reduces the objective function value over a number of optimization stages by initially operating on a small number of design variables, which is gradually increased stage after stage. In order to show the effect of using coarsening of variables for handling the optimization problem, independent of the effect of the algorithm, the recently developed approach (enhanced colliding bodies optimization) is employed in the entire stages of the present method. Besides, we want to demonstrate the positive effect of using multi-DVC cascade optimization procedure even if the utilized algorithm itself is a powerful method. In order to test the performance of the algorithm, four dome truss design examples with 120, 600, 1180 and 1410 elements are optimized. The numerical results prove that the utilized method is an effective tool for finding optimum design of structures with frequency constraints.

References listed at the end of the paper:


ABSTRACT: This paper studies optimal topology design of damped vibrating plate structures subject to initial excitations. The design objective is to minimize an integrated square performance measure. The artificial density of the plate element is the topology design variable and the material volume is given. The Lyapunov’s second method is applied to reduce the calculation of performance measure to the solution of the Lyapunov equation. An adjoint sensitivity analysis method is used, which only needs to solve the Lyapunov equation twice. However, when the problem has a large number of degrees of freedom, the solution process of Lyapunov equation is computationally costly. Thus, the full model is transformed to a reduced space by mode reduction method. To further reduce the scale of reduced model, we propose a mode screen method to decrease the number of eigenmodes. Numerical examples of optimum topology design of bending plates are presented for illustrating validity and efficiency of our new algorithm.

References listed at the end of the paper:


ABSTRACT: Topology optimization to minimize the bottom–layer temperature and the structure compliance of the multi–layered thin–walled structure is carried out in this paper. A multi–layered thin–walled structure with improved performances in load–carrying and heat insulation inspired by a species of oceanic gastropods found on a hot and highly pressurized deep–sea floor is proposed. Using genetic algorithm to perform the optimization process, it is proved that the optimal topology under integrated thermal and load conditions is a sandwich structure of three layers similar to the original bionic structure of the oceanic gastropods. Soft layer with good heat insulation is placed as the middle layer, whereas hard layers with fast heat transmission are placed as the top and bottom layers to carry load. The concept of bionic three–layered structure is then applied to the skin design of an airfoil. The analysis for aerodynamic heating of the airfoil with different skin structures shows that the bionic multi–layered structure is an optimal design in both layer thickness and layer sequence.

References listed at the end of the paper:

During the optimization, the degenerated shell based on Reissner as design variables so that the curvatures of shell surface as well as the trimmed boundaries can be varied.

Coordinates of shell surface control points, but also the coordinates of trimming curve control points are chosen as design variables so that the curvatures of shell surface as well as the trimmed boundaries can be varied during the optimization. The degenerated shell based on Reissner-Mindlin theory is formulated with exact complex geometry is normally modeled with multiple untrimmed patches due to the tensor-product form of a Non-Uniform Rational B-Spline (NURBS) surface, and then the patches are put together for analysis. In the present work, the isogeometric shape optimization of trimmed shell structures using the information of trimmed NURBS surfaces is proposed. To treat the trimmed shell structures efficiently, two-dimensional Trimmed Surface Analysis (TSA) which is the isogeometric approach for treating a topologically complex geometry with a single patch is extended and adopted to the analysis and optimization of shell structures. Not only the coordinates of shell surface control points, but also the coordinates of trimming curve control points are chosen as design variables so that the curvatures of shell surface as well as the trimmed boundaries can be varied during the optimization. The degenerated shell based on Reissner-Mindlin theory is formulated with exact...
direction vectors and their analytic derivatives. Method of Moving Asymptotes (MMA) is used as the optimization algorithm, and the shape sensitivities with respect to the coordinates of surface control points and trimming curve control points are formulated with exact direction vectors and their analytic derivatives. The developed sensitivity formulations are validated by comparing with the results of Finite Difference Method (FDM), and they show excellent agreements. Numerical examples are treated to confirm the ability of the proposed approach.

References listed at the end of the paper:

ABSTRACT: Aircraft design is a challenging process which is constantly looking for developing new and lighter structural components. The application of topology optimization techniques is growing widespread in the aeronautical industry as it has proven to be highly useful for saving important weight amounts in recent aircraft designs. The objective of this research is to obtain optimal and novel aeronautical architectures through topology optimization while considering uncertainty in loads and material properties. For this, a methodology that combines the Sequential Optimization and Reliability Assessment (SORA) with external optimization software has been developed in order to perform Reliability-Based Topology Optimization (RBTO). The methodology is then compared against the classical way of obtaining novel architectures in aeronautical industry, which lie in the application of Deterministic Topology Optimization (DTO) considering partial safety factors in some data influencing the structural responses. The comparison draws weight savings of up to 3 % in the examples proposed when applying RBTO which could be highly significant in an aircraft structure. Moreover it has been proven that when performing a RBTO approach the layout of the final design can be different depending on the safety level required, which may influence the next phases of aircraft design process.

References listed at the end of the paper:

- Buchanan S (2007) Development of a wingbox rib for a passenger jet aircraft using design optimization and constrained to traditional design and manufacture requirements. Altair Engineering CAE Technology Conference, Michigan

ABSTRACT: In this work, reliability based design optimization (RBDO) of two aeroelasticity stability problems is addressed: (i) divergence, which arises in static aeroelasticity, and (ii) flutter, which arises in dynamic aeroelasticity. A set of design variables is considered as random variables, and the mean mass is minimized for including the probability of failure by divergence or flutter. The optimization...
process requires repeated evaluation of reliability, which is a major contributor to the total computational cost. To reduce this cost, a polynomial chaos expansion (PCE)-based metamodel is created over a grid in the parameter space. These precomputed PCEs are then interpolated for reliability calculation at intermediate points in the parameter space, as demanded by the optimization algorithm. Two new modifications are made to this method in this work. First, the Gauss quadrature rule is used — instead of statistical simulation — to estimate the chaos coefficients for higher computational speed. Second, to increase this computational gain further, a non-uniform grid is chosen instead of a uniform one, based on relative importance of the design parameters. This relative importance is found from a global sensitivity analysis. This new modified method is applied on a rectangular unswept cantilever wing model. For both optimization problems, it is observed that the proposed method yields accurate results with a considerable computational cost reduction, when compared to simulation based methods. The effect of grid spacing is also explored to achieve the best computational efficiency.

References listed at the end of the paper:


ABSTRACT: The newly designed structures are employed to improve the high pressure turbine (HPT) disk to the expected performance. The twin-web disk (TWD) has been proven to be the future trend of the HPT disk due to its breakthrough in weight loss, strength and heat transfer efficiency compared to the conventional single web disk (SWD). Because of the multi-physics working conditions and intense coupling of multiple disciplines, the conventional design of the HPT disk is a labor intensive work. A series of design procedures, including asymmetrical computational fluid dynamics (CFD) analysis, inverse distance weighted (IDW) interpolation method, multidisciplinary feasible method (MDF), and design of experiments (DOE), are proposed to obtain the proper design for both TWD and SWD in an efficient way. In the present work, the multidisciplinary design of optimization (MDO) has been performed to find the proper shape of the TWD disk with the minimum mass. The results showed that the TWD exhibits a better performance in heat transfer and weight loss than SWD. The modeling and optimization procedure of this work can be referred for engineering design.

References listed at the end of the paper:


Sajjad Zargham, Thomas Arthur Ward, Rahizar Ramli and Irfan Anjum Badruddin, “Topology optimization: a review for structural designs under vibration problems”, Structural and Multidisciplinary Optimization, Vol. 53, No. 6, pp 1157–1177, June 2016, ABSTRACT: This article provides a comprehensive review of structural optimization employing topology methods for structures under vibration problems. Topology optimization allows creative and radical design modifications, compared to shape and size optimization techniques. Various works of structural topology optimization, which are subjected to vibration as the response function of the optimization process, are reviewed. Different types of calculus and numerical methods commonly used for solving structural topological optimization problems are briefly discussed. Moreover, different aspects of topology optimization related to vibration problems are explained. The articles reviewed are largely confined to linear systems that concern small vibration amplitudes. Accordingly, the works related to vibration topological optimization are classified according to the method employed (homogenization, evolutionary structural optimization, solid isotropic material with penalization, or level set). The reviewed works are tabulated according to their methodology, year, and the objective functions and applications of each work. Although the homogenization and evolutionary methods were common in the past, the solid isotropic material with penalization (SIMP) method is the most popular method applied in recent years. The advantages of the level set method show promise for future applications. References listed at the end of the paper:
· Heyman J (1951) Plastic design of beams and frames for minimum material consumption. Quart Appl Math 8:373–381
· Holland JH (1975) Adaptation in national and artificial systems. University of Michigan Press, Ann Arbor
· Huang X, Xie YM (2010a) Evolutionary topology optimization of continuum structures: methods and applications. Wiley
· Jianbin Du, Olhoff N (2005) Topology optimization of continuum structures with respect to simple and multiple eigenfrequencies. 6th World Congresses of Structural and Multidisciplinary Optimization, Rio de Janeiro, Brazil
· Li Q, Steven GP, Querin OM, Xie YM (1999a) Shape and topology design for heat conduction by evolutionary structural optimization. Int J Heat Mass Transf 42(17):3361–3371
· Sethian JA (1999) Level set methods and fast marching methods: evolving interfaces in computational geometry, fluid mechanics, computer vision, and materials science. Cambridge University Press
· Sigmund O (1994) Design of material structures using topology optimization. Danish center for applied mathematics and mechanics. Technical University of Denmark, Lyngby
· Venkayya VB, Khot NS, Reddy VS (1968) Optimization of structures based on the study of strain energy distribution. DTIC Document, USAF Flight Dynamics Lab, WPAFB, Dayton
Alemseged Gebrehiwot Weldeyesus and Mathias Stolpe, “Free material optimization for laminated plates and shells”, Structural and Multidisciplinary Optimization, Vol. 53, No. 6, pp 1335-1347, June 2016, ABSTRACT: Free Material Optimization (FMO) is a powerful approach for conceptual optimal design of composite structures. The design variable in FMO is the entire elastic material tensor which is allowed to vary almost freely over the design domain. The imposed requirements on the tensor are that it is symmetric and positive semidefinite. Most of today’s studies on FMO focus on models for two- and three-dimensional structures. The objective of this article is to extend existing FMO models and methods to laminated plate and shell structures, which are used in many engineering applications. In FMO, the resulting optimization problem is generally a non convex semidefinite program with many matrix inequalities which requires special-purpose optimization methods. The FMO problems are efficiently solved by a primal-dual interior point method developed and implemented by the authors. The quality of the proposed FMO models and the method are supported by several large-scale numerical experiments. References listed at the end of the paper:

- Zarghamee M (1968) Frequency optimization. AIAA J 6:749–750

References listed at the end of the paper:
Abolfazl Khalkhalhi, Majid Mostafapour, Seyed Mohamad Tabatabaie and Behnam Ansari, “Multi-objective crashworthiness optimization of perforated square tubes using modified NSGAII and MOPSO”, Structural and Multidisciplinary Optimization, Vol. 54, No. 1, pp 45-61, July 2016,

ABSTRACT: In this paper, multi-objective optimization of perforated square tubes is performed considering absorbed energy, peak crushing force and weight of the tube as three conflicting objective functions. In the multi-objective optimization problem (MOP), absorbed energy and peak crushing force are defined by polynomial models extracted using the software GEvoM based on the train and test data obtained from the numerical simulation of quasi-static crushing of the perforated square tubes using ABAQUS. To verify the numerical procedure, 16 different experimental tests are performed and then the experimental and numerical results are compared together. The comparison shows reasonable similarities between the numerical and experimental results. The MOP is solved using modified Non-dominated Sorting Genetic Algorithm II (NSGAII) and Multi-objective Particle Swarm Optimization (MOPSO) and then the solutions are combined for non-dominated sorting to obtain the non-dominated individuals of 3-objective optimization. 105 optimum points are extracted from the multi-objective optimization process. Finally, Nearest to Ideal Point (NIP) method and Technique for Ordering Preferences by Similarity to Ideal Solution (TOPSIS) method are employed to find trade-off optimum design points out of all non-dominated individuals compromising all three objective functions together.

References listed at the end of the paper:
29. Pareto V (1896) Cours d’économie politique. Rouge: Lausanne, Switzerland

Masatoshi Shimoda, Tomoki Okada, Tomohiro Nagano and Jin-Xing Shi, “Free-form optimization method for buckling of shell structures under out-of-plane and in-plane shape variations”, Structural and Multidisciplinary Optimization, Vol. 54, No. 2, pp 275-288, August 2016, ABSTRACT: In the present work, in order to tackle the linear elastic buckling problem, we develop a shape optimization process based on a free-form optimization method to optimize a shell structure under out-of-plane
and in-plane shape variations. The free-form optimization method is a node-based method in which mesh regularity can be maintained and shape design parameterization is not required. It has the advantages of sufficient efficiency for treating large-scale problems and the ability to realize a smooth shape. The buckling coefficient in buckling mode 1 is set as the objective function in the shape optimization problem. We consider repeated eigenvalues and volume constraint for the whole optimization process. Three numerical examples are presented in this work to illustrate the shape optimization algorithm and to show that it can increase the buckling strength substantially, especially under shape variation in the out-of-plane direction.

References listed at the end of the paper:

Topological optimization of inelastic structures is a method used to optimize the shape, material distribution, or topology of structures to achieve optimal performance. This method is particularly useful in applications where weight reduction or energy absorption are critical, such as in automotive crashworthiness design. The process involves solving a series of optimization problems, where the objective is to minimize a certain cost function, such as the mass of the structure or the maximum strain energy, subject to various constraints such as stress limits, displacement limits, or manufacturing constraints.

In the context of crashworthiness, topological optimization can be used to design structures that can absorb a maximum amount of energy during a collision. This is achieved by creating optimal shapes and material distributions that can redistribute the forces during impact. The optimization process can be performed using various techniques and optimization algorithms, including gradient-based methods, evolutionary algorithms, and genetic algorithms.


ABSTRACT: Although topology optimization is well established in most engineering fields, it is still in its infancy concerning highly non-linear structural applications like vehicular crashworthiness. One of the approaches recently proposed and based on Hybrid Cellular Automata is modified here such that it can be applied for the first time to thin-walled structures. Classical methods based on voxel techniques, i.e., on solid three-dimensional volume elements, cannot derive structures made from thin metal sheets where the main energy absorption mode is related to plastic buckling, folding and failure. Because the main components of car structures are made from such thin-walled beams and panels, a special approach using SFE CONCEPT was developed, which is presented in this paper.

References listed at the end of the paper:

- Vanderplaats Research and Development, Inc. (2012) GENESIS – software for structural analysis and optimization
ABSTRACT: Possessing the unique properties of lower mass and higher performances, the structure with Negative Poisson’s Ratio (NPR) can be widely used in aerospace and vehicle industry. By combing the NPR structure filled core and the traditional crash box, a novel NPR crash box is first proposed in this work to improve the performances of the crash box. The performances of the novel NPR crash box are fully studied by comparing to the traditional crash box and the aluminum foam filled crash box. A parameterized model of the NPR crash box, which integrates the design parameters of the basic NPR cell structure, is built to improve the analysis and optimization efficiency, the accuracy of the parameterized model is also verified by comparing to traditional FEM model. Multi-objective optimization model of the NPR crash box is established by combining the parameterized model, optimal Latin square design method and response surface model approach. Non-dominated sorting genetic algorithm-II (NSGA-II) is then applied to optimize the design parameters of the basic NPR cell structure to improve the performances of the NPR crash box. The results indicate that the novel NPR
crash box can improve the performances of the crash box remarkably and the combination of parameterized model and multi-objective genetic algorithms optimize the NPR crash box efficiently. The presented new method also serves as a good example for other application and optimization of NPR structure.

References listed at the end of the paper:


ABSTRACT: In this study, the structural optimization of notched composite laminates under in plane shear and normal tension loads were carried out. The objective function of the optimization problem was selected to be the maximum stiffness and the minimum strain respectively along with the orientation angles as the optimization variables. In order to determine the ultimate failure load, a previously developed progressive failure approach was adopted. Although numerous studies exist in the literature on this subject, within the scope of the present study, correlations with the experimental results were examined qualitatively by comparing predicted and experimentally determined damage states. Prior to obtaining the optimized results, a further investigation into the response of the structure under pure shear was studied by a parametric approach. A zeroth order optimization tool known as Nelder&Mead was utilized to obtain the optimized configurations. It was shown that the developed optimization scheme is suitable for an exact determination of maximum stiffness and the minimum strain for the given materials and geometry. The results were presented for various load configurations

References listed at the end of the paper:
manufacturing aspects. 25th International Congress of the Aeronautical Sciences

structures vol ECSS


References listed at the end of the paper:

based contour optimization under operational loads are presented. The approach and its features are presented first. A weighted objective function is used to include the manufacturing effort determined by a Manufacturing Effort Model (MEM) together with the mass of the profile into a stress, displacement and stability constraint optimization problem. The manufacturing effort is modeled through a fuzzy approach from qualitative linguistic statements of extrusion experts. The constrained optimization problem is solved by a Sequential Quadratic Programming (SQP) algorithm, and Pareto optimality criteria. Struct Multidiscip Optim 30:335–341


Rainer Wehrle and Horst Baier, “Grid based contour parameterization and optimization of extruded aluminum profiles considering structural and manufacturing aspects”, Structural and Multidisciplinary Optimization, Vol. 54, No. 4, pp 1031-1044, October 2016,

ABSTRACT: A multi-criteria optimization method for cross section shape optimization of extruded aluminum profiles under structural loads is presented. It is based on a new geometrical parameterization technique and can be applied to arbitrary cross sections, enabling large geometrical and topological changes. The constrained optimization problem is solved by a Sequential Quadratic Programming (SQP) algorithm, and Pareto-optimal solutions with regard to manufacturing effort and structural aspects are determined. For that purpose, a weighted objective function is used to include the manufacturing effort determined by a Manufacturing Effort Model (MEM) together with the mass of the profile into a stress, displacement and stability constraint optimization problem. The manufacturing effort is modeled through a fuzzy approach from qualitative linguistic statements of extrusion experts. The approach and its features are presented first by a clamped beam test example. It is then applied to larger practical cases. The results of an automotive roof pillar gained via the grid based contour optimization via a level-set method. 10th World Congress on Structural and Multidisciplinary Optimization, Orlando, Florida, USA


ABSTRACT: We introduce a topology optimization method for the stiffness-based design of structures made of plates. Our method renders topologies made distinctly of plates, thereby producing designs that better conform to manufacturing processes tailored to plate structures, such as those that employ stock plates that are cut and joined by various means. To force the structural members to be plates, we employ the geometry projection method to project an analytical description of a set of fixed-thickness plates onto a continuous density field defined over a 3-dimensional, uniform finite element grid for analysis. A size variable is assigned to each plate and penalized so that the optimizer can entirely remove a plate from the design. The proposed method accommodates the case where the plates in the topology are rectangular and solid, and the case where the boundaries of the plates can change and holes can be introduced. The latter case is attained by composition with a free density field. We present examples that demonstrate the effectiveness of our method and discuss future work.

References listed at the end of the paper:

This paper studies maximum out-of-plane buckling load design of thin bending plates for a given amount of material. Two kinds of plates are considered. One is made of periodic homogeneous porous material. Another is uniformly stiffened solid plate. The plate material, thickness, design domain of its middle plane and boundary conditions are given. The pattern of prescribed in-plane external load or displacements along the part of boundaries, which move freely, is given. Both plate topology and micro-structural topology of porous material or stiffener layout are concurrently optimized. The artificial element material densities in both macro and micro-scale are chosen as design variables. The volume preserving nonlinear density filter is applied to obtain the black-white optimum topology and comparison of its different sensitivities is made to show the reason for oscillation during optimization process in Appendix. The new numerical implementation of asymptotic homogenization method (NIAH, Cheng (Acta Mech Sinica 29(4): 550–556, 2013) and Cai (Int J
Solids Struct 51(1), 284–292, 2014) is applied to homogenization of periodic plate structures and analytic sensitivity analysis of effective stiffness with respect to the topological design variables in both macro-scale and micro-scale. On basis of that, this paper implements the sensitivity analysis of out-of-plane buckling load by using commercial FEA software and enables the application of gradient-based search algorithm in optimization. Several numerical implementation details are discussed. Three numerical examples are given to show the validity of this method.

References listed at the end of the paper:
ABSTRACT: This paper proposes a new ITPS panel with special corrugated-core webs which are designed with cutouts for weight saving. The structural design problem was formulated with mass per unit area of the ITPS as the objective function and some functional requirements as constraints. We developed the optimizer fulfilling both thermal and structural functions for minimal areal density. The optimization problem was solved by interpolating the residual error of response surface approximation (RSA) with Radial Basis Function (RBF) to establish the improved RSA (IRSA). The 400 preliminary design points were obtained using Latin Hypercube Sampling method. The quadratic polynomial RSA of the ITPS sandwich panel performance was generated by the least squares method (LSM) based on finite element results and IRSA was used to optimize the constraints. Transient heat transfer, stress and buckling analyses were conducted using finite element method (FEM). Finally, a new ITPS panel with optimal dimensions was obtained. The optimization results show that the areal density of the new ITPS panel decreases by 26.27% compared with the previous research, which proves the potential of this new design optimization method for the future spacecraft vehicles.

References listed at the end of the paper:

References listed at the end of the paper: methods applied are based on the assumptions of perfect plasticity and small deformations. The yield criteria of the mean or pointwise yield condition for the entire finite element instead of multiple point-wise conditions. This approach shows promising results in numerical application to the optimization of a circular plate, considering a possibility of employing the yield criteria of the mean or pointwise yield conditions in different areas of the plate in particular. The methods applied are based on the assumptions of perfect plasticity and small deformations.


ABSTRACT Structural optimization based on the shakedown theory is a powerful and promising technique. However, due to the nonlinearities of physical materials and the number of variable loads in real structures, it is computationally complex and time-consuming. To simplify the occurring non-linear, non-convex optimization problems, the paper suggests reducing the number of yield conditions. The so-called a yield criterion of the mean (integral yield condition) is analysed and explained in detail, which allows taking into account one yield condition for the entire finite element instead of multiple point-wise conditions. This approach shows promising results in numerical application to the optimization of a circular plate, considering a possibility of employing the yield criteria of the mean or pointwise yield conditions in different areas of the plate in particular. The methods applied are based on the assumptions of perfect plasticity and small deformations.

References listed at the end of the paper:

Wei-Qing Sun and Wei Cheng, “Finite element model updating of honeycomb sandwich plates using a response surface model and global optimization technique”, Structural and Multidisciplinary Optimization, Vol. 55, No. 1, pp 121-139, January 2017,

ABSTRACT: Honeycomb sandwich plates are used widely in the aerospace industry. Building accurate finite element models of honeycomb sandwich plates is necessary for analyzing and optimizing the microvibration that occurs in spacecraft. This study investigated two types of finite element dynamic models of honeycomb plates: a sandwich shell model and a shell-volume-shell model. Two response surface model-based optimization methods and a particle swarm optimization method were compared for updating the finite element models. Finally, we validated the accuracy of the two optimized honeycomb sandwich plate finite element dynamic models by comparing the results obtained by the frequency response functions with experimental data.

References listed at the end of the paper:


In this paper, an attempt has been made to calculate the optimal values of effective parameters on the stress distribution around a quasi-square cutout using different optimization algorithms such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Ant Colony Optimization (ACO). To achieve this goal, the analytical results of symmetric laminated composite plates containing a square cutout have been used. The analytical solution can be achieved with the development of the Lekhnitskii solution method. This method is based on using complex variable method in the analysis of two-dimensional problems. In order to use the method in stress analysis of laminates containing a square cutout, by using conformal mapping, the area outside the square cutout is mapped to the area outside of a unit circle. Effective parameters on stress distribution around the square cutout in symmetric laminated plates considered as design variables include: load angle, cutout orientation, bluntness and the stacking sequence of the laminate. Cost function in this problem is the maximum stress created around the cutout calculated by the analytical solution method.

ABSTRACT: In this paper, an attempt has been made to calculate the optimal values of effective parameters on the stress distribution around a quasi-square cutout using different optimization algorithms such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Ant Colony Optimization (ACO). To achieve this goal, the analytical results of symmetric laminated composite plates containing a square cutout have been used. The analytical solution can be achieved with the development of the Lekhnitskii solution method. This method is based on using complex variable method in the analysis of two-dimensional problems. In order to use the method in stress analysis of laminates containing a square cutout, by using conformal mapping, the area outside the square cutout is mapped to the area outside of a unit circle. Effective parameters on stress distribution around the square cutout in symmetric laminated plates considered as design variables include: load angle, cutout orientation, bluntness and the stacking sequence of the laminate. Cost function in this problem is the maximum stress created around the cutout calculated by the analytical solution method. Another goal of this paper is to investigate the performance of aforementioned optimization algorithms. The results show that the PSO algorithm converges earlier than the other two methods and have the better cost function.

References listed at the end of the paper:

· Abueiffoutouh NM (1993) “Preliminary design of unstiffened composite shells.”, Symp 7th Tech Conf ASC 686–693
ABSTRACT: Constraint aggregation makes it feasible to solve large-scale stress-constrained mass minimization problems efficiently using gradient-based optimization where the gradients are computed using adjoint methods. However, it is not always clear which constraint aggregation method is more effective, and which values to use for the aggregation parameters. In this work, the accuracy and efficiency of several aggregation methods are compared for an aircraft wing design problem. The effect of the type of aggregation function, the number of constraints, and the value of the aggregation parameter are studied. Recommendations are provided for selecting a constraint aggregation scheme that balances computational effort with the accuracy of the computed optimal design. Using the recommended aggregation method and associated parameters, a mass of within 0.5 % of the true optimal design was obtained.

References listed at the end of the paper:

Example the optimum corrugation often has the maximum corrugation height. The obtained results provide insights into the multi-objective optimization of a trapezoidal corrugated core with elastomer coating. The multi-objective optimization of a trapezoidal corrugated core with elastomer coating.

**ABSTRACT:** Morphing concepts have great importance for the design of future aircraft as they provide the opportunity for the aircraft to adapt their shape in flight so as to always match the optimal configuration. This enables the aircraft to have a better performance, such as reducing fuel consumption, toxic emissions and noise pollution or increasing the maneuverability of the aircraft. However, the requirements of morphing aircraft are conflicting from the structural perspective. For instance, the design of a morphing skin is a key issue since it must be stiff to withstand the aerodynamic loads, but flexible to enable the morphing deformations. This work presents novel insights into the multi-objective optimization of a trapezoidal corrugated core with elastomer coating. The geometric parameters of the coated composite corrugated panels are optimized to minimize the in-plane stiffness and the weight of the skin and to maximize the flexural out-of-plane stiffness of the skin. These objective functions were calculated by use of an equivalent finite element code. The gradient-based aggregate method is selected to solve the optimization problem and is validated by comparing to the GA multi-objective optimization technique. The trend of the optimized objectives and parameters are discussed in detail; for example the optimum corrugation often has the maximum corrugation height. The obtained results provide important insights into the design of morphing corrugated skins.


References listed at the end of the paper:

• Dayyani I, Shaw AD, Saavedra Flores EI, Friswell MI (2015a) The mechanics of composite corrugated structures: a review with applications in morphing aircraft. Compos Struct 133:358–380

V. Kobelev, “The anisotropic pressure vessel of minimal mass”, Structural and Multidisciplinary Optimization, Vol. 55, No. 1, pp 375-380, January 2017,

ABSTRACT: A pressure vessel made of anisotropic material is held together against the gas pressure tanks to tensile forces within the walls. The optimization problem consists in searching the shape and the thickness distribution of membrane shells, made of anisotropic material. The closed form solution of the optimization problem is obtained and corresponding isoperimetric inequality is proved for anisotropic Hill yield criteria. References listed at the end of the paper:
• Ventsel E, Krauthammer T (2001) Thin plates and shells, theory, analysis, and applications. Marcel Dekker, New York

ABSTRACT: Optimization with Unified Particle Swarm Optimization (UPSO) method is performed for the enhancement of buckling load capacity of composite plates having damage under hygrothermal environment which has received little or no attention in the literature. Numerical results are presented for effect of damage in buckling behavior of laminated composite plates using an anisotropic damage model. Optimized critical buckling temperature of laminated plates with internal flaw is computed with the fiber orientation as the design variable by employing a UPSO algorithm and results are compared with undamaged case for various aspect ratios, ply orientations, and boundary conditions. FEM formulation and programming in the MATLAB environment have been performed. The results of this work will assist designers to address some key issues concerning composite structures. It is observed that the degradation of buckling strength of a structural element in hygrothermal environment as a result of internal flaws can be avoided to a large extent if we use these optimized ply orientations at design phase of the composite structure. This specific application proves the contribution of present work to be of realistic nature.

References listed at the end of the paper:

In this study, we optimally design the core of a metal sandwich panel used in high-speed railway vehicles to minimize the amount of metal solid in the core and subsequently reduce its weight. The optimum core must satisfy constraints regarding sound transmission class (STC) and compliance. Because the solid-void layout in the core strongly affects the acoustic and static characteristics of sandwich panels, the core layout should be carefully designed when reducing the amount of metal solid. To this end, three topology-optimization problems and one size-optimization problem are formulated and sequentially solved. A single unit cell is periodically repeated in the core. Thus, structural and acoustic topology-optimization problems are first formulated and solved for the unit cell. Based on the optimal topologies obtained for the unit cell, a moderate initial solid-void layout in the unit cell is determined for the size-optimization problem to optimally design core. The effectiveness of the current design approach for the core of the sandwich panel is validated by comparing the STC and compliance values of the optimal core design and a reference design.

References listed at the end of the paper:


ABSTRACT: In this study, we optimally design the core of a metal sandwich panel used in high-speed railway vehicles to minimize the amount of metal solid in the core and subsequently reduce its weight. The optimum core must satisfy constraints regarding sound transmission class (STC) and compliance. Because the solid-void layout in the core strongly affects the acoustic and static characteristics of sandwich panels, the core layout should be carefully designed when reducing the amount of metal solid. To this end, three topology-optimization problems and one size-optimization problem are formulated and sequentially solved. A single unit cell is periodically repeated in the core. Thus, structural and acoustic topology-optimization problems are first formulated and solved for the unit cell. Based on the optimal topologies obtained for the unit cell, a moderate initial solid-void layout in the unit cell is determined for the size-optimization problem to optimally design core. The effectiveness of the current design approach for the core of the sandwich panel is validated by comparing the STC and compliance values of the optimal core design and a reference design.

References listed at the end of the paper:


Logan DL (2011) A first course in the finite element method. Cengage Learning, India


ABSTRACT: To improve the far-field directivity properties of a given mid-range acoustic horn, previously designed by shape optimization to exhibit almost ideal transmission properties in the frequency range 1.6–9.05 kHz, we apply layout optimization of thin sound-hard material in the interior of the horn. The purpose of the optimization is to place scattering material to prevent the sound intensity to increasingly be concentrated, with increasing frequency, along the horn axis. Absence or presence of thin sound-hard material is modeled by an equivalent surface transmission impedance, and the optimization algorithm determines the distribution of air or sound-hard material along a “ground structure” in the form of a grid inside the horn. The surface impedance is numerically handled using a newly developed finite-element formulation that allows exact enforcement of a vanishing impedance, corresponding to air, which would not be possible using a standard formulation. Horns provided with the optimized scatterers show a much improved angular coverage, compared to the initial
configuration, with beam widths that exceed 60 deg. uniformly over the operational frequency range, without destroying the good transmission properties of the initial horn.

References listed at the end of the paper:


Rienstra SW, Hirschberg A (2015) An introduction to acoustics. Revised and updated version of reports IWDE 92-06 and IWDE 01-03, Eindhoven University of Technology


Yedeg EL (2016) On the use of thin structures to control the far-field properties of an acoustic device. Tech. Rep UMINF 16.12, Department of Computing Science, Umeå University


ABSTRACT: The paper deals with the conceptual design of a beam under bending. The common problem of designing a beam in a state of pure bending is discussed in the framework of Pareto-optimality theory. The analytical formulation of the Pareto-optimal set is derived by using a procedure based on the reformulation of the Fritz John Pareto-optimality conditions. The shape of the cross section of the beam is defined by a number of design variables pertaining to the optimization process by means of efficiency factors. Such efficiency factors are able to describe the bending properties of any beam cross section and can be used to derive analytical formulae. Design performance is determined by the combination of cross section shape, material and process. Simple expressions for the Pareto-optimal set of a beam of arbitrary cross section shape under bending are derived. This expression can be used at the very early stage of the design to choose a possible cross section shape and material for the beam among optimal solutions.

References listed at the end of the paper:


ABSTRACT: Structural topology optimisation has mainly been applied to strength and stiffness objectives, due to the ease of calculating the sensitivities for such problems. In contrast, dynamic and buckling objectives
require time consuming central difference schemes, or inefficient non-gradient algorithms, for calculation of the sensitivities. Further, soft-kill algorithms suffer from numerous numerical issues, such as localised artificial modes and mode switching. This has resulted in little focus on structural topology optimisation for dynamic and buckling objectives. In this work it is found that nominal stress contours can be derived from applying the vibration and buckling mode shapes as displacement fields, defined as the dynamic and buckling von Mises stress, respectively. This paper shows that there is an equivalence between the dynamic von Mises stress and the frequency sensitivity numbers for element removal and addition in bidirectional evolutionary structural optimisation. Likewise, it was found that the contours of buckling von Mises stress and buckling sensitivity numbers are analogous; therefore an equivalence is shown for element removal and addition. The examples demonstrate consistent resulting topologies from the two different formulations for both dynamic and buckling criteria. This article aims to develop a simple alternative, based on visual correlation with a mathematical verification, for topology optimisation with dynamic and buckling criteria.

References listed at the end of the paper:

· Munk DJ, Vio GA, Steven GP (2016a) A new formulation for the BESO method to solve the Zhou-Rozvany problem. (under review). Struct Multidiscip Optim
· Munk DJ, Vio GA, Steven GP (2016b) A novel moving iso-surface threshold technique for the vibration optimisation of structures subjected to dynamic loading. AIAA J. (accepted)

ABSTRACT: In the present study, Multi-objective optimization of composite cylindrical shell under external hydrostatic pressure was investigated. Parameters of mass, cost and buckling pressure as fitness functions and failure criteria as optimization criteria were considered. The objective function of buckling has been used by performing the analytical energy equations and Tsai-Wu and Hashin failure criteria have been considered. Multi-objective optimization was performed by improving the evolutionary algorithm of NSGA-II. Also the kind of material, quantity of layers and fiber orientations have been considered as design variables. After optimizing, Pareto front and corresponding points to Pareto front are presented. Trade of points which have optimized mass and cost were selected by determining the specified pressure as design criteria. Finally, an optimized model of composite cylindrical shell with the optimum pattern of fiber orientations having appropriate cost and mass is presented which can tolerate the maximum external hydrostatic pressure.

References listed at the end of the paper:

- Xie YM, Steven GP (1997) Evolutionary structural optimization. Springer, Germany

References listed at the end of the paper:


ABSTRACT: Optimization for structural crashworthiness and energy absorption has become an important topic of research attributable to its proven benefits to public safety and social economy. This paper provides a comprehensive review of the important studies on design optimization for structural crashworthiness and energy absorption. First, the design criteria used in crashworthiness and energy absorption are reviewed and the surrogate modeling to evaluate these criteria is discussed. Second, multiobjective optimization, optimization under uncertainties and topology optimization are reviewed from concepts, algorithms to applications in relation to crashworthiness. Third, the crashworthy structures are summarized, from generically novel structural configurations to industrial applications. Finally, some conclusions and recommendations are provided to enable academia and industry to become more aware of the available capabilities and recent developments in design optimization for structural crashworthiness and energy absorption.
Davis SC, Diegel SW, Boundy RG (2013) Transportation energy data book. 32 edn., Oak Ridge National Lab
· Lanzi L, Castelletti LML, Anghileri M (2004b) Multi-objective optimisation of composite absorber shape under crashworthiness requirements. Compos Struct 65:433–441
· Lee Y, Ahn J-S, Park G Crash optimization of automobile frontal and side structures using equivalent static loads. In: 11th World Congress on Structural and Multidisciplinary Optimization, Sydney, NSW, Australia, 2015
· Liu Y (2008a) Crashworthiness design of multi-corner thin-walled columns. Thin-Walled Struct 46:1329–1337
· Liu Y (2008c) Optimum design of straight thin-walled box section beams for crashworthiness analysis. Finite Elem Anal Des 44:139–147
· Liu Y (2010a) Crashworthiness design of thin-walled curved beams with box and channel cross sections. Int J Crashworth 15:413–423
· Liu Y (2010b) Thin-walled curved hexagonal beams in crashes - FEA and design. Int J Crashworth 15:151–159
· Messac A, Sundararaj GI, Tappeta RV, Renaud JE (2000b) Ability of objective functions to generate points on nonconvex Pareto frontiers. AIAA J 38:1084–1091
· Pedersen CBW (2003a) Topology optimization design of crushed 2D-frames for desired energy absorption history. Struct Multidisc Optim 25:368–382
To TARlochan F, Samer F, Hamouda AMS, Ramesh S, Khalid K (2013) Design of thin wall structures for energy absorption


Sun G, Song X, Baek S, Li Q (2014a) Robust optimization of foam-filled thin-walled structure based on sequential Kriging


· Viana FA, Simpson TW, Balabanov V, Toropov V (2014) Metamodeling in multidisciplinary design optimization: how far have we really come? AIAA J 52:670–690
· Zarei HR, Kroger M (2008c) Optimization of the foam-filled aluminum tubes for crush box application. Thin-Walled Struct 46:214–221
· Zurada JM (1992) Introduction to artificial neural systems vol 8. West publishing company, St. Paul
ABSTRACT: This paper focuses on Deterministic and Reliability Based Design Optimization (DO and RBDO) of composite stiffened panels considering post-buckling regime and progressive failure analysis. The ultimate load that a post-buckled panel can hold is to be maximised by changing the stacking sequence of both skin and stringers composite layups. The RBDO problem looks for a design that collapses beyond the shortening of failure obtained in the DO phase with a target reliability while considering uncertainty in the elastic properties of the composite material. The RBDO algorithm proposed is decoupled and hence separates the Reliability Analysis (RA) from the deterministic optimization. The main code to drive both the DO and RBDO approaches is written in MATLAB and employs Genetic Algorithms (GA) to solve the DO loops because discrete design variables and highly nonlinear response functions are expected. The code is linked with Abaqus to perform parallel explicit nonlinear finite element analyses in order to obtain the structural responses at each generation. The RA is solved through an inverse Most Probable failure Point (MPP) search algorithm that benefits from a Polynomial Chaos Expansion with Latin Hypercube Sampling (PCE-LHS) metamodel when the structural responses are required. The results led to small reductions in the maximum load that the panels can bear but otherwise assure that they will collapse beyond the shortening of failure imposed with a high reliability.

References listed at the end of the paper:
ABSTRACT: The problem of optimal design of shape and orientation of fibers in composite material, leading to the local inhomogeneity of its parameters, is considered in this paper. The paper concerns the problem of curvilinear fibers arrangement in the composite material, so that the structural element made from this material can fulfill the requirements imposed on its thermal properties. An equivalent homogeneous orthotropic model of the composite is utilized for this purpose and next, basing on this model, the attempt is taken to determine the most profitable orientation and arrangement of fibers in the layers of the composite in order to obtain the desired behavior of structure. To solve this problem, the optimization method based on evolutionary algorithm is applied, and it is supplemented with finite element method for heat transfer analysis.

References listed at the end of the paper:


ABSTRACT: For tailoring the non-uniform axial compression, each sub-panel of stiffened shells should be designed separately to achieve a high load-carrying efficiency. Motivated by the challenge caused by numerous variables and high computational cost, a fast procedure for the minimum weight design of non-uniform stiffened shells under buckling constraint is proposed, which decomposes a hyper multi-dimensional problem into a hierarchical optimization with two levels. To facilitate the post-buckling optimization, an efficient equivalent analysis model of stiffened shells is developed based on the Numerical Implementation of Asymptotic Homogenization Method. In particular, the effects of non-uniform load, internal pressure and geometric imperfections are taken into account during the optimization. Finally, a typical fuel tank of launch vehicle is utilized to demonstrate the effectiveness of the proposed procedure, and detailed comparison with other optimization methodologies is made.

References listed at the end of the paper:

· Starnes JH Jr, Haftka RT (1979) Preliminary design of composite wings for buckling, strength, and displacement constraints. AIAA J 16(8):564–570

ABSTRACT: Perforated pipeline structure is widely utilized in the oil industry for its special functionality of communicating media with the ambient environment. A typical application is the slotted liner in SAGD (Steam Assisted Gravity Drainage) process, where the pipeline structure is manufactured with open slots to spread hot steam and collect the melted oil. Generally, a dense opening layout is employed to reduce flow resistance. On the other hand, inclusion of the many openings severely reduces the structural strength and stiffness, which causes the pipeline prone to deformation or even failure. Therefore, there exist the two conflicting requirements for design of the pipeline opening layout, and an interesting solution is proposed in this paper. To be specific, the pipeline structure is discretized into shell elements which are categorized into multiple types: without opening, with opening type 1, with opening type 2, etc. These element types are treated as different material phases, and design of the pipeline opening layout is transformed into a multi-material topology optimization problem. Multi-material level set method is employed to solve it, subject to the compliance minimization objective. In addition, a lower bound of opening quantity is applied by properly configuring the material fraction constraint, which ensures the low flow resistance. The effectiveness of the proposed method is proven through a few numerical case studies.

References listed at the end of the paper:

ABSTRACT: The focus of this paper is on topology optimization of continuum structures subject to thermally induced buckling. Popular strategies for solving such problems include Solid Isotropic Material with Penalization (SIMP) and Rational Approximation of Material Properties (RAMP). Both methods rely on material parameterization, and can sometimes exhibit pseudo buckling modes in regions with low pseudo-densities. Here we consider a level-set approach that relies on the concept of topological sensitivity. Topological sensitivity analysis for thermo-elastic buckling is carried out via direct and adjoint formulations. Then, an augmented Lagrangian formulation is presented that exploits these sensitivities to solve a buckling constrained problem. Numerical experiments in 3D illustrate the robustness and efficiency of the proposed method.

References listed at the end of the paper:

Ali Elham and Michel J.L. van Tooren, “Multi-fidelity wing aerostructural optimization using a trust region filter-SQP algorithm”, Structural and Multidisciplinary Optimization, Vol. 55, No. 5, pp 1773-1786, May 2017, ABSTRACT: A trust region filter-SQP method is used for wing multi-fidelity aerostructural optimization. Filter method eliminates the need for a penalty function, and subsequently a penalty parameter. Besides, it can easily be modified to be used for multi-fidelity optimization. A low fidelity aerostructural analysis tool is presented, that computes the drag, weight and structural deformation of lifting surfaces as well as their sensitivities with respect to the design variables using analytical methods. That tool is used for a mono-fidelity wing aerostructural optimization using a trust region filter-SQP method. In addition to that, a multi-fidelity aerostructural optimization has been performed, using a higher fidelity CFD code to calibrate the results of the lower fidelity model. In that case, the lower fidelity tool is used to compute the objective function, constraints and their derivatives to construct the quadratic programming subproblem. The high fidelity model is used to compute the objective function and the constraints used to generate the filter. The results of the high fidelity analysis are also used to calibrate the results of the lower fidelity tool during the optimization. This method is applied to optimize the wing of an A320 like aircraft for minimum fuel burn. The results showed about 9% reduction in the aircraft mission fuel burn. The results showed about 9% reduction in the aircraft mission fuel burn.

References listed at the end of the paper:


ABSTRACT: This paper deals with the preliminary design of a composite structure where the design variables are the thicknesses and the percentages of fiber orientations in the zones of the structure. In this paper, we propose to include the design and manufacturing rules in the preliminary design. A stacking sequence generator is used to compute admissible stacking sequences with respect to these rules and which correspond to the design variables. Given that an admissible stacking sequence does not exist for every set of values of the design variables, a repair operator is proposed to cope with this problem. It aims at changing the values of the percentages of the fiber orientations in order to guarantee the existence of admissible stacking sequences with respect to the manufacturing rules. The repair operator is integrated into an optimization loop which uses a genetic algorithm to perform the preliminary design of a composite structure. Its efficiency is shown with a test case which involves a large number of fiber orientations and stacking sequences.

References listed at the end of the paper:

· Meddaikar Y, Irisarri F-X, Abdalla M (2015) Blended Composite Optimization combining Stacking Sequence Tables and a Modified Shepard’S Method, 11th World Congress on Structural and Multidisciplinary Optimization Sydney Australia

ABSTRACT: This paper presents a new hybrid Particle Swarm Algorithm (PSO) for optimization of laminated composite structures. The method combines the standard PSO heuristics with Genetic Algorithm operators in order to improve the algorithm performance. Thus, operations that are important to the optimization of laminated composites such as mutation and layer swap are incorporated into the method. A specially designed encoding scheme is used to represent the laminate variables and the associated velocities. A study is carried-out to select the best variant of the proposed method for the optimization of laminated composites, considering different swarm topologies and genetic operators. Both strength maximization and weight minimization problems are considered. A meta-optimization procedure is used to tune the parameters of each variant in order to avoid biased results. The results showed that the proposed method led to excellent results for both traditional and dispersed laminates, representing a significant improvement over the standard PSO algorithm.

References listed at the end of the paper:


ABSTRACT: The paper is concerned with the sensitivity analysis of structural responses in context of linear and non-linear stability phenomena like buckling and snapping. The structural analysis covering these stability phenomena is summarised. Design sensitivity information for a solid shell finite element is derived. The mixed formulation is based on the Hu–Washizu variational functional. Geometrical non-linearities are taken into account with linear elastic material behaviour. Sensitivities are derived analytically for responses of linear and non-linear buckling analysis with discrete finite element matrices. Numerical examples demonstrate the shape optimisation maximising the smallest eigenvalue of the linear buckling analysis and the directly computed critical load scales at bifurcation and limit points of non-linear buckling analysis, respectively. Analytically derived gradients are verified using the finite difference approach.

References listed at the end of the paper:

- Barthold FJ, Gerzen N, Kijanski W, Materna D (2016) Efficient variational design sensitivity analysis, springer international publishing, Cham, 229–257


ABSTRACT: Structural optimization of a 1.2 m diameter space mirror is carried out using OptiStruct tool of HyperWorks 12 to minimize mass and constrain optical aberrations. Zerodur is used as the material for the mirror. A typical open-back mirror of the same diameter and material weighs around 90 kg. For optimization, constraints were imposed on defocus, coma and trefoil aberrations. Aberrations like piston and tilt are caused by rigid body displacements of the mirror can be compensated by on-board control mechanisms and hence ignored for this study. Also, astigmatism is controlled by the design of Mirror Fixation Devices (MFD). Since MFD design is out of the scope of this study, astigmatism is also ignored. Optimization runs are carried out for various boundary conditions. The optimized design weighs 63 kg and has acceptable optical performance. Suggestions are also presented to further minimize the mass while maintaining an acceptable level of optical performance.

The purpose of this paper is to present an extended integrated layout and topology optimization method dealing with the multi-frame and multi-component fuselage structure systems design. Considering an aircraft or aerospace fuselage system including main structure, numbers of frames and featured components located on the frames, a simultaneous optimization procedure is proposed here including geometrical design variables of components and frames as well as topological design variables of main structure and frame structures. The multi-point constraints (MPC) scheme is used to simulate the rivets or bolts connecting the components, frames and structures. The finite circle method (FCM) is implemented to avoid the overlaps among different components and frames. Furthermore, to deal with the difficulties of large numbers of non-overlapping constraints, a penalty method is used here to compose the global strain energy and non-overlapping constraints into a single objective function. To guarantee the fuselage system’s balance, overlapping constraints, a penalty method is used here to compose the global strain energy and non-overlapping constraints among different components and frames. The finite circle method (FCM) is implemented to avoid the overlaps located on the frames, a simultaneous optimization procedure is proposed here including geometrical design variables of components and frames as well as topological design variables of main structure and frame structures. The multi-point constraints (MPC) scheme is used to simulate the rivets or bolts connecting the components, frames and structures. The finite circle method (FCM) is implemented to avoid the overlaps among different components and frames. Furthermore, to deal with the difficulties of large numbers of non-overlapping constraints, a penalty method is used here to compose the global strain energy and non-overlapping constraints into a single objective function. To guarantee the fuselage system’s balance, the constraint on the system centroid is also introduced into the optimization. Different numerical examples are tested and the optimized solutions have demonstrated the validity and effectiveness of the proposed formulation.

References listed at the end of the paper:


ABSTRACT: Thin-walled structures are of great importance in automotive crashworthiness design, because of their high crash energy absorption capability and their high potential for lightweighting. To identify the best compromise between these two requirements, numerical optimization is needed. Size and shape optimization is relatively well explored while topology optimization for crash is still an open issue. Hence, this paper proposes an approach based on hybrid cellular automata (HCA) for crashworthiness topology optimization with a special focus on thin-walled structures. First approaches have been published, e.g. Duddeck et al. (Struct Multidiscip Optim 54(3):415–428, 2016), using a simple rule to define the target mass for the inner loop of the HCA. To improve the performance, a modified scheme is proposed here for the outer optimization loop, which is based on a bi-section search with limited length. In the inner loop, hybrid updating rules are used to redistribute the mass and a mass correction technique is proposed to make the real mass converge to the target mass strictly. The efficiency and correctness of the proposed method is compared with LS-OPT for axial crash cases. Two different methods of defining the target mass in the outer loop are studied, the proposed bi-section search with limited length shows its advantage in two types of three-point bending crash optimization cases. Another advantage of this method is that it requires no significantly increasing number of evaluations when the number of design variables increases. This is demonstrated by applying this method to a crashworthiness optimization problem with 380 design variables.

References listed at the end of the paper:


Hunkeler S, Duddeck F (2014) Topology optimization for crashworthiness of thin-walled structures. In: 11th world congress on computational mechanics (WCCM XI), Barcelona, Spain


ABSTRACT: Aiming at uncertainty propagation and dynamic reanalysis of closely-spaced eigenvalues, with consideration of uncertainties in design variables, a modified stochastic perturbation method is proposed. Concerning quasi-symmetric or partial-symmetric structures that frequently appear, one of their primary features is closely-distributed natural frequencies. For structure with closely-spaced eigenvalues, due to its instability and sensitivity to the changes of design variables and its excessively concentrated adjacent eigenvalues, conventional uncertainty analysis or dynamic reanalysis methods for distinct eigenvalue are no longer available. Initially, the spectral decompositions of stiffness and mass matrices are provided; by transfer technique, the eigen-problem of closely-spaced eigenvalues is converted to that of repeated eigenvalues with two perturbation parts appended; then the perturbed closely-spaced eigenvalue is rewritten as the sum of original closely-spaced eigenvalues’ mean value and surrogate model which approximates the first-order perturbation term by polynomial chaos expansions. According to this method, statistical quantities of perturbed closely-spaced eigenvalues are calculated directly and accurately, which contributes to its uncertainty analysis and dynamic reanalysis. Furthermore, the capability of proposed method in dealing with relatively large uncertainties and complex engineering structure is demonstrated. The accuracy and efficiency of proposed method have been verified sufficiently by numerical examples.

References listed at the end of the paper:


ABSTRACT: The paper deals with the optimization of the S-Lay submarine pipe-laying. The considered laying model is based on a nonlinear elastic beam model with elastic contact interactions with rigid structures of roller supports and the seabed, solved in the Abaqus software. The optimization problem is formulated so as to determine the main parameters of pipe-laying. In order to maximize the efficiency of the optimization procedure, a specialized Particle Swarm Optimization variant is developed. The introduced $\delta$-PSO employs an additional displacement of agent positions, through which the optimization is directed towards solutions based on offshore engineering practice. Two different cases of submarine pipe laying were used for testing. In these tests, the specialized PSO was compared to standard PSO and Mesh Adaptive Direct Search, which it both outperformed. The $\delta$-PSO specialization is easy to implement in PSO or other swarm intelligence methods, and hopefully can provide similar improvements in other applications.

References listed at the end of the paper:
Dassault Systèmes (2011b) Analysis user’s manual, Volume II: Analysis. Dassault Systèmes
Dassault Systèmes (2011c) Analysis user’s manual, Volume IV: Elements. Dassault Systèmes
Veritas DN, Veritas DN (1982) Rules for submari

ABSTRACT: This paper presents a new approach for optimizing shell structures considering their mid surface design including cut-outs. Therefore we introduced a manufacturing constraint to the 3D topology optimization based on the density method in order to receive an optimized structure without undercuts and with a constant wall thickness, so that these structures can be manufactured by deep drawing in one step. It is shown that introducing cut-outs while increasing the shell thickness can improve the performance of shell structures considering their stiffness at a constant mass.

References listed at the end of the paper:
- Boljanovic V (2014) Sheet metal forming processes and die design. Industrial Press, South Norwalk
- Franke T, Vietor T, Fiebig S, Horstmann GM (2015) Robust and production-oriented topology optimization of cast parts including manufacturing restrictions and process simulation, NAFEMS seminar Optimierung und Robust Design, Wiesbaden, Germany

Jun Yan, Zunyi Duan, Erik Lund and Jingyuan Wang, “Concurrent multi-scale design optimization of composite frames with manufacturing constraints”, Structural and Multidisciplinary Optimization, Vol. 56, No. 3, pp 519-533, September 2017,
example of compliance minimization, subject to constraint on the composite volume. The linear constraints and optimization problems are solved by Sequential Linear Programming (SLP) optimization algorithm with move limit strategy. Numerical results show the potential of weight saving and structural robustness design with the proposed concurrent optimization model. The multi-scale optimization model, considering specific manufacturing constraints, provides new choices for the design of the composite frame structure in aerospace and other industries.

References listed at the end of the paper:
ABSTRACT: A design problem of finding an optimally stiff membrane structure by selecting one–dimensional fiber reinforcements is formulated and solved. The membrane model is derived in a novel manner from a particular three-dimensional linear elastic orthotropic model by appropriate assumptions. The design problem is given in the form of two minimization statements. After finite element discretization, the separate treatment of each of the two statements follows from classical results and methods of structural optimization: the stiffest orientation of reinforcing fibers coincides with principal stresses and the separate selection of density of fibers is a convex problem that can be solved by optimality criteria iterations. Numerical solutions are shown for two particular configurations. The first for a statically determined structure and the second for a statically undetermined one. The latter shows related but non-unique solutions.


References listed at the end of the paper:

- Lund E (1994) Finite element based design sensitivity analysis and optimization. Institute of Mechanical Engineering, Aalborg University, Denmark

Aytac Arikoglu, “Multi-objective optimal design of hybrid viscoelastic/composite sandwich beams by using the generalized differential quadrature method and the non-dominated sorting genetic algorithm II”, Structural and Multidisciplinary Optimization, Vol. 56, No. 4, pp 885-901, October 2017,

ABSTRACT: In this study, the multi-objective optimal design of hybrid viscoelastic/composite sandwich beams for minimum weight and minimum vibration response is aimed. The equation of motion for linear vibrations of a multi-layer beam is derived by using the principle of virtual work in the most general form. These governing equations together with the boundary conditions are discretized by the generalized differential quadrature method (GDQM) in the frequency domain for the first time. Also, the time and temperature dependent properties of the viscoelastic materials are taken into consideration by a novel ten-parameter fractional derivative model that can realistically capture the response of these materials. The material variability is accounted for by letting an optimization algorithm choose a material freely out of four fiber-reinforced composite materials and five viscoelastic damping polymers for each layer. The design parameters, i.e., the orientation angles of the composites, layer thicknesses and the layer materials that give the set of optimal solutions, namely the Pareto frontier, is obtained for the three and nine-layered clamped-free sandwich beams by using a variant of the non-dominated sorting genetic algorithms (NSGA II).

References listed at the end of the paper:

References listed at the end of the paper:


Christian Krogh, Mathias H. Junghersen, Erik Lund and Esben Lindgaard, “Gradient-based selection of cross sections: a novel approach for optimal frame structure design”, Structural and Multidisciplinary Optimization, Vol. 56, No. 5, pp 959-972. November 2017, ABSTRACT: Optimization of frame structures composed of beams, columns and joints is considered. The problem is to find the optimal combination of standard cross sections from a provided catalog. The approach taken utilizes the Discrete Material Optimization (DMO) method to parameterize the problem and optimize using a gradient based method. It has roots in continuum topology optimization and thus strong parallels are drawn hereto in terms of methodology. The MATLAB implementation can take mass, compliance and stress criteria into account. In addition continuous joint stiffness design variables will indicate whether the joint should be rigid or pinned. Issues related to the non-convexity of the design spaces and the numerous local minima are discussed. The numerical results with benchmark models of varying complexity successfully validate the method as a design tool.

References listed at the end of the paper:

During deploying and folding processes using physics via an optimization process. Firstly, we investigate the steady bending load in deployable space structures. A novel hinge with three tape springs is investigated and designed.

**ABSTRACT:**


**REFERENCES:**

conducted to verify the physics-based simulation results. Secondly, a parametric analysis is carried out to prove that both the tape spring thickness and subtended angle have significant effect on steady-state moment. A Response Surface Methodology (RSM) is employed to define an optimal surrogate model aimed at maximizing the steady-state moment, subjected to allowable stress. Finally, the Large Scale Generalized Reduced Gradient (LSGRG) optimization algorithm is used to solve the optimal design problem. Optimization results show that steady-state moment is increased by 19.5% while satisfying a maximum stress constraint. The proposed method is promising for designing novel deployable structures with high stability and reliability.

References listed at the end of the paper:

ABSTRACT: In this paper, an optimum rib layout design method for reducing radiated noise is proposed based on topology optimization and acoustic contribution analysis. According to radiated noise depends on acoustic transfer vector (ATV) and normal velocity, the influence of rib layout on ATV is analyzed and it is found rib layout has little influence on ATV. Only if a region has maximum acoustic contribution, the normal velocities on this region can have the most remarkable influence on radiated noise. So the determination procedure of region with maximum acoustic contribution is introduced. Based on this, the topology optimization model is established to minimize the normal velocities on this region. Ribs can be arranged according to the optimum topologies to reduce the normal velocities, which in turn results in a reduction of radiated noise. The topology optimization model is used to obtain the optimal rib layout by taking a plate-like structure as an example. The plate is fixed along all side edges and excited by a time-harmonic external point load with different prescribed frequencies. The radiated noise is simulated using the finite element method and boundary element method. Four plates are manufactured according to the optimal rib layouts for different single frequency excitations. Modal test and sound measurement are conducted to validate the proposed method. The influence of loading position on the topology optimization results is also investigated and discussed.

References listed at the end of the paper:

- Du JB, Olhoff N (2007a) Topological design of freely vibrating continuum structures for maximum values of simple and multiple eigenfrequencies and frequency gaps. Struct Multidiscip Optim 34:91–110

ABSTRACT: This paper presents a novel methodology to minimize the weight of a composite plate, taking into account both its structural integrity and its manufacturing constraints. This optimization problem has been abstracted, and reduced to, a graph problem where finding the optimum is equivalent to finding the shortest path in the graph. This graph is an implicit ternary decision tree and path finding is accomplished with a parallelized breadth-first search procedure. As a result of this search, the procedure is able to provide both a global optimum and a Pareto front. The implementation of an implicit decision tree as a way to optimize a laminate stacking sequence is a novel idea, in spite that both issues have been tackled in numerous publications separately. Its benefits are clearly stated in this work.

References listed at the end of the paper:


ABSTRACT: Simultaneously optimizing the thickness of the base structure and the location of piezoelectric sensors/actuators as well as control gains is investigated for minimizing the sound radiation from the vibrating curved shell integrated with sensors/actuators under harmonic excitation. The finite element formulation of the piezoelectric curved shell structure is described. The piezoelectric element is coupled into the base shell element using nodal displacement constraint equations. The active control of structural vibration-acoustic radiation is formulated using the velocity feedback algorithm. Based on both passive and active control measures, an integrated optimization model of the vibro-acoustic problem is proposed, in which the sound power is taken as the objective function. The thickness of the base shell elements and the parameters of control system, including the location of sensors/actuators and control gains, are chosen as the design variables. In order to restrict the complexity of the control system, the number of sensors/actuators is considered as a constraint. A simulated annealing algorithm is extended to handle the vibro-acoustic optimization problem with the continuous and discrete variables co-existing. Numerical examples demonstrate the effectiveness of the optimization scheme and the correctness of the computation program.

References listed at the end of the paper:
ABSTRACT: Crashworthiness design for manufacturing of thin-walled structures remains a main challenge in vehicle industry. Conventionally, there have been two main stream procedures (1) conducting the crashworthiness optimization and manufacturing design separately in a sequential manner; or (2) neglecting the effects of manufacturing process on final outcomes. Note that most of the energy absorbing members in vehicle
body are fabricated by stamping process which likely results in non-uniform thickness, substantial residual strains/stresses especially for high strength steel or advanced high strength steels, etc. Furthermore, the uncertainties of the material properties, stamping process and geometry generally propagate from manufacturing phase to operational phase, likely leading to the uncontrollable fluctuations of crashing responses. In other words, a deterministic optimization could result in unreliable or unstable designs. To address these critical issues, a multiobjective reliability-based design optimization was proposed here to optimize the double-hat thin-walled structure by coupling with stamping uncertainties. First, the finite element analysis results of stamping process are transferred to crashworthiness simulation. As such the uncertainties of material properties, process parameters and resultant geometry can be propagated from forming stage to crashing stage in a non-deterministic context. Second, the surrogate modeling techniques were adopted to approximate the forming and crashing responses in terms of mean and standard deviation. Third, the multiobjective particle swarm optimization (MOPSO) algorithm was employed to seek optimal reliable design solutions which were combined with Monte Carlo Simulation (MCS). The optimal results of the double-hat structure show that the proposed method not only significantly improved the formability and crashworthiness, but also was capable of enhancing the reliability of Pareto solutions.

References listed at the end of the paper:

optimization to treat beams having local plate buckling modes as the fundamental modes as well as beams switching phenomena of multiple eigenv alues. The use of the bound formulation also helps the proposed basis and double-pillar with TWB structure via support vector regression.


ABSTRACT: The use of the finite element method (FEM) for buckling topology optimization of a beam cross section requires large numerical cost due to the discretization in the length direction of the beam. This investigation employs the finite prism method (FPM) as a tool for linear buckling analysis, reducing degrees of freedom of three-dimensional nodes of FEM to those of two-dimensional nodes with the help of harmonic basis functions in the length direction. The optimization problem is defined as the maximization problem of the lowest eigenvalue, for which a bound variable is introduced and set as the design objective to treat mode switching phenomena of multiple eigenvalues. The use of the bound formulation also helps the proposed optimization to treat beams having local plate buckling modes as the fundamental modes as well as beams
having global buckling modes. The axial stress is calculated according to the distribution of material modulus which is interpolated using the SIMP approach. Optimization problems finding cross-section layouts from rectangular, L-shaped and generally-shaped design domains are solved for various beam lengths to ascertain the effectiveness of the proposed method.

References listed at the end of the paper:

- Bui HC (2009) Buckling analysis of thin-walled sections under general loading conditions. Thin-Walled Struct 47:730–739
- Cheung YK, Tham LG (1997) The finite strip method, 1st edn. CRC Press, Boca Raton
- Hancock GJ, Pham CH (2015) Buckling analysis of thin-walled sections under localised loading using the semi-analytical finite strip method. Thin-Walled Struct 86:35–46

ABSTRACT: The localized analytical sensitivity for eigenfrequency is extended to the non-linear problem of 3D continuum buckling analysis. Implemented in a finite element approach the inherent complexity of mode switching and multiple eigenvalues is found not to be a practical problem. The number of necessary redesigns is of the order 10-20 as illustrated by a specific example, where also different cases of stiffness interpolation are exemplified.

References listed at the end of the paper:


ABSTRACT: In this paper, the parameters influencing the stress distribution around regular polygon cutouts in orthotropic plates and symmetrical composite laminates are studied, and then the genetic algorithm is used to determine the optimal values of effective parameter for attaining the lowest normalized stress and the highest failure strength. The parameters examined for this purpose are cutout geometry, curvature radius of cutout corners, cutout orientation, fiber angle, and load angle and stacking sequence of laminated composite. An analytical method is used to calculate the stress distribution around different cutouts under different in-plane loads. Using conformal mapping and complex variable method, the Lekhnitskii’s method that is originally introduced for circular and elliptical cutouts is expanded for cutouts with different shapes. The results show that the failure strength of perforated plates can be improved by choosing the appropriate shape of cutout and the optimal values of the effective parameters. The results show that contrary to expectation, the best cutout geometry is not always a circle, as in some cases by choosing the appropriate values of bluntness parameter,
cutout orientation, and stacking sequence for a laminate with non-circular cutout the failure strength higher than that of a circular cutout can be achieved.

References listed at the end of the paper:
- Lekhnitskii SG (1968) Anisotropic plates. DTIC Document
- Mushkelisvili N (1966) Some basic problems of the mathematical theory of elasticity. Cambridge Univ Press


ABSTRACT: This paper aims to compare the structural designs derived from Deterministic Topology Optimization (DTO) and Reliability-Based Topology Optimization (RBTO). The target is to prove that including uncertain data in preliminary stages of the design process such as topology optimization can help to reduce the weight of the component to be conceived. To compare both approaches the same Reliability-Based Design Optimization (RBDO) sizing problem is formulated over the bar structures emerged from the DTO and RBTO results. The RBTO is performed through the RBDO algorithm Sequential Optimization and Reliability Assessment (SORA) based on its robustness, accuracy and decoupled nature, which allows to use an external optimization software when dealing with the topology optimization problem. Three application examples, including two 2D bar structures and a 3D simplified aircraft rear fuselage are studied. The results show that the
designs based on RBTO are lighter than the designs based on DTO when both structures are compared in a subsequent reliability-based size optimization including the same probabilistic information.

References listed at the end of the paper:

This study investigates efficient design optimization frameworks for composite structures with uncertainties related to material properties and loading. The integration of two decoupled reliability-based design optimization methodologies with a decoupled discrete material optimization is proposed to determine material and fiber orientation for three-dimensional composite structures. First, a deterministic and decoupled discrete material optimization is used for baseline comparison. The objective is to minimize the cost of composite structures with the design variables comprising of the piecewise patch orientations and material properties of the fiber reinforced composites. The reliability-based design optimization includes a hybrid method, and also the sequential optimization and reliability assessment method. In the sequential optimization and reliability assessment method, the inverse reliability analysis is evaluated using a stochastic response surface method and a first order reliability approach. Comparing the methods based on the optimal material and fiber orientations, the uncertainties in loads and material properties lead to different optimal layouts compared to the deterministic solutions. The numerical results also reveal that the hybrid method applied in reliability based designs results in negligible additional computational cost.

References listed at the end of the paper:


ABSTRACT: This paper proposes a optimization method that is capable of simultaneous design of multiple layers in a composite laminate with respect to multiple objective functions. The optimization process obtains a continuous orientation of an orthotropic material for each layer of the laminate. Each layer by itself is a single design domain, which allows multiple domains to be stacked in various orientations. Multiple optimization objectives are considered resulting in layers that perform different functions. The layers are modeled within a three-dimensional structure and by discretizing the structure using three-dimensional elements, the interaction between individual layers can be modeled. This also allows the optimization method to obtain a three-dimensional orientation vector. In this study, the individual layers are assumed to be thin, limiting the orientation vector to the mid-plane of the layer. The optimization model is tested on a two-layer laminate in which one layer is optimized for thermal control by directing heat toward specified sections while shielding other sections and the second layer is optimized to reduce the total deformation of the laminate structure that results from the thermal load. The results of simultaneous optimization for both layers are shown for several different configurations of boundary conditions.

References listed at the end of the paper:
ABSTRACT: The structural performance of a grid-shell depends directly on the geometry of the design. Form-finding methods, which are typically based on the search for bending-free configurations, aid in achieving structurally efficient geometries. This manuscript proposes two form-finding methods for grid-shells: one method is the potential energy method, which finds the form in equilibrium by minimizing the total potential energy in the system; the second method is based on an augmented version of the ground structure method, in which the load application points become variables of the topology optimization problem. The proposed methods, together with the well-known force density method, are evaluated and compared using numerical examples. The advantages and drawbacks of the methods are reviewed, compared and highlighted.

References listed at the end of the paper:
- ACI Committee 318, American Concrete Institute (2014) Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)

- References listed at the end of the paper:
- Michell A (1904) The limits of economy of material in frame structures. Phil Mag 8(47):589–597
- Rozvany GIN, Sokół T (2013) Validation of numerical methods by analytical benchmarks, and verification of exact solutions by numerical methods. Topology Optimization in Structural and Continuum Mechanics
- Zegard T (2014) Structural optimization: from continuum and ground structures to additive manufacturing. PhD thesis, University of Illinois at Urbana-Champaign, USA
ABSTRACT: Including stability in truss topology optimization is critical to avoid unstable optimized designs in practical applications. While prior research addresses this challenge by implementing local buckling and linear prebuckling, numerical difficulties remain due to the global stability singularity phenomenon. Therefore, the goal of this paper is to develop an optimization formulation for truss topology optimization including global stability without numerical singularities, within the framework of the preliminary design of large-scale structures. This task is performed by considering an appropriate simultaneous analysis and design formulation, in which the use of a disaggregated form for the equilibrium equations alleviates the singularities inherent to global stability. By implementing a local buckling criterion for hollow truss elements, the resulting formulation is well-suited for the preliminary design of large-scale trusses in civil engineering applications. Three applications illustrate the efficiency of the proposed approach, including a benchmark truss structure and the preliminary design of a footbridge and a dome. The results demonstrate that including local buckling and global stability can considerably affect the optimized design, while offering a systematic means of avoiding unstable solutions. It is also shown that the proposed approach is in a good agreement with linear prebuckling assumptions.

References listed at the end of the paper:
- ArcelorMittal (2016) Cold-finished round hollow structural sections
- Descamps B, Filomeno Coelho R (2013) R Metaheuristic Applications in Structures and Infrastructures, Elsevier B. V., chap Graph theory in evolutionary truss design optimization, pp 241–268

ABSTRACT: This paper addresses the problem of combining topology and shape optimization approaches by exploiting suitable methods from both discrete as well as nonlinear optimization. The topology decisions are made iteratively within the general optimization process by a branch-and-bound algorithm. In every node of the branch-and-bound tree a sequence of nonlinear subproblems which consist of a shape and topology optimization component are solved by using sequential quadratic programming (SQP). The topology component follows the solid isotropic material with penalization (SIMP) idea. One important application of the here presented approach in engineering consists of assisting the product development process in early stages. Here, we consider the design of multi-chambered sheet metal profiles. This work deals with the construction of the branch-and-bound tree and how effective node selection rules can be obtained, as well as with the resulting nonlinear subproblems and the applied SQP method. Finally, numerical results for different load scenarios and topology constraints are presented.

References listed at the end of the paper:

Haichao An, Shenyuan Chen and Hai Huang, “Multi-objective optimization of a composite stiffened panel for hybrid design of stiffener layout and laminate stacking sequence”, Structural and Multidisciplinary Optimization, Vol. 57, No. 4, pp 1411-1426, April 2018,
ABSTRACT: This paper presents a two-level approximation method for multi-objective optimization of a composite stiffened panel. The purpose is to seek the minimum structural mass and maximum fundamental frequency subject to given displacement constraints and manufacturing limitations. The design variables are the stiffener layout, and laminate stacking sequences for stiffeners and the panel skin. By introducing the concept of ground structure in both stiffener layout and laminate stacking sequence, the design problem is formulated with mixed discrete and continuous variables. Two types of discrete variables represent the existence of each stiffener and the existence of each ply in the laminate, respectively, with continuous ones for ply thicknesses. Considering the objectives are of different dimensions, a weighted min-max objective function is defined and minimized. The problem is firstly made explicit with branched multipoint approximate functions. Genetic algorithm (GA) is then adopted to optimize two types of discrete variables, determining which stiffeners/layers are deleted or retained. For fitness calculation in GA, a second-level approximation is built to optimize continuous ply thicknesses of the necessary layers that are retained. By giving different initial designs of stiffener layout and laminate stacking sequences, reasonable optimization results, which are tradeoffs between the considered two objectives, are obtained as design options. From the number of required structural analysis, it shows that the proposed method has a good efficiency in seeking rational solutions, which are tradeoffs between conflicting objectives and also feasible designs satisfying all considered constraints.

References listed at the end of the paper:

This paper proposes a novel technique for the design of hybrid composite laminates. The method explores design space with several implicit decision trees in order to obtain the Pareto front, applying a number of manufacturing and structural considerations. The research is carried out using a parallelized breadth first search algorithm aided by dynamic programming and dynamic tree trimming; as a consequence the searching process is significantly accelerated. This novel procedure is applied to a well-known design case, where it identifies the best carbon-epoxy and glass-epoxy laminate combinations in terms of weight versus cost, and finds the Pareto front with less computational effort than alternative methods used in the past to solve the same problem. Since a full set of feasible solutions is produced with this new methodology, some important conclusions are obtained regarding hybrid laminate design criteria.

References listed at the end of the paper:


---


**ABSTRACT:** This paper proposes a novel technique for the design of hybrid composite laminates. The method explores design space with several implicit decision trees in order to obtain the Pareto front, applying a number of manufacturing and structural considerations. The research is carried out using a parallelized breadth first search algorithm aided by dynamic programming and dynamic tree trimming; as a consequence the searching process is significantly accelerated. This novel procedure is applied to a well-known design case, where it identifies the best carbon-epoxy and glass-epoxy laminate combinations in terms of weight versus cost, and finds the Pareto front with less computational effort than alternative methods used in the past to solve the same problem. Since a full set of feasible solutions is produced with this new methodology, some important conclusions are obtained regarding hybrid laminate design criteria.
Carl Scarth and Jonathan E. Cooper, “Reliability-based aeroelastic design of composite plate wings using a stability margin”, Structural and Multidisciplinary Optimization, Vol. 57, No. 4, pp 1695-1709, April 2018, ABSTRACT: Reliability-based design is concerned with ensuring that constraints are enforced with acceptable probability under inherent variability in properties. In aircraft design, such a constraint may be that aeroelastic instability does not occur at velocities encountered by the aircraft. This approach can be complicated, as the aeroelastic instability speed is a discontinuous function of material properties, on account of particular modes only becoming unstable for some parameter values. In reliability analysis, it is common to use surrogate models due to the computational expense associated with Monte Carlo Simulation, however, such methods can be inaccurate when emulating discontinuous functions such as the aeroelastic instability speed. In this paper, an alternative approach is proposed in which Gaussian process surrogate models are fitted directly to each of the modal eigenvalues at the design air-speed, and used to emulate a stability margin based upon the most critical eigenvalue. Using this approach, it is shown that the reliability may be estimated for the aeroelastic stability using smooth emulators, thereby overcoming the problems associated with discontinuities. The method is demonstrated for layup optimisation of composite plate wings with uncertain ply angles, in which the probability of aeroelastic instability occurring is minimised for a prescribed air-speed. In uncertainty quantification, a good agreement is found with Monte Carlo Simulation with an order of two magnitudes reduction in model runs. Through reliability-based design, reductions in the probability of failure of up to 99.8% are achieved by increasing the stability margin at the design speed. References listed at the end of the paper:

- Eastep FE, Tischler VA, Venkayya VB, Khot NS (1999) Aeroelastic tailoring of composite structures


ABSTRACT: By coupling thin-walled metal and aluminium honeycomb structures, a composite energy-absorbing structure with a high strength to weight ratio was designed. The validity of equivalent models of the thin-walled metal structure and the aluminium honeycomb was separately verified by carrying out trolley impact and quasi-static compression tests. The polynomial response surface models (PRSMs) of specific energy absorption (SEA) and initial peak force ($F_p$) during a collision were respectively established based on an orthogonal experimental design (OED) and the polynomial response surface method. The precisions of the three PRSMs were, in descending order, quartic, cubic, and quadratic PRSM (PRSM-4 > PRSM-3 > PRSM-2) as found by error analysis. The three PRSMs were separately optimised by using single-objective particle swarm optimisation (SOPSO) and the optimal values of $SEA$ and $F_p$ within the design range obtained from the PRSM-4 were respectively 33.5224 kJ/kg and 231.6860 kN among these PRSMs. The relative errors between the
above optimal results of the PRSM-4, and the results obtained by numerical simulation, were 0 and -0.67%, respectively. Moreover, a Pareto front of double optimisation objective $SEA$ and $F_{\text{max}}$ was obtained after being optimised by multi-objective particle swarm optimisation (MOPSO), and $SEA = 33.0936$ kJ/kg (the maximum $SEA$) and $F_{\text{min}}$ was 232.3510 kN (the minimum $F_{\text{max}}$) as separately obtained by using the PRSM-4.

The errors between the above results and those ($SEA = 33.5224$ kJ/kg and $F_{\text{max}} = 233.2406$ kN) obtained through numerical simulation were separately 1.28% and -0.38%, which also indicates that the optimisation result is reliable.

References listed at the end of the paper:

Optimization of continuum structures subjected to external harmonic excitation

Bin Niu, Xiaomeng He, Yao Shan and Rui Yang, “On objective functions of minimizing the vibration response of continuum structures subjected to external harmonic excitation”, Structural and Multidisciplinary Optimization, Vol. 57, No. 6, pp 2291-2307, June 2018,

ABSTRACT: This work deals with the topological design of vibrating continuum structures. The vibration of continuum structure is excited by time-harmonic external mechanical loading with prescribed frequency and amplitude. In comparison with well-known compliance minimization in static topology optimization, various objective functions are proposed in literature to minimize the response of vibrating structures, such as power flow, vibration transmission, and dynamic compliances, etc. Even for the dynamic compliance, different definitions are found in literature, which have quite different formulations and influences on the optimization results. The aim of this paper is to provide a comparison of these different objective functions and propose reference forms of objective functions for design optimization of vibration problems. Analytical solutions for two degrees of freedom system and topological design of plane structures in numerical examples are compared using different optimization formulations for given various excitation frequencies. The results are obtained by the finite element method and gradient based optimization using analytical sensitivity analysis. The optimized topologies and vibration response of the optimized structures are presented. The influence of excitation frequencies and the eigenfrequencies of the structure are discussed in the numerical examples.

References listed at the end of the paper:

• Du JB, Olhoff N (2007b) Topological design of freely vibrating continuum structures for maximum values of simple and multiple eigenfrequencies and frequency gaps. Struct Multidiscip Optim 34(2):91–110
• Jensen JS (2011) Waves and vibrations in inhomogeneous structures - bandgaps and optimal designs. Technical University of Denmark, Lyngby
• Olhoff N, Du J (2016) Generalized incremental frequency method for topological design of continuum structures for minimum dynamic compliance subject to forced vibration at a prescribed low or high value of the excitation frequency. Struct Multidiscip Optim 54(5):1113–1141
• Sigmund O (1994) Design of material structures using topology optimization. Technical University of Denmark, Lyngby
ABSTRACT: An integrated optimization that comprehensively considers design and manufacturing factors such as the geometric appearance, laminate constitutions, laminate distribution, laminate thickness and stacking sequence, is proposed for designing a carbon fiber reinforced polymer wheel hub of a racecar. First, the driving conditions of the racecar are analyzed to determine the performance requirements. Then, under the condition that the geometric design regions are partitioned and the constitutions of fiber plies with different directions are defined, laminate design and manufacturing model is established. A multi-objective optimization is then performed to achieve a lightweight, high-stiffness laminate structure in different design regions. Next, number of plies in each region is obtained from the thickness of laminate, and then, the stacking sequence is optimized to improve the stiffness of the laminate structure. Finally, laminate transitions for different regions are investigated. The results showed that laminate design and manufacturing optimization can reduce the weight of the wheel hub and improve the performance of the wheel hub under static, dynamic and impact conditions. The proposed optimization approach provides a feasible solution for a performance-based design of composite structures.

References listed at the end of the paper:


Fei Lei, Ruibin Qiu, Yingchun Bai and Chengfeng Yuan, “An integrated optimization for laminate design and manufacturing of a CFRP wheel hub based on structural performance”, Structural and Multidisciplinary Optimization, Vol. 57, No. 6, pp 2309-2321, June 2018,
The results of numerical simulation of the structures is taken as the design objective, and the natural vibration frequency and static stiffness are thus obtained. Based on this, a size optimization for lightweight design is conducted, in which the self-growth law of biological branch systems is considered. The optimal and distinct distribution of internal stiffener plates with the maximum overall structural stiffness in accordance with the adaptive growth law. The optimal and distinct distribution of internal stiffener plates with the most effective load path is thus obtained. Based on this, a size optimization for lightweight design is conducted, in which the self-weight of the structures is taken as the design objective, and the natural vibration frequency and static stiffness in the direction that is sensitive to machining accuracy are set as constraints. Finally, an optimized structure is obtained. The effectiveness of the proposed method is verified by using a precision grinder bed as an example. The results of numerical simulation and 3D-printed model experiment indicate that both the dynamic and the

ABSTRACT: Naturally evolved biological structures exhibit the optimal characteristics of light weight, high stiffness, and high strength. Based on the growth mechanism of biological branch systems in nature, an optimization method for internal stiffener plate distribution in box structures is suggested. Under the given load and support conditions, the internal stiffener plates of machine pedestal structures grow, bifurcate, and degenerate towards the direction of maximum overall structural stiffness in accordance with the adaptive growth law. The optimal and distinct distribution of internal stiffener plates with the most effective load path is thus obtained. Based on this, a size optimization for lightweight design is conducted, in which the self-weight of the structures is taken as the design objective, and the natural vibration frequency and static stiffness in the direction that is sensitive to machining accuracy are set as constraints. Finally, an optimized structure is obtained. The effectiveness of the proposed method is verified by using a precision grinder bed as an example. The results of numerical simulation and 3D-printed model experiment indicate that both the dynamic and the
References listed at the end of the paper:


References

- Zhao L, Ma J, Chen WY, Guo H (2011) Lightweight design and verification of gantry machining center crossbeam based on structural bionics. J Bionic Eng 8:201–206

static performance of the optimized structure are improved, while the structural weight is reduced by compared with the initial structure. The suggested design method provides a new solution approach for the design optimization of machine pedestal structures.
ABSTRACT: This work extends the Discrete Material and Thickness Optimization approach to structural optimization problems where strength considerations in the form of failure criteria are taken into account for laminated composite structures. It takes offset in the density approaches applied for stress constrained topology optimization of single-material problems and develops formulations for multi-material topology optimization problems applied for laminated composite structures. The method can be applied for both stress- and strain-based failure criteria. The large number of local constraints is reduced by the use of aggregate functions, and the developed approach is demonstrated for optimization problems involving both constant and varying thickness laminated composites.

References listed at the end of the paper:

ABSTRACT: Jounce bumpers are indispensable components in vehicle suspension systems. It can attenuate impact energy and improve the ride comfort performances during transient pulse impacts from roads. However, the traditional jounce bumpers cannot achieve ideal mechanical performance and are difficult for parametric optimization due to its various shapes which are hard for parameterization. In this paper, a cylinder auxetic structure was introduced and applied as the suspension jounce bumper. Auxetic jounce bumper can be primarily defined by several variables. With tunable structure parameters, a large region of mechanical performances can be realized. In order to evaluate and optimize the performance of auxetic jounce bumpers, they were assembled into vehicle models to conduct virtual ride comfort tests under bump road. The maximum vertical acceleration of vehicle was defined as the objective function of the optimization problem of auxetic jounce bumper. On the purpose of improving optimization efficiency, Gaussian process regression method was employed to establish the metamodel of auxetic jounce bumper based on the sample set created by orthogonal design of experiments method. A series hybrid GA-SQP (Genetic algorithm-Sequential quadratic programming) algorithm, provided with both global and fast local searching abilities, was used for the optimization of auxetic jounce bumper. For comparison, GA algorithm was also applied for auxetic jounce bumper optimization alone. It is proved that the proposed optimization process is accurate and can improve optimization efficiency. Then the optimized design through hybrid algorithm was compared with original design. The maximum vertical acceleration of vehicle when travelling through bump was reduced with optimized design, and the vehicle ride comfort performance was improved.

References listed at the end of the paper:
• Liu YY, Ma ZD (2007) Nonlinear analysis and design investigation of a negative Poisson’s ratio material. ASME Int Mech Eng Congress Exposition
ABSTRACT: Variable-stiffness panel is very promising for the cutout reinforcement of composite structures. However, due to the increase of design variables, the optimization of variable-stiffness panels becomes very challenging, even if surrogate model is utilized, because the fidelity of surrogate model is difficult to guarantee for high-dimensional problems. In this study, isogeometric analysis method (IGA) is employed to predict the buckling load of variable-stiffness panels, which can produce accurate prediction with less computational cost compared to traditional FEA, moreover, it can provide analytical sensitivity for optimization. On this basis, an adaptive gradient-enhanced kriging (GEK) model assisted by a novel multiple points infilling criterion is constructed for the global optimization of variable-stiffness composite panels. The proposed method is compared with traditional surrogate model, and results show that the proposed method can find a better optimum design in a more efficient manner. It can be concluded that the proposed method is able to fully explore the advantages of IGA including exact modelling, analysis and analytical sensitivity, which is particularly suitable for the design of variable-stiffness panels and other complex structures.

References listed at the end of the paper:


- van den Brink WM, Vankan WJ, Maas R (2012) Buckling optimized variable stiffness laminates for a composite fuselage window section. Int C Aer SCI B

ABSTRACT: A constrained isogeometric design optimization method is presented for lattice structures located on a specified curved surface. Lattices on curved surfaces have been utilized in various engineering applications like medical stents, non-pneumatic wheel frames, and so on. When it comes to design problems, however, the lattice needs to be located on a specified surface for its manufacturability as well as performance, which results in nonlinear constraints in configuration design. We define lattice structures and their design variables on planar rectangular surfaces, and utilize the concept of free-form deformation (FFD) and the global curve interpolation to obtain the analytical expressions for the control net of lattice structure on curved surfaces. The material derivative of the analytical expressions eventually leads to precise design velocity field. The analytical configuration design sensitivity for a spatial Timoshenko beam is derived. In numerical examples, we verify the derived configuration design sensitivity and the developed computation scheme of design velocity field by comparison with finite differences, and several configuration design optimization examples are demonstrated.

References listed at the end of the paper:

ABSTRACT: A topology optimization approach is proposed for the optimal design of bi-material distribution on underwater shell structures. The coupled finite element method (FEM) / boundary element method (BEM) scheme is used for the system response analysis, where the strong interaction between the structural and the acoustic domain is considered. The Burton-Miller formulation is used to overcome the fictitious eigen-frequency problem when using a single Helmholtz boundary integral equation for exterior acoustic problems. The design variables are the artificial densities of design material elements in a bi-material model constructed by the solid isotropic material with penalization (SIMP) method, and the minimization of sound power level (SWL) is chosen to be the design objective. In this study, the adjoint operator method is employed to calculate the sensitivity of the objective function with respect to the design variables. Based on the sensitivity information, the gradient-based optimization solver is finally applied for updating the design variables during the optimization process. Numerical tests are provided to illustrate the correctness of the sensitivity analysis approach and the validity of the proposed optimization procedure. Results show that the heavy fluid feedback has a big impact on the final design, and thus it is necessary to conduct a strong coupling scheme between the fluid and structures. In addition, the optimal design is strongly frequency dependent, and performing an optimization in a frequency band is generally needed.

References listed at the end of the paper:
· Huang X, Xie YM (2008) Bi-directional evolutionary topology optimization of continuum structures with one or multiple materials. Comput Mech 43(3):393

ABSTRACT: A Lagrange parameterization of lamination parameters which are used for optimization of variable stiffness laminates is presented. The advantages of the approach are: a) the design variables become independent of the finite element mesh and, b) the smoothness of the solution is inherently guaranteed. Due to independency of design variables of the finite element mesh, the reduction in the number of design variables is drastic, once variable stiffness laminates usually demand a fine mesh. The lamination parameters formulation allows a more precise and concise approach to laminate design, removing difficulties related to fiber direction and stacking sequence, increasing the chances to find a global optimal solution. In this paper, the Lagrange parameterization is used for the maximization of the buckling load of a variable stiffness composite plate.

References listed at the end of the paper:
- Hahn HT, Tsai SW (1980) Introduction to composite materials. CRC Press, Boca Raton

ABSTRACT: The advance in digital fabrication technologies and additive manufacturing allows for the fabrication of complex truss structure designs but at the same time posing challenging structural optimization problems to capitalize on this new design freedom. In response to this, an iterative approach in which Sequential Linear Programming (SLP) is used to simultaneously solve a size and shape optimization subproblem subject to local stress and Euler buckling constraints is proposed in this work. To accomplish this, a first order Taylor expansion for the nodal movement and the buckling constraint is derived to conform to the SLP problem formulation. At each iteration a post-processing step is initiated to map a design vector to the exact buckling constraint boundary in order to facilitate the overall efficiency. The method is verified against an exact non-linear optimization problem formulation on a range of benchmark examples obtained from the literature. The results show that the proposed method produces optimized designs that are either close or identical to the solutions obtained by the non-linear program formulation while significantly decreasing the computational time. This enables more efficient size and shape optimization of truss structures considering practical engineering constraints.

References listed at the end of the paper:


Freund R (2004) Truss design and convex optimization. MIT Course notes, Massachusetts Institute of Technology


ABSTRACT: This paper illustrates the application of a two-level approximation method for truss topology optimization with local member buckling constraints and restrictions on member intersections and overlaps. Previously developed for truss topology optimization with stress and displacement constraints, that method is achieved by starting from an initial ground structure, and, combined with genetic algorithm (GA), it can handle both discrete and continuous variables, which denote the existence and cross-sectional areas of bar members respectively in the ground structure. In this work, this method is improved and extended to consider member buckling constraints and restrict intersection and overlap of members for truss topology optimization. The temporary deletion technique is adopted to temporarily remove buckling constraints when related bar members are deleted, and in order to avoid unstable designs, the validity check for truss topology configuration is conducted. By using GA to search in each possible design subset, the singularity encountered in buckling-constrained problems is remedied, and meanwhile, as the required structural analysis is replaced with explicit approximation functions in the process of executing GA, the computational cost is significantly saved. Moreover, for the consideration of restrictions on member intersecting and overlapping, the definition of such phenomena and mathematical expressions to recognize them are presented, and a new fitness function is developed to include such considerations. Numerical examples are presented to show the efficacy of the proposed techniques.
References listed at the end of the paper:


ABSTRACT: Numerical optimization is an indispensable part of the design process of laminated composite structures. Several optimality criteria-based algorithms exist which rely on a sequential resizing and scaling approach. This paper presents a novel design algorithm applicable for stiffness and eigenfrequency optimization of composite structures with concurrent consideration of resizing and scaling operations. A method is introduced that allows for an efficient consideration of nonlinear constraints. This is done by determining stable concurrent scaling parameters from first-order constraint change ratio estimations. Optimization is carried out using optimality criteria in three independent steps, namely with respect to fiber angles, ply thickness ratios, and total laminate thickness. Sensitivity analyses are performed analytically at low computational costs. Numerical examples demonstrate the efficiency and fast convergence of the method. Compared to established algorithms, the number of required function evaluations is reduced significantly.

References listed at the end of the paper:


ABSTRACT: This paper focuses on the uncertainty quantification in the mechanical behavior of CNT-reinforced polymer composite and its effect on the reliability-based optimization of in-plane functionally graded plates. Random process representations were adopted to model the spatial randomness of the elastic properties. A plate under uniform pressure loading was optimized to maximize the plate stiffness using the minimum amount of the reinforcement by in-plane grading the CNT volume fraction. The functionally graded plate used 45% less reinforcement compared to the homogeneous plate. The First Order Second Moment method is used for the reliability analysis of the plate. The uncertainties led to an average increase of 48% in the CNT volume fraction compared to the deterministic design. The functionally graded plate showed the same uncertainty level in the overall stiffness as its equivalent homogeneous plate.

References listed at the end of the paper:

- Bhuiyan M, Pucha RV, Kalaitzidou K (2016) 3D RVE models able to capture and quantify the dispersion, agglomeration and orientation state of CNT in CNT/PP nanocomposites. Front Mater 3:1–13
ABSTRACT: Deformable mirrors are vital components in fundus imaging modality incorporating adaptive optics systems. The application of precisely controlled electric currents to multiple electrodes located under the mirror surface deform its shape so that optical aberrations caused by a patient’s eye can be nullified. The higher number of actuators used, the more accurately the mirror surface can be transformed to a target shape. However, deformable mirror manufacturability limitations demand that the number of electromagnetic actuators be minimized, so there is a pressing need for an efficient method to determine the layout of a minimum number of actuators that will deliver desired aberration correction performance. In this paper, we present an actuator layout design method based on the degree to which each actuator contributes to mirror shaped adjustment, calculated according to the amount of electric current supplied to individual actuators. This method minimizes the number of actuators while preventing the error between a target mirror shape and the actual deformed mirror shape from exceeding a certain limit. To assess the aberration correction performance for each actuator layout, we also provide a method for optimizing the electric currents supplied to an array of actuators that will correctly adjust the mirror surface to target Zernike modes, corresponding to defocus, astigmatism, coma and trefoil aberrations, given the imposition of upper and lower limits upon the currents supplied to the actuators.

References listed at the end of the paper:


ABSTRACT: A novel design concept for buckling-induced mechanical metamaterials for energy absorption using topology optimization is presented. The force-displacement curves of the mechanical metamaterials are analyzed according to the curves of their unit cells, and the energy-absorbing characteristics of mechanical metamaterials are evaluated. Two topology optimization models are proposed. One maximizes the buckling-induced dissipated energy to facilitate the design of metamaterials with high energy absorption and low elastic strain energy. The other maximizes the dissipated energy with a constraint that the mechanical metamaterials should be self-recoverable. An energy interpolation scheme is employed to avoid numerical instabilities in the geometric nonlinear finite element analysis. A two-phase algorithm is proposed to find the optimized result from a uniform initial guess, and sensitivity analysis is performed. The optimized design has a larger amount of buckling-induced dissipated energy than the previously proposed structural prototypes. Moreover, the self-recoverable mechanical metamaterial is successfully designed by topology optimization.

References listed at the end of the paper:


Bret R. Hauser and Bo P. Wang, “Optimal design of a parallel beam system with elastic supports to minimize flexural response to harmonic loading using a combined optimization algorithm”, Structural and Multidisciplinary Optimization, Vol. 58, No. 4, pp 1453-1465, October 2018,

ABSTRACT: Mechanical systems subject to vibration are prevalent across many industries. Although potentially different in application, they sometimes share the need to minimize aspects of flexural deformation given harmonic loading and the need to consider a variety of both input and response-based constraints in the process. Practical design efforts also sometimes include the need for consideration of the optimal response of a platform-style product, including responses of multiple design variants supported by a common base structure. Harmonic problems can be especially challenging to optimize due to the likelihood that the response will be multi-modal; influenced by system natural frequencies throughout the design space. Further, analysis of these systems often involves large and complex computer models which require significant resources to execute. A harmonically loaded, platform-style parallel beam system with multiple family variants is used as an example in this work to demonstrate a proposed method for identifying an optimum in a constrained, multi-modal response environment with consideration for Expensive Black Box Functions (EBBF). The presented method proposes a combined approach where the high modality, EBBF’s domain is first surveyed for potential areas of optimal response using a method of Steepest Feasible Descent (SFD), followed by a local search in the optimal region using a more efficient direct search method. The method of SFD is a modification of the classical method of Steepest Descent, made useful for constrained models by a penalty system including both deterministic and programmatic methods. A sensitivity-based search vector method also helps to manage situations where significant difference in magnitude exists among the design variables. Evidentiary support for these key program elements is provided using standardized test functions. The effectiveness of the method is demonstrated by seeking a minimum flexural response for a parallel beam system subject to elastic support and response constraints.

References listed at the end of the paper:
from non-study examined shape optimization of an I-sectioned curved beam and rib formation from unstable structure growth in optimization. Structural and Multidisciplinary Optimization, Vol. 58, No. 4, pp 1769-1782, October 2018.

ABSTRACT: A thin-walled curved beam is a complex structure. Sectional deformation occurs due to induced out-of-plane force when the beam is bent. Bending stiffness is significantly lowered due to this deformation. Installation of ribs to support this induced force is often an effective countermeasure to ensure stiffness. This study examined shape optimization of an I-sectional curved beam. Ribbed structures were successfully created from non-ribbed structures by adding humps to the initial structure. It was discovered that instability of the...
shape optimization occurs under the influence of the induced force. Here, ‘instability’ refers to the amplification of initial perturbations similar to buckling phenomena. In the present case, the humps grew and formed ribbed structures. The bending stiffness of the ribs was significantly improved. In addition, simple thickening of flange parts also effectively improves the bending stiffness. As these two structural improvements progress simultaneously, branching of the optimization occur. This branching depends on the given volume constraint. A parameter study targeting volume observed branching to ribbed or thickened non-ribbed structures. This instability enables a leap from a non-ribbed to a ribbed structure in the optimization.

References listed at the end of the paper:

- Fukada Y (2017) Stress redistribution as an effect of non-uniform in-plane laminate stresses in laminate composite plates. Compos Struct 159:505–516
- Timoshenko S (1923) Bending stresses in curved tubes of rectangular cross-section. Trans ASME 45:135–140

ABSTRACT: This paper demonstrates a conjoint method integrating the proposed Hybrid Contribution Analysis (HCA) method, the Artificial Neutral Network (ANN) meta-model, the modified Non-dominated Sorting Genetic Algorithm II (MNSGAII) and the Ideal Point Method (IPM), used for multi-objective lightweight and crashworthiness optimization of the side structure of an automobile body. First of all, the static-dynamic stiffness models of the automobile body and the vehicle side crashworthiness model are separately established and validated against corresponding actual experiments. Next, the initially selected parts for optimization are screened using the proposed HCA method to determine the final parts for optimization, thicknesses of which are taken as design variables. After that, design of experiment (DoE) couple with ANN-based meta-models are utilized to approximate the output performance indicators of the automobile body, based on which the modified NSGA-II (MNSGAII) with epsilon-elimination technique is then employed to solve the multi-objective optimization process, considering the total mass and the torsional stiffness of the automobile body, the maximum intrusion deformation of the measuring point P1 on the inner panel of B-pillar and the measuring point D1 on the inner panel of front door as four optimization objectives. Finally, the IPM method identifies the optimal trade-off solution from the obtained Pareto set, and a comprehensive comparison between the optimized design and the baseline design further confirms the validity of the proposed conjoint method. Specially, the four-objective Pareto set approximately embodies that of each pair of separately run two-objective optimization, thus providing more optimization schemes for designers.

References listed at the end of the paper:


Ariffin AH et al. (2014) Development of mobile deformable barrier for side impact crashworthiness evaluation in ASEAN new car assessment programme (ASEAN NCAP) vol 663. doi:https://doi.org/10.4028/www.scientific.net/AMM.663.562


Jixie Qiangdu J Mech Strength 38:502

Thin oblique impact loading. Thin Walled Struct 102:111


Srinivas GR, Deb A, Chou CC (2016) Lightweighting of an automotive front end structure considering frontal NCAP and pedestrian lower leg impact safety requirements. SAE Technical Papers 2016-April. doi:https://doi.org/10.4271/2016-01-1520

and ply
intermediate voids in the s
original DMTO formulation, material had to be removed from the top in order to prevent non-
intermediate voids is introduced in the Discrete Material and Thickness Optimization (DMTO) method. With
J.H. Sjolund, D. Peeters and E. Lund, "Optimisation of multi-vehicle impact of a thin-walled structure",
Struct 23:31–40
genetic algorithm coupled with grey relational analysis. Eng Optim 50:615–633
structure of automobile body. Struct Multidiscip Optim 57:829–847
combined grey relational and principal component analysis. Struct Multidiscip Optim 1–21. doi: https://doi.org/10.1007/s00158-017-
1749-6
Xu F, Tian X, Li G (2015) Experimental Study on Crashworthiness of Functionally Graded Thickness Thin-Walled Tubular
Adv Eng Softw 96:70–82. https://doi.org/10.1016/j.advengsoft.2016.02.003
Thin-Walled Struct 75:8–17. https://doi.org/10.1016/j.tws.2013.10.022
99:35–44. https://doi.org/10.1016/j.tws.2015.11.007
https://doi.org/10.1016/j.ijmechsci.2013.01.016
132:393–405. https://doi.org/10.1016/j.compstruct.2015.05.034
Walled Struct 122:193–207
Zhou G, Ma ZD, Li GY, Cheng AG, Duan LB, Zhao WZ (2016) Design optimization of a novel NPR crash box based on multi-

J.H. Sjolund, D. Peeters and E. Lund, “A new thickness parameterization for Discrete Material and Thickness Optimization”, Structural and Multidisciplinary Optimization, Vol. 58, No. 5, pp 1885–1897, November 2018, ABSTRACT: In this work, a new thickness parameterization which allows for internal ply-drops without intermediate voids is introduced in the Discrete Material and Thickness Optimization (DMTO) method. With the original DMTO formulation, material had to be removed from the top in order to prevent non-physical intermediate voids in the structure. The new thickness formulation relies on a relation between density variables and ply-thicknesses rather than constitutive properties. This new formulation allows internal ply-drops which is
essential for composite structures as it is common practice to cover dropped plies as to avoid delaminations. Furthermore, it is demonstrated how the new thickness formulation in some cases improves the convergence characteristics. Finally, it is also shown how solid-shell elements can be utilized within the DMTO method for structural optimization of tapered laminated composite structures.

References listed at the end of the paper:

- MUST (2018) The MUltidisciplinary Synthesis Tool (MUST). Department of Materials and Production, Aalborg University


ABSTRACT: A way to approximate the compliance of composites for optimisation is described. A two-level approximation scheme is proposed inspired by traditional approximation concepts such as force approximations.
and convex linearisation. In level one, an approximation in terms of the reciprocal in-plane stiffness matrix is made. In level two, either the lamination parameters, or the nodal fibre angle distribution are used as design variables. A quadratic approximation is used to build the approximations in terms of the fibre angles. The method of conservative, convex separable approximations is used for the optimisation. Conservativeness is guaranteed by adding a convex damping function to the approximations. Two numerical examples, one optimising the compliance of a plate clamped on the left, loaded downwards on the bottom right, another one optimising the compliance of a plate loaded with a shear force and a moment show the computational efficiency of the proposed optimisation algorithm.

References listed at the end of the paper:

- Tsai SW, Hahn HT (1989) Introduction to composite materials. Technomic, Westport

ABSTRACT: Sandwiched morphing skin, composed of cellular based structure and flexible face-sheets, is one of the most promising concepts which can be used for morphing aircraft. Apparently, cellular based structure, with ability to endure aerodynamic pressure and morphing capability, is the most critical component of sandwiched morphing skin. This paper presents a design process for optimal topologies of cellular based structures for two-dimensional morphing skins, and this design procedure is effortless to be adjusted to be applied under different sets of boundary and loading conditions. The topology optimization problem formulation is established based on the simplified isotropic material with penalization (SIMP) interpolation method coupled with the method of moving asymptotes (MMA), meanwhile, Heaviside filter is adopted for reducing the occurrence of transition elements. After several iterations, various optimized topologies of unit cell are calculated corresponding to different morphing applications such as span morphing, sweep morphing and two-dimensional morphing. The mechanical properties of cellular topologies are investigated by comparing with conventional regular honeycomb structure and zero Poisson’s ratio structure via simulation after establishing 3D models of topologies. Results indicate that the design method using topology optimization technique is entirely feasible and optimal topologies of cellular based structure appear to provide superior performance.

References listed at the end of the paper:


ABSTRACT: The location optimization of sensors is a essential problem in structural health monitoring systems. Taking the cost of sensors into account, it is uneconomical to install sensors on every part of a structure and moreover in aeronautical industry, the weight is a crucial factor. In this paper, a optimal placement optimization of sensor locations for structural health monitoring systems is studied. Several techniques of optimization of sensors are approached and applied in a shell structure. The structure, a laminate of carbon fiber, was modeled by the finite element method (FEM) and then subject to free vibration. Genetic algorithms (GAs) are then employed to locate the best sensor distribution to cover a specific number of low frequency modes. Numerical results have demonstrated the overall efficiency of sensor delivery methods. Specific problems occurred, especially regarding the method of effective independence, being less efficient and discrepant in relation to the other methods employed. In summary, the results obtained in this paper provide an optimal position for sensors in real SHM systems and experiments.

References listed at the end of the paper:

- Doebling SW, Farrar CR, Prime MB, Shevitz DW (1996) Damage identification and health monitoring of structural and mechanical systems from changes in their vibration characteristics: a literature review
- Haftka RT (2016) Requirements for papers focusing on new or improved global optimization algorithms. Struct Multidisc Optim 54(1):1–1
- Stepiński T, Uhil T, Staszewski W (2013) Advanced structural damage detection: from theory to engineering applications. Wiley
Niels L. Petersen and Pauli Pedersen, “Buckling load optimization for 2D continuum models, with alternative formulation for buckling load estimation”, Structural and Multidisciplinary Optimization, Vol. 58, No. 5, pp 2163-2172, November 2018,

ABSTRACT: Buckling load estimation of continua modeled by finite element (FE) should be based on non-linear equilibrium. When such equilibrium is obtained by incremental solutions and when sensitivity analysis as well as iterative redesigns are included, the computational demands are large especially due to optimization. Therefore, examples presented in the literature relate to few design variables and/or few degrees of freedom. In the present paper a non-incremental analysis is suggested, and a simple sensitivity analysis as well as recursive redesign is proposed. The implicit geometrical non-linear analysis, based on Green-Lagrange strains, apply the secant stiffness matrix as well as the tangent stiffness matrix, both determined for the equilibrium corresponding to a given reference load, obtained by the Newton-Raphson method. For the formulated eigenvalue problem, which solution gives the estimated buckling load, the tangent stiffness matrix is of major importance. In contrast to formulations based on incremental solutions, the tangent stiffness matrix is here divided into two matrices, the stress stiffness matrix that is linear depending on stresses and the remaining part of the tangent stiffness matrix. Examples verify the effectiveness of the proposed procedure.

References listed at the end of the paper:


ABSTRACT: Suspended glass panels are monolithic or laminated frameless windows sustained by a number of holders, typically located in the vicinity of the edges. These panels can be used, among other purposes, as noise barriers. The vibro-acoustic behaviour of glass windows is critical at low frequencies, where the problem is often tackled by increasing the thickness, thus the mass, of the panels. As a consequence, solutions which preserve low mass are greatly sought by industries. In this study, the vibro-acoustic behaviour of different suspended glass panels is addressed. An optimization procedure is implemented, aiming at finding the position of the holders which maximizes the acoustic transmission loss (TL) averaged at low- and very low-frequency ranges. First, an iterative procedure, based on comparison of experimental and numerical modal data, has been implemented to extract the material properties (Young’s modulus and Poisson’s ratio) of the panels. Second, these properties have been used in an optimization procedure based on finite difference approximation of the objective function, the averaged transmission loss. The vibro-acoustic analyses, required by the optimization procedure, have performed by means of hybrid finite element method/statistical energy analysis (FEM/ SEA). 16 different design cases have been considered in the optimizations, i.e. 2 different frequency ranges (20-300 Hz and 20-1000 Hz), 2 panel geometries (square 1m x 1m and rectangular 2.5m x 0.8m), 2 constitutive material properties (monolithic tempered glass and laminated tempered glass) and 2 mounting solutions (4 and 6 holders). The transmission losses of the optimized and the standard configurations, where the holders are placed close to the edges, are compared.

References listed at the end of the paper:
• Cremer L (1942) Theory of the sound blockage of thin walls in case of oblique incidence. Akust Z 7:81–104
Suchao Xie (1), Haihong Li (1), Chengxing Yang (2) and Shuguang Yao (1),
(1) School of Traffic & Transportation Engineering, Central South University, Changsha, 410075, China
(2) School of Mechanical, Aerospace and Civil Engineering, University of Manchester, UK

ABSTRACT: To improve the crashworthiness of subway vehicles, a composite energy-absorbing structure (EAS) is designed by coupling a thin-walled metal tube and aluminium honeycomb structures. On this basis, the effectiveness of the composite structure and aluminium honeycomb finite element model (FEM) is validated by conducting trolley impact tests and quasi-static compression experiments. Based on the verified FEM, the surrogate models, including polynomial response surface (PRS), Kriging, radial basis function (RBF) and supported vector regression (SVR), are established to get the relationship between crashworthiness indexes and design variables. Then, the most accurate model is employed for crashworthiness optimisation through comparing the accuracies of these four models. Owing to the mutually effects among components of the composite EAS and the relatively complex mathematical formulae acquired by the high-precision surrogate model, a hybrid particle swarm optimisation (HPSO) algorithm is put forward. The performance of the HPSO is tested by a typical engineering optimisation case. The results indicate that the HPSO algorithm presents various advantages (e.g. strong global search capability, high optimisation accuracy, etc.). By optimising the mathematical model of the composite EAS, the optimal configurations of the structure are obtained, which confirms that the HPSO algorithm has favourable applicability and performance in the crashworthiness optimisation of the EASs for subway vehicles.

References listed at the end of the paper:

ABSTRACT: Automotive body frame comprises semi-rigid connected thin-walled beams (TWBs) that are fabricated from several stamped metal sheets. At conceptual design stage, cross-sectional shape design of the frame is a critical and intractable technique. In practice, design engineers mostly rely on empirical and intuitive trial-and-error approach to make decisions on the design of cross-sectional shape. This approach is laborious, time-consuming and unreliable, thus this article proposes a two-level multiple cross-sectional shape optimization approach. Our previously proposed transfer stiffness matrix method (TSMM) is adopted for the exact static and dynamic analyses of the frame. The dynamic stiffness matrix is refined by Love’s rod theory to take into account Poisson’s ratio effect. Moreover, scale vector method is introduced to remarkably reduce design variables. Then the shape optimization problem is formulated as a mass minimization problem, with exact static stiffness, dynamic frequency stiffness and four manufacturing constraints. Genetic algorithm (GA) is employed to solve the constrained nonlinear optimization problem. Afterwards, numerical examples with both of top-level and low-level shape optimization are carried out to demonstrate the validity of the proposed method. At last, parallel computing is introduced to notably speed up the optimization, and the shape optimization method is integrated into our object-oriented MATLAB toolbox to promote the conceptual development of auto-body.

References listed at the end of the paper:
- Goldberg DE (1989) Genetic algorithms in search, optimization and machine learning. Addison-Wesley, MA
Seyed Farhad Hosseini, Behnam Moetakef-Imani, Saeid Hadidi-Moud and Behrooz Hassani, “Pre-bent shape design of full free-form curved beams using isogeometric method and semi-analytical sensitivity analysis”, Structural and Multidisciplinary Optimization, Vol. 58, No. 6, pp 2621-2633, December 2018,

ABSTRACT: In this paper, isogeometric analysis (IGA) is employed to solve the problem of a curved beam with free-form geometry, arbitrary loading, and variable flexural/axial rigidity. The main objective of the study is to develop a unified approach for full free-form curved beam problems that can be integrated with a newly developed semi-analytical sensitivity analysis to solve pre-bent shape design problems. The required set of B-spline control points are calculated using an interpolation technique based on chord-length parameterization. The one-to-one correspondence is considered for parameters of the geometry, loading, and rigidity which is proven to have extreme importance. An IGA curved beam element is suggested based on the Euler-Bernoulli beam theory for the general curvilinear coordinate. The validity and effectiveness of the proposed formulation is confirmed by application to a variety of examples. Moreover, three shape optimization examples are taken into consideration. In the first two examples, the pre-bent shapes of spiral and Tschinhausen curved beams with free-form geometry under distributed loading are obtained. In the third example, the pre-bending problem of wind turbine blades is addressed as an industrial example.
Haichao An, Shenyen Chen and Hai Huang, “Stacking sequence optimization and blending design of laminated composite structures”, Structural and Multidisciplinary Optimization, Vol. 59, No. 1, pp 1-19, January 2019, ABSTRACT: The stacking sequence optimization problem for multi-region composite structures is studied in this work by considering both blending and design constraints. Starting from an initial stacking sequence design, unnecessary plies can be removed from this initial design and layer thicknesses of necessary plies are optimally determined. The existence of each ply is represented with discrete 0/1 variables and ply thicknesses are treated as continuous variables. A first-level approximate problem is constructed with branched multipoint approximate functions to replace the primal problem. To solve this approximate problem, genetic algorithm is firstly used to optimize discrete variables, and meanwhile, a blending design scheme is proposed to generate a blended structure. Starting from the thinnest region, this scheme shares all layers of current thinnest region with its adjacent regions. For non-shared layers in the adjacent regions, local mutation is implemented to add or delete plies to make them efficient designs. The whole process is repeated until the blending rule is satisfied. After that, a second-level approximate problem is built to optimize the continuous variables of ply thicknesses for retained layers. Those procedures are repeated until the optimal solution is obtained. Numerical applications, including a two-patch panel and a corrugated central cylinder in a satellite, are conducted to demonstrate the efficacy of the optimization strategy.

References listed at the end of the paper:
ABSTRACT: This paper presents a novel topology optimization formulation for shell-infill structures based on a distance regularized parametric level-set method (PLSM). In this method, the outer shell and the infill are represented by two distinct level sets of a single-level set function (LSF). In order to obtain a controllable and uniform shell thickness, a distance regularization (DR) term is introduced to formulate a weighted bi-objective function. The DR term is minimized along with the original objective, regularizing the parametric LSF close to a signed distance function. With the signed distance property, the area between the two-level sets can be contoured as the shell with a uniform thickness. Additionally, the presented formulation retains one important merit of the PLSM that new holes are able to nucleate during the optimization process. With respect to the material of the shell, the infill is filled with a weaker and lighter material with tunable parameters. Particularly, the infill can be pre-designed with isotropic microstructures. Three compliance minimization examples are provided to demonstrate the effectiveness of this formulation.

References listed at the end of the paper:
ABSTRACT: The stiffened plates are of demonstrable advantages and potential in offering high resistance to such extreme loading scenarios as blast. Since the distribution of the stiffeners has considerable effect on their performance, its design signifies an important topic of research. However, existing research has mainly focused on empirical design, and the configurations were largely experience based, which limits structural explosion-proof capacity. In order to improve the performance of stiffened plates against blast loading, we introduced here two new structural configurations of stiffened plates. In this study, the modified ant colony optimization (MACO) algorithm which introduces the mass constraint factor to the pheromone update function and integrates the idea of crossover and mutation was used to design the subjected to given working conditions. Specifically, material distribution of stiffeners is taken to be the design variables, and minimization of the maximum deflection of the center point of the plate to be the design objective under predetermined mass constraints. Compared with the baseline structure, the optimal designs largely improved the explosion-proof performance through distributing stiffener topology on the plates. The results showed that the optimum designs all present the reinforcement stiffeners to link with the fixed boundaries against the deformation. Moreover, the optimum designs placed more reinforcement materials in the central regions instead of four angles, and with the increase of the mass fraction, the reinforcement placement gradually extends from the center to the edges. The proposed method and new topological configurations are expected to provide some insights into design for novel protective structures.

References listed at the end of the paper:


Tangying Liu, Guangyong Sun, Jianguang Feng, Jingtao Zhang and Qing Li, “Topographical design of stiffener layout for plates against blast loading using a modified ant colony optimization algorithm”, Structural and Multidisciplinary Optimization, Vol. 59, No. 2, pp 335-350, February 2019,

ABSTRACT: This study proposes a non-deterministic robust topology optimization of ply orientation for multiple fiber-reinforced plastic (FRP) materials, such as carbon fiber–reinforced plastic (CFRP) and glass fiber–reinforced plastic (GFRP) composites, under loading uncertainties with both random magnitude and random direction. The robust topology optimization is considered here to minimize the fluctuation of structural performance induced by load uncertainty, in which a joint cost function is formulated to address both the mean and standard deviation of compliance. The sensitivities of the cost function are derived with respect to the design variables in a non-deterministic context. The discrete material optimization (DMO) technique is extended here to accommodate robust topology optimization for FRP composites. To improve the computational efficiency, the DMO approach is revised to reduce the number of design variables by decoupling the selection of FRP materials and fiber orientations. In this study, four material design examples are presented to demonstrate the effectiveness of the proposed methods. The robust topology optimization results exhibit that the composite structures with the proper ply orientations are of more stable performance when the load fluctuates.

References listed at the end of the paper:

This work explores the use of solid-shell elements in the framework of isogeometric shape optimization of shells. The main difference of these elements with respect to pure shell ones is their volumetric nature which can provide recognized benefits to analyze, for example, structures with non-linear behaviors. From the design point of view, we show that this geometric representation of the thickness is also of great interest since it offers new possibilities: continuous sizing variations can be imposed by modifying the distance between the control points of the outer surfaces. In other words, shape and sizing optimization can be performed in an identical manner. Firstly, we carry out a range of numerical experiments in order to carefully compare the results with the commonly adopted technique based on the Kirchhoff-Love formulation. These studies reveal that both solid-shell and Kirchhoff-Love strategies lead to very similar optimal shapes. Then, we apply a bi-step strategy to integrate shape and sizing optimization. We highlight the potential of the proposed approach on a stiffened cylinder where the cross section along the stiffener is optimized leading to a final design with smooth thickness variations. Finally, we combine the benefits of both Kirchhoff-Love and solid-shell formulations by setting up a multi-model optimization process to efficiently design a roof.


ABSTRACT: In this paper, a new systematic approach is suggested for better exploration of given uncertain buckling loads in the problem of optimal designs of hybrid symmetric laminated composites. Laminated composites are made up of 16-layered carbon-epoxy, glass-epoxy, and hybrid carbon-glass plies with discrete ply angles as design variables. In the analysis, the ply angles and the type of constituents in the laminates are varied, and one source of uncertainty, namely, uncertainty in buckling load is incorporated. In order to form nested optimization, a new improved rank-based version of Quantum-inspired Evolutionary Algorithm (QEA) is proposed and different versions of QEA and Genetic Algorithm (GA) are utilized. Using anti-optimization approach, the worst case biaxial compressive loading is obtained by Golden Section Search (GSS) method and the buckling load capacity is maximized. Numerical results of the optimal configurations are obtained under several bi-axial loading cases, panel aspect ratios, and materials. The results are investigated from different perspectives and sensitivity analyses are performed.

References listed at the end of the paper:
- Kaveh A (2017b) Applications of metaheuristic optimization algorithms in civil engineering Springer, Switzerland
ABSTRACT: This work presents a new methodology for the topology optimization of piezoelectric actuators in laminated composite structures with the objective of controlling external perturbation induced by structural vibrations. The linear-quadratic regulator (LQR) optimal control technique is used and the topology optimization is formulated seeking to find the optimum localization of the macro-fiber composite (MFC) active piezoelectric patch by means of the maximization of the controllability index. For the structural model, we propose a simplified MFC/structure interaction model. It is assumed that the MFC is one of the orthotropic material layers with an initial strain arising from the application of an electric potential. This strain acts on the remainder of the structure and its effect is considered analytically. Numerical results show that the proposed MFC structure interaction model presents good agreement with experiments and numerical simulations of models that take into account the electromechanical effect. Results of the actuator location optimization show that the implemented technique improves the structural vibration damping. Results and comparisons are presented for the vibration control strategy using the LQR controller.

References listed at the end of the paper:


set of anisotropic loading conditions, are approximated on a single scale using a simple mapping approach. We significantly improve chances of convergence to near optimal designs. Rank


With the goal of identifying optimal elastic single-scale microstructures for multiple loading situations, the paper shows that qualified starting guesses, based on knowledge of optimal rank-3 laminates, significantly improves chances of convergence to near optimal designs. Rank-3 laminates, optimal for a given set of anisotropic loading conditions, are approximated on a single scale using a simple mapping approach. We
demonstrate that these mapped microstructures perform relatively close to theoretical energy bounds. Microstructures with a performance even closer to the bounds can be obtained by using the approximated rank-3 structures in a further step as starting guesses for inverse homogenization problems. Due to the nonconvex nature of inverse homogenization problems, the starting guesses based on rank-3 laminates outperform classical starting guesses with homogeneous or random material distributions. Furthermore, the obtained single-scale microstructures are relatively simple, which enhances manufacturability. Results, obtained for a wide range of loading cases, indicate that microstructures with performance within 5–8% of the theoretical optima can be guaranteed, as long as feature sizes are not limited by minimum size constraints.

References listed at the end of the paper:


ABSTRACT: Curved thick beams with smoothly variable cross-section size are very common in practical engineering problems. Designing the variable size based on the traditional finite element methods often leads to non-smooth solutions. To guarantee the smoothness of size distribution, an isogeometric analysis (IGA)-based design approach is proposed in this work to optimize the cross-section size of curved Timoshenko beams for natural frequencies. Due to the geometric exactness and high-order continuity of IGA, there is high accuracy of natural frequency prediction and sensitivity analysis for design optimization. It is found that small numbers of design variables lead to parameterization-dependent solutions, while large numbers of design variables induce design fluctuation. To avoid the undesirable design fluctuation, a stability transformation method-based K-S aggregation constraint scheme is proposed to regularize the size distribution and also achieve the stable convergence of optimal solutions. Multiple design studies including the deterministic and reliability-based optimization problems are performed to demonstrate the applicability and effectiveness of the proposed approach.

References listed at the end of the paper:
ABSTRACT: This paper proposes a novel multiscale concurrent topology optimization for cellular structures with nonuniform microstructures based on the kriging metamodel, Structural and Multidisciplinary Optimization, Vol. 59, No. 4, pp 1273-1299, April 2019, using a spectral coarse basis preconditioner. The built kriging metamodel is then employed to predict the effective properties of all the nonuniform microstructures within macrostructure. At macroscale, the variable thickness sheet (VTS) method is employed to generate an overall free material distribution patterns using the predicted effective properties of all the nonuniform microstructures. With the help of shape interpolation technology, all the nonuniform microstructures within macrostructure are well connected with each other due to the similar topological features at their interfaces. Using the proposed method, the macrostructural topology as well as the locations and configurations of the spatially varying nonuniform microstructures can be simultaneously optimized to ensure a sufficiently large multiscale design space. Numerical examples are provided to demonstrate the validity and advantages of the proposed method.

References listed at the end of the paper:


Huang X, Xie Y (2009) Bi-directional evolutionary topology optimization of continuum structures with one or multiple materials. Comput Mech 43:393


References listed at the end of the paper:


Federico Ferrari and Ole Sigmund, “Revisiting topology optimization with buckling constraints”, Structural and Multidisciplinary Optimization, Vol. 59, No. 5, pp 1401-1415, May 2019,

ABSTRACT: We review some features of topology optimization with a lower bound on the critical load factor, as computed by linearized buckling analysis. The change of the optimized design, the competition between stiffness and stability requirements and the activation of several buckling modes, depending on the value of such lower bound, are studied. We also discuss some specific issues which are of particular interest for this problem, as the use of non-conforming finite elements for the analysis, the use of inconsistent sensitivity that may lead to wrong signs of sensitivities and the replacement of the single eigenvalue constraints with an aggregated measure. We discuss the influence of these practices on the optimization result, giving some recommendations.


Simitses GJ (1973) Optimal versus the stiffened circular plate. AIAA J 11:1409–1412


ABSTRACT: This paper develops the coordinative optimization method based on system reliability for laminated structures. The proposed method improves the rough RBO based on first layer failure (FLF) criterion for composite laminates, and the coupling optimization method of thickness and sequence in traditional RBO strategy based on last layer failure criterion (LLF) is improved. In this paper, the finite element analysis is used to obtain the response for the failure based on two-dimension Hashin failure criterion (the limit function). Obviously, the stiffness of composite materials will decline due to destruction of elements. Therefore, stiffness degradation is considered to describe the process of damage evolution. Subsequently, combining with the branch-bound method (B&B), we can complete the search of main failure sequences and calculate the system reliability with the help of the second-order upper bound theory. In order to guarantee the efficiency and accuracy of optimization, the adaptive GA algorithm is introduced in the whole optimization procedure. After
the proposed optimization policy is given in detail, two laminated structures are presented and the results are compared with the traditional optimal method based on safety factor, which demonstrates the validity and reasonability of the developed methodology.

References listed at the end of the paper:
- Park JS, Kim CG, Hong CS (2015) Bimodal bound of system reliability for random composite structures. AIAA J 34:1494–1500
ABSTRACT: This study firstly presents a multi-material topology optimization approach for thin plates with variable thickness based on Kirchhoff plate theory. For this purpose, an alternating active-phase algorithm in conjunction with the block Gauss-Seidel method is utilized to transform a multiphase topology optimization problem with multiple volume fraction constraints to many binary phase topology optimization sub-problems with only one volume fraction constraint. Accordingly, the number of design variables depends only on one active phase in each of those sub-problems no matter how many phases the original problem are. In addition, moved and regularized Heaviside function (MRHF) that plays the role of a filter is also investigated in the framework of multiple materials field. The mathematical formulations of stiffness and compliance sensitivity with respect to multi-directional variable thickness linked to thin plate potential energy are derived in terms of multiphase design variables. Numerical examples demonstrate interactions of variables thickness and multiple materials to thin mid-plates with the same amount of volume fraction and total structural volume.

References listed at the end of the paper:


ABSTRACT: An approximate thickness optimization of a rectangular Kirchhoff-Love plate with variable stiffness under uniform load is performed in this paper. The authors propose an original method for formulating problems of optimal design for plate structures of variable thickness. Partial discretization, which is described in this paper, reduces the number of independent variables in the problem formulation to only one, making the problem possible to solve via application of the Pontryagin’s minimum principle. The optimization problem relates to the search for the optimal plate thickness distributions, which provides the minimum structural volume of the material used while simultaneously meeting all constraint conditions. The optimal design task is formulated as a control theory problem, maintaining the formal structure of the minimum principle, and then is transformed into a two-point boundary value problem. Such an approximate solution, meeting all necessary optimality conditions, is found by using Dircol software for a chosen illustrative example.

References listed at the end of the paper:


ABSTRACT: The paper presents an integrated design approach of composite bay door with pre-deformation and variable thickness optimization. Firstly, design and optimization of functional composite curved surface are discussed. To avoid adopting locking mechanism, a design of pre-deformation is used in aircraft bay door to keep the door closed. In this paper, the curve of composite bay door is considered as part of design variables. By means of the internal forces caused by the deformation of curve, the aircraft bay door could be able to fix in target position firmly and stably. The pre-deformation of bay door is controlled by particular parametric Bezier curve, which provides abundant changing range to meet the needs. Secondly, the variable thickness optimization of composite laminates is introduced. To take full advantage of designability of composites, variable thickness design is actualized through partitioning in bay door, not only considering the weight reduction of the structure, but also ensuring the enough strength and stiffness in the critical load positions where the strength and stiffness requirements are harsh. Furthermore, the integrated optimization is carried out based on the method of concurrent subspace optimization (CSSO).

References listed at the end of the paper:


Libin Duan, Haobin Jiang, Guoqing Geng, Xuerong Zhang and Zhanjiang Li, “Parametric modeling and multiobjective crashworthiness design optimization of a new front longitudinal beam”, Structural and Multidisciplinary Optimization, Vol. 59, No. 5, pp 1789-1812 May 2019,

ABSTRACT: The front longitudinal beam (FLB) is the most important energy-absorbing and crashing force–transmitting structure of a vehicle under front-impact collision. For better weight reduction and crashworthiness of the FLB, a new structure, variable rolled blank–variable cross-sectional shape FLB (VRB-VCS FLB), is proposed. It has both the continuous variation of thickness and variable cross-sectional shape in space. As the thickness distribution and cross-sectional shape change continuously, the proposed structure evolves into three distinct forms, i.e., the uniform-thickness FLB, variable rolled blank FLB, and variable cross-sectional shape FLB. However, literature on parametric modeling and crashworthiness design optimization of the VRB-VCS FLB is very limited. This paper proposes a parametric modeling method of VRB-VCS FLB with manufacturing constraints. Multiobjective crashworthiness design optimization is performed to explore the lightweightness and crashworthiness performance of the VRB-VCS FLB. Firstly, thickness distribution and cross-sectional shape parameters are defined. Secondly, local parametric subsystem front-impact model is established to balance accuracy and efficiency. Thirdly, a multiobjective optimization model of VRB-VCS FLB is constructed.
Finally, a fully automated design of experiment platform is established to improve the data collection efficiency, and epsilon-support vector regression technique and non-dominated sorting genetic algorithm II are utilized to search the Pareto optimal frontier. The numerical results show that the lightweightness and crashworthiness of the VRB-VCS FLB are significantly improved when compared with the uniform-thickness FLB.

References listed at the end of the paper:

- Chahardoli S, Nia AA (2017) Investigation of mechanical behavior of energy absorbers in expansion and folding modes under axial quasi-static loading in both experimental and numerical methods. Thin Wall Struct 120:319–332
References listed at the end of the paper:


Qi Chen, Xianmin Zhang and Benliang Zhu, “A 213-line topology optimization code for geometrically nonlinear structures”, Structural and Multidisciplinary Optimization, Vol. 59, No. 5, pp 1863-1879 May 2019, ABSTRACT: This paper presents a 213-line MATLAB code for topology optimization of geometrically nonlinear structures. It is developed based on the density method. The code adopts the ANSYS parametric design language (APDL) that provides convenient access to advanced finite element analysis (FEA). An additive hyperelasticity technique is employed to circumvent numerical difficulties in solving the material density-based topology optimization of elastic structures undergoing large displacements. The sensitivity information is obtained by extracting the increment of the element strain energy. The validity of the code is demonstrated by the minimum compliance problem and the compliant inverter problem. References listed at the end of the paper:

ABSTRACT: Level set–based optimization for two-dimensional structural configurations with thin members is presented. A structural domain with thin thickness is defined as a narrow band region on the zero-level contour of the level set function. No additional constraints or penalty functional is required to enforce semi-uniformity in member thickness. Design velocity is calculated on the zero level set, not on domain boundaries, and extended to level set grids in the narrow band. For complicated structural layouts, multiple level set functions are employed. The effectiveness of the proposed method is verified by solving optimization problems of bar configurations. Since no thickness constraints are employed, structurally unfavorable distorted joints seen in other literature do not appear in the results.

References listed at the end of the paper:


ABSTRACT: In this study, we propose a distributed-parametric material orientation optimization method for the optimal design of laminated composite shell structures consisting of anisotropic materials. We consider the compliance as the objective function and minimize it under the state-equation constraint. The material orientation in all the layers is treated as the design variable. The optimal design problem is formulated as a distributed-parameter optimization problem based on the variational method, and the sensitivity function with respect to the material orientation variation is theoretically derived. The optimal orientation variations are determined using the Hessian gradient method with Poisson’s equation, where the derived sensitivity function is applied as the fictitious internal heat generation under the Robin condition to reduce the objective function while maintaining a smooth material orientation. With the proposed method, we can conventionally obtain the arbitrary optimal distribution of the material orientations of all the layers of complicated large-scale shell structures like aircraft or automotive bodies without design variable parameterization. The optimal results of the design examples show that the proposed optimization method can effectively obtain the optimal distribution of the material orientation in laminated shell structures.

References listed at the end of the paper:


ABSTRACT: Airfoil design for stationary gas turbines is a challenging task involving both aerodynamic and structural aspects. The paper describes a multidisciplinary optimization process for axial compressor airfoils which is able to find optimal designs w.r.t. multiple objectives and constraints starting from a reference design and very few specifications of the new compressor. The process allows to simultaneously execute arbitrarily many instances of design evaluation processes independently from each other, which speeds it up, not just due to parallelization, but also because fast-running low-fidelity evaluation may take the design lead at an early design stage, whereas high-fidelity evaluation processes simultaneously contribute with more reliable results on the actual performance. For consistency of aerodynamic and structural analysis, an innovative method for direct loaded-to-unloaded design transformation is incorporated. Additionally, the process accounts for design robustness by utilizing production tolerances as an optimization objective. Therefore, a procedure is developed which allows to find the production tolerance which may be allowed without violating any constraints. An application example demonstrates that the proposed optimization process incorporating automatic detection of failure-critical eigenmode bands is able to shift them such that structurally reliable, robust, and simultaneously aerodynamically efficient designs are obtained.

References listed at the end of the paper:
otherwise brittle material. Optimisation of the geometry and material behaviour enables a non-optimisation model. The proposed optimisation is beneficial in improving the crashworthiness of composites, as static and crash loads have been only considered separately, but never at the same time. The novelty of this characteristic of these elements as variables. The method enables the simultaneous consideration of static and structural crashworthiness. For the first time, homogeneous contribution has been identified as a metric for deformation capability. It promotes homogeneous contribution of aluminum and composite elements.


ABSTRACT: In this paper, a multi-objective optimisation for the initial design of crashworthy composite structures is proposed. The focus is on the optimisation model with its minimisation of inhomogeneous deformation capability. It promotes homogeneous contribution of all crash elements, as a representative of structural crashworthiness. For the first time, homogeneous contribution has been identified as a metric for crashworthiness of composite structures and been transferred into a mathematical expression. The structural model uses discrete elements for very efficient computation in combination with the genetic algorithm NSGA-II. Clustering as a machine learning technique is applied to the Pareto set of solutions in order to identify representative structural solutions. The approach uses positioning of elements and the shape of the spring characteristic of these elements as variables. The method enables the simultaneous consideration of static and crash loads, which is demonstrated by a case study featuring a composite aircraft fuselage substructure. So far, static and crash loads have been only considered separately, but never at the same time. The novelty of this approach is in the combination of an appropriate simplified modelling technique and a new formulation of the optimisation model. The proposed optimisation is beneficial in improving the crashworthiness of composites, as optimisation of the geometry and material behaviour enables a non-linear response to be obtained in an otherwise brittle material.
Zunyi Duan, Jun Yan, Ikjin Lee, Erik Lund and Jingyuan Wang, “A two-step optimization scheme based on equivalent stiffness parameters for forcing convexity of fiber winding angle in composite frames”, Structural and Multidisciplinary Optimization, Vol. 59, No. 6, pp 2111-2129 June 2019,

ABSTRACT: For stiffness design optimization of composite frame structures, one of the major problems when using fiber winding angles as design variables directly is the lack of convexity of the objective function, which may lead to different local optima depending on initial designs when a traditional gradient-based optimization algorithm is applied. Therefore, the present paper adopts a gradient-based two-step optimization scheme to cope with the difficulty and search for a better optimal design of composite frames in which the fiber winding angles are taken as design variables. To realize the two-step optimization scheme, the equivalent stiffness parameters of a composite beam with circular cross-section are derived in explicit expressions and used to force the convexity of the design optimization of the composite frame. The stiffness matrices are linearly expressed in terms of the stiffness parameters, which guarantee the convexity of the design variable feasible region in the stiffness parameter space. The equivalent stiffness parameters are adopted to keep invariance of physical quantities between fiber winding angle and equivalent stiffness parameter spaces. In the two-step optimization scheme, the minimum identification problem with the constraint that the objective function at the new starting point is less than or equal to the previous objective function at the optimum point in fiber winding angle space is established. Then, the two-step optimization scheme can be implemented in the fiber winding angle and structural equivalent stiffness parameter spaces, respectively, until the minimum identification problem is not possible to identify a new starting point. The proposed two-step optimization scheme for composite frames fully takes advantage of the stiffness parameters in convexity and fiber winding angles as practically physical quantities, respectively. The sensitivity information of the objective function with respect to fiber winding angles and equivalent stiffness parameters is derived by the analytical sensitivity analysis method. Numerical examples show that the two-step optimization scheme can effectively force convexity of the optimization model and help to eliminate the initial design dependency. The effectiveness of the proposed two-step scheme is further verified through the particle swarm optimization (PSO) algorithm which is an evolutionary algorithm with global optimization capability.

References listed at the end of the paper:

Xu Han, Weigang An and Andres Tovar, “Targeting the force-displacement response of thin-walled structures subjected to crushing load using curve decomposition and topometry optimization”, Structural and Multidisciplinary Optimization, Vol. 59, No. 6, pp 2303–2318 June 2019,

ABSTRACT: This work introduces a new approach to targeting the dynamic response of thin-walled energy-absorbing structures through the decomposition of the force-displacement (FD) response and the use of topometry (thickness) optimization. The proposed method divides the nonlinear optimization problem into a series of analytical subproblems. In each iteration, an explicit dynamic analysis is carried out and the dynamic response of the structure is then used to define the subproblem. Numerical examples show that the algorithm can tailor the FD response of the structure to a target FD curve. Progressive collapse, which is a high-energy collapse mode and desired in design for crashworthy, is observed in the optimized thin-walled structures. The proposed algorithm is computationally efficient as it uses a fewer explicit simulations to reach the target response.

References listed at the end of the paper:


July 2019.

ABSTRACT: To resist external pressure, stiffened spherical domes have been widely used in underwater vehicles. In traditional design of these thin-walled structures, uniform stiffeners are usually utilized and overly conservative safety factor method is employed to envelop the multi-source uncertainties mainly caused by manufacturing. In this study, a concept of non-uniformly stiffened spherical dome (NUSPD) is developed to improve the structural buckling capacity. Furthermore, an efficient reliability-based design optimization (RBDO) framework is established for NUSPD, which includes a deterministic optimization loop to fix the stiffener layout, and subsequently followed by a RBDO loop to determine the detailed stiffener dimensions and decrease the structural weight under geometric and material property uncertainties. Since the RBDO of stiffened spherical domes is very complex, an improved enhanced chaos control method together with surrogate model is proposed to improve the convergence rate. Finally, the efficiency of the proposed RBDO framework is demonstrated by the NUSPD example.

References listed at the end of the paper:


Bhattacharyya. (2017) Locally flattened or dented domes under external pressure. Thin-Walled Struct 97:44–52


· Nguyen DD, Dao HB, Vu TTA (2016) On the nonlinear stability of eccentrically stiffened functionally graded annular spherical segment shells. Thin-Walled Struct 106:258–267

ABSTRACT: The immense design freedom offered by additive manufacturing yields tremendous benefits, but it also raises the question of how to best go about designing components to exploit this design freedom. In early design phases, design tools need to utilize this freedom, but do so with low computational cost and with a good estimate of the final weight to correctly assess the part’s influence on the overall product design. This is especially important for aerospace designs. In this paper, a design methodology is devised for cellular structures to be manufactured using additive manufacturing techniques, specifically for such early design phases. This design methodology uses adaptive meshing techniques to design the topology of the cellular structure, after which the struts of that cellular structure are optimized separately to reduce the dimensionality of the problem. The method is demonstrated for a small generic bracket and an aircraft bracket design from the literature. For these problems, our method is fast enough to evaluate many thousands of design options. This results in identifying promising candidate designs for further detailed design work.

References listed at the end of the paper:


Jiani Zeng, Zhengdong Huang, Yongfu Chen, Wei Liu and Shanshan Chu, “A simulated annealing approach for optimizing composite structures blended with multiple stacking sequence tables”, Structural and Multidisciplinary Optimization, Vol. 60, No. 2, pp 537-563 August 2019, ABSTRACT: This paper presents an approach to design composite panels via multiple stacking sequence tables (SST) such that the continuity constraints between adjacent regions are maintained. Traditional SST methods determine all the stacking sequences with only one SST, but this simplification limits the design option space. To increase the design freedom, this research utilizes multiple SSTs to blend the stacking sequences of a laminated structure. In the design process of the proposed approach, the monotonicity property of predicted laminate thicknesses is employed to determine the number of SSTs, and an SST rebuilding method is developed to satisfy the blending constraints. In the implementation of the simulated annealing algorithm for solving the optimal design problem, an SST difference code is introduced to represent feasible solutions, and a particular neighborhood structure is proposed to sufficiently explore the solutions in design space. Finally, the 18-region benchmark problem is chosen to validate the efficiency and accuracy of the proposed method. The results reveal that, compared with other existing methods, the proposed method can generate manufacturable solutions with lower weights under the symmetry and balance constraints.

References listed at the end of the paper:

- Gibson RF (1994) Principles of composite material mechanics. 4rd. CRC Press, Boca Raton


ABSTRACT: In this paper, the research on crashworthiness optimization of thin-walled structures is presented. The model of “S”-shaped frame subjected to complex crush load is analyzed. The objective of the study is to determine the optimal dimensions of the space frame cross section so as to achieve the maximal energy absorption of the structure and to fulfill the design requirements related to the crushing force value and the geometry relationship. The Visual Crash Studio (VCS) software, based on the macro element methodology, is used to simulate the response of a thin-walled beam during the impact and to determine crashworthy parameters. The results present a very good correlation with the finite element calculations but can be obtained in a much shorter time. The VCS software was coupled to evolutionary algorithm developed to determine the best solution. The optimization procedures revealed the necessity of a new design criterion related to maximal bending moments in the structure. This formulation enabled to obtain very good results after short processing on a PC computer. The proposed approach may be successfully used at early stages of the crashworthiness analysis.

References listed at the end of the paper:

• Liu Y (2010b) Crashworthiness design of thin-walled curved beams with box and channel cross sections. Int J Crashworthiness 15(4):413–423


ABSTRACT: An effective multi-objective optimization methodology that combines the isogeometric analysis (IGA) and adaptive chaotic particle swarm algorithm is presented for optimizing ceramic volume fraction (CVF) distribution of functionally graded plates (FGPs) under eigenfrequencies. The CVF distribution is represented by the B-spline basis function. Mechanical behaviors of FGPs are obtained with NURBS-based IGA and the recently developed simple first-order shear theory. The design variables are the CVFs at control points in the thickness direction, and the optimization objective is to minimize the mass of structure and maximize the first natural frequency. A recently developed multi-objective adaptive chaotic particle swarm algorithm with high efficiency is employed as an optimizer. All desirable features of the developed approach will be illustrated through four numerical examples, confirming its effectiveness and reliability.

References listed at the end of the paper:


ABSTRACT: Meta-heuristic and hyperheuristic algorithms are milestones that make the topology optimization practical for dynamic and nonlinear problems. However, researchers are continuing to improve these methods to get better results. Plastic behavior, complex deformation, and load-dependent material properties of the vehicle components during a crash event are challenging issues that are faced in this context. This research focuses on enhancing search efficiency of the hybrid cellular automata (HCA) algorithm with the aim of improving the energy absorption of vehicle structures exposed to high-impact collisions. An attempt is made to utilize an ideal amount of material in the structures to obtain a more uniform distribution of the plastic strain. Thus, the design is based on this criterion throughout the whole structure during the entire collision time. The variable neighborhood radius concept realizes an intelligent search strategy for the modified HCA (MHCA) algorithm. This innovation, applied here to topology optimization design, makes the MHCA algorithm more functional to control plastic strain energy. To confirm this, the crash analysis is performed using the finite-element software package LS-DYNA. An additional benefit of using this method is the quick and stable convergence while the energy absorption relative to the mass fraction is remarkably improved.

References listed at the end of the paper:


https://doi.org/10.1007/s00158-006-0040-z


ABSTRACT: To date, topology optimization has proven to be the most beneficial, yet most complex, structural optimization technique available to engineers and scientists. However, particularly in the aerospace industry, there exists little application to real-world design problems, including all the complexities required to ensure that the resulting design complies with the regulations. In this paper, a topology optimization algorithm is developed to solve aerospace design problems. Two problems are considered in this work. The first is the design of an aircraft landing gear. The final topology is compared to a design found using standard engineering practices to show the benefits of topology optimization. The second problem uses the topology optimization methodology to design an aircraft engine mount. The main goal of this paper is to demonstrate that topology optimization can be used to find minimum weight structures to aerospace design problems, using Federal Aviation Regulations to ensure that the resulting designs meet the airworthiness standards of the aviation industry.

References listed at the end of the paper:
· Huang X, Xie Y (2009) Bi-directional evolutionary topology optimization of continuum structures with one or multiple materials. Comput Mech 43:393–401
· Munk D, Verstreæte D, Vio G (2017a) Effect of fluid-thermal-structural interactions on the topology optimization of a hypersonic transport aircraft wing. Fluids Struct 75:45–76
· Niu M (1988) Airframe structural design. Hong Kong Commilit Press LTD, Hong Kong
· Remouchamps A, Bruyneel M, Fleury C, Grihon S (2011) Application of a bi-level scheme including topology optimization to the design of an aircraft pylon. Struct Multidiscip Optim 44:739–750
Renato Picelli, A. Neofytou and H. Alicia Kim, “Topology optimization for design-dependent hydrostatic pressure loading via the level-set method”, Structural and Multidisciplinary Optimization, Vol. 60, No. 4, pp 1313-1326 October 2019,

ABSTRACT: A few level-set topology optimization (LSTO) methods have been proposed to address complex fluid-structure interaction. Most of them did not explore benchmark fluid pressure loading problems and some of their solutions are inconsistent with those obtained via density-based and binary topology optimization methods. This paper presents a LSTO strategy for design-dependent pressure. It employs a fluid field governed by Laplace’s equation to compute hydrostatic fluid pressure fields that are loading linear elastic structures. Compliance minimization of these structures is carried out considering the design-dependency of the pressure load with moving boundaries. The Ersatz material approach with fixed grid is applied together with work equivalent load integration. Shape sensitivities are used. Numerical results show smooth convergence and good agreement with the solutions obtained by other topology optimization methods.

References listed at the end of the paper:

ABSTRACT: High-accuracy numerical method for uncertainty propagation analysis is a crucial issue in the field of structural reliability design. In this work, a novel iterative algorithm is proposed to study the free vibration of the functionally graded (FG) thin plates with material uncertainties. As a highly accurate approach distinct from the existing non-iterative model, the frequency analysis of FG thin plates can be achieved by updating the lower and upper bounds of natural frequency step by step. Based on the classic plate theory, the governing equations of the FG thin plate resting on an elastic medium are derived and the analytical formulation for the natural frequency is presented. By introducing interval parameters to quantify the material uncertainties, a non-probabilistic model for evaluating the natural frequency response of the embedded FG thin plate is developed. Subsequently, the deduction of the novel iterative algorithm for solving the non-probabilistic model is given based on interval mathematics. The developed model and the proposed iterative algorithm are validated by the Monte Carlo method, and then the detailed parametric studies are carried out to explore the combined influences of material uncertainties, power-law index, and elastic foundation parameters, as well as size parameters on the natural frequency of the FG thin plate. Numerical results can provide useful guidance in the precise design of FG structures.

References listed at the end of the paper:
- Ebrahimi F, Rastgo A (2008a) An analytical study on the free vibration of smart circular thin FGM plate based on classical plate theory. Thin-Walled Struct 46(12):1402–1408
- Lv Z, Qiu ZP, Yang WY, Shi QH (2018) Transient thermal analysis of thin-walled space structures with material uncertainties subjected to solar heat flux. Thin-Walled Struct 130:262–272
adjoint variable methods. The shape gradient functions theoretically derived are applied to the H shape variation in the normal direction to the surface are derived based on the volume constraint. The unsteady op control the dynamic responses at arbitrary domains and times for an arbitrary time-dependent response of shell structures. The design objective is to minimize the dynamic compliance or to shell structures.


ABSTRACT: In this study, we propose a parameter-free free-form optimization method to control the time-dependent response of shell structures. The design objective is to minimize the dynamic compliance or to control the dynamic responses at arbitrary domains and times for an arbitrary time-dependent loading under volume constraint. The unsteady optimum design problems are formulated as a distributed-parameter shape optimization problem based on the variational method, and the shape gradient functions with respect to the shape variation in the normal direction to the surface are derived based on the material derivative and the adjoint variable methods. The shape gradient functions theoretically derived are applied to the $H^1$ gradient.
method for shells, a gradient method in the function space. With the proposed approach, the optimum free form of the shell structures for the time-dependent response problems can be obtained while minimizing the objective functional and maintaining the smoothness of the form. Several shape design examples under a continuous dynamic force or an impulse force are demonstrated to show the effectiveness of the proposed method, and the results are discussed.

References listed at the end of the paper:

Braden T. Warwick, Chris K. Mechéfske and II Yong Kim, “Topology optimization of a pre-stiffened aircraft bulkhead”, Structural and Multidisciplinary Optimization, Vol. 60, No. 4, pp 1667–1685 October 2019, ABSTRACT: The bulkhead of an aft-fuselage twin-engine mounted aircraft is a pivotal structural component from a noise and vibrations perspective as it is the main transmission path for the engine-induced vibration to propagate into the passenger cabin. Despite this, there has yet to be a successful implementation of topology optimization (TO) on a pre-stiffened aircraft bulkhead. This work is the first to investigate TO on a pre-stiffened
bulkhead with a frequency-based problem statement. The objective function was set to maximize the first eigenfrequency to maximize the stiffness to mass ratio of the bulkhead. Frequency constraints were implemented to eliminate the natural frequencies within range of the engine excitation frequency. A volume fraction constraint was set such that the mass of the solution was less than the mass of similar bulkhead stiffeners reported in the literature. The first successful implementation of topology optimization on a pre-stiffened aircraft bulkhead was obtained. Two designs satisfying the optimality criterion were generated, both of which were able to improve bulkhead structural integrity, reduce mass, and eliminate resonance from ± 10% of the engine excitation frequency. This work demonstrates that TO is a useful tool to help aerospace engineers improve the vibro-acoustic properties of the bulkhead without sacrificing mass or structural integrity. The methodology introduced in this work can be easily integrated into aircraft design, as it uses tools widely available in the aerospace industry.

References listed at the end of the paper:

References listed at the end of the paper:


Artem Karev, Lothar Harzheim, Rainer Iimmel and Matthias Erzgraber, “Free sizing optimization of a front hood using the ESL method: overcoming challenges and traps”, Structural and Multidisciplinary Optimization, Vol. 60, No. 4, pp 1687-1707 October 2019

ABSTRACT: Topology and free sizing optimization are very important tools in the early design phase. Yet, they are only well established for optimization problems based on linear analysis. In the nonlinear analysis area—in particular crash—such kind of optimization cannot be applied due to the unavailability of gradients. A workaround is to create linear auxiliary load cases approximating the nonlinear load case at different time steps, which can be used in optimization based on linear statics analysis. The equivalent static load (ESL) method provides a procedure to create such auxiliary load cases in a well-defined way. However, it is a great challenge to translate nonlinear requirements and responses to linear statics system. For this reason, strain energy is often used as objective function even if it does not reflect the real objective in the optimization task. In this study, different formulations for a front hood free sizing optimization problem are assessed for their ability to translate the actual objective of the nonlinear system to the linear statics system. It turns out that even though such formulations can be found, they show no advantage in comparison to simpler formulations. The best performance was obtained using mass as objective function, whereas the strain energy formulation fails due to the tendency to favor huge mesh deformations in void areas. The reason for such behavior and the related issues appearing especially in topology and free sizing optimization are discussed in detail. Finally, recommendations are given on how to improve the performance of ESL-based optimization.
Bin Niu, Yao Shan and Erik Lund, “Discrete material optimization of vibrating composite plate and attached piezoelectric fiber composite patch”, Structural and Multidisciplinary Optimization, Vol. 60, No. 5, pp 1759-1782 November 2019,

ABSTRACT: This work deals with the layout optimization of piezoelectric fiber composite patches on a vibrating laminated composite plate and the discrete material design of the composite plate. The vibration of the composite plate is excited by an external mechanical loading, and a sinusoidal voltage with given amplitude and frequency is applied on the piezoelectric fiber composite patches. The analysis of the composite structure with piezoelectric fiber composite patches is performed via a finite element method in condensed form, where the piezoelectric effects are considered as induced force. As a view to minimize the dynamic response of the vibrating laminated composite structure, the Discrete Material Optimization method is employed to perform the design optimization of piezoelectric fiber composite patches and the stacking sequence, fiber angles, and selection of material for the composite structure. Numerical examples are presented to demonstrate the effectiveness of the proposed method.

References listed at the end of the paper:


https://doi.org/10.1177/0954407018809298


Scott Townsend (1) and H. Alicia Kim (1,2)
(1) School of Engineering, Cardiff University, Cardiff, CF24 3AA, UK
(2) Department of Structural Engineering, University of California, San Diego, CA, 92093, USA


ABSTRACT: Shell structures are some of the most widely used in engineering applications. Flat plates, stiffened panels, and wing ribs are each examples of components for which the design features may be dictated by the critical buckling load. Despite this practical significance, there exists only a handful of studies in the literature documenting applications of topology optimization which consider buckling performance. This is due to several issues innate to this domain, including mode switching, spurious behavior in void regions, and the presence of repeated eigenvalues. Herein, we propose a level set method capable of effectively optimizing structures despite these challenges in the context of linear buckling. We demonstrate the usefulness of such in the design of several common shell structures and explore the trade-off between stiffness and buckling load performance.

References listed at the end of the paper:


Bendose M, Sigmund O (2003) Topology optimization: theory, methods and applications. isbn: 3-540-42992-1


ABSTRACT: This paper proposes a constraint satisfaction problem algorithm based on implicit decision trees and dynamic programming for the design of multiple composite panels subjected to a set of blending rules and external forces. This decision tree is built incrementally on the ‘fly’, adding plies from a particular set, and does not require any guiding laminate or stacking sequence table for blending purposes. The upper bound algorithm complexity is provided in this work. The technique is applied to the design of a well-known composite multi-panel problem addressed in previous studies; the novel procedure exhibits high-quality solutions (in terms of structure weight) and low computational cost (in terms of laminate evaluations). The novel algorithm scalability is also checked showing that the node tree expansion is independent of the number of panels to be designed. This algorithm could therefore be a suitable choice for large-scale multi-panel design problems.

References listed at the end of the paper:


ABSTRACT: Fiber patch placement (FPP) is a manufacturing technique for discrete variable stiffness composites. In the FPP approach, a structural component is assembled from a multitude of discrete fiber patches. However, due to the discontinuous fibers at patch edges, complex stress distributions occur. To date, a holistic FPP design framework that combines a tailored patch placement method with a dedicated mechanical model for the analysis of patched laminates does not exist. This article introduces a novel approach for the design of fiber patched laminates. It is based on the sequential placement of patches on a finite element shell mesh, using a critical element and angle selection routine in order to optimally locate and orientate fiber patches. They are added to the 3D mesh by employing a highly efficient kinematic draping algorithm. Strength-critical regions of the resulting fiber patched laminates are identified by state-of-the-art finite element analysis and extracted to a shear-lag–based mechanical submodel dedicated to the detailed analysis of patched laminates. The patch placement routine terminates once all design optimization criteria are met. The efficiency of applying optimized patch reinforcements on a continuous fiber-reinforced base laminate is demonstrated using the example of an individualized biomedical component. The work at hand presents the first patched laminate design framework combining a patch placement strategy coupled with a dedicated mechanical model. As a consequence, a substantial progress in the design of patch laminated structures is achieved.

References listed at the end of the paper:

Hui Liu, Hongming Zong, Ye Tian, Qingping Ma and Michael Yu Wang, “A novel subdomain level set method for structural topology optimization and its application in graded cellular structure design”, Structural and Multidisciplinary Optimization, Vol. 60, No. 6, pp 2221-2247 December 2019,

ABSTRACT: A novel subdomain structural topology optimization method is proposed for the minimum compliance problem based on the level sets with the parameterization of radial basis function (RBF). In this method, the level set function evolves on each subdomain separately and independently according to the requirements of objective functions and additional constraints. This makes the parameterization in the proposed subdomain method much faster and more cost-effective than that in the classical global method, as well as the evolution of the level set function since it can be achieved on each subdomain in parallel. In addition, the microstructures on arbitrary two adjacent subdomains can be connected perfectly, without any mismatch around the interfaces of the microstructures. Several typical examples are conducted to verify the correctness and effectiveness of the developed subdomain method. The effects of some factors on the optimized results are also investigated in detail, such as the RBF types, the connectivity types of microstructures, and the size of subdomain division. Without scale separation assumption, several layered graded cellular structures are successfully designed by employing the proposed method under the condition of corresponding repetition constraints. To improve the computational efficiency, a multi-node extended multiscale finite element method (EMSfEM) is used to solve the structural static equilibrium equation for the three-dimensional layered structure optimization problems. Furthermore, a MATLAB code is also provided in the Appendix for readers to reproduce the results of the two-dimensional problems in this work.

References listed at the end of the paper:

ABSTRACT: For the traditional variance-based global sensitivity analysis, the total effect of individual variable commonly involves the interactions with other variables. To further decompose the interactive effects, this paper proposes a new global sensitivity measure based on derivative-integral and variance decomposition and its application in structural crashworthiness”, Structural and Multidisciplinary Optimization, Vol. 60, No. 6, pp 2249-2264 December 2019.

Jie Liu, Qiming Liu, Xu Han, Chao Jiang and Yourui Tao, “A new global sensitivity measure based on derivative-integral and variance decomposition and its application in structural crashworthiness”
examples and an engineering application are investigated to demonstrate the reasonability and superiority of the proposed sensitivity measure.

References listed at the end of the paper:


ABSTRACT: Mechanical attributes of interest are always mutually exclusive in the design process of tape spring hinge. Here we present a complete optimization framework consisting of computational mechanics, optimization design, engineering application, and experimental research to compromise mechanical attributes such that an optimal solution set can be obtained to provide design strategies for engineering practices. Tape spring hinge in folding and unfolding processes with large non-linearity is firstly simulated using quasi-static analysis technique. During the quasi-static process, the ratio of kinetic energy to strain energy is observed to determine mass scaling parameters that measure the precision of analysis. Based on the parameters analyzed, moment-rotation responses of tape spring hinge in quasi-static folding and unfolding processes are investigated and experimentally verified. Yield theory derived from the combination of thin shell theory and Tresca yield criterion is introduced to control the yield of the hinge during folding and deploying processes. In addition, tape spring hinge is released transiently when in spatial conditions; thus the fundamental frequency is calculated and selected herein to be a measurement of stiffness that is maximized to avoid the vibration. Then a multi-objective optimization model is established using the derived yield theory control equation and critical moment as optimization constraints, with the fundamental frequency and strain energy as objectives. The non-dominated sorting genetic algorithm is used to solve the optimization model, and then feasible solution distribution and Pareto frontier are obtained. These results are compared and discussed with two additional single-objective optimizations. Ultimately we achieve the optimal design for tape spring hinge, which is verified well with numerical simulation.

References listed at the end of the paper:


Seffen KA, Pellegrino S (1997) Deployment of a rigid panel by tape-springs. Cambridge University Department of Engineering


Mohammad Yaghmaei and Ali Ghoddosian, “A level set topology optimization method using a biharmonic equation based on plate theory”, Structural and Multidisciplinary Optimization, Vol. 60, No. 6, pp 2431-2459, December 2019,

ABSTRACT: This study aims to propose a new level set optimization method capable of adjusting the complexity of resulting structure without loss of its optimality. The key idea is the deformational behavior of plates. We consider the level set function as the deflection of a fictitious plate on an elastic foundation subjected to the accumulative topological derivative load. The governing equation of this plate contains linear and biharmonic operators. The linear operator, arising from elastic foundation, directly connects the topological derivative to the level set function and plays the main role in creating new holes over the working domain based on the value of the topological derivative. While the biharmonic operator, arising from physical behavior of plate, performs as a filter and adjusts complexity of optimized structure. In the present paper, the topological derivative at a certain point is obtained by measuring the influence of removing element on an objective function. To impose a constraint, the classical controllers are added to the procedure. The results of several numerical examples confirm the validity and efficiency of the proposed optimization method.

References listed at the end of the paper:

- Ferreira AJM (2009) MATLAB codes for finite element analysis. Springer

**ABSTRACT:** Current finite element analysis (FEA) and optimizations require boundary conditions, i.e., constrained nodes. These nodes represent structural supports. However, many realistic structures do not have...
such concrete supports. In a robust optimization, i.e., optimization for uncertain load inputs, it is desirable to involve support uncertainty. However, such a robust optimization has not been available since constrained nodes are required to convert the stiffness matrix to an invertible matrix. This paper demonstrates a quite simple robust optimization based on a pseudo-inverse stiffness matrix and eigenvalue analysis that successfully creates optimal design without constrained nodes. The optimization strategy is to minimize the largest eigenvalue of the pseudo-inverse matrix. It was found that optimization for multiple eigenvalues, i.e., multiple load inputs, is required as the nature of the minimax problem. The created structures are capable of carrying multiple load inputs—bending, torsion, and more complex loads. Configurations created in rectangular design domains exhibited hollow monocoque structures.

References listed at the end of the paper:

This paper deals with two optimisation problems related to axisymmetric membrane shells made of homogeneous, linear and isotropic materials, subjected to an internal pressure. The design variables are the meridian shape and the thickness distribution (possibly not constant). In the first part of the paper, a general background on the mechanics of thin-walled shells is presented and the two optimisation problems concerning the search for meridian profile and thickness distribution which minimise the mass once fixed the internal load (which, in the present work, is called the direct problem) and which maximise the volume once fixed the load position. Journal of Advanced Mechanical Design, Systems, and Manufacturing 10(4):JAMDSM0057.

References listed at the end of the paper:


ABSTRACT: This paper deals with two optimisation problems related to axisymmetric membrane shells made of homogeneous, linear and isotropic materials and subjected to an internal pressure. The design variables are the meridian shape and the thickness distribution (possibly not constant). In the first part of the paper, a general background on the mechanics of thin-walled shells is presented and the two optimisation problems concerning the search for meridian profile and thickness distribution which minimise the mass once fixed the internal volume (which, in the present work, is called the direct problem) and which maximise the volume once fixed the mass (the dual problem) are formulated. The direct problem is studied and solved in closed form in several works available in the literature. All these works refer to the case of shells made of brittle materials. Herein, an extension to ductile materials is proposed. Moreover, the dual problem is solved in closed form, highlighting that the domain of boundary conditions for which a solution exists is more restricted with respect to that of the direct problem.
This research concerns the crashworthiness enhancement of a model of a Boeing 737-200 fuselage section. Using a validated numerical specimen, four thin-walled crushable hybrid energy absorbers are added to the aircraft as vertical struts. The absorbers are composed of a hollow aluminium tube, a star-shaped glass fibre-reinforced polymer inner matrix and foam extrusions. The absorbers—each with variable tube edge and thickness, composite thickness and core height—are single- and multi-objectively optimised. Surrogate models and genetic algorithms are used for the minimisation of acceleration loads, injury levels and the strut’s weight. Results yield a more efficient frames’ collapse evolution with plastic dissipation increased by over 50%. Consequently, acceleration peaks are up to 50% lower at the two measured locations while maintaining low mass values. Injury levels were also reduced from severe to moderate according to an Eiband test. This led to an ~50% lower a.

References listed at the end of the paper:

- ABAQUS 2016 Documentation (2016) Dassault Systèmes
- Boeing Commercial Airplanes (2013) 737 Airplane characteristics for airport planning. D6-58325-6


ABSTRACT: This research concerns the crashworthiness enhancement of a model of a Boeing 737-200 fuselage section. Using a validated numerical specimen, four thin-walled crushable hybrid energy absorbers are added to the aircraft as vertical struts. The absorbers are composed of a hollow aluminium tube, a star-shaped glass fibre-reinforced polymer inner matrix and foam extrusions. The absorbers—each with variable tube edge and thickness, composite thickness and core height—are single- and multi-objectively optimised. Surrogate models and genetic algorithms are used for the minimisation of acceleration loads, injury levels and the strut’s weight. Results yield a more efficient frames’ collapse evolution with plastic dissipation increased by over 50%. Consequently, acceleration peaks are up to 50% lower at the two measured locations while maintaining low mass values. Injury levels were also reduced from severe to moderate according to an Eiband test.
ABSTRACT: Traditional crash box is unable to efficiently solve the problem of bending deformation during the collision process, which limits the energy absorption performance and crashworthiness. This paper introduces the structure of cactus into the design of crash box and attempts to redesign a new one with stable folding deformation. By imitating the cactus characteristic, the bionic crash box consists of two parts: one is the corrugated angular structure, and the other is its thickness functionally gradient distribution along the axial direction. Based on the sensitivity analysis, the parameters which have great influences on the energy absorption performance are selected as the design variables. The multi-objective optimization design is conducted based on response surface model and Latin hypercube design of experiment. Simulation results show that the bionic crash box can effectively weaken the damage to the autobody and improve the energy absorption performance through stable folding deformation.

References listed at the end of the paper:


Under axial pressure or shear load, thin-walled plate and shell structures are easily destroyed by buckling. This paper presents the design method for finding the optimal stiffener layout on thin-walled grooved tubes under axial compression. The Thin-Walled Struct 41(1):31–46


Tanlak N, Sommez FO (2014) Optimal shape design of thin-walled tubes under high-velocity axial impact loads. Thin-Walled Struct 84:302–312


Wu HQ, Xin Y (2008) True stress-true strain curves used in finite element vehicle model. IEEE vehicle power and propulsion conference (VPPC), Harbin, China


Xiaohu Dong, Xiaohong Ding, Guojie Li and Gareth Peter Lewis, “Stiffener layout optimization of plate and shell structures for buckling problem by adaptive growth method”, Structural and Multidisciplinary Optimization, Vol. 61, No. 1, pp 301-318, January 2020,

ABSTRACT: Under axial pressure or shear load, thin-walled plate and shell structures are easily destroyed by buckling. This paper presents the design method for finding the optimal stiffener layout on thin-walled plate and shell structures against the buckling by using the adaptive growth method (AGM), which is based on the growth mechanism of branch systems in nature. Firstly, a mathematical model for optimization of the stiffener layout against buckling is established, and a Karush-Kuhn-Tucker (KKT)-based iteration formula is derived. Next, the stiffeners grow or degenerate from “seeds” according to the adaptive growth principle. Several examples,
including imperforated and perforated rectangular plates with unilateral axial pressure and shear loading, are demonstrated to validate the effectiveness of the suggested method, and well-defined stiffener layouts are obtained. The results show that the stiffener layout is clear, and the buckling resistance performance of the optimized stiffened structures is greatly improved.

References listed at the end of the paper:
- Chen SY, Dong TS, Shui XF (2019) Simultaneous distribution and sizing optimization for stiffeners with an improved genetic algorithm with two-level approximation. Eng Optim Published online. https://doi.org/10.1080/0305215X.2018.1558444

ABSTRACT: A multi-objective collaborative optimal design procedure for steel frames equipped with buckling-restrained braces (BRBs) is proposed under the framework of performance-based seismic design (PBSD) in order to minimize the damage of the primary structure as well as the material cost. For this purpose, a so-called BRB energy dissipation ratio is defined and introduced in the optimization to characterize the involvement of fuse-type BRBs in hysteretic energy dissipation in building stories. Three groups of constraints obtained from the rules on geometrical and conceptual design, the requirements regarding strength and stability, and the PBSD-based story drift limits are considered. To address the discrete-continuous hybrid design variables, a hybrid coding scheme is proposed to modify the non-dominated sorting genetic algorithm II (NSGA-II). The rationality of the proposed procedure is demonstrated by a case study on a seven-story planar steel frame with BRBs. The demonstration indicates that the proposed optimization procedure can make BRBs play the role of a structural fuse successfully in steel frames. The BRB energy dissipation ratios of case C are distributed nearly uniformly along the structural height. The weak-beam-strong-column design principle can be satisfactorily achieved through the maximization of the story BRB energy dissipation ratios. Additionally, the modified hybrid coding NSGA-II algorithm is computationally efficient and stable.

References listed at the end of the paper:
- Federal Emergence Management Agency (1997) NEHRP guidelines for the seismic rehabilitation of buildings. FEMA 273, Washington, DC
- OpenSees version 2.5.0 (2016) Computer software. Pacific Earthquake Engineering Research Center, Berkeley, CA http://opensees.berkeley.edu/

ABSTRACT: The deployable composite cylindrical thin-walled (DCCTW) hinges have application prospects as deployable structures of satellite and solar array, but the mechanical characteristics of the DCCTW hinges have not been considered comprehensively. Taking progressive damage into consideration, the mechanical properties of DCCTW hinges have been reassessed, and a new optimal design method is presented in this paper. Firstly, a simplified model of DCCTW hinge was established. Both analytical and numerical analyses of the simplified model have been conducted. Secondly, the finite element (FE) method has been used to analyze the folding and torsional behavior of DCCTW hinge based on progressive damage theory. Thirdly, design of experiment (DOE) has been carried out using optimal Latin hypercube sampling method. The surrogate model has been established based on the DOE process and elliptical basis functions (EBF). Sensitivity analysis of mass, peak moment of folding, torsional failure angle, and peak moment of torsion have been conducted. Lastly, considering lightweight, the higher peak moment of folding and torsion, the optimization was implemented by multi-objective particle swarm optimization (MOPSO) algorithm, two different optimal designs of DCCTW hinge have been obtained at the same time. The maximum relative error between FE analysis results and optimal design results with the surrogate model is 7.46%, which also reflects the accuracy of the surrogate model. The proposed optimization method can be applied to optimize other composite flexible hinges in consideration of progressive damage.

References listed at the end of the paper:


Concurrent design of hierarchical structures with three-dimensional parameterized lattice microstructures for additive manufacturing"
Penalization (SIMP) model. At the microscale, each macroelement is regarded as an individual microstructure controlled by an aspect ratio variable. The equivalent properties of parameterized lattice microstructures can be derived by interpolating the effective elastic matrices of several typical microstructure unit cells, which avoid expensive iterative homogenization calculations during optimization procedures. Hence, the multiscale concurrent design method can optimize the macroscopic distribution and their spatially varying microstructural configurations simultaneously at an affordable computation cost. Several numerical examples are presented to demonstrate the effectiveness of the proposed approach. Furthermore, the obtained hierarchical structures with non-uniform lattice microstructures show good manufacturability and remarkably improved structural performance by means of the additive manufacturing and experimental testing, compared to the designs with uniform lattice microstructures.

References listed at the end of the paper:

REFERENCES

- Sigmund OLE (1994) Materials with prescribed constitutive 31
Zhirui Fan, Jun Yan, Mathias Wallin, Matti Ristinmaa, Bin Niu and Guozhong Zhao, “Multiscale eigenfrequency optimization of multimaterial lattice structures based on the asymptotic homogenization method”, Structural and Multidisciplinary Optimization, Vol. 61, No. 3, pp 983-998, March 2020,

ABSTRACT: Ultralight lattice structures exhibit excellent mechanical performance and have been used widely. In structural design, the fundamental frequency is highly important. Therefore, a multiscale topology optimization method was utilized to optimize the fundamental frequency of multimaterial lattice structures in this study. Two types of optimization problems were studied, namely, maximizing the natural fundamental frequency with mass constraints and minimizing compliance with frequency constraints. The Heaviside-penalty-based discrete material optimization method was adopted for the optimal selection of candidate materials. The asymptotic homogenization method was used to evaluate the equivalent macroscale properties according to the microstructure of the lattice material. To enable gradient optimization, sensitivities were outlined in detail. A density filter with a volume-preserving Heaviside projection was used to eliminate the risk of a checkerboard pattern and reduce the number of gray elements. A polynomial penalization scheme was employed to eliminate localized spurious eigenmodes in the low-density region. Finally, several numerical examples were performed to validate the proposed method. These numerical examples resulted in novel microstructural configurations with remarkably improved vibration resistance.

References listed at the end of the paper:


ABSTRACT: Periodic porous structural features such as ribs are commonly adopted in the construction of strong and light weight structures. This paper presents a method to create and control periodic structures in topology optimization. The developed method is a resonant coupling of topology optimization and biological pattern formation. The pattern formation excites spatial waves that provide triggers for forming ordered periodic structures in the topology optimization. The period is well controllable, which allows structural designers to choose a suitable period according to non-structural requirements like productivity or styling.
Optimization trials for wide cantilevers and in-plane shear-loaded plates successfully demonstrated the creation of the intended periodic structures. The obtained periodic structures exhibit superior rigidity. The proposed method does not force the formation of a periodic structure when an ordered periodic structure is not appropriate. The present work also discovered a phenomenon in conventional topology optimizations. Numerous optima and spontaneous symmetry breaking occur when the loading condition has translational symmetry, i.e., uniformity along an axis. Under such conditions, conventional optimizations create porous structures with an uncertain period. This paper also presents MATLAB code for the proposed method.

References listed at the end of the paper:

Jingjuan Zhai, Linyuan Shang and Guozhong Zhao, “Topology optimization of piezoelectric curved shell structures with active control for reducing random vibration”, Structural and Multidisciplinary Optimization, Vol. 61, No. 4, pp 1439-1452, April 2020,

ABSTRACT: This paper investigates topology optimization of the surface electrode coverage on piezoelectric sensor/actuator layers attached to a curved shell structure subjected to stationary random force excitation, with the aim to minimize the random vibration response under active control. In the optimization model, the power spectral density (PSD) of displacement response at the specified point is considered as the objective function. The pseudo-densities describing the surface electrode distribution are assigned as the design variables, and an artificial active damping model with penalization is employed to suppress intermediate density values. The voltage across each actuator is determined by velocity feedback control law. Pseudo excitation method (PEM) is introduced to analyze random vibration response of a piezoelectric curved shell structure with active control. In this context, the adjoint variable method for the sensitivity analysis of displacement PSD with respect to topological design variables is derived. Numerical examples fully demonstrate the validity of the proposed approach.

References listed at the end of the paper:


ABSTRACT: Since the high-fidelity model (HFM) of hierarchical stiffened shells is time-consuming, the sampling points based on HFM are generally few, which would result in a certain randomness of the sampling process. In some cases, the prediction accuracy of the variable-fidelity surrogate model (VFSM) is prone to be not robust and reliable. In order to improve the robustness of the prediction accuracy of VFSM, a two-step adaptive updating approach is proposed for the robust establishment of VFSM. In the first step, the leave-one-out (LOO) cross validation is carried out for sampling points of the low-fidelity model (LFM), aiming at finding out those with large prediction error. Then, these points are evaluated by HFM and then added into the original HFM set. In the second step, another LOO cross validation is performed on sampling points of the hybrid bridge function linking HFM and LFM. Based on the Voronoi diagram method, new updating points are chosen from where the largest prediction error of the bridge function lies, and then the VFSM is updated. After above two-step updating process, the VFSM is established. Three simple examples of test functions are firstly presented to verify the effectiveness and efficiency of the proposed method. Further, the proposed method is applied to an engineering example of hierarchical stiffened shells. In order to provide evaluation indexes for prediction accuracy and robustness of VFSM, the VFSM is established by multiple times, and the mean value and the standard deviation of the relative root mean square error (RRMSE) values of the multiple sets of VFSM are calculated. Results indicate that, under the similar computational cost, the mean value and the standard deviation of the RRMSE values of the proposed method decrease by 24.1% and 82.0% than those of the traditional VFSM based on the direct sampling method, respectively. Therefore, the high prediction accuracy and robustness of the proposed method is verified. Additionally, the total computational time of the proposed VFSM decreases by 70% than that of the surrogate model based on HFM when achieving the similar prediction accuracy, indicating the high prediction efficiency of the proposed VFSM.

References listed at the end of the paper:
Masatoshi Shimoda, Yoshiaki Muramatsu and Ryosuke Tsukihara, “Minimization of maximum failure criterion of laminated composite shell structure by optimizing distributed-material orientation”, Structural and Multidisciplinary Optimization, Vol. 61, No. 4, pp 1547-1571, April 2020,

ABSTRACT: In this study, we propose a distributed-parameter optimization method for the material-orientation design aiming at maximizing the strength of a laminated composite shell structure with anisotropic material, which is homogenized based on a laminate theory. The modified Tsai–Hill criterion is employed as a failure criterion in this study, and its maximum value is minimized with the state equation constraint. The issue of non-differentiability inherent in this min–max problem is avoided by transforming the singular local measure to a smooth differentiable integral functional using the Kreisselmeier–Steinhauser function. The optimum design problem is formulated as a distributed-parameter optimization problem, and the sensitivity function with respect to the material-orientation variation is theoretically derived based on a variational method. The optimal material-orientation variation is determined using the H1 gradient method with Poisson’s equation proposed by the authors, where the sensitivity function are applied as Robin condition to vary and optimize the material-orientation distribution. We transfer the sensitivity function to the internal heat generation and determine the material-orientation variation using Poisson’s equation to ensure continuous distribution of material orientation. The optimum design examples show that the proposed optimization method can effectively and efficiently obtain the optimum material orientation with the smooth curvilinear distribution and minimize the maximum strength measured by a failure criterion.

References listed at the end of the paper:


Sobol sensitivity analysis is employed to analyze the effects of the design parameters (t, a, and r) on the objective responses (EA and PCF). The results show that the design variables t and a have a greater effect on the sensitivity of the EA and PCF functions for the eccentric distance of h = 0 and 40 mm. The interaction between punch angle a and punch radius r has significant effect on EA. To
improve the crashworthiness of the expanding circular tubes, a multi-objective optimization is applied to achieve the maximum EA and minimum PCF values, and weight factors are introduced to investigate the crashworthiness optimization under single-eccentric loading and multiple-eccentric loading. The optimization solutions of the expanding circular tubes under different single-eccentric loadings have considerable implications. For multiple-eccentric loading, the results show that the crashworthiness of the expanding circular tube energy absorber can be better balanced.

References listed at the end of the paper:

Kun Yan and Bo Ping Wang, “Two new indices for structural optimization of free vibration suppression”, Structural and Multidisciplinary Optimization, Vol. 61, No. 5, pp 2057-2075, May 2020,

ABSTRACT: This study develops two new indices in structural optimization to minimize peak response and settling time of free vibration, respectively. The two new indices are developed by substituting weight functions into a classic quadratic integral index. With the weight functions, the contributions of structural responses in different time intervals to the value of performance index can be adjusted according to requirements. In such a way, the new indices can approximately evaluate structural performances in reduction of the peak response and settling time, respectively. The new indices have the advantages that they retain the benefits of the classical index for the ease of numerical calculation and sensitivity analysis. Furthermore, they are easy to implement by slightly modifying various developed optimization approaches. Finally, four numerical examples are considered. The proposed two new indices show good performance in reducing the peak response and settling time of free vibration.

References listed at the end of the paper:

- Dong X, Yoon D, Okwudire CE (2017) A novel approach for mitigating the effects of pre-rolling/pre-sliding friction on the settling time of rolling bearing nanopositioning stages using high frequency vibration. Precis Eng 47:375–388

**ABSTRACT:** Front longitudinal beam (FLB) is an important structure for the analysis of force transmission and energy absorption path in different crashing scenarios. In the present paper, the finite element (FE) model of a full-scale vehicle yun-100 Zotye is employed to explore the energy absorption of FLB, and aiming at its poor energy absorption problem, circular beam was used as the original topology optimization space of FLB. The advantages of both static and dynamic topology optimization methods are fully considered, and a variable density method is combined with a hybrid cellular automaton (HCA) method. The substructure dissipated energy and force for frontal crash in a full-scale vehicle are obtained at a speed of 13.8 m/s. The maximum stiffness in axial is obtained through the static topology optimization method and the maximum energy-absorbing structure of FLB which is satisfied with axial strength obtained through the dynamic topology optimization method. According to the results of topology optimization, a multi-cell thin-walled structure is interpreted as the novel FLB. A parametric study on geometric parameters is also performed to explore their effects on crashing characteristics of novel FLB, and it is found that they significantly influenced the crashworthiness of multi-cell thin-walled structure (especially the absorption of energy). Furthermore, in order to maximize the characteristics of novel FLB, a multi-objective optimization process is carried out using non-dominated sorting genetic algorithm (NSGA-II). The optimized FLB after multi-objective optimization is applied to Zotye of 100% vehicle frontal crash. The results showed that the peak value of acceleration decreased by 10.3% and the mass of the optimized FLB reduced to 0.59 kg. It indicated that the optimized FLB manifested excellent crashworthiness and better protective characteristics.

References listed at the end of the paper:

mechanical property space of three
Natl Acad Sci 112(37):11502
permeability. Int J Solids Struct 43(22
orthotropic infill
J Numer Methods Eng 113(8):1148
load. Engineering 2(2):250
References listed at the end of the paper:
the microstructure was not
pre
microstructure with enhanced buckling strength. Structural stability is evaluated using linear buckling, nonlinear
consisting of repeated unit cells of a reference truss lattice microstructure and a topology optimized
microstructure with enhanced buckling strength. Structural stability is evaluated using linear buckling, nonlinear
pre-buckling, and post-buckling analyses, subjected to two benchmark loading cases representing uniaxial
compression and shear loading. Numerical results indicate that geometric and material nonlinearities play a
surprisingly small role in uniaxial loading, whereas strong effects are seen for the shear loading case for which the
microstructure was not optimized.

References listed at the end of the paper:

  fractions, vol 137
- Clausen A, Aage N, Sigmund O (2016) Exploiting additive manufacturing infill in topology optimization for improved buckling
  over large deformation. Adv Mater 27(37):5523–5527
- Geymonat G, Müller S, Triantafyllidis N (1993) Homogenization of nonlinearly elastic materials, microscopic bifurcation and
  J Numer Methods Eng 113(8):1148–1163
- Guedes J, Kikuchi N (1990) Preprocessing and postprocessing for materials based on the homogenization method with adaptive
- Huang X, Radman A, Xie YM (2011) Topological design of microstructures of cellular materials for maximum bulk or shear
- Larsen UD, Sigmund O, Bouwstra S (1997) Design and fabrication of compliant micromechanisms and structures with negative
  Natl Acad Sci 112(37):11502–11507
  mechanical property space of three-dimensional lattice architectures. Acta Mater 140:424–432

Fengwen Wang and Ole Sigmund, “Numerical investigation of stiffness and buckling response of simple and

ABSTRACT: This study systematically investigates stiffness and buckling response of finite structures
consisting of repeated unit cells of a reference truss lattice microstructure and a topology optimized
microstructure with enhanced buckling strength. Structural stability is evaluated using linear buckling, nonlinear
pre-buckling, and post-buckling analyses, subjected to two benchmark loading cases representing uniaxial
compression and shear loading. Numerical results indicate that geometric and material nonlinearities play a
surprisingly small role in uniaxial loading, whereas strong effects are seen for the shear loading case for which the
microstructure was not optimized.
ABSTRACT: For practical applications of optimized truss structures, it is essential to include global and local stability in order to obtain stable and realistic structures. The challenge of including both global and local stability has previously been approached in many ways. However, these proposals often lead to ill-conditioned optimization problems, with convergence issues due to the concavity of the problem. In this paper, a new method for handling both global and local stability in truss optimization is presented. The proposed method is based on the finite element limit analysis method. Initially, the global stability problem is solved by a convex semidefinite constraint, and subsequently, the concave local stability problem is included through an iterative process, where the local stability constraints are linearized and solved by a convex sub-problem. This step-wise approach diminishes convergence issues due to the concavity of the problem. The proposed method is demonstrated through three different applications showing significant effects of including global and local stability in the optimized designs, while at the same time demonstrating the validity and potential of the proposed method.

References listed at the end of the paper:


Mathworks (2016) MATLAB R2016b


Poulsen PN, Olesen JF (2015) Bærende konstruktioner 1. Polyteknisk Forlag


ABSTRACT: In this work, a density-based method is applied for synthesizing compliant mechanisms using topology optimization. This kind of mechanisms uses the elastic strain as the basis for kinematic actuation and it is widely used in precision mechanical devices, in biomedical engineering, and recently in MicroElectroMechanical Systems (MEMS). Geometrical and material (compressible hyperelasticity) nonlinearities are taken into account to obtain mechanisms near real-world applications. A strength criterion for the optimization problem is applied, to design compliant mechanisms that fulfill the desired kinematic tasks while complying with a stress threshold. The addition of a stress constraint to the formulation also aims to alleviate the appearance of hinges in the optimized design. Employing benchmark examples, we investigate the influence of a nonlinear formulation with a stress constraint in the final designs. It is shown that material nonlinearity plays an important role for stress constraint problems. The use of a projection scheme helps to obtain optimized topologies with a high level of discreteness. The Method of Moving Asymptotes (MMA) is applied for design variables updating and the required derivatives are calculated analytically by the adjoint method.

References listed at the end of the paper:


ABSTRACT: Vehicles experience off-axial loads as well as axial loads during collisions. Hence, it is essential to have oblique loads be involved in investigating thin-walled tubes in vehicles as energy absorbers. In this paper, to find the optimum design of a segmented tube in terms of various collision scenarios, the RSM D-Optimal Design is used along with MULTIMOORA as a multiple-attribute decision-making (MADM) method. The tube consists of three parts having different thicknesses and lengths. Energy absorption, initial peak load, and maximum load in three angles of loads (0°, 15°, and 30°), and masses of the tube were defined as independent objectives. Design points were constructed to obtain all responses through finite elements method (FEM). It was found that the obtained models of responses predict the crashworthiness with acceptable
accuracy. Then the optimization provides fifteen Pareto front designs of tubes through fifteen different scenarios. Finally, the integration of MULTIMOORA within a combinatorial weighting method selected the best tube from the optimums. The contrast between the optimum basic tube and the selected segmented tube demonstrated that the latter was capable of increasing the energy absorption by 24–41%, and reducing the initial peak load by 50–60% for the three applied loads.

References listed at the end of the paper:


ABSTRACT: Topology optimization on a unit cell is a common technique to improve the fundamental frequencies of periodic cellular solid structures. During this procedure, the effective properties of cellular solids are primarily computed by the homogenization method. This homogenization method is based on the classic continuum theory under the assumption that the unit cell is infinitely small. Hence, this classic strategy is inadequate to interpret the size dependence of the optimal results. The aim of this study was to describe and examine size dependence in relation to the topology design of the unit cell to achieve maximization of the structural fundamental frequencies. For this purpose, we determined the effective properties of the cellular solids and constructed the optimization formulation based on the couple-stress theory rather than the classic theory. A modified bound formulation of the objective and constraint functions was used to avoid the non-differentiability of repeated frequencies. Although the existing theory does not reflect size dependence, our optimization formulation was able to identify the size dependence of both the microstructural topologies and the fundamental frequencies. The size-dependent results are achieved by varying of the mechanisms to achieve the maximal fundamental frequencies in response to cell size variation. The present formulation is suitable for the unit cell design of cellular solid structures that possess local dimensions comparable to the cell size, and this novel formulation has expanded the application scope of the classic microstructural design problem for periodic materials.

References listed at the end of the paper:

· Sigmund O (1994a) Design of material structures using topology optimization. Department of Solid Mechanics. Technical University of Denmark

ABSTRACT: The design of large and lightweight wind turbines is a current challenge in the wind energy industry. In this context, this work aims to present a novel methodology to reduce the mass of composite wind turbine blades by combining evolutionary and topology optimization schemes in a staggered mode. First, the optimal laminate layout in the outer shell skin of the blade is determined by using genetic algorithms and by assuming that the shear webs are fully dense. Considering this optimized shell skin, the material is removed from the shear webs by using topology optimization. In both cases, the blade is assumed to be subjected to an extreme load scenario, with constraints on the tip displacement, the stresses, the natural vibration frequencies, and buckling phenomena. As an extra feature, the methodology integrates the inverse finite element method to recover the aerodynamically efficient shape of the blade when it is working in normal load scenario as well as to increase the tower clearance safety margin under the extreme load scenario. To illustrate the performance of the methodology, the design of a 28.5-m composite blade is presented. Results show mass savings of up to 23% and a significant increase of the tower clearance safety margin. Furthermore, it is observed that after the classical genetic optimization of the shell skin, there is still margin to achieve additional mass savings via topology optimization of the shear webs without compromising the structural response of the blade.

References listed at the end of the paper:

- Akin JE (2003) Finite element analysis concepts via SolidWorks. Rice University, Houston
- Albanesi AE (2011) Inverse design methods for compliant mechanisms. PhD thesis, Faculty of Engineering and Water Sciences National Littorial University, Santa Fe, Argentina


ABSTRACT: A new thin-walled honeycomb structure for Li-ion battery packaging is designed and optimized in this study. Compared with other battery packaging structures, the designed honeycomb structure described here uses a grid to reinforce its strength. At the same time, the weight is reduced to improve the energy density of the entire package. Moreover, the new thin-walled structure can better protect the internal battery and improve the safety of an electric vehicle (EV). A space mapping (SM) algorithm is used to efficiently optimize the thin-walled honeycomb structure due to the expensive computational cost of each evaluation of a fine FE model. Compared with other SM algorithms, the coarse model of SM is based on a pseudo-plane-strain model. The result shows that the magnitude of stress and the distribution of stress are significantly improved compared with the initial structure. Moreover, the computational cost of optimization for the problem is also decreased significantly due to importing the coarse model.

References listed at the end of the paper:


ABSTRACT: This study is aimed to compare and optimise the crashing performances of an axisymmetric rectangular tube (ART) and a uniform thickness tube (UTT) under offset loading. Both ART and UTT are strengthened with diaphragms. Numerical simulations for the initial UTT with diaphragms under offset loading
were firstly performed based on the experimentally validated finite element model (FEM), which illustrated that deformation process varied from stable mode to bending-sliding mode with an increase offset distance of 0–60 mm. Then, design of experiment (DOE) method was employed to determine the design domains of UTT and ART under various offset distances. Based on the results of DOE, three deformation regions were identified and parametric studies showed that the thicknesses of tubes and diaphragms had significant effects on their crashing performances. Subsequently, the irregular design domains derived from the impact condition with offset distance of 45 mm were selected to search the optimal thickness configurations of both UTT and ART. Finally, the multi-objective optimisation (MOD) was conducted by using non-dominated sorting genetic algorithm (NAGA-II) to minimise the initial peak crushing force (IPCF,) and maximise the specific energy absorption (SEA,) under multiple offset loadings. The obtained Pareto fronts showed that ART generally achieved higher IPCF, and SEA; however, ART outperformed UTT for both IPCF, and SEA, in certain design domains. The outcomes provide insights into the design and selection of thin-walled structures for engineering applications.

References listed at the end of the paper:
· Azarakhshe, Ghamarian A (2017) Collapse behavior of thin-walled conical tube clamped at both ends subjected to axial and oblique loads. Thin-Walled Struct 112:1–11
· Han DC, Park SH (1999) Collapse behavior of square thin-walled columns subjected to oblique loads. Thin-Walled Struct 35(3):167–184
· Nagel GM, Thambiratnam DP (2004b) A numerical study on the impact response and energy absorption of tapered thin-walled tubes 46(2):201–216
• Santosa SP, Wierzbicki T, Hanssen AG, Langseth M (2000) Experimental and numerical studies of foam-filled sections

ABSTRACT: The new “modified Tsai-Hill failure criterion” introduced in Shimoda et al. (SAMO, 2020) does not possess a convex fracture envelope for all possible set of its coefficients. An extended version of the modified Tsai-Hill failure criterion is introduced. The extended version encompasses several known failure criterions for the anisotropic materials. The convexity of the fracture envelope for composite materials and metallic alloys is briefly discussed. Albeit the convexity of the failure envelope is not necessary from the physical viewpoint, the convexity is favorable for the application of optimization methods.

References listed at the end of the paper:

- Jenkins CF (1920) Report on materials of construction used in aircraft and aircraft engines, Great Britain Aeronaut. Res. Committee

Hamed Farokhi (1), Omar Bacarreza (2) and M.H. Ferri Aliabadi (2)
(1) Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK
(2) Department of Aeronautics, Imperial College London, London, SW7 2AZ, UK


ABSTRACT: In this paper, a multi-objective probabilistic design optimisation approach is presented for reliability and robustness analysis of composite structures and demonstrated on a mono-omega-stringer stiffened panel. The proposed approach utilises a global surrogate model of the composite structure while accounting for uncertainties in material properties as well as geometry. Unlike the multi-level optimisation approach which freezes some parameters at each level, the proposed approach allows for all parameters to change at the same time and hence ensures global optimum solutions in the given parameter design space (for both probabilistic and deterministic optimisations) within a certain degree of accuracy. The proposed approach
is used in this study to conduct extensive multi-objective probabilistic and deterministic optimisations (without considering safety factors) on a mono-stringer stiffened panel. In particular, a global surrogate model is developed utilising the computational power of a high-performance computing facility. The inputs of the surrogate model are the omega-stringer geometry and the mechanical properties of the composite material, while the outputs are the fundamental linear buckling load (LBL) and the nonlinear post-buckling strength (NPS). LBL and NPS are obtained via detailed parametric finite element models of the mono-stringer stiffened panel; in the nonlinear model, the interface between the skin and the omega-stringer is modelled via cohesive elements to allow for debonding in the post-buckled regime. Extensive multi-objective optimisations are conducted on the surrogate model using deterministic and probabilistic approaches to examine the omega-stringer geometric parameters mostly affecting the system robustness and reliability. The differences between deterministic and probabilistic designs are highlighted as well.

References listed at the end of the paper:
- Herencia JE, Hafika RT, Weaver PM, Friswell MI (2008a) Lay-up optimization of composite stiffened panels using linear approximations in laminate space. AIAA J 46:2387–2391
ABSTRACT: In this paper, we introduce geometry optimization into an existing topology optimization workflow for truss structures with global stability constraints, assuming a linear buckling analysis. The design variables are the cross-sectional areas of the bars and the coordinates of the joints. This makes the optimization problem formulations highly nonlinear and yields nonconvex semidefinite programming problems, for which there are limited available numerical solvers compared with other classes of optimization problems. We present problem instances of truss geometry and topology optimization with global stability constraints solved using a standard primal-dual interior point implementation. During the solution process, both the cross-sectional areas of the bars and the coordinates of the joints are concurrently optimized. Additionally, we apply adaptive optimization techniques to allow the joints to navigate larger move limits and to improve the quality of the optimal designs.

References listed at the end of the paper:
In practical engineering, the design scheme is generally a compromise solution that meets various requirements. In most cases, the traditional optimization method provides a single optimized solution, which

**ABSTRACT:** In practical engineering, the design scheme is generally a compromise solution that meets various requirements. In most cases, the traditional optimization method provides a single optimized solution, which
may be prone to fail during the subsequent design stage because some unpredictable requirements may be not considered in the preliminary optimization process. For example, maximizing fundamental frequency is generally regarded as the optimization objective for aerospace structures under the vibration environment in the preliminary design stage. However, the optimized solution may fail for strength, buckling, or other requirements during the subsequent detailed design stage. Therefore, it is crucial to provide multiple alternative solutions for insurance. In this paper, a diverse discrete material optimization (DDMO) framework is proposed for multi-patch laminates. It can optimize the material topology layout and fiber orientations of composite structures simultaneously and provide multiple alternative solutions that have diversity in design space and different potential performance. In this paper, a diversity index for discrete variables is proposed and the discrete material optimization (DMO) method with the diversity index constraint is employed to perform the DDMO. Two illustrative examples are used to verify the effectiveness of the proposed optimization framework, including a simple example of a composite plate and a complex engineering example of an S-shaped curved shell. Results indicate that, the proposed method can provide multiple diverse alternative solutions with similar performance in the optimization objective, which are verified to have better potential performance than the single solution by the traditional single design method. Moreover, multiple design options by the diverse optimization method can contribute to reducing the probability of redesign and shortening the design cycle.

References listed at the end of the paper:

ABSTRACT: This work deals with the multi-scale optimisation of composite structures by adopting a general global-local (GL) modelling strategy to assess the structure responses at different scales. The GL modelling approach is integrated into the multi-scale two-level optimisation strategy (MS2LOS) for composite structures. The resulting design strategy is, thus, called GL-MS2LOS and aims at proposing a very general formulation of the design problem, without introducing simplifying hypotheses on the laminate stack and by considering, as design variables, the full set of geometric and mechanical parameters defining the behaviour of the composite structure at each pertinent scale. By employing a GL modelling approach, most of the limitations of well-established design strategies, based on analytical or semi-empirical models, are overcome. The GL-MS2LOS makes use of the polar formalism to describe the anisotropy of the composite at the macroscopic scale (where it is modelled as an equivalent homogeneous anisotropic plate). In this work, deterministic algorithms are exploited during the solution search phase. The challenge, when dealing with such a design problem, is to develop a suitable formulation and dedicated operators, to link global and local models physical responses and
their gradients. Closed-form expressions of structural responses gradients are rigorously derived by taking into account for the coupling effects when passing from global to local models. The effectiveness of the GL-MS2LOS is proven on a meaningful benchmark: the least-weight design of a cantilever wing subject to different design requirements. Constraints include maximum allowable displacements, maximum allowable strains, blending, manufacturability requirements and buckling factor.

References listed at the end of the paper:

- Ansly (2013) ANSYS, mechanical APDL basic analysis guide. Release 15.0. ANSYS Inc, Southpointe, 257 Technology Drive: Canonsburg, PA 15317
- Barbero EJ (2013) Finite element analysis of composite materials using ANSYS®
- . Taylor & Francis Inc
- The MathWork Inc (2011) Optimization toolbox user’s guide
- Tsai S, Hahn T (1980) Introduction to composite materials. Technomic
- Tsai S, Pagano N J (1968) Invariant properties of composite materials. Tech. rep., Air force materials lab Wright-Patterson AFB Ohio

ABSTRACT: Crash-box is a significant part of automotive passive safety system and serves as a main energy absorption device in frontal impact scenario. In this paper, a novel crash-box integrating an outer thin-walled tube and an inner auxetic cellular core has been designed and comprehensively investigated under axial load. The impact simulation of the auxetic crash-box has been carried out, and the results show that introduction of the auxetic core can improve its energy absorption capacity without increasing too much peak impact force. Based on the sensitivity analysis, the effects of its geometric parameters on the crashworthiness performance have been studied. Finally, collaborative optimization of the auxetic crash-box has been performed to simultaneously improve its crashworthiness under the low-speed (15 km/h) and high-speed (40 km/h) impact cases. In the optimization procedure, the least square support vector regression (LS-SVR) method and an improved particle swarm optimization (IPSO) algorithm with time-varying coefficients have been utilized. The results demonstrate that the optimized crash-box can comprehensively improve the energy absorption and impact force characteristics effectively. The auxetic crash-box and the collaborative optimization approach provide extensive references for the application of auxetic structure in vehicle crashworthiness design.

References listed at the end of the paper:

- Fang JG, Gao YK, Sun YG, Qiu N, Li Q (2015a) On design of multi-cell tubes under axial and oblique impact loads. Thin-Walled Struct 95:115–126

ABSTRACT: The existing approach in aircraft wing design optimizes the structure for strength and buckling design criteria followed by a flutter stability check, which leads to design that may not be optimal. This study proposes the flutter stability as an integral of weight optimization by a two-step procedure. Step 1 comprises series of flutter and static analyses of finite element (FE) models with different weapon configurations and aerodynamic loads, which give limiting values of wing tip deflection and wing twist as flutter constraints. Step 2 focuses on weight optimization of the laminate for strength and stiffness design parameters along with the flutter constraints. The algorithm minimizes structural weight by ply drop, which is based on evaluation of the fitness value of laminates generated by a stochastic operator. The ply drop design algorithm is applied to optimize the FE model of a fourth-generation fighter aircraft wing box with three representative aerodynamic loads and three weapon configurations. The application evolved optimal laminate with seamless and symmetric plies, which has 35% lesser weight compared with the initial model having quasi-isotropic laminates for given strength and flutter stability design requirement. The application of genetic algorithm (GA) to get an initial laminate instead of quasi-isotropic laminates further improved the design by 2.5% weight reduction.

References listed at the end of the paper:

- Daley BN, Lord DR (1955) Aerodynamic characteristics of several 6 percent thick airfoils at angles of attack from at high subsonic speeds. NACA


ABSTRACT: This paper investigates the application of the co-rotational method to solve geometrically nonlinear topology optimization problems. The main benefit of this approach is that the tangent stiffness matrix is naturally positive definite, which avoids some numerical issues encountered when using other approaches. Three different methods for constructing the tangent stiffness matrix are investigated: a simplified method, where the linear elastic stiffness matrix is simply rotated; the consistent method, where the tangent stiffness is derived by differentiating residual forces by displacements; and a symmetrized method, where the consistent tangent stiffness is approximated by a symmetric matrix. The co-rotational method is implemented for 2D plane quadrilateral elements and 3-node shell elements. Matlab code is given in the appendix to modify an existing, freely available, density-based topology optimization code so it can solve 2D problems with geometric nonlinear analysis using the co-rotational method. The approach is used to solve four benchmark problems from the literature, including optimizing for stiffness, compliant mechanism design, and a plate problem. The solutions are comparable with those obtained with other methods, demonstrating the potential of the co-rotational method as an alternative approach for geometrically nonlinear topology optimization. However, there are differences between the methods in terms of implementation effort, computational cost, final design, and objective value. In summary, schemes involving the symmetrized tangent stiffness did not outperform the other schemes. For problems where the optimal design has relatively small displacements, then the simplified method is suitable. Otherwise, it is recommended to use the consistent method, as it is the most accurate.

References listed at the end of the paper:
optimization of continuum supporting structures with functional surfaces is presented based on the SIMP concept of aperture field distribution into the de

ABSTRACT:


ABSTRACT: In microwave antenna applications, continuum structures usually support attached functional surfaces to realize some specific electromagnetic performance. Topology optimization of continuum supporting structures with functional surfaces is a challenge for microwave antenna applications. By introducing the concept of aperture field distribution into the design domain, a weighting approach for the topology optimization of continuum supporting structures with functional surfaces is presented based on the SIMP
model. With the weighting aperture field distribution, the objective function of compliance in the previous SIMP method is changed to a weighted compliance. By selecting an optimized control factor, a different truss topology structure with several components from the previous method is clearly obtained. The effectiveness of the proposed method is validated through three typical applications: array antennas, reflector antennas, and conformal antennas with planar and curved functional surfaces.

References listed at the end of the paper:

ABSTRACT: Design and optimization of morphing wings are of current research interest as they promise increasing efficiency and flexibility of future aircraft. A challenging task is to find structural layouts of morphing wings that enable aerodynamically optimized shape changes without defining the target shape a priori. The current paper addresses this task and presents a method that combines the optimization of the active structure of a wing section, parameterized by Lindenmayer cellular systems, with an aerodynamic evaluation. Neither the structural layout nor the target shape has to be defined a priori. This aim is achieved by a multidisciplinary optimization using evolutionary algorithms with aerodynamic and structural objectives. The developed method allows to optimize the topology of the internal structure, the placement of linear contraction, and expansion actuators as well as the setting of their actuation degree concurrently. It is shown that the present approach allows to find optimized internal layouts containing active structural elements for morphing wing sections.

References listed at the end of the paper:


Florian Dexl, Andreas Hauffe and Klaus Wolf, “Multidisciplinary multi-objective design optimization of an active morphing wing section”, Structural and Multidisciplinary Optimization, Vol. 62, No. 5, pp 2423-2440, November 2020,
A genetic algorithm (GA) is proposed in this paper to solve the problem of obtaining the original footprint given the 3D deformed shape. The forward process from 2D footprint to 3D gridshell can be captured by physics principles and naval prospects. We develop a discrete differential geometry-based model of elastic gridshell to investigate their form-finding process. Even though the forward process from 2D footprint to 3D gridshell can be captured by physics-based simulation, the inverse problem of obtaining the original footprint given the 3D deformed shape still lacks a generalized method. In this paper, we propose a genetic algorithm (GA)-based inverse design method to explore the planar footprint of an elastic gridshell as well as the corresponding geometric constraints. Genetic features extracted from the original planar form are encoded into various chromosomes to constitute a population in every generation. With the fitness function constructed based on the objective design of complex aircraft structures using evolutionary algorithms. P IMech Eng G-J Aerosp Eng 225(10):1153–990. https://doi.org/10.1007/s13272-015-0171-2


ABSTRACT: An initially two-dimensional grid of elastic rods may be actuated into a three-dimensional shell-like structure, through buckling, when the end-points of the rods are constrained to a shrunk boundary. The shape of the 3D gridshell is a joint result of elasticity and geometric constraint. We develop a discrete differential geometry-based model of elastic gridshell to investigate their form-finding process. Even though the forward process from 2D footprint to 3D gridshell can be captured by physics-based simulation, the inverse problem of obtaining the original footprint given the 3D deformed shape still lacks a generalized method. In this paper, we propose a genetic algorithm (GA)-based inverse design method to explore the planar footprint of an elastic gridshell as well as the corresponding geometric constraints. Genetic features extracted from the original planar form are encoded into various chromosomes to constitute a population in every generation. With the fitness function constructed based on the deviation of the candidate solution from the 3D target shape, the population evolves gradually until the individual of the smallest fitness value representing the optimal footprint and final boundary constraints is found under seven predefined geometric constraints. Given a series of representative target shapes, e.g., hemispherical cap, paraboloid structure, Gaussian curve shape, and semi-ellipsoid, their original footprints are quantified using a network of 10 elastic rods. Excellent agreement is obtained between the prescribed 3D shape and the simulated buckled structures as small fitness value is obtained and little difference between them is observed, which validates the effectiveness of the proposed GA-based inverse design method.

References listed at the end of the paper:


ABSTRACT: Undevelopable stiffened curved shells have been widely used in engineering fields. The shape of the undevelopable curved surface is generally characterized with the non-straight generatrix and variable cross sections, which makes it challenging to automatically model and optimize stiffeners on the undevelopable curved surface. Therefore, the data-driven modelling and optimization framework are proposed for undevelopable stiffened curved shells in this paper. Firstly, a novel mesh deformation method is developed for the data-driven modelling of undevelopable stiffened curved shells based on RBF neural network machine learning method. Its main idea is to firstly define a developable curved shell (background mesh domain) having similar topological characteristics with the undevelopable curved shell (target mesh domain), and then train the mapping relationship between the background mesh domain and the target mesh domain by RBF neural network, and finally the complicated modelling problem of the undevelopable stiffened curved shell can be transformed into a simple modelling problem of developable stiffened curved shell by means of the mapping relationship. Moreover, based on the efficient global optimization (EGO) surrogate method, a data-driven layout optimization method is established for minimizing the structural weight of undevelopable stiffened curved shells. Finally, three representative optimization examples are carried out, including modelling and optimization of stiffeners on hyperbolic parabolic curved surfaces, blade-shaped curved surfaces and S-shaped variable cross-sectional curved surfaces. Optimal results indicate that the structural weight of undevelopable stiffened curved shells decreases significantly after the optimization, indicating the effectiveness of the proposed modelling and optimization framework.

References listed at the end of the paper:

ABSTRACT: Geometrical imperfections significantly affect the load-carrying capacity of thin-walled structures (TWSs). Herein, we develop a topology optimization method for the stiffeners of thin-walled structures considering the worst-case critical buckling load with spatially varying geometrical uncertainties. The thickness
imperfections of the thin-walled structures are modeled using a non-probabilistic bounded field model because of a lack of sufficient probability information. The bounded field uncertainty is discretized using series expansion and represented as a set of uncorrelated uncertain coefficients. Then, as an inner loop of the topology optimization problem, the worst-case critical buckling load is assessed under the non-probabilistic field description. The outer loop optimization problem is expressed as determining the optimum stiffener topology that maximizes the worst-case critical buckling load under constrained material volume, and the nested optimization problem is solved via a gradient-based algorithm. Numerical examples demonstrate that the proposed method for stiffener optimization improves the stability of thin-walled structures with uncertain geometrical imperfections.

References listed at the end of the paper:

ABSTRACT: Grid structures are among the most lightweight elements for stiffening the plates and shells or as self-sufficient structures. There are different known grid patterns, which are composed of variable numbers of parallel ribs. Selecting an optimum pattern and geometries for a grid to achieve the minimum weight and maximum load-bearing capacity is a challenging procedure for designers. In the current study, a variable ribs model (VRM) is proposed to find the optimum architecture of a grid plate. Therefore, using a genetic algorithm process, a multi-objective optimization is implemented to maximize the axial or shear buckling loads at a minimum possible weight of a grid structure. Eleven geometrical parameters including thickness, width, and the number of ribs as well as the orientation of the grid plate are considered the design variables. The multi-objective optimization is carried out employing the ε-constraint method. The buckling loads are obtained based on the first-order shear deformation plate theory using the Ritz method.

References listed at the end of the paper:


ABSTRACT: Variable stiffness (VS) composites made by fiber steering have received intensive attention due to the tailorable of the stiffness and strength properties. However, a significantly larger number of elements are required to converge for VS composites, which results in much longer runtime and makes the design and optimization more complicated. In this paper, an efficient design optimization method assisted by multi-fidelity surrogate models is presented for the buckling design of VS composites. To reduce the computational burden, a multi-fidelity surrogate model called hierarchical Kriging is constructed through a few expensive high-fidelity samples and many cheap low-fidelity samples. Fine and coarse finite element (FE) analysis is performed respectively to calculate the structural responses for corresponding datasets. The efficient global optimization based on a modified expected improvement criterion is employed and used to adaptively add new samples of variable-fidelity. Two case studies, a composite plate subjected to uniform uniaxial compression and a composite cylinder under pure bending, are investigated. The effects of different number of design variables and coarse FE model mesh density on the optimum configuration are studied to demonstrate the effectiveness and robustness of the method. The results indicate that the present method can remarkably reduce the number of high-fidelity FE evaluations and improve the optimization efficiency when compared with available methods in the literature. Additionally, the investigation in the mechanism of loading carrying capacity improvement shows that the increase is mainly due to the load redistribution.

References listed at the end of the paper:


**ABSTRACT:** This paper presents the high order frequency-amplitude relationship for nonlinear transversely vibrating beams with odd and even nonlinearities, using Homotopy Perturbation Method with an auxiliary term (HPMAT). The governing equations of vibrating buckled beam, beam carrying an intermediate lumped mass, and quintic nonlinear beam are investigated to exhibit the reliability and ability of the proposed asymptotic approach. It is demonstrated that two terms in series expansions are sufficient to obtain a highly accurate periodic solutions. The integrity of the analytical solutions is verified by numerical results.

References listed at the end of the paper:

Ali Mohammad Moniri Bidgoli; Ali Reza Daneshmehr; Reza Kolahchi, “Analytical bending solution of fully clamped orthotropic rectangular plates resting on elastic foundations by the finite integral transform method”,
ABSTRACT: This paper presents a nonlinear model of a clamped-clamped microbeam actuated by an electrostatic load with stretching and thermoelastic effects. The frequency of free vibration is calculated by discretization based on the Differential Quadrature (DQ) Method. The frequency is a complex value due to the thermoelastic effect that dissipates energy. By separating the real and imaginary parts of frequency, the quality factor of thermoelastic damping is calculated. Both the stretching and thermoelastic effects are validated by the referenced papers. This paper shows that the main nonlinearity of this model is voltage, which makes the difference between linear and nonlinear models. The variation of thermoelastic damping (TED) versus geometrical parameters, such as thickness, gap distance and length, is investigated and these results are compared by linear and nonlinear models in high voltages. This paper also shows that in high voltages the linear model has a large margin of error for calculating thermoelastic damping (TED) and thus the nonlinear model should be used.

References listed at the end of the paper:


ABSTRACT: In this article, finite difference method (FDM) is used to study the size-dependent free vibration characteristics of rectangular nanoplates considering the surface stress effects. To include the surface effects in the equations, Gurtin-Murdoch continuum elasticity approach has been employed. The effects of surface properties including the surface elasticity, surface residual stress and surface mass density are considered to be the main causes for size-dependent behavior that arise from the increase in surface-to-volume ratios at smaller scales. Numerical results are presented to demonstrate the difference between the natural frequency obtained by considering the surface effects and that obtained without considering surface properties. It is observed that the effects of surface properties tend to diminish in thicker nanoplates, and vice versa.

References listed at the end of the paper:


ABSTRACT: This study introduces the Differential Transform Method (DTM) in the analysis of the free vibration response of a rotating closed section composite, Timoshenko beam, which features material coupling between flapwise bending and torsional vibrations due to ply orientation. The governing differential equations of motion are derived using Hamilton’s principle and solved by applying DTM. The natural frequencies are calculated and the effects of the bending-torsion coupling, the slenderness ratio and several other parameters on the natural frequencies are investigated using the computer package, Mathematica. Wherever possible, comparisons are made with the studies in open literature.

References listed at the end of the paper:
ABSTRACT: A new modified Adomian Decomposition Method (ADM) was utilized to obtain an analytical solution for the buckling of the nanocantilever actuators immersed in liquid electrolytes. The nanoactuators in electrolytes are subject to different nonlinear forces including ionic concentration, van der Waals, external voltage and electrochemical forces. The Duan–Rach modified Adomian decomposition method was used to obtain a full explicate solution for the buckling of nanoactuators free of any undetermined coefficients. The results were compared with those of Wazwas ADM and of a finite element method available in the literature and excellent agreement was found between them. References listed at the end of the paper:
ABSTRACT: Linear dynamic response of simply supported nanobeams subjected to a variable axial force is assessed by Galerkin numerical approach. Constitutive behavior is described by three functional forms of elastic energy densities enclosing nonlocal and strain gradient effects and their combination. Linear stationary dynamics of nanobeams is modulated by an axial force which controls the global stiffness of nanostructure and hence its angular frequencies. Influence of the considered elastic energy densities on dynamical response is investigated and thoroughly commented. References listed at the end of the paper:


References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: In this paper, numerical spline-based differential quadrature is presented for solving the boundary and initial value problems, and its application is used to solve the fixed rectangular membrane vibration equation. For the time integration of the problem, the Runge–Kutta and spline-based differential quadrature methods have been applied. The Runge–Kutta method was unstable for solving the problem, with large errors in its results, but the spline-based differential quadrature method obtained results that agree with the exact solution. The relative errors were calculated and investigated for different values of time and spatial nodes of discretisation. It seems that the spline-based differential quadrature method is proper for the full simulation of membrane vibration in both spatial and temporal solutions. For the time solving of the membrane vibration, conventional methods, such as the Runge–Kutta method, are not useful even if the time steps are considered too small.

References listed at the end of the paper:

ABSTRACT: A 5th order shear deformation theory considering transverse shear deformation effect as well as transverse normal strain deformation effect is presented for static flexure analysis of simply supported isotropic plate. The assumed displacement field accounts for non-linear variation of in-plane displacements as well as transverse displacement through the plate thickness. The condition of zero transverse shear stresses on the upper and lower surface of plate is satisfied. Hence the present formulation does not require the shear correction factor generally associated with the first order shear deformable theory. Governing equations and boundary conditions of the theory are obtained using the principle of virtual work. Closed-form analytical solutions for simply supported square isotropic thick plates subjected to single sinusoidal distributed loads are obtained. Numerical results for static flexure analysis include the effects of side to thickness ratio and plate aspect ratio for simply supported isotropic plates. Numerical results are obtained using MATLAB programming. The results of present theory are in close agreement with those of higher order shear deformation theories and exact 3D elasticity solutions.

References listed at the end of the paper:


ABSTRACT: In this paper, we present an analytical method for solving a well-posed boundary value problem of mathematical physics governing the vibration characteristics of an internal flow propelled fluid-structure interaction where the pipeline segment is idealized as an elastic hollow beam conveying an incompressible fluid on a viscoelastic foundation. The effect of Coriolis and damping forces on the overall dynamic response of the system is investigated. In actuality, for a pipe segment supported at both ends and subject to a free motion, these two forces generate conjugate complex frequencies for all flow velocities. On employing integral transforms and complex variable functions, a closed form analytical expression is derived for the overall dynamic response. It is demonstrated that a concise mathematical expression for the natural frequency associated with any mode of vibration can be deduced from the algebraic product of the complex frequency pairs. By a way of comparative analysis for damping decrement physics reminiscent with laminated structures, mathematical expressions are derived to illustrate viscoelastic damping effects on dynamic stability for any flow velocity. The integrity of the analytical solution is verified and validated by confirming theresults in literature in appropriate asymptotic limits.

References listed at the end of the paper:

ABSTRACT: This paper deals with the determination of displacement function and thermal stresses of a finite length isotropic functionally graded hollow cylinder subjected to uniform temperature field. The solution of the governing thermoelastic equation is obtained, as suggested by Spencer et al. for anisotropic laminates. Numerical calculations are also carried out for FGM (Functionally graded material) system consisting of ceramic Alumina (Al₂O₃), along with Nickel (Ni) as the metallic component varying with distance in one direction and illustrated graphically.

References listed at the end of the paper:


ABSTRACT: Plates and shells are significant structural components in many engineering and industrial applications. In this study, the free vibration analysis of annular plates is investigated. To this aim, two different numerical methods including the differential quadrature and the discrete singular convolution methods are performed for numerical simulations. Moreover, the Frequency values are obtained via these two methods and finally, the performance of these methods is investigated.

References listed at the end of the paper:


ABSTRACT: This study provides an approach to predict the springback phenomenon during post-solidification cooling in a functionally graded hybrid composite cylindrical shell with a transverse isotropic structure. Here, the material properties are given with a general parabolic power-law function. During the theoretical analysis, an appropriate transformation is introduced in the equilibrium equation, which is resulting in a hypergeometrical differential equation. Thermoelastic solutions are obtained and analyzed for a homogeneous, nonhomogeneous, and elastic-plastic state. The solution is validated by applying it to the multilayered functionally graded cylindrical shell using the transfer or propagator matrix method.

References listed at the end of the paper:

ABSTRACT: The efficiency and robustness of reliability methods are two important factors in the first-order reliability method (FORM). The conjugate choice control (CCC) and directional chaos control method (DCC) are developed to improve the robustness and efficiency of the FORM formula using the stability transformation method. In this paper, the CCC and DCC methods are applied for the reliability analysis of a nanocomposite beam as a complex engineering problem, which is reinforced by carbon nanotubes (CNTs) under buckling force. The probabilistic model for nanocomposite beam is developed through the buckling failure mode which is computed by using the Euler-Bernoulli beam model. The robustness and efficiency CCC and DCC are compared using the stable solution and a number of call limit state functions. The results demonstrate that the CCC method is more robust than the DCC in this case, while the DCC method is simpler than the CCC.

References listed at the end of the paper:

ABSTRACT: The finite element method is employed for the flexural-torsional linear buckling analysis of beams of arbitrarily shaped composite cross-section taking into account generalized warping (shear lag effects due to both flexure and torsion). The contacting materials, that constitute the composite cross section, may include a finite number of holes. A compressive axial load is applied to the beam. The influence of nonuniform warping is considered by the usage of one independent warping parameter for each warping type, i.e. shear warping in each direction and primary as well as secondary torsional warping, multiplied by the respective warping function. The calculation of the four aforementioned warping functions is implemented by the solution of a corresponding boundary value problem (longitudinal local equilibrium equation). The resulting stress field is corrected through a shear stress correction. The equations are formulated with reference to the independent warping parameters additionally to the displacement and rotation components.

References listed at the end of the paper:
[29] Schärdt, R., Verallgemeinerte Technische Biegetheorie. Springer Verlag, Berlin, Germany, 1989 (German).

ABSTRACT: In this paper, the nonlinear conjugate map is applied based on the conjugate Hasofer-Lind and Rackwitz-Fiessler (CHL-RF) method to evaluate the reliability index using the first order reliability method of the embedded nanocomposite beam, which is made of a polymer reinforced with carbon nanotubes (CNTs). The structure is simulated with the Timoshenko beam model. The Mori-Tanaka model is applied for calculating the effective material properties of the nanocomposite beam and the surrounding elastic medium is considered as spring and shear constants. The governing equations are derived based on the energy method and the Hamilton’s principle. Moreover, using an analytical method, the buckling performance function of the structure is obtained. The effects of the basic random variables including the length-to-thickness ratio of the beam (L/h), the spring constant, and the shear constant of the foundation with respect to the volume fraction of CNTs are investigated based on the reliability index of the nanocomposite beam which is subjected to an axial force of 20 GPa. The results indicate that the failure probabilities of the studied nanocomposite beams are sensitive to the length-to-thickness ratio of the beam (L/h) and the spring constant of the foundation variables.

References listed at the end of the paper:


**ABSTRACT:** In this paper, nonlinear dynamic behaviour of the carbon nanotube conveying fluid in slip boundary conditions is studied using the variation iteration method. The developed solutions are used to investigate the effects of various parameters on the nonlinear vibration of the nanotube. The results indicate that an increase in the slip parameter leads to a decrease in the frequency of vibration and the critical velocity, while the natural frequency and the critical fluid velocity increase as the stretching effect increases. Also, as the nonlocal parameter increases, the natural frequency and the critical velocity decreases. The analytical solutions help to have better insights and understand the relationship between the physical quantities of the problem.

**References listed at the end of the paper:**


ABSTRACT: A comparison of the buckling analysis of the nanoplate and nanocomposite plate with a central square hole embedded in the Winkler foundation is presented in this article. In order to enhance the mechanical properties of the nanoplate with a central cutout, the uniformly distributed carbon nanotubes (CNTs) are applied through the thickness direction. In order to define the shape function of the plate with a square cutout, the domain decomposition method and the orthogonal polynomials are used. At last, to obtain the critical buckling load of the system, the Rayleigh-Ritz energy method is provided. The impacts of the length and width of the plate, the dimension of the square cutout, and the elastic medium on the nanoplate and nanocomposite plate are presented in this study.

References listed at the end of the paper:


ABSTRACT: The harmony search algorithm is applied to the optimum designs of functionally graded (FG)-carbon nanotubes (CNTs)-reinforced pipes conveying fluid which are subjected to a moving load. The structure is modeled by the Reddy cylindrical shell theory, and the motion equations are derived by Hamilton's principle. The dynamic displacement of the system is derived based on the differential quadrature method (DQM). Moreover, the length, thickness, diameter, velocity, and acceleration of the load, the temperature and velocity of the fluid, and the volume fraction of CNT are considered for the design variables. The results illustrate that the optimum diameter of the pipe is decreased by increasing the volume percentage of CNTs. In addition, by increasing the moving load velocity and acceleration, the FS is decreased.

References listed at the end of the paper:

ABSTRACT: In this study, the dynamic buckling of the embedded laminated nanocomposite plates is investigated. The plates are reinforced with the single-walled carbon nanotubes (SWCNTs), and the Mori-Tanaka model is applied to obtain the equivalent material properties of them. Based on the sinusoidal shear deformation theory (SSDT), the motion equations are derived using the energy method and Hamilton's principle. The Navier’s method is used in conjunction with the Bolotin's method for obtaining the dynamic instability region (DIR) of the structure. The effects of different parameters such as the volume percentage of SWCNTs, the number and orientation angle of the layers, the elastic medium, and the geometrical parameters of the plates are shown on DIR of the structure. Results indicate that by increasing the volume percentage of SWCNTs the resonance frequency increases, and DIR shifts to right. Moreover, it is found that the present results are in good agreement with the previous researches.

References listed at the end of the paper:
ABSTRACT: In this paper, the dynamic analysis of the composite sandwich truncated conical shells (STCS) with various boundary conditions subjected to the low velocity impact was studied analytically, based on the higher order sandwich panel theory. The impact was assumed to occur normally over the top face-sheet, and the contact force history was predicted using two solution models of the motion which were derived based on Hamilton’s principle by considering the displacement continuity conditions between the layers. In order to obtain the contact force and the displacement histories, the differential quadrature method (DQM) was used. In this investigation, the effects of different parameters such as the number of layers of the face sheets, the boundary conditions, the semi vertex angle of the cone, and the impact velocity of the impactor on the impact response of the complete model were studied.

References listed at the end of the paper:


ABSTRACT: In this paper, the effect of different boundary conditions on the free vibration analysis response of a sandwich plate is presented using the higher order shear deformation theory. The face sheets are orthotropic laminated composites that follow the first order shear deformation theory (FSDT) based on the Reissner-Mindlin (RM) kinematics field. The motion equations are derived considering the continuity boundary conditions between the layers based on the energy method and Hamilton’s principle. The frequency and mode shapes of the structure are obtained using the differential quadrature method (DQM). The effects of different parameters such as the face sheet-to-core stiffness ratio, the boundary conditions, and the core-to-face sheet thickness ratio on the frequency of the sandwich plate are shown. Moreover, the numerical results indicate that the frequency of the CCCC and CFFF sandwich plates predict the higher and lower frequency, respectively.

References listed at the end of the paper:


ABSTRACT: The development of mathematical models for describing the dynamic behaviours of fluid conveying pipes, micro-pipes and nanotubes under the influence of some thermo-mechanical parameters results into nonlinear equations that are very difficult to solve analytically. In cases where the exact analytical solutions are presented either in implicit or explicit forms, high skills and rigorous mathematical analyses were employed.
It is noted that such solutions do not provide general exact solutions. Inevitably, comparatively simple, flexible yet accurate and practicable solutions are required for the analyses of these structures. Therefore, in this study, approximate analytical solutions are provided to the nonlinear equations arising in flow-induced vibration of pipes, micro-pipes and nanotubes using Galerkin-Newton-Harmonic Method (GNHM). The developed approximate analytical solutions are shown to be valid for both small and large amplitude oscillations. The accuracies and explicitness of these solutions were examined in limiting cases to establish the suitability of the method.

References listed at the end of the paper:


ABSTRACT: In this paper, the shape influence of piezoelectric beams including triangle, trapezoid, rectangle, inverted trapezoid, convex parabola, concave parabola, and comb-shaped (a combination of two triangular beams with a connector of 4 mm length) are addressed and analyzed by FEM. The analysis is performed for a bimorph piezoelectric beam. The analyzed parameters include the beam length, thickness and width of the piezoelectric layer. The study is performed using COMSOL Multiphysics software for all seven shapes. The results show that due to the mechanical properties of the beams, the natural frequency of the triangular beam is more for all considered parameters. In addition, as the width of the beam end increases, the natural frequency reduces, too. Since natural frequency is inversely related to electric power, the inverted trapezoidal beam has the highest electric power and the triangular beam has the lowest one.

References listed at the end of the paper:

ABSTRACT: In this paper, the dynamic response of resonating nano-beams is investigated using a strain gradient elasticity theory. A nonlinear model is obtained based on the Galerkin decomposition method to find the dynamic response of the investigated beam around its statically deflected position. The mid-plane stretching, axial residual stress and nonlinear interaction due to the electrostatic force on the deflected beam are included in the proposed nonlinear beam model. Comparing the beam natural frequency using strain gradient theory with experimental data shows an excellent agreement among both approaches. The normalized natural frequency is shown to be increasing nonlinearly with the decrease of the applied DC voltage as well as beam thickness. The results also reveal that increasing the tension axial stress increases the natural frequency; however its influence decreases when decreasing the beam thickness. To investigate the effect of AC actuation voltage on the beam resonant frequency, a Lindstedt-Poincare based perturbation method is utilized and validated by comparison with experimental data. The results show that increasing the AC actuation voltage makes the beam stiffer by increasing its resonant frequency.

References listed at the end of the paper:
ABSTRACT: This research deals with free vibration and static bending of a simply supported functionally graded (FG) plate with the porosity effect. Material properties of the plate which are related to its change are position-dependent. Governing equations of the FG plate are obtained by using the Hamilton’s principle within first-order shear deformation plate theory. In solving the problem, the Navier solution is also used. In this study, the effect of the porosity and material distribution parameters on the static and vibration responses of the FG plate is presented and discussed.

References listed at the end of the paper:

ABSTRACT: In this paper, free and forced vibration of simply-supported Single-walled carbon nanotube is investigated under the moving nanoparticle by considering nonlocal cylindrical shell model. To validate the theoretical results, modal analysis of nanotube is conducted using ANSYS commercial software. Excellent agreement is exhibited between the results of two different methods. Furthermore, the dynamic response of SWCNT under moving nanoparticle is also studied. It is assumed that the nanoparticle travels along the center of nanotube with constant velocity and the van der Waals force between CNT and particle is taken into account. The dynamic response of the SWCNT under the influence of C, particle obtained using dynamic Green’s function and modal expansion. The obtained results show that the nonlocal scale effect decreases the natural frequency and dynamic displacement of the CNT.

References listed at the end of the paper:
ABSTRACT: In the present study, the buckling analysis of the rectangular nanoplate subjected to non-biaxial non-uniform compression using the modified couple stress continuum theory with various boundary conditions has been considered. The simplified first order shear deformation theory (S-FSDT) has been employed and the governing differential equations have been obtained using the Hamilton’s principle. An analytical approach has been applied to obtain exact results from various boundary conditions. Due to the fact that there is not any research about the buckling of nanoplates based on the S-FSDT including the couple stress effect, the obtained results have been compared with the molecular dynamic simulation and FSDT papers which use the Eringen nonlocal elasticity theory. At the end, the results have been presented by making changes in some parameters such as the aspect ratio, the effect of various non-uniform loads and the length scale parameter.

References listed at the end of the paper:

ABSTRACT: This study presents the effect of porosity on mechanical behaviors of a power distribution functionally graded beam. The Euler-Bernoulli beam is assumed to describe the kinematic relations and constitutive equations. Because of technical problems, particle size shapes and micro-voids are created during the fabrication which should be taken into consideration. Two porosity models are proposed. The first one describes properties in the explicit form as linear functions of the porosity parameter. The second is a modified model which presents porosity and Young’s modulus in an implicit form where the density is assumed as a function of the porosity parameter and Young’s modulus as a ratio of mass with porosity to the mass without porosity. The modified proposed model is more applicable than the first model. The finite element model is developed to solve the problem by using the MATLAB software. Numerical results are presented to show the effects of porosity on mechanical behaviors of functionally graded beams.

References listed at the end of the paper:

ABSTRACT: The columns of frame structures are the key load-bearing components and the exterior columns are susceptible to attack in terrorist blasts. When subjected to blast loads, the columns would suffer a loss of bearing capacity to a certain extent due to the damage imparted which may lead to their collapse and even cause the progressive collapse of the whole structure. The concrete-filled steel columns have been extensively used in the world due to the existence of all suitable characteristics of concrete and steel, more ductility, increasing concrete confinement using the steel wall, the large energy-absorption capacity and the appropriate fire behavior. In the present study, the concrete-filled steel square columns have been simulated under the influence of the blast load using the ABAQUS software. These responses have been compared for scaled distances based on the distance to the source and the weight of the explosive material. As a result, it can be seen that although concrete deformation has been restricted using the steel tube, the inner layer of concrete has been seriously damaged and the column displacement has been decreased by increasing the scaled distance. We also concluded that the concrete-filled steel columns have the high ductility and the blast resistance.

References listed at the end of the paper:

ABSTRACT: The present study investigates the buckling of a thick sandwich plate under the biaxial non-uniform compression using the modified couple stress theory with various boundary conditions. For this purpose, the top and bottom faces are orthotropic graphene sheets and for the central core the isotropic soft materials are investigated. The simplified first order shear deformation theory (S-FSDT) is employed and the governing differential equations are obtained using the Hamilton’s principle by considering the Von-Karman’s nonlinear strains. An analytical approach is applied to obtain exact results with different boundary conditions. Due to the fact that there is no research on the stability of micro/nano sandwich plates based on S-FSDT including the couple stress effect, the obtained results are compared with the FSDT studies which use the Eringen nonlocal elasticity.

References listed at the end of the paper:


ABSTRACT: Bending, buckling and vibration behaviors of nonlocal Timoshenko beams are investigated in this research using a variational approach. At first, the governing equations of the nonlocal Timoshenko beams are obtained, and then the weak form of these equations is outlined in this paper. The Ritz technique is selected to investigate the behavior of nonlocal beams with arbitrary boundary conditions along them. To find the equilibrium equations of bending, buckling, and vibration of these structures, an analytical procedure is followed. In order to verify the proposed formulation, the results for the nonlocal Timoshenko beams with four classical boundary conditions are computed and compared wherever possible. Since the Ritz technique can efficiently model the nano-sized structures with arbitrary boundary conditions, two types of beams with general boundary conditions are selected, and new results are obtained.

References listed at the end of the paper:

References listed at the end of the paper:


References listed at the end of the paper:


ABSTRACT: This study presents a modified continuum model to investigate the vibration behavior of single and multi-carbon nanotubes (CNTs). Two parameters are exploited to consider size dependence; one derived from the energy equivalent model and the other from the modified couple stress theory. The energy equivalent model, derived from the basis of molecular mechanics, is exploited to describe size-dependent material properties such as Young and shear moduli for both zigzag and armchair CNT structures. A modified couple stress theory is proposed to capture the microstructure size effect by assisting material length scale. A modified kinematic Timoshenko nano-beam including shear deformation and rotary inertia effects is developed. The analytical solution is shown and verified with previously published works. Moreover, parametric studies are performed to illustrate the influence of the length scale parameter, translation indices of the chiral vector, and orientation of CNTs on the vibration behaviors. The effect of the number of tube layers on the fundamental frequency of CNTs is also presented. These findings are helpful in mechanical design of high-precision measurement nano-devices manufactured from CNTs.

References listed at the end of the paper:


ABSTRACT: The present study investigates buckling characteristics of both nonlinear symmetric power and sigmoid functionally graded (FG) beams. The volume fractions of metal and ceramic are assumed to be distributed through a beam thickness by the sigmoid-law distribution (S-FGM), and the symmetric power function (SP-FGM). These functions have smooth variation of properties across the boundary rather than the classical power law distribution which permits gradually variation of stresses at the surface boundary and eliminates delamination. The Voigt model is proposed to homogenize micromechanical properties and to derive the effective material properties. The Euler-Bernoulli beam theory is selected to describe Kinematic relations. A finite element model is exploited to form stiffness and buckling matrices and solve the problem of eigenvalue numerically. Numerical results present the effect of material graduations and elasticity ratios on the buckling behavior of FG beams. The proposed model is helpful in stability of mechanical systems manufactured from FGMs.

References listed at the end of the paper:

ABSTRACT: In this paper we develop a numerical procedure using finite element and augmented Lagrangian methods that simulates electro-mechanical pull-in states of both cantilever and fixed beams in microelectromechanical systems (MEMS) switches. We devise the augmented Lagrangian methods for the well-known Euler-Bernoulli beam equation which also takes into consideration of the fringing effect of electric field to allow a smooth transition of the electric field between center of a beam and edges of the beam. The numerical results obtained by the procedure are tabulated and compared with some existing results for beams in MEMS switches in literature. This procedure produces stable and accurate numerical results for simulation of these MEMS beams and can be a useful and efficient alternative for design and determining onset of pull-in for such devices.

References listed at the end of the paper:


ABSTRACT: In this study, the mechanical buckling response of refined hyperbolic shear deformable (FG) functionally graded nanobeams embedded in an elastic foundation is investigated based on the refined hyperbolic shear deformation theory. Material properties of the FG nanobeam change continuously in the thickness direction based on the power-law model. To capture small size effects, Eringen’s nonlocal elasticity theory is adopted. Employing Hamilton’s principle, the nonlocal governing equations of FG nanobeams embedded in the elastic foundation are obtained. To predict the buckling behavior of embedded FG nanobeams, the Navier-type analytical solution is applied to solve the governing equations. Numerical results demonstrate the influences of various parameters such as elastic foundation, power-law index, nonlocal parameter, and slenderness ratio on the critical buckling loads of size dependent FG nanobeams.

References listed at the end of the paper:


ABSTRACT: In the present study, the dynamic buckling of the graphene sheet coupled by a viscoelastic matrix was studied. In light of the simplicity of Eringen's non-local continuum theory to considering the nanoscale influences, this theory was employed. Equations of motion and boundary conditions were obtained using Mindlin plate theory by taking nonlinear strains of von Kármán and Hamilton's principle into account. On the other hand, a viscoelastic matrix was modeled as a three-parameter foundation. Furthermore, the differential quadrature method was applied by which the critical load was obtained. Finally, since there was no research available for the dynamic buckling of a nanoplate, the static buckling was taken into consideration to compare the results and explain some significant and novel findings. One of these results showed that for greater values of the nanoscale parameter, the small scale had further influences on the dynamic buckling.

References listed at the end of the paper:
References listed at the end of the paper:


ABSTRACT: Semi-analytical solutions for vibration analysis of nonlocal piezoelectric Kirchhoff plates resting on viscoelastic foundation with arbitrary boundary conditions are derived by developing Galerkin strip distributed transfer function method. Based on the nonlocal elasticity theory for piezoelectric materials and Hamilton's principle, the governing equations of motion and boundary conditions are first obtained, where external electric voltage, viscoelastic foundation, piezoelectric effect, and nonlocal effect are considered simultaneously. Subsequently, Galerkin strip distributed transfer function method is developed to solve the governing equations for the semi-analytical solutions of natural frequencies. Numerical results from the model are also presented to show the effects of nonlocal parameter, external electric voltages, boundary conditions, viscoelastic foundation, and geometric dimensions on vibration responses of the plate. The results demonstrate the efficiency of the proposed methods for vibration analysis of nonlocal piezoelectric Kirchhoff plates resting on viscoelastic foundation.

References listed at the end of the paper:
ABSTRACT: In this paper, the first-order shear deformation theory is used to derive theoretical formulations illustrating the nonlinear dynamic response of functionally graded porous plates under thermal and mechanical loadings supported by Pasternak’s model of the elastic foundation. Two types of porosity including evenly distributed porosities (Porosity-I) and unevenly distributed porosities (Porosity-II) are assumed as effective properties of FGM plates such as Young’s modulus, the coefficient of thermal expansion, and density. The strain-displacement formulations using Von Karman geometrical nonlinearity and general Hooke’s law are used to obtain constitutive relations. Airy stress functions with full motion equations which is employed to shorten the number of governing equations along with the boundary and initial conditions lead to a system of differential equations of the nonlinear dynamic response of porous FGM plates. Considering linear parts of these equations, natural frequencies of porous FGM plates are determined. By employing Runge-Kutta method,
the numerical results illustrate the influence of geometrical configurations, volume faction index, porosity, elastic foundations, and mechanical as well as thermal loads on the nonlinear dynamic response of the plates. Good agreements are obtained in comparison with other results in the literature.

References listed at the end of the paper:


[12] Duc, N.D., Cong, P.H., Nonlinear vibration of thick FGM plates on elastic foundation subjected to thermal and mechanical loads using the first-order shear deformation plate theory, Cogent Engineering, 2, 2015, 1045222.


ABSTRACT: In this paper, a transient thermal stress investigation on a simply supported thin elliptical plate during sectional heating with time-dependent temperature supply is considered. The solution of heat conduction equation with corresponding initial and boundary conditions is obtained by employing an integral transform approach. The governing equation solution for the small deflection theory is obtained and utilized to preserve the intensities of thermal bending moments, involving the Mathieu and modified functions and its derivatives. The deflection results show an approximately good agreement with the previously given results. It is also demonstrated that the temperature field in a circular solution could be resulted in a particular case of the present mathematical solution. The obtained numerical results utilizing computational implements are precise enough for practical purposes.

References listed at the end of the paper:

ABSTRACT: This paper presents Best Theory Diagrams (BTDs) constructed from various non-polynomial theories for the static analysis of thick and thin symmetric and asymmetric cross-ply laminated plates. The BTD is a curve that provides the minimum number of unknown variables necessary for a fixed error or vice versa. The plate theories that belong to the BTD have been obtained by means of the Axiomatic/Asymptotic Method (AAM). The different plate theories reported are implemented by using the Carrera Unified Formulation (CUF). Navier-type solutions have been obtained for the case of simply-supported plates loaded by a bisinusoidal transverse pressure with different length-to-thickness ratios. The BTDs built from non-polynomials functions are compared with BTDs using Maclaurin expansion. The results suggest that the plate models obtained from the BTD using non-polynomial terms can improve the accuracy obtained from Maclaurin expansions for a given number of unknown variables of the displacement field.

References listed at the end of the paper:
isotropic metallic and functionally graded plates employing non


Carrera, E., Miglioretti, F., Selection of appropriate multilayered plate theories by using a genetic like algorithm, Composite Structures, 94(3), 2012, 1175-1186.


Petrolo, M., Lamberti, A., Miglioretti, F., Best theory diagram for metallic and laminated composite plates, Mechanics of Advanced Materials and Structures, 23(9), 2016, 1114-1130.


Filippi, M., Carrera, E., Zenkour, A. M., Static analyses of FGM beams by various theories and finite elements, Composites Part B: Engineering, 72, 2015, 1-9.


ABSTRACT: In this paper, the equivalent linearization method with a weighted averaging proposed by Anh (2015) is applied to analyze the transverse vibration of quintic nonlinear Euler-Bernoulli beams subjected to axial loads. The proposed method does not require small parameter in the equation which is difficult to be found for nonlinear problems. The approximate solutions are harmonic oscillations, which are compared with the previous analytical solutions and the exact solutions. Comparisons show the accuracy of the present solutions. The impact of nonlinear terms on the dynamical behavior of beams and the effect of the initial amplitude on frequencies of beams are investigated. Furthermore, the effect of the axial force and the length of beams on frequencies are studied.

References listed at the end of the paper:

ABSTRACT: In this paper, the wave propagation approach is presented to analyze the vibration and wave power reflection in FG rectangular plates based on the first order shear deformation plate theory. The wave propagation is one of the useful methods for analyzing the vibration of structures. This method gives the reflection and propagation matrices that are valuable for the analysis of mechanical energy transmission in devices. It is assumed that the plate has two opposite edges simply supported while the other two edges may be simply supported or clamped. It is the first time that the wave propagation method is used for functionally graded plates. In this study, firstly, the matrices of reflection and propagation are derived. Second, these matrices are combined to provide an exact method for obtaining the natural frequencies. It is observed that the obtained results of the wave propagation method are in a good agreement with the obtained values in literature. At the end, the behavior of reflection coefficients for FG plates are studied for the first time.

References listed at the end of the paper:


ABSTRACT: In the present study, the buckling analysis of single-walled carbon nanotubes (SWCNT) on the basis of a new refined beam theory is analyzed. The SWCNT is modeled as an elastic beam subjected to unidirectional compressive loads. To achieve this aim, the new proposed beam theory has only one unknown variable which leads to one equation similar to Euler beam theory and is also free from any shear correction factors. The equilibrium equation is formulated by the nonlocal elasticity theory in order to predict small-scale effects. The equation is solved by Navier’s approach by which critical buckling loads are obtained for simple boundary conditions. Finally, to approve the results of the new beam theory, some available well-known references are compared.

References listed at the end of the paper:

ABSTRACT: This research presents the modeling and analysis for the buckling and postbuckling behavior of sandwich plates under thermal and mechanical loads. The lay-up configurations of plates are laminated composite with concentric stiffener and surface mounted piezoelectric actuators. The plates are in contact with a three-parameter elastic foundation including softening and/or hardening nonlinearity. Several types of grid shapes of stiffeners are studied such as ortho grid, angle grid, iso grid, and orthotropic grid. The equations of structures are formulated based on the classical lamination theory incorporating nonlinear von-Karman relationships. The stress function and Galerkin procedure are applied to derive explicit formulations of the equilibrium paths. New results are introduced to give the influences of voltage through the thickness of piezoelectric actuators, different stiffeners, and nonlinear elastic foundations.

References listed at the end of the paper:

The present study introduces a generalized 2-unknown’s higher order shear deformation theory (HSDT) for isotropic and orthotropic plates. The well-known Shimpi’s two-unknown’s HSDT is reproduced as a special case. Reddy’s shear strain shape function (SSSF) is also adapted to the present generalized theory. The results show that both Shimpi and the adapted Reddy’ HSDT are essentially the same, i.e., both present the same static results. This is due to the fact that both theories use polynomial SSSFs. This study presents a new optimized cotangential SSSF. The generalized governing equation obtained from the principle of virtual
displacement is solved via the Navier closed-form solution. Results show that transverse shear stresses can be improved substantially when non-polynomial SSSFs are utilized. Finally, this theory is attractive and has the potential to study other mechanical problems such as bending in nanoplates due to its reduced number of unknown’s variables.

References listed at the end of the paper:


ABSTRACT: This study derives kinematic admissible bending moment – axial force (M-P) interaction relations for mild steel by considering elastic-plastic idealizations. The interaction relations can predict strains, which is not possible in a rigid perfectly plastic idealization. The relations are obtained for all possible cases pertaining to the locations of neutral axis. One commercial rolled steel T-section is considered for studying the characteristics of interaction curves for different models. On the basis of these interaction curves, most significant cases for the position of neutral axis which are enough for the establishment of interaction relations are suggested.

References listed at the end of the paper:

ABSTRACT: In this note, small amplitude free vibration of a double-beam system in presence of inner layer nonlinearity is investigated. The nonlinearity is due to inner layer material and is not related to large amplitude vibration. At first, frequencies of a double-beam system with linear inner layer are studied and categorized as synchronous and asynchronous frequencies. It is revealed that the inner layer does not affect higher modes significantly and mainly affects the first frequency. Then, equation of motion in the presence of cubic nonlinearity in the inner layer is derived and transformed to the form of Duffing equation. Using an analytical solution, the effect of nonlinearity on the frequency for simply-supported and clamped boundary conditions is analyzed. Results show that the nonlinearity effect is not significant and, in small amplitude free vibration analysis of a double-beam system, the material nonlinearity of the inner layer could be neglected.

References listed at the end of the paper:


ABSTRACT: Optimization concept in the context of shear deformation theories was born for the development of accurate models to study the bending problem of structures. The present study seeks to extend such an approach to the dynamic analysis of plates. A compact and unified formulation with non-polynomial shear strain shape functions (SSSFs) is employed to develop a static and free vibration analysis of simply supported...
functionally graded plates. In this context, three new non-polynomial displacement fields are proposed using trigonometric and hyperbolic SSSFs. Then, the non-polynomial SSSFs are optimized by varying the arguments of the trigonometric and hyperbolic functions. Additionally, the Mori–Tanaka approach is used to estimate the effective properties of the functionally graded plates. The Principle of Virtual Displacement (PVD) and the Hamilton's Principle along with the Navier closed-form solution technique are used to obtain exact results. The obtained numerical results are in a good agreement with 3D and 2D higher order shear deformation theory solutions available in the literature.

References listed at the end of the paper:


ABSTRACT: In this study, the second type of Green and Naghdi's thermoelasticity theory is applied to present the vibration of a nanobeam subjected to rectified sine wave heating based upon the nonlocal thermoelasticity theory. Both Young's modulus and thermal conductivity are considered to be linear functions of the temperature. The Laplace transform domain is adopted to solve the governing partial differential equations using the state space approach. Numerical computations are carried out using the inverse of Laplace transforms. The effects of nonlocal parameter and angular frequency on the thermal vibration quantities are discussed. The results of all quantities are illustrated graphically and investigated.

References listed at the end of the paper:

ABSTRACT: This paper examines the solution of a damped beam equation whose damping characteristics are well-defined by the fractional derivative (FD). Homotopy Analysis Method (HAM) is applied for calculating the dynamic response (DR). Unit step and unit impulse functions are deliberated for this analysis. Acquired results are illustrated to show the movement of the beam under various sets of parameters with different orders of the FDs. Here FD is defined in the Caputo sense. Obtained results have been compared with the solutions achieved by Adomian decomposition method (ADM) to show the efficiency and effectiveness of the presented method.

References listed at the end of the paper:
ABSTRACT: This article investigates the static behavior of functionally graded plate under mechanical loads by using a new quasi 3D model. The theory is designated as fifth-order shear and normal deformation theory (FOSNDT). Properties of functionally graded material are graded across the transverse direction by using the rule of mixture i.e. power-law. The effect of thickness stretching is considered to develop the present theory. In this theory, axial and transverse displacement components respectively involve fifth-order and fourth-order shape functions to evaluate shear and normal strains. The theory involves nine unknowns. Zero transverse shear stress conditions are satisfied by employing constitutive relations. Analytical solutions are obtained by implementing the double Fourier series technique. The results predicted by the FOSNDT are compared with existing results. It is pointed out that the present theory is helpful for accurate structural analysis of isotropic and functionally graded plates compared to other plate models.

References listed at the end of the paper:


ABSTRACT: Size-dependent longitudinal and torsional vibrations of nano-beams are examined by two-phase mixture integral elasticity. A new and efficient elastodynamic model is conceived by convexly combining the local phase with strain- and stress-driven purely nonlocal phases. The proposed stress-driven nonlocal integral mixture leads to well-posed structural problems for any value of the scale parameter. Effectiveness of stress-driven mixture is illustrated by analyzing axial and torsional free vibrations of cantilever and doubly clamped nano-beams. The local/nonlocal integral mixture is conveniently replaced with an equivalent differential law equipped with higher-order constitutive boundary conditions. Exact solutions of fundamental natural frequencies associated with strain- and stress-driven mixtures are evaluated and compared with counterpart results obtained by strain gradient elasticity theory. The provided new numerical benchmarks can be effectively employed for modelling and design of Nano-Electro-Mechanical-Systems (NEMS). References listed at the end of the paper.
References:


ABSTRACT: Nonlinear behavior of a functionally graded cantilever beam is analyzed under non-uniform hygro-thermal effect. To solve this problem, finite element method is applied within plane solid continua. Total Lagrangian approach is utilized in the nonlinear kinematic relations. Newton-Raphson method with incremental displacement is used in nonlinear solution. Comparison study is performed. Effects of material distribution, temperature and moisture changes on nonlinear deflections of the functionally graded beam are presented and discussed.

References listed at the end of the paper:

ABSTRACT: The primary aim of this manuscript is to present the approximate analytical solutions of the time fractional order \(a\) \((1 < a \leq 2)\) Vibration Equation (VE) of large membranes with the use of an iterative technique namely Residual Power Series Method (RPSM). The fractional derivative is defined in the Caputo sense. Example problems have been solved to demonstrate the efficacy of the present method and the results obtained are verified graphically. The convergence analysis of the proposed method has also been included in this article. It is seen that the present method is found to be reliable, very effective and easy to implement for various kinds of fractional differential equations used in science and engineering.

References listed at the end of the paper:


ABSTRACT: Nonlinear vibration behavior of beam is an important issue of structural engineering. In this study, a mathematical modeling of a forced nonlinear vibration of Euler-Bernoulli beam resting on nonlinear elastic foundation is presented. The nonlinear vibration behavior of the beam is investigated by using a modified multi-level residue harmonic balance method. The main advantage of the method is that only one nonlinear algebraic equation is generated at each solution level. The computational time of using the new
method is much less than that spent on solving the set nonlinear algebraic equations generated in the classical harmonic balance method. Besides the new method can generate higher-level nonlinear solutions neglected by previous multi-level residue harmonic balance methods. The results obtained from the proposed method compared with those obtained by a classical harmonic balance method to verify the accuracy of the method which shows good agreement between the proposed and classical harmonic balance method. Besides, the effect of various parameters such as excitation magnitude, linear and nonlinear foundation stiffness, shearing stiffness etc. on the nonlinear vibration behaviors are examined.

References listed at the end of the paper:

ABSTRACT: This paper presents a static analysis of laminated composite doubly curved shells using refined kinematic models with polynomial and non-polynomial functions recently introduced in the literature. To be specific, Maclaurin, trigonometric, exponential and zig-zag functions are employed. The employed refined models are based on the equivalent single layer theories. A simply supported shell is subjected to different mechanical loads, specifically: bi-sinusoidal, uniform, patch, hydrostatic pressure and point load. The governing equations are derived from the Principle of Virtual work and solved via Navier-Type closed form solutions. The results are compared with results from Layer-wise solutions and different higher order shear deformation theories available. It is shown that refined models with non-polynomial terms are able to accurately predict the through-the-thickness displacement and stress distributions maintaining less computational effort compared to a Layer-wise models.

References listed at the end of the paper:


ABSTRACT: In this paper, the buckling and vibration behaviour of functionally graded flexoelectric nanobeam is examined. The vibration and buckling formulations of functionally graded nanobeam are developed by using a new theory that’s presented exclusively for flexoelectric nano-materials. So by considering Von-Karman strain and forming enthalpy equation based on displacement, polarization and electric potential, electromechanical coupling equations are developed base on Hamilton’ principle. By considering boundary condition of simply support and clamped-clamped and also Euler-Bernoulli beam model, pre-buckling, buckling and the vibration behaviour of functionally graded nanobeam affected by flexoelectric will be investigated.

References listed at the end of the paper:

ABSTRACT: In this research effort, the generalized warping and distortional problem of straight or curved beams of arbitrary cross section, loading and boundary conditions is presented. An inclined plane of curvature is considered. Additionally, the stiffness of diaphragmatic plates has been introduced in the formulation in order to compare with the case where rigid diaphragms are assumed. Isogeometric tools (NURBS) are employed in order to obtain the results for the 1D formulation and 3D shell models are developed in FEM commercial software for composite cross sections with diaphragms. The number of intermediate diaphragms according to bridges design specifications is compared to the analyzed diaphragmatic arrangements in order to assess the overall structural behavior of bridges decks. For this purpose, examples of curved beam models with open or closed cross sections and various arrangements of diaphragms have been studied.

References listed at the end of the paper:
[31] Cantieni R., Dynamic load test on highway bridges in Switzerland, 60 years experience of EMPA, Report no.211, Dubendorf, Switzerland, 1983.

ABSTRACT: This research presents, buckling and free vibration analysis of fiber metal-laminated (FML) plates on a total and partial elastic foundation using the generalized differential quadrature method (GDQM). The partial foundation consists of multi-section Winkler and Pasternak type elastic foundation. Taking into consideration the first-order shear deformation theory (FSDT), FML plate is modeled and its equations of motion and boundary conditions are derived using Hamilton’s principle. The formulations include Heaviside function effects due to the nonhomogeneous foundation. The novelty of this study is considering the effects of partial foundation and in-plane loading, in addition to considering the various boundary conditions of FML plate. A computer program is written using the present formulation for calculating the natural frequencies and buckling loadings of composite plates without contacting with elastic foundation and composite plates resting on partial foundations. The validation is done by comparison of continuous element model with available results in the literature. The results show that the constant of total or partial spring, elastic foundation parameter, thickness ratio, frequency mode number and boundary conditions play an important role on the critical buckling load and natural frequency of the FML plate resting on partial foundation under in-plane force.

References listed at the end of the paper:

ABSTRACT: In this study, the small scale effect on the linear free-field vibration of a nano-circular plate has been investigated using nonlocal elasticity theory. The formulation is based on the classical theory and the linear strain in cylindrical coordinates. To take into account the small scale and the linear geometric effects, the governing differential equation based on the nonlocal elasticity theory was extracted from Hamilton principle while the inertial effect, as well as the shear stresses effect was ignored. Effect of nonlocal parameter is investigated by solving the governing equation using Adomian decomposition method (ADM) for the clamped and simply supported boundary conditions. By using this method, the first five axisymmetric natural frequencies and displacements of nano-circular plate are obtained one at a time and some numerical results are given to illustrate the influence of nonlocal parameters on the natural frequencies and displacements of the nano-circular plate. For the purpose of comparison, the linear equations were solved by the analytical method. Excellent agreements were observed between the two methods. This indicates that the latter method can be applied to seek the linear solution of nano-circular plates with high accuracy while simplifying the problem.

References listed at the end of the paper:

ABSTRACT: This paper develops a computational model for nonlinear bending analysis of functionally graded (FG) plates using a four-node quadrilateral element SQ4T within the context of the first order shear deformation theory (FSDT). In particular, the construction of the nonlinear geometric equations are based on Total Lagrangian approach in which the motion at the present state compared with the initial state is considered to be large. Small strain-large displacement theory of von Kármán is used in nonlinear formulations of the quadrilateral element SQ4T with twice interpolation strategy (TIS). The solution of the nonlinear equilibrium equations is obtained by the iterative method of Newton-Raphson with the appropriate convergence criteria. The present numerical results are compared with the other numerical results available in the literature in order to demonstrate the effectiveness of the developed element. These results also contribute a better knowledge and understanding of nonlinear bending behaviors of these structures.

References listed at the end of the paper:

ABSTRACT: This paper deals with an analytical approach to predict the nonlinear buckling behavior of functionally graded graphene-reinforced composite laminated cylindrical shells under axial compressive load surrounded by Pasternak’s elastic foundation in a thermal environment. Piece-wise functionally graded graphene-reinforced, composite layers are sorted with different types of graphene distribution. The governing
equations are established by using Donnell’s shell theory with von Kármán nonlinearity terms and three-term solution of deflection is chosen for modeling the uniform deflection of pre-buckling state, linear and nonlinear deflection of post-buckling state. Galerkin method is applied to determine the critical axial compressive buckling load expression, post-buckling load-deflection and load-end shortening relations of the shell. The effects of environment temperature, foundation, geometrical properties, and graphene distribution on buckling behavior of shell, are numerically evaluated.

References listed at the end of the paper:
[14] Li, S.L., Batra, R.C., Buckling of axially compressed thin cylindrical shells with functionally graded middle layer, Thin-Walled Structures, 44(10), 2006, 1039–1047.

ABSTRACT: An effort is made to gain insight on the effect of carbon nanotubes (CNTs) on the impact response of carbon fiber reinforced composites (CFRs) under low velocity impact. Certain amount of CNTs could lead improvements in mechanical properties of composites. In the present investigation, ABAQUS/Explicit finite element code (FEM) is employed to investigate various damages modes of nano composites including matrix cracking, fiber damage and delamination by employing Hashin’s criterion and cohesive zone modeling. The obtained results for 0, 0.5, 1, 2 and 4% CNTs demonstrate that by including CNTs in composite plates, damage could be reduced. However, adding further CNTs cause sudden reduction of impact tolerance capability of the composite plates, particularly, damage due to delamination.

References listed at the end of the paper:
ABSTRACT: In this paper, a displacement-based, variationally consistent, two variable refined theory for shear deformable beams is presented. The beam is assumed to be of linearly elastic, homogeneous, isotropic material and has a uniform rectangular cross-section. In this theory, the beam axial displacement and beam transverse displacement consist of bending components and shearing components. The assumed displacement field of this theory is such that, bending components do not take part in the cross-sectional shearing force, and shearing components do not take part in the cross-sectional bending moment. This theory utilizes linear strain-displacement relations. The displacement functions give rise to the beam transverse shear strain (and hence to the beam transverse shear stress) which varies quadratically through the beam thickness and maintains transverse shear stress-free beam surface conditions. Hence the shear correction factor is not required. Hamilton’s principle is utilized to derive governing differential equations and variationally consistent boundary conditions. This theory involves only two governing differential equations of fourth-order. These governing equations are only inertially coupled for the case of dynamics and are decoupled for the case of statics. This theory is simple and has a strong resemblance with the Bernoulli-Euler beam theory. To demonstrate the efficacy of the present theory, illustrative examples pertain to the static bending and free vibrations of shear deformable isotropic rectangular beams are presented.

References listed at the end of the paper:
[23] Levinson, M., On Bickford's consistent higher order beam theory, Mechanics Research Communications, 12(1), 1985, 01-09.

ABSTRACT: Vibration behavior of different types of porous functionally graded (FG) conical sandwich shells are investigated based on a modified high order sandwich shells theory for the first time. Sandwich shell includes FG face sheets covering a homogeneous core and the second one includes homogeneous face sheets and a FG core. Power law rule modified by considering two types of porosity distributions is used to model the functionally graded materials. All materials are temperature dependent and uniform, linear and nonlinear temperature distributions are used to model the effect of the temperature variation in the sandwiches. Governing equations are obtained by the Hamilton’s energy principle and solved with Galerkin method. To verify the results, they are compared with ones achieved by finite element method obtained by Abaqus software for special cases with the results in literatures.

References listed at the end of the paper:

[33] Sofiyev A.H., Osmancelbioglu E., The free vibration of sandwich truncated conical shells containing functionally graded layers within the shear deformation theory. Composites Part B: Engineering, 120, 2017, 197-211.
[38] Sofiyev, A. H., Review of research on the vibration and buckling of the FGM conical shells. Composite Structures, 211, 2019, 301-317.

ABSTRACT: Thermal buckling behavior of functionally graded Euler-Bernoulli beams in thermal conditions is investigated analytically. The beam with material and thermal properties dependent on the temperature and position is considered. Based on the transformed-section method, the functionally graded beam is considered as an equivalent homogeneous Euler-Bernoulli beam with an effective bending rigidity under an eccentric thermal load. Then, the thermal elastic buckling equation associated with the bending deflection about the neutral axis is established. The easily usable closed-form solutions for the critical thermal buckling temperature of functionally graded beams under uniform and non-linear temperature rise are obtained and used to calculate the thermal buckling temperature. Some results are evaluated and compared with those by other investigators to validate the accuracy of the presented method. The effects of material compositions, temperature-dependent material properties, slenderness ratios and restraint conditions on thermal buckling behaviors are discussed. It is believed that the proposed model provides engineers and designers an easy and useful method to investigate the effects of various parameters affecting the thermal buckling characteristics of functionally graded beams.

References listed at the end of the paper:


ABSTRACT: The need of polygonal elements to represent the domain is gaining interest among structural engineers. The objective is to perform static analysis and topology optimization of a given continuum domain using the rational fraction type shape functions of six node hexagonal elements. In this paper, the main focus is to perform the topology optimization of two-dimensional plate structures using Evolutionary Swarm Intelligence Firefly Algorithms (ESIFA) and three-dimensional shell structures using optimality criteria. The optimization of plates carrying in plane loading is performed with minimum weight as objective. Two different types of shell structures are optimized using maximum strain energy as criteria. The optimal distribution of the material in the design domain obtained using six node hexagon elements is compared with the optimal distribution of material obtained using quadrilateral elements. A few problems from the literature have been solved and this study has proved that hexagon element gives better results over traditional quadrilateral elements.

References listed at the end of the paper:


ABSTRACT: In this work, the nonlinear buckling and post-buckling behavior of shallow arches made of Shape Memory Alloy (SMA) is investigated. Arches are susceptible to large deflections, due to their slenderness, especially when the external load exceeds the serviceability limit point. Beyond this, loss of stability may occur, the famous snap-through buckling. For this reason, curved beams can be used in passive vibration control devices for seismic response mitigation, and the geometrically nonlinear analysis is needed for the accurate prediction of their response. Thus, in this research effort, the assumptions of the Euler-Bernoulli beam theory are considered, and the Von Karman strain field is employed to account for large deflections. The formulation of the problem is displacement-based regarding the axial (tangential) and transverse (normal) displacements, while the two governing equations are coupled and nonlinear. In order to introduce the SMA constitutive law, the stress-strain experimental curves described in the literature are employed together with a fiber approach at
specific control cross-sections along the beam. The numerical solution of the longitudinal problem is achieved using the Analog Equation Method (AEM), a Boundary Element Method (BEM) based technique, and the iterative procedure is based on a Newton-Raphson scheme by using a displacement control algorithm to trace the fully nonlinear equilibrium path and overcome the limit points. Several representative examples are studied, not only to validate the proposed model but also to investigate the nonlinear buckling and post-buckling of SMA shallow arches.

References listed at the end of the paper:

ABSTRACT: In this research, the numerical and experimental analysis of the carbon fiber composite lattice conical structure has been performed to assess the buckling stability of the structure before and after the lateral impact. In the experimental analysis, the carbon fiber composite lattice conical structure was constructed with the winding method and using elastic molds and metal mandrel. In order to investigate the buckling stability of the structures before each lateral impact, they are subjected to be compressive-axial loading. The rest of the structures first subjected under the axial-compressive loading, then in the next step, a compressive loading is applied to determine the effect of the impact on the compressive strength of the damaged structures. In the numerical analysis, the ABAQUS software is used to modeling and performing the mentioned analysis. Finally, the comparison of the results shows that the effect of the lateral impact causes how many reductions will be occurred in the buckling strength. So, it should be considered during the design of the applied structures. On the other hand, the low difference between the numerical and experimental simulations shows that the experimental and numerical methods can be used to analyze the structures with different geometric characteristics and material.

References listed at the end of the paper:

ABSTRACT: A comprehensive set of ten artificial neural networks is developed to suggest optimal dimensions of type ‘C’ Bi-lobe tanks used in the shipping of liquefied natural gas. Multi-objective optimization technique considering the maximum capacity and minimum cost of vessels are implemented for determining optimum vessel dimensions. Generated populations from a genetic algorithm are used by Finite Element Analysis to develop new models and find primary membrane and local stresses to compare with their permissible ranges using PYTHON coding. The optimum design space is mathematically modeled by training ten artificial neural networks with design variables generated by the Taguchi method. The results are compared with actual design data and the 93% achieved accuracy shows the precision of the developed design system.

References listed at the end of the paper:


ABSTRACT: This study introduces the free vibration analysis of multilayered symmetric sandwich Timoshenko beams, made of functionally graded materials with two edge cracked, using the finite element
method and linear elastic fracture mechanic theory. The FG beam consists of 50 layers, located symmetrically to the neutral plane, whose material properties distribution change along the beam thickness, according to power and exponential laws. The constituent of each layer of the beam is different, but each layer is isotropic and homogeneous. Natural frequency values of a cantilever beam are calculated using a developed MATLAB code. There is good agreement between the present results and the published results from the literature. A detailed study is carried out to observe the effect of crack location, crack depth ratio, power law index and material distribution on the first four natural frequencies.

References listed at the end of the paper:


ABSTRACT: In this study, weight optimization of the prismatic core sandwich panel under transverse and longitudinal loadings has been independently investigated. To solve the optimization problems corresponding to the mentioned loadings, a new Improved Constrained Differential Evolution (ICDE) algorithm based on the multi-objective constraint handling method is implemented. The constraints of the problems are buckling load and yield stress. By comparing the results of the ICDE with those obtained by the other evolutionary algorithms based on the penalty function method in the previous studies, it is discerned that the results of the transverse loading obtained in this study are equal to those of the previous works, but the results of the ICDE in the longitudinal loading are better.

References listed at the end of the paper:


ABSTRACT: Functionally graded materials are commonly used in thermal environment to change the properties of constituent materials. The new numerical procedure of functionally graded skew plates in thermal environment is presented in this study based on the C0-form of the novel third-order shear deformation theory. Without the shear correction factor, this theory is also taking the desirable properties and advantages of the third-order shear deformation theory. We assume that the uniform distribution of temperature is embedded across the thickness of this structure. Both the rule of mixture and the micromechanics approaches are considered to describe the variation of material compositions across the thickness. Numerical solutions and comparison with other available solutions suggest that this procedure based on novel third-order shear deformation theory is accuracy and efficiency.

References listed at the end of the paper:

[37] Hudson, C.W., J.J. Carruthers, and A.M. Robinson, Multiple objective optimisation of composite sandwich structures for rail vehicle floor panels, Composite Structures, 92(9), 2010, 2077-2082.

[37] Hudson, C.W., J.J. Carruthers, and A.M. Robinson, Multiple objective optimisation of composite sandwich structures for rail vehicle floor panels, Composite Structures, 92(9), 2010, 2077-2082.


ABSTRACT: The honeycomb sandwich structures are commonly and efficiently adopted in the development of light mass satellite structures as a result of their inherent high stiffness and strength properties. Through a comprehensive study, the equivalent finite element modeling of honeycomb sandwich structures utilizing miscellaneous modeling approaches is introduced. For the sake of validating results, both theoretical analysis and experimental modal testing are implemented upon a honeycomb sandwich plate utilizing free-free boundary conditions. Based on the results, the sandwich theory and its related shell-volume-shell approach introduce a good match with the experimental results. The aforementioned approach is utilized extensively during the process of satellite structural design and modeling. In addition, a parametric study is executed so as to relate the geometric and material variations to the resonant modal frequencies. The study results indicate a crucial influence of both honeycomb core and facing sheets thicknesses on the modal frequency values.

References listed at the end of the paper:

ABSTRACT: This article proposes a refined higher order nonlocal strain gradient theory for stresses and deflections of new model of functionally graded (FG) sandwich nanoplates resting on Pasternak elastic foundation. Material properties of the FG layers are supposed to vary continuously through-the-thickness according to a power function or a sigmoid function in terms of the volume fractions of the constituents. The face layers are made of FG material while the core layer is homogeneous and made of ceramic. In this study, an analytical approach is proposed using the higher-order shear deformation plate theory and nonlocal strain gradient theory with combination of various boundary conditions. Numerical outcomes are reported to display the impact of the material distribution, boundary conditions, elastic foundation parameters and the sandwich nanoplate geometry on the deflections and stresses of FG sandwich nanoplates. The exactness of this theory is determined by comparing it to other published outcomes.

References listed at the end of the paper:

References listed at the end of the paper:

References listed at the end of the paper:


ABSTRACT: In this paper, a new 8-node solid-shell finite element is proposed. The transverse shear strains and transverse normal strains of the element are separately interpolated and related to the C-displacement approximation at tying points to overcome the shear- and trapezoidal-locking phenomena. From the bending strain approximation suggested for degenerated shell elements, the assumed bending strains for the solid-shell element are firstly established. The membrane strains of the element are smoothed on domains defined by dividing the middle surface's element into 1, 2, 3 or 4 sub-cells in accordance with the cell-based strain smoothing (CS) technique. The formulations of the membrane stiffness matrices are explicitly integrated on the boundary lines of the smoothing sub-cells. The proposed CSn-Q8 element, in which n is the number of smoothing sub-cells, is verified through static analysis of several benchmark plate and shell problems. Numerical results show the improved performance of the CSn-Q8 element in comparison with other references.

References listed at the end of the paper:
other FGM plates under any temperature distributions can be obtained instantly. The stability equations and boundary conditions terms are derived through the plate's thickness are considered. Formulations are derived based on the classical plate theory (CPT) considering the von Karman geometrical nonlinearity taking the physical need.

Temperatures of Thin Plates


ABSTRACT: This work investigates the relations between the critical temperature of the thin FGM plates under various temperature distributions through the thickness resting on the Pasternak elastic foundation. Both rectangular and skew plates are investigated. The uniform, linear, and nonlinear temperature distributions through the plate’s thickness are considered. Formulations are derived based on the classical plate theory (CPT) considering the von Karman geometrical nonlinearity taking the physical neutral plane as the reference plane. The partial differential formulation is separated into two sets of ordinary differential equations using the extended Kantorovich method (EKM). The stability equations and boundary conditions terms are derived according to Trefftz criteria using the variational calculus expressed in an oblique coordinate system. Novel multi-scale plots are presented to show the linear relations between the critical temperatures under various temperature distributions. The critical temperature of plates with different materials are also found linearly related. Resulting relations should be a huge time saver in the analysis process, as by knowing one critical temperature of the one FGM plate under one temperature distribution many other critical temperatures of many other FGM plates under any temperature distributions can be obtained instantly.
References listed at the end of the paper:

[23] Zhang, Y. F., and Liu, J. T., A widespread internal resonance phenomenon in functionally graded material plates with longitudinal speed, Scientific Reports, 9(1), 2019, 1907.
ABSTRACT: Constructal Design Method, finite element method and exhaustive search are applied to analyze different arrangements of steel plates with rectangular or trapezoidal stiffeners. As performance parameters, the maximum deflection and maximum von Mises stress are considered. A non-stiffened plate adopted as reference is studied together with 25 plates with rectangular stiffeners and 25 plates with trapezoidal stiffeners. The results show that trapezoidal stiffeners are more effective in minimizing the maximum deflection in comparison with rectangular stiffeners. However, regarding the minimization of stress, the rectangular stiffeners normally present better performance. When both performance parameters are concomitantly considered, a slight advantage of 4.70% for rectangular geometry is identified.
References listed at the end of the paper:


ABSTRACT: The present work introduces the thermoelastic vibrations of nonlocal nanobeams resting on a two-parameter foundation. The governing equations are formulated for linear Winkler–Pasternak foundation type based on the generalized dual-phase-lag heat conduction and nonlocal beams theories. The nanobeam is subjected to a temperature ramping function. The coupled equations of the problem are formulated and solved by Laplace transform technique. The effects of the nonlocal parameter and different foundation parameters on the field variables are illustrated graphically and discussed. The results obtained are consistent with previous analytical and numerical results.

References listed at the end of the paper:


ABSTRACT: This work presents forced vibration responses of a cantilever beam made of functionally graded material under a harmonic load. The material properties of beam vary along the axial direction. The kinematics of the beam are considered within Timoshenko beam theory. The governing equations of problem are derived by using the Lagrange procedure. In the solution of the problem the Ritz method is used and algebraic polynomials are used with the trivial functions for the Ritz method. In the solution of the forced vibration problem, the Newmark average acceleration method is used in the time history. In this study, free and forced vibration responses of the axially functionally graded beam are investigated in detail. In the numerical examples, the effects of material graduation, geometric and dynamic parameters on the free and forced vibration response of axially graded beam are investigated.

References listed at the end of the paper:
transverse and longitudinal buckling pressure are found numerically by minimizing method and the formula for the lateral buckling pressure is obtained. The scope of models, the basic differential equations under uniform compressive lateral pressure is solved at mixe

No. 1, pp 345

Conditions Subjected to Uniform Lateral Pressure

Ab

[52] Asiri, S. A., Akbas, Ş.D., Bilim ıleri Enstitüsü


ABSTRACT: In this study, the buckling problem of shells consisting of functionally graded materials (FGMs) under uniform compressive lateral pressure is solved at mixed boundary conditions. After creating the FGM models, the basic differential equations of FGM shells under compressive lateral pressure are derived within the scope of classical shell theory (CST). The basic differential equations are solved with the help of Galerkin method and the formula for the lateral buckling pressure is obtained. The minimum values of the lateral buckling pressure are found numerically by minimizing the obtained expression according to the numbers of transverse and longitudinal waves. The accuracy is confirmed by comparing the numerical values for the lateral
buckling pressure of homogeneous and FGM shells with the results in the literature. The influences of FGM profiles and shell characteristics on the magnitudes of lateral buckling pressure are investigated in detail by performing specific numerical analyzes.

References listed at the end of the paper:

[23] Huang, H., Zhang, Y., Han, Q., Inelastic buckling of FGM cylindrical shells subjected to combined axial and torsional loads, International Journal of Structural Stability and Dynamics, 17(9), 2017, 1771010.


More papers pub